Best Management and Technical Practices for Site Assessment and Remediation

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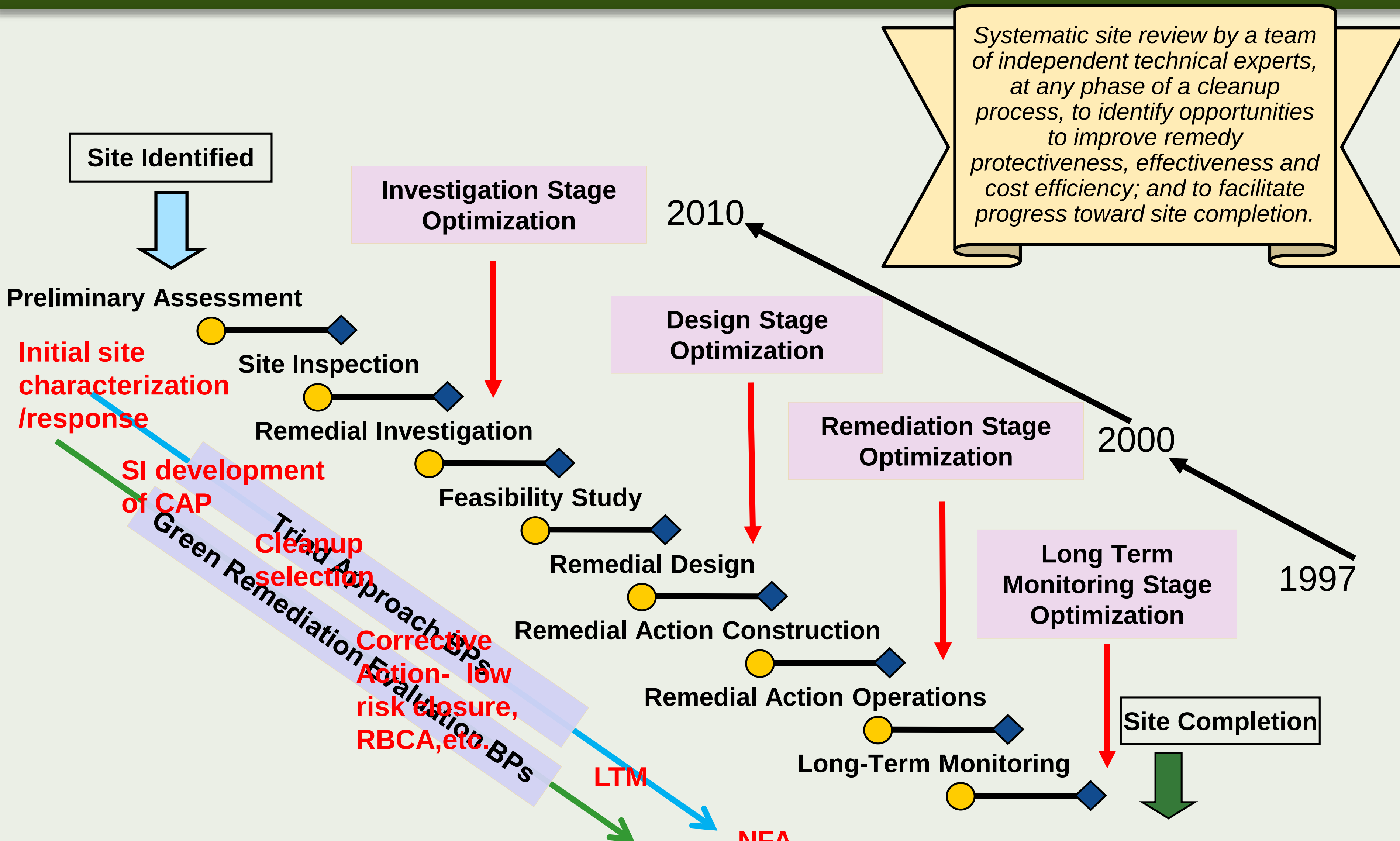
EPA
United States
Environmental Protection
Agency

Framing the Challenge

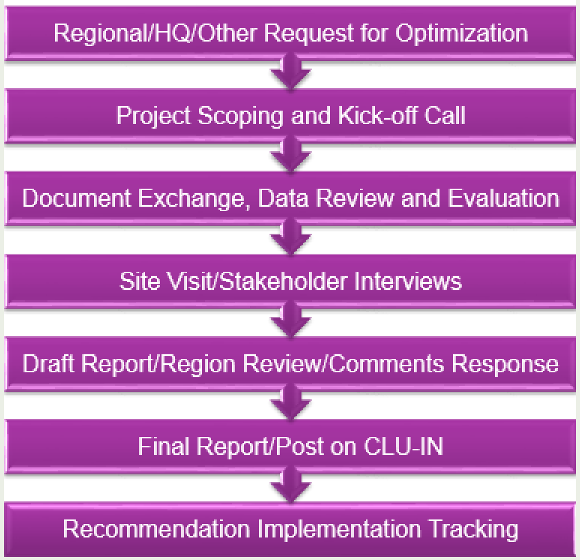
- **UST Universe- As of EOY FY2015**
  - 565,956 federally regulated USTs at 204,000 sites
  - 528,521 releases reported- 456,660 cleanups
  - 71,861 remaining to cleanup
    - Limited funding
    - Many complex sites
    - Remediation systems in place
- **Superfund Optimization Experience**
  - 20 years, 200+ sites
  - Common challenges lead to identification of BMPs
- **Montana DEQ training experience 2012**
  - UST/LUST site complexity- perceptions

History of EPA Superfund Optimization Program



www.epa.gov/superfund/cleanup/postconstruction/optimize.htm
www.cluin.org/optimization/

Optimization Review Process



Optimization Support in Superfund Completed Events 1997-2016

Region	Events/Region			Total Events 1997 to Date	% per Region
	1997-2010	2011-2015	2016 to Date		
1	10	7	4	21	10%
2	12	12	1	25	12%
3	18	6	1	25	12%
4	11	1	0	12	6%
5	12	4	0	16	8%
6	5	11	0	16	8%
7	6	13	0	19	9%
8	4	11	2	17	8%
9	6	20	1	27	13%
10	10	14	1	25	12%
Total	94	99	10	203	100%

Optimization Characterization Phase Typical Findings/ Recommendations

1. Low density/high uncertainty
2. CSM out of date or underdeveloped
3. Existing data not fully leveraged
4. Over-reliance on high cost traditional methods
5. Scale of measurements not sufficient for heterogeneity
6. End data users not adequately considered

Optimization Design/Remedy Phase Typical Findings/ Recommendations

1. Gaps in CSM
2. Shortcomings in modeling
3. Unaddressed issues in design
4. High cost estimates
5. Remedy effectiveness can be improved by conducting phases
6. Explanations for uncertainties can become apparent during start-up
7. Can confirm validity of current site plans and progress

Optimization Long term O&M Phases Typical Findings/ Recommendations

1. CSM needs update
   a) Sources
   b) Low/ high permeability zones
   c) NAPL
2. Endpoint and metrics for site completion need better definition
3. Need for improved data management, analysis and reporting
   a) Tracking/reporting performance
   b) Spatial/temporal data
   c) Historic data (paper → electronic)

Recent Optimization Experiences in the Tanks Universe

- **7 LUST sites**
- **General observations**
  - Voluntarily nominated sites for third-party evaluation based on site complexity and persistent barriers to closure
  - Source area remedial activities, such as SVE, UST removal and excavation significantly reduced impacts at sites
  - Issues associated with the location of remedial systems installed by others were promptly recognized and managed
- **Observations from desktop and full reviews**
  - Technical decisions typically made based on funding rather than stepwise approach to assess receptors and implement closure strategy
    - Observed outcomes:
      - Imprecise or uncertain CSMs
      - No fully defined closure strategy
      - Potential receptors not fully evaluated or monitored
      - Insufficient remedial system functionality, efficiency, effectiveness towards site closure or…
      - Inadequate monitoring to evaluate metrics

Recent Optimization Experiences in the Tanks Universe

- **Examples of Observed outcomes**
  - Imprecise or uncertain CSMs
    - Multiple sites should consider potential for submerged LNAPL
    - Additional plume delineation recommended at 6 of 7 sites
  - Closure Strategy
    - Goal of remediation was uncertain at some sites
    - Long-term plume management or aggressive soil/aquifer restoration
  - Receptors
    - Multiple sites need additional information on public supply and private drinking wells
    - Some sites require more thorough investigation of VI pathway due to magnitude and proximity to receptors
    - Additional identification and evaluation of receptors required

Recent Optimization Experiences in the Tanks Universe

- **Examples of Observed outcomes**
  - » Remediation system performance, metrics/monitoring
    - – Some sites had significant resource expenditures and investment in P&T systems that did not function appropriately
    - – At one site a technology (deemed problematic by the optimization team) was piloted and yielded inconclusive results
    - – At multiple sites injected mixture of surfactants and persulfate which did not enhance NAPL recovery
    - – At one site reinjection of treated water caused mounding and NAPL spreading

Cost Considerations For Optimization Reviews

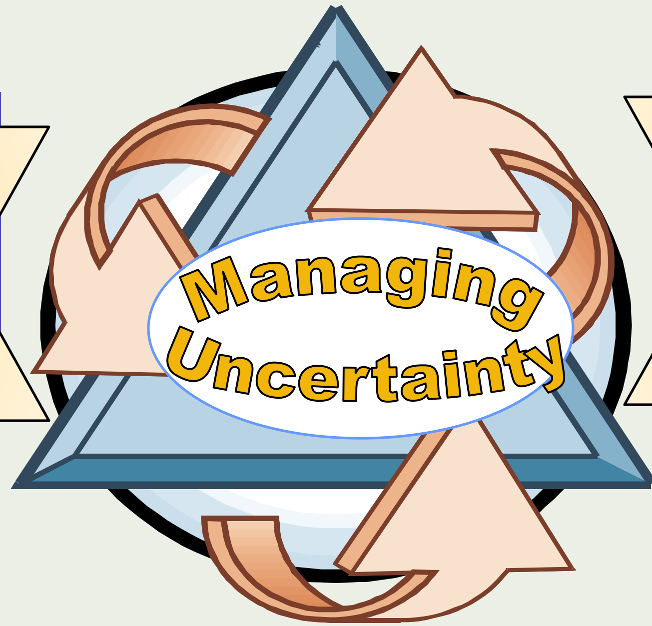
- **TIFSD housed in the SF program but…**
  - » Operate Brownfields Technical Support Center
  - » Provide technical support at UST sites, corridors, pilots
  - » State training
- **Regional concerns about cost of recommendations**
  - » Encourage organizations to look at life cycle costs
  - » Recommendations prioritized and can be phased
  - » Cost of investigation vs. remediation
  - » SF, BF, UST, RCRA experience- P&T neither cheap nor fast

What are BMPs?

A set of methods or techniques found to be the most effective and practical means in achieving an objective while making the optimum use of resources

The Triad Approach – Source of Many BMPs

A process for building a consensus vision for conducting environmental investigation and remediation



A work strategy that incorporates the flexibility to adapt to information generated by real-time measurement technologies

Real-time = within a timeframe that allows the project team to react to the information while in the field

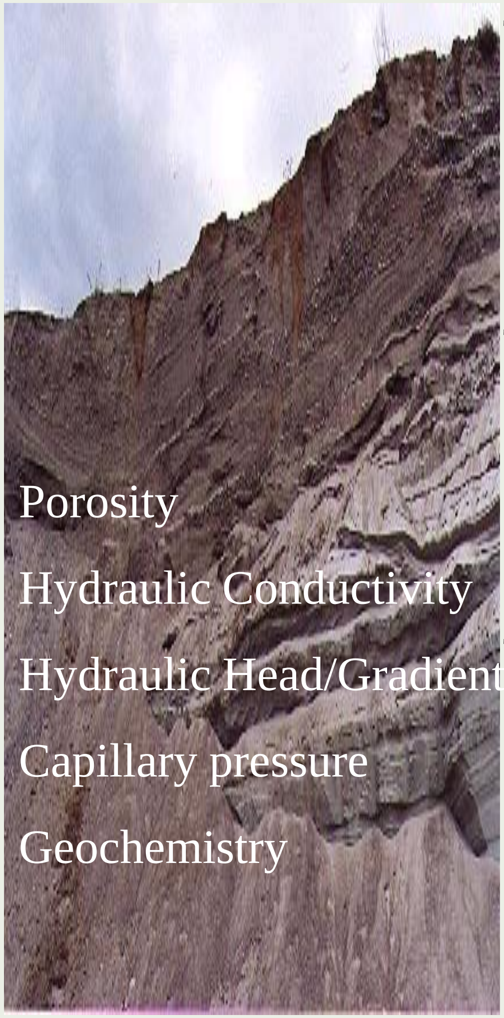
Synthesizes practitioner experience, successes, and lessons learned into an institutional framework

Common Triad Related BMPs and Recent Program/Process Revelations in SF Remedial

Comprehensive team formation	Adaptive site management	Project life cycle CSM	Stakeholder outreach
Systematic planning	Dynamic work strategies	Real-time measurement technologies	Demonstration of method applicability
High resolution collaborative data	3-D visualization and analysis	Data management and communication	Optimization

- Data management
  - Historically reports as mechanism to exchange information, now data as deliverable, active data management
  - Data warehouse, data interoperability, economies of scale
- High Resolution Site Characterization
  - Direct sensing tools, scale appropriate measurements
  - Collaborative data approaches
- Real-time data visualization
  - Conceptual Site Model (CSM) lifecycle management

Recent Experience Leads to New Thinking for Media Too

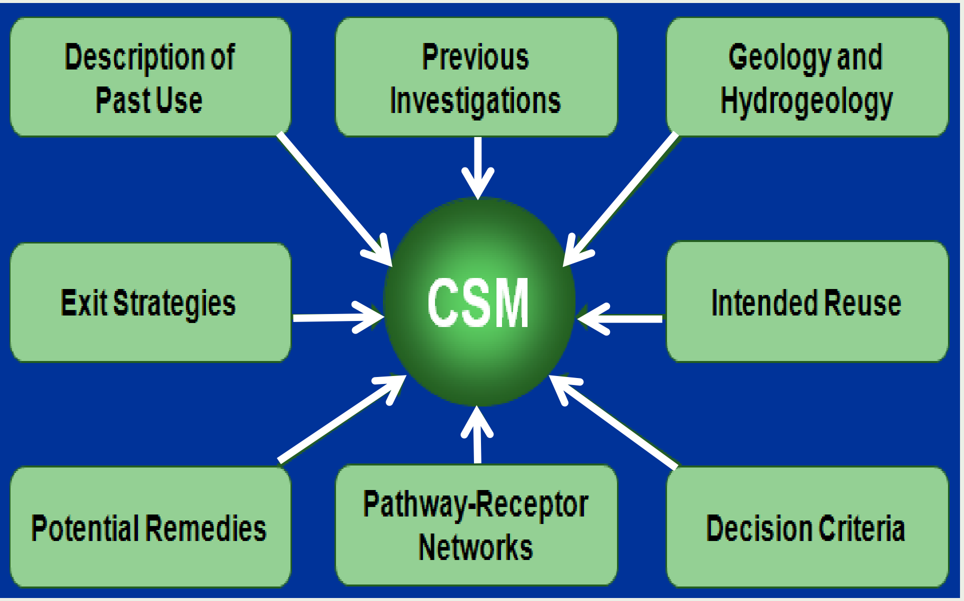


- **Historical perspective**
  - Soil- EPA Superfund has historically focused on high quality analytical samples collected at discrete soil locations
  - Groundwater- EPA has historically used monitoring wells, pump tests, etc. to characterize and monitor sites
- **Challenges encountered**
  - Discrete soil sampling designs do not address matrix variability/heterogeneity- resulting in highly variable or statistically uncertain decision making
  - Large scale averages of aquifer materials obscure primary contaminant transport and mass storage areas
- **New thinking**
  - Soil- Incremental and composite techniques that provide large scale averages are better suited to represent exposure scenarios, control matrix variability/ sample heterogeneity, and make statistically confident decisions
  - Groundwater- large scale averages derived from aquifer materials can be misleading resulting in poorly performing or applied remedies. HRSC techniques provide measurements at scales more appropriate for remedy design.

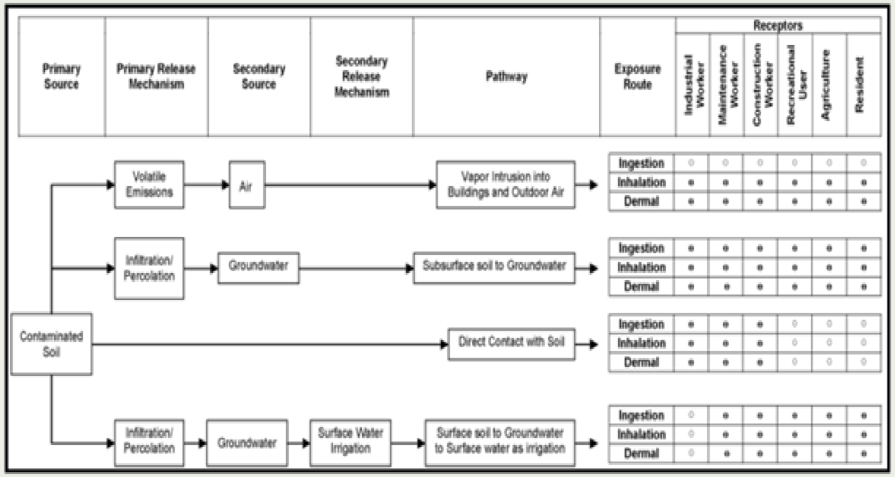
The CSM is Critical Regardless of Regulatory Framework

- ♦ **Written and graphical expression of site knowledge**
- ♦ **Primary basis for project design and execution**
- ♦ **Updated throughout project life cycle**
- ♦ **Essential to successful projects**

Primary Anatomy of a CSM



- ♦ P-RN diagrams are NOT FULL CSMs – too simple to serve all CSM functions
- ♦ However, they are a critical COMPONENT of CSMs



- ♦ CSM should incorporate all actual and potential P-RNs
- ♦ Investigation efforts confirm or refute each element of P-RNs

Project Life Cycle CSM Supports Project Phases

Environmental Cleanup Best Management Practices: Effective Use Of The Project Life Cycle Conceptual Site Model. EPA 542-F-11-011

General Environmental Cleanup Steps	CSM Life Cycle	Best Management Practices: SPP	Best Management Practices: DWS/RTMT	CERCLA - Superfund	RCRA	Brownfields	UST	VCUP Varies by State	IRP/ERP	MMRP
Site Assessment	Conceptual Preliminary CSM Baseline CSM			Preliminary Assessment (PA) Site Inspection (SI) National Priorities List (NPL) No Further Remedial Action Planned (NFRAP)	Facility Assessment (RFA)	Phase I Environmental Site Assessment (ESA)	Initial Site Characterization Initial Response	PA SI	PA SI	PA SI MR Site Prioritization Protocol (MRSPP)
Site Investigation and Alternatives Evaluation	Characterization CSM Stage			Remedial Investigation/ Feasibility Study (RI/FS) Removal Actions - Emergency/ Time Critical/Non-Time-Critical	Facility Investigation (RFI) Corrective Measures Study (CMS)	Phase II ESA	SI Corrective Action Plan (CAP)	RI/FS	RI/FS NFRAP	RI/FS
Remedy Selection	Design CSM Stage			Proposed Plan Record of Decision (ROD)	Statement of Basis (SB) Final Decision and Response to Comments	Remedial Action Plan (RAP)	Cleanup Selection	ROD	Proposed Plan ROD	Remedy Selection
Remedy Implementation	Remediation/ Mitigation CSM Stage			Remedial Design (RD) Remedial Action (RA) – Interim and Final	Corrective Measure Implementation (CMI)	Cleanup and Development	Corrective Action - Low-impact site cleanup - Risk-based remediation - Generic remedies - Soil matrix cleanup	RD RA	RD RA – Interim and Final Remedy in Place (RIP)	RD Time Critical Removal Action (TCRA) RA RIP
Post-Construction Activities	Post-Remedy CSM Stage			Operational & Functional Period Operation & Maintenance (O&M) Long term monitoring (LTM) Optimization Long Term Response Action (Fund-lead groundwater/surface water restoration)	O&M On-site inspections and oversight	Property Management Long-term O&M Redevelopment Activities (Private- and Public-led)	LTM	O&M LTM	Shakedown period Operating Properly and Successfully O&M LTM	Shakedown period Long Term Management
Site Completion	Quantitative			Construction Complete (CC) Preliminary or Final Close Out Report (PCOR/FCOR) Site Completion - FCOR Site Deletion O&M as appropriate	Certification of Completion Corrective Action Complete with Controls or without Controls	CC Property Management	No Further Action (NFA)	CC	Response Complete (RC) NFA	RC NFA

Abbreviations:

SPP = Systematic Project Planning
DWS = Dynamic Work Strategies
RTMT = Real Time Measurement Technologies

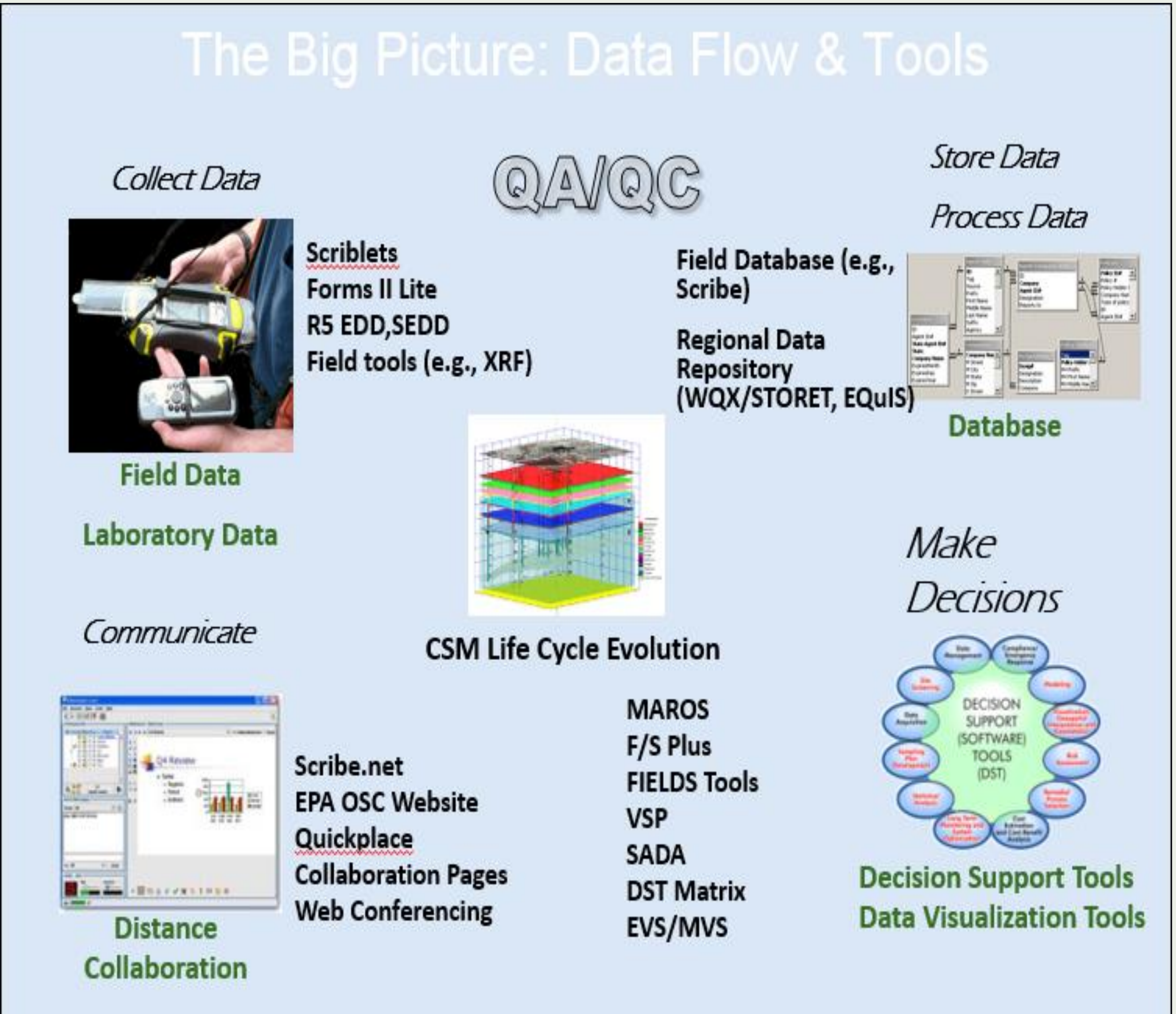
CERCLA = Comprehensive Environmental Response, Compensation and Liability Act
RCRA = Resource Conservation and Recovery Act

UST = Underground Storage Tanks
VCUP = Voluntarily Clean Up Programs

IRP/ERP = Installation Restoration Program/ Environmental Restoration Program
MMRP = Military Munitions Response Program

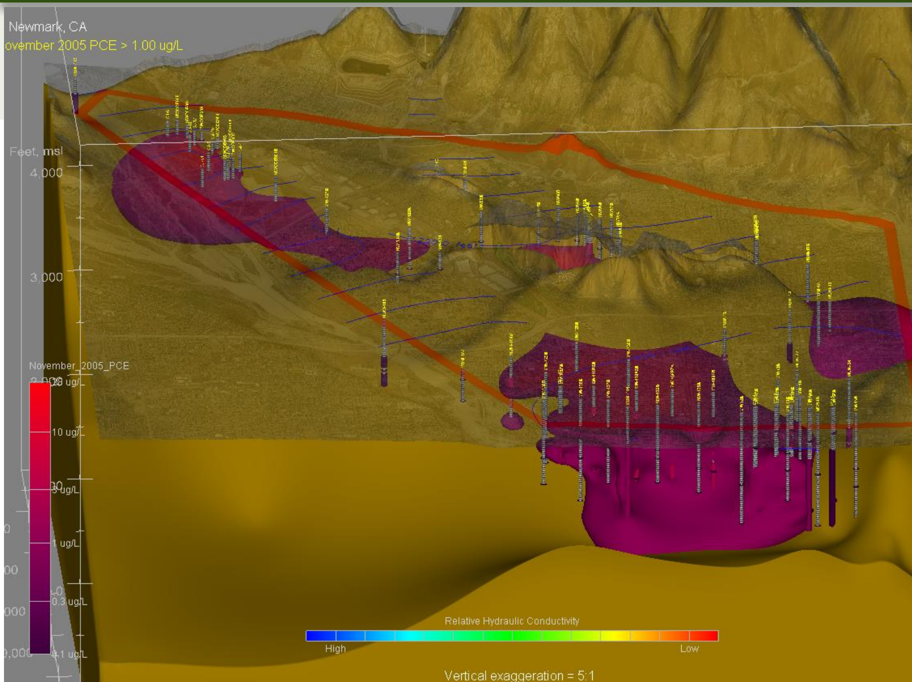
Data Management is Key

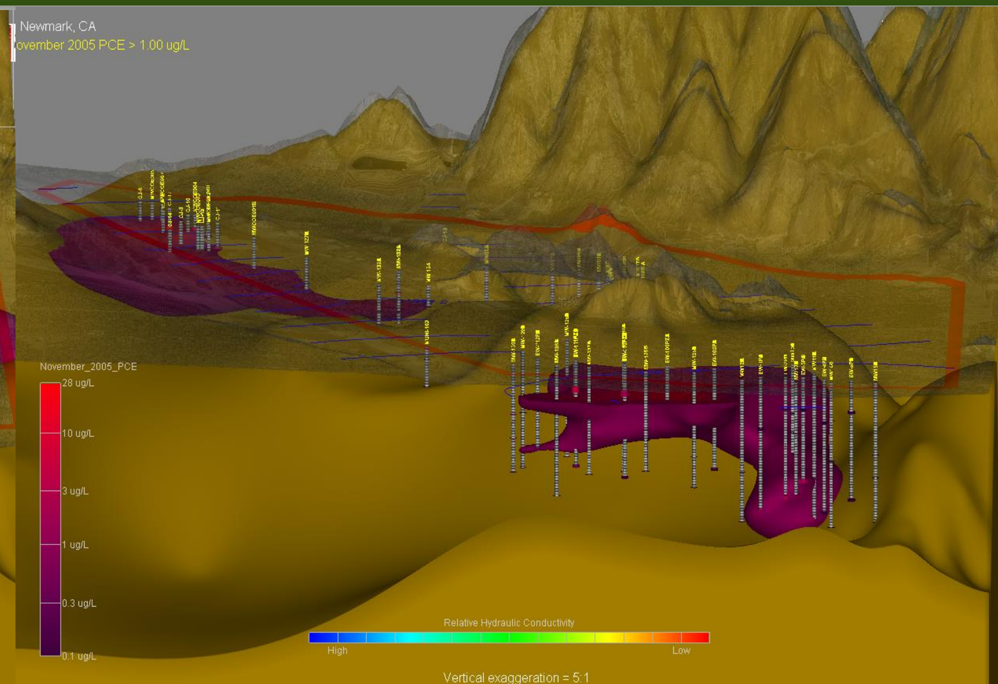
Plans required- Region, Site, Project



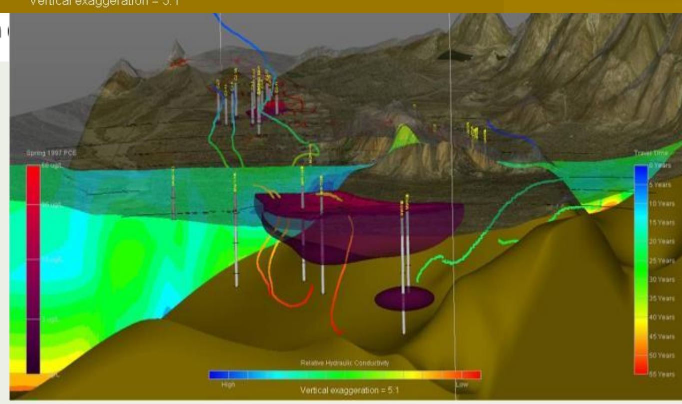
- **Data acquisition**
  - Occurs quickly, involves large amounts of data
  - Data must be integrated into CSM quickly to inform continued data acquisition while mobilized
- **Data input**
  - Automatic/manual systems to QC at point of generation accurately transfer to databases
- **Decision Support**
  - Statistical, visualization, modeling
- **Communicate**
  - Force interpretation, compress timeframes

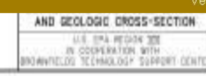
Data Management Leads to a Robust Conceptual Site Model





- Investigation efforts confirm or refute each





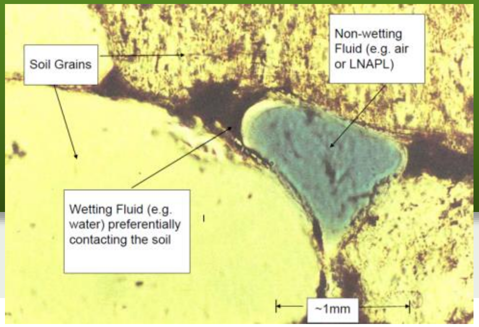
2010 to present

Donald Rumsfeld,

Feb. 12, 2002
U.S. Department of Defense

Death of the Pancake Model

- **Bad news…**
  - » LNAPL body structure can be complex
  - » Sometimes measurable LNAPL never enters monitoring wells
  - » Even purposely screened within/across the LNAPL body, and after years of monitoring.
- **Good news…**
  - » Mobile LNAPL remarkably stable if prevailing hydraulic conditions maintained
  - » The geometry and structure of the LNAPL body can be reliably mapped
  - » Allows near-surgical precision for remediation targeting
- **So now what?**
  - » Remediation strategy based on LNAPL as the source of dissolved phase COCs versus LNAPL migration risk
  - » Enter risk based corrective action, petroleum mixing zones, low risk closures



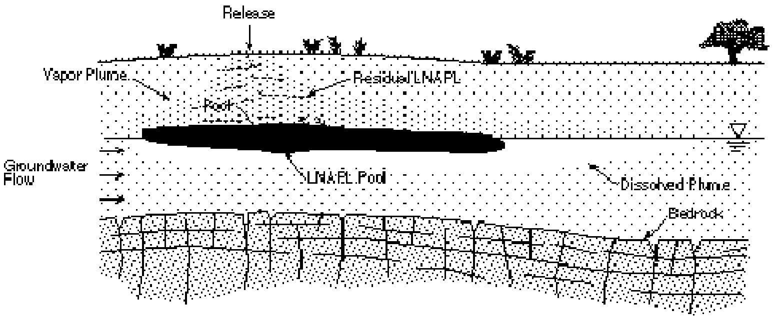
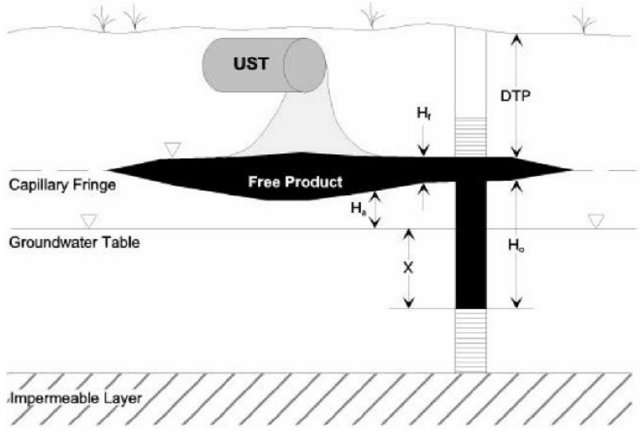


Figure 3-8
Typical distribution of light nonaqueous phase liquid (LNAPL) in the subsurface

Figure 2 – Tank and Pancake Conceptual Model



A Few Notes On NAPL
Actual versus Apparent LNAPL Thickness

- **Observed LNAPL well thickness**
  - LNAPL inside/outside of wells not always in equilibrium
  - Inconsistencies between soil types
  - Changes with water elevation fluctuations
  - Impacted by hydraulic scenarios (unconfined, confined, perched groundwater conditions)
  - Poor indicator of LNAPL presence and recoverability
    - Transmissivity gaining in use and acceptance
- **Determine actual thickness using well baildown tests**
  - Modified aquifer slug test solutions for K_o (Bower & Rice)
  - K_o estimated from changes in oil thickness (Lundy & Zimmerman)
  - K_w estimated from rising water table (Lundy & Zimmerman)
  - K_o estimated from recovery of the oil table (Huntley)

Source: Parcher, Unknown

- ***Recommended Actions***
  - *Assess/mitigate immediate threats to safety –Sec 1 (p.11)*
  - Conduct a site characterization and develop a conceptual site model (CSM) – see Section 3 (p.39)
  - Delineate a lateral inclusion zone – see Section 4 (p.44)
  - Determine vertical separation distances for each building within the lateral inclusion zone – see Section 5 (p.48)
  - Evaluate vapor source and attenuation of PHC vapors – see Section 5 (p.48), Section 8(p.66), Section 9 (p.75), Section 10 (p.81), Section 12 (p.100), and Section 13 (p.106)
  - Mitigate PVI, as appropriate – see Section 1 (p.11)

Challenging to Meet Recommended VI Actions in the Absence of HRSC Techniques, Tools, and Strategies *(Table 1)*

✓ *Conduct a site characterization and develop a conceptual site model (CSM)*

Once the immediate threats to safety have been mitigated (or it is determined that immediate threats do not exist), determine whether there is a long-term threat to human health and the environment from intrusion of petroleum vapors. Site characterization[20] and CSM development provide information about the full extent and location of the contamination; the nature and characteristics of the contamination; the characteristics of the site that influence contaminant migration, including the potential for biodegradation of PHCs; and the locations of receptors. Information derived from the CSM helps ensure that sources, pathways, and receptors throughout the site are considered; this knowledge can lead to selection of the most appropriate sampling locations and techniques. A systematic soil gas sampling program may also aid in defining the full extent and location of contamination, detecting the presence of preferential transport pathways, and locating pockets of PHC vapors. Preferential transport pathways are avenues of least resistance to the migration of contaminants whether in the dissolved phase, LNAPL phase, or vapor phase. They include both natural and man-made features such as:

Natural

- gravel lenses and channels
- solution channels in karst terrain
- bedding planes
- fractures, joints, and faults in consolidated rock

Man-made

- utility corridors (including sewer lines themselves) and trenches
- elevator pits
- sumps and drainage pits
- other types of excavations

[20]The term *site characterization* is used throughout this document for consistency. *Site characterization* is often used interchangeably with *site assessment*, *site evaluation*, *site investigation*, and sometimes *site check* as they all mean assembling and collecting information and data about a site.

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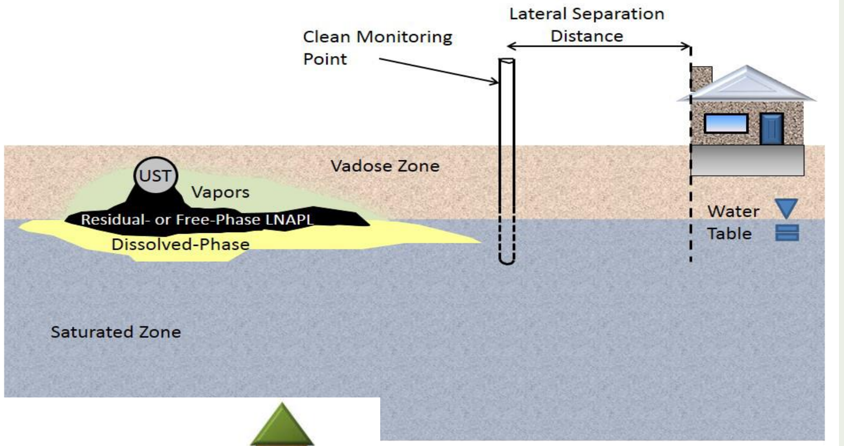
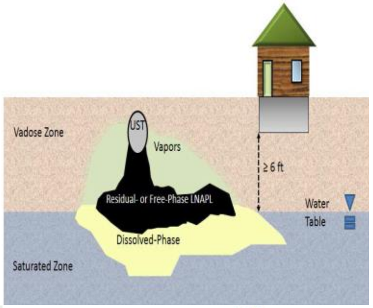




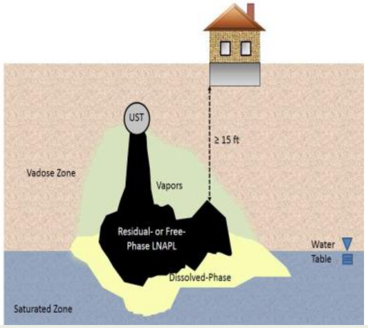
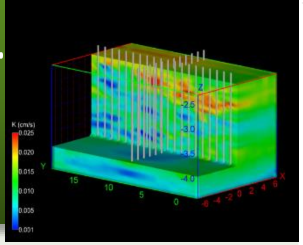


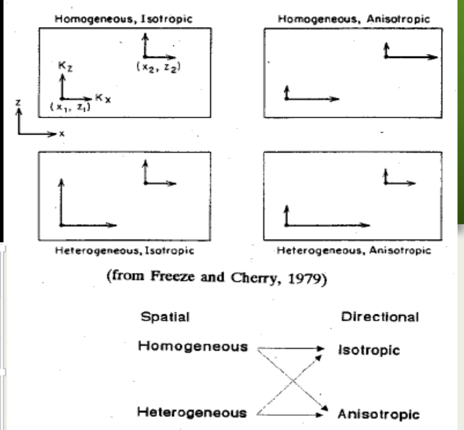
Table 1. Recommended Actions For Addressing PVI At Leaking Underground Storage Tank Sites

Recommended Actions	Purpose And Objectives	Procedures
Assess and mitigate immediate threats to safety (see Section 1, p.11)	Identify potential threat of explosion or fire due to petroleum vapors or methane. Threat may be indicated by: • LNAPL visible in building, possibly as sheen in sump • Noticeable petroleum odor; headache, dizziness, or nausea • Atypical, unusual, or disagreeable taste or smell in the water supply NOTE: Methane cannot be detected on the basis of odor, taste, or visible signs	• Investigate all reports of petroleum odors and other indicators within buildings • Detection of the presence of methane; requires specialized devices • Alert first responders so that they can, if necessary, evacuate building occupants as necessary until the potential for fire or explosion has been assessed and mitigated as needed
Conduct a site characterization and develop a conceptual site model (CSM) (see Section 3, p.39)	Characterize the physical, biological and chemical systems at the site, with emphasis on determining the spatial and temporal relationship between receptors and sources of contamination by: • Determining the full extent and location of contamination and its nature • Assessing the potential for biodegradation of PHCs • Defining the hydrologic and geologic characteristics of the site • Identifying potential receptors in the vicinity • Identifying whether preferential transport pathways are present and connect PHC vapor sources with potential receptors. Preferential transport pathways Include both natural (i.e., geologic) and man-made (i.e., underground utilities, excavations) features.	• Collect sufficient site data and information to construct CSM • Identify data gaps • Update CSM as new data become available • Where preferential transport pathways connect PHC vapor sources to receptors (e.g., buildings), indoor air sampling paired with sub-slab vapor sampling is recommended
Delineate a lateral inclusion zone (see Section 4, p.44)	Screen out buildings that are not likely to be impacted by PVI to narrow the investigation to only those buildings that have a greater potential for PVI and for which further investigation should be conducted. The lateral inclusion zone is site-specific and: • Based on the extent of contamination and distance between clean monitoring points • Decreases in extent as additional data are collected to reduce uncertainty in the CSM	• Construct lateral inclusion zone based on distance between clean monitoring points (includes consideration of the presence of preferential transport pathways)
Determine vertical separation distances (see Section 5, p.48)	Further screen out buildings that are not likely to be impacted by PVI to focus the investigation on potential receptors that overlie contamination in the dissolved, vapor, and/or LNAPL phase. The vertical separation distance is: • The thickness of clean, biologically-active soil	• For each building within the lateral inclusion zone, collect additional soil gas, soil, and groundwater samples as necessary to determine the vertical separation distance. Additional investigation is generally unnecessary

Let’s Start with Groundwater-

Challenges, Strategies, and Tools

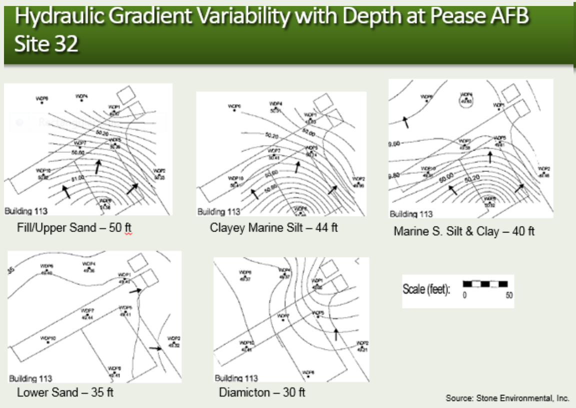


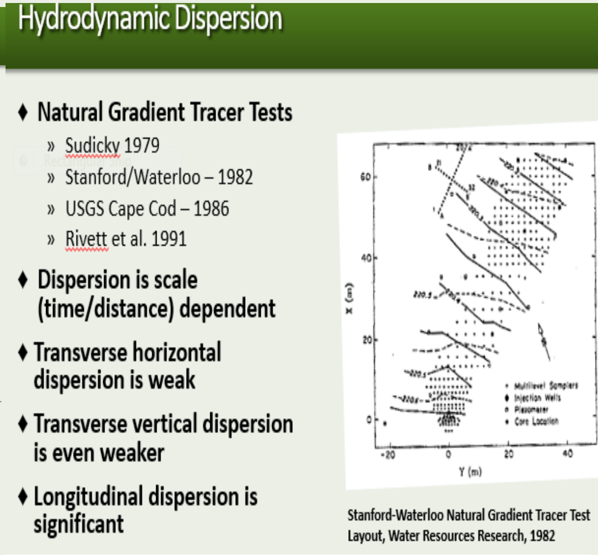


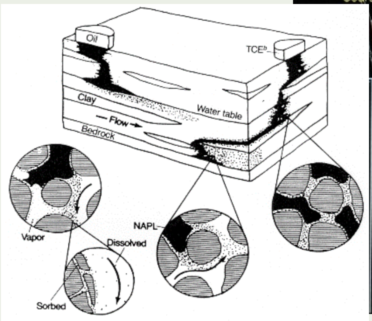
Challenges

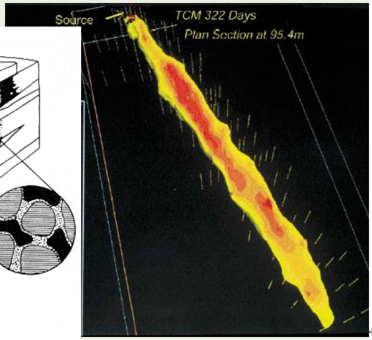
- **Heterogeneous, anisotropic conditions**
- **Hydraulic gradient- 3 dimensional, temporal variation**
- **Advection/Dispersion**
- **Contaminant phase**
  - NAPL (density, viscosity, mobility, dissolution)
  - Gas
  - Solute (dissolved)
  - Sorbed

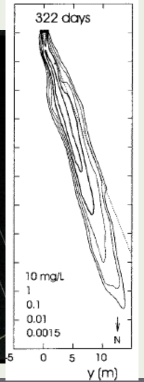
Location	Horizontal K Correlation Length (m)	Vertical K Correlation Length (m)	Investigator
Borden, Ontario	2.8	0.12	Sudicky (1986)
Otis, ANGB	2.9 – 8	0.18 – 0.38	Hess et al. (1992)
Columbus AFB	12.7	1.6	Rehfeldt et al.
Aefligan	15 – 20	0.05	Hess et al. (1992)
Chalk River, Ontario	1.5	0.47	Indelman et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

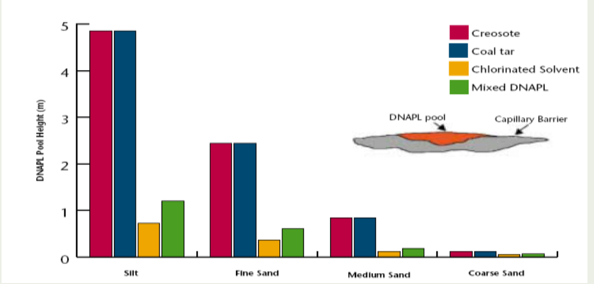












Let's Start with Groundwater-
Challenges, Strategies, and Tools

Strategies*

- **Transects**
- **Vertical profiling**
- **HRSC, direct sensing**
- **Collaborative data sets**
- **Well placement, screen interval**

Tools*

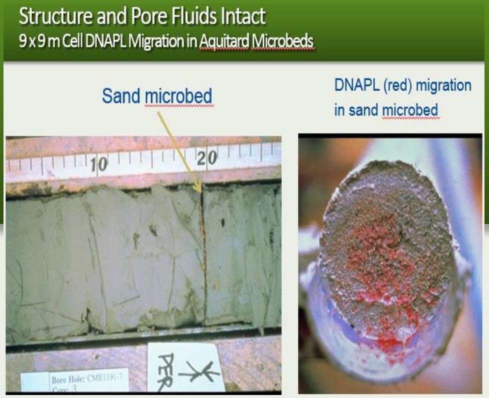
- **Direct push**
- **Direct sensing- MIP, LIF, FFD**
- **Geophysical and geologic**
  - CPT, EC, GPR, EM, resistivity
- **Hydrostratigraphic**
  - Waterloo APS, HPT, piezocone
- **Soil gas**
  - Passive, active

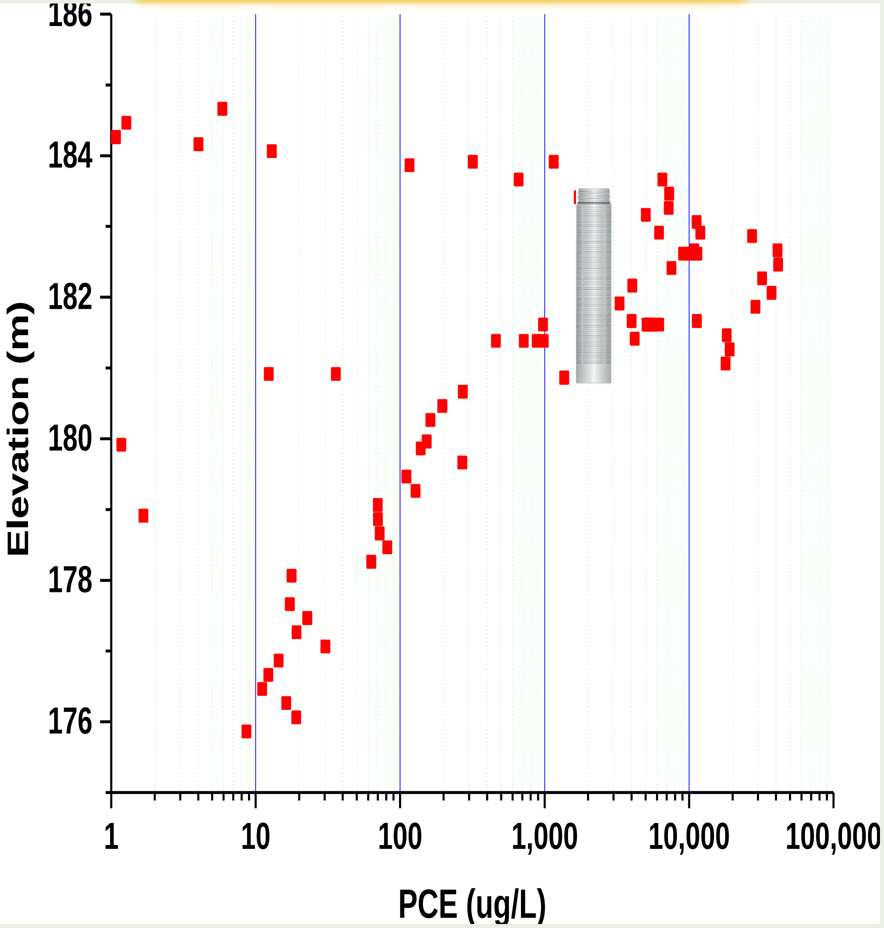
* Partial list

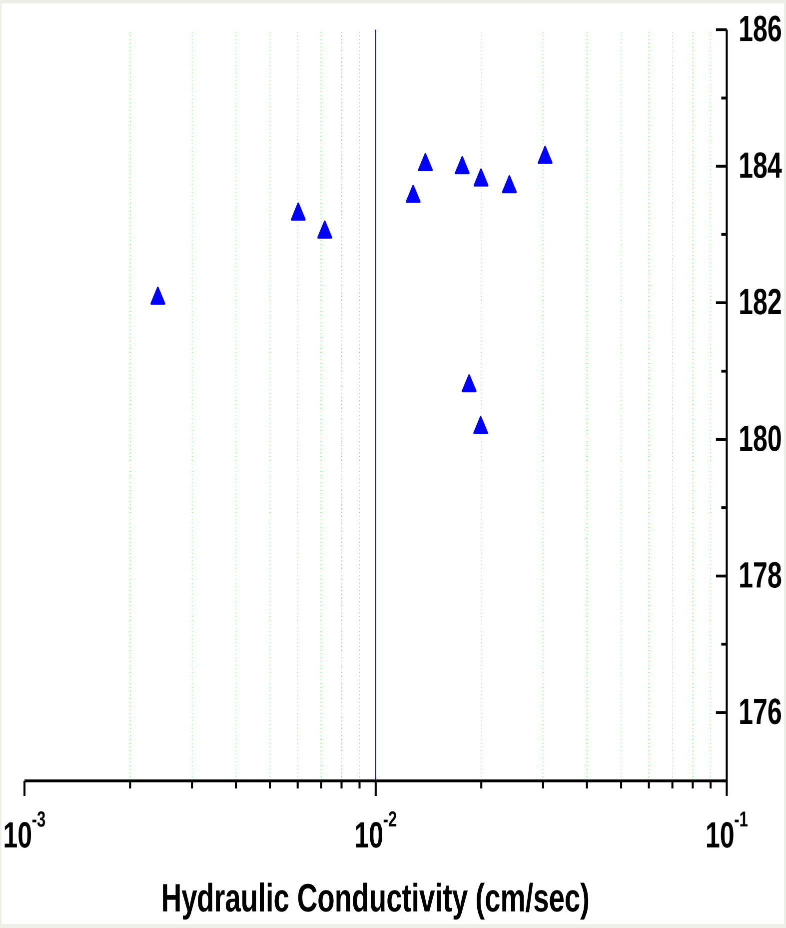
Sampling Scale and Averaging

How "Well" Do You Know Your Site

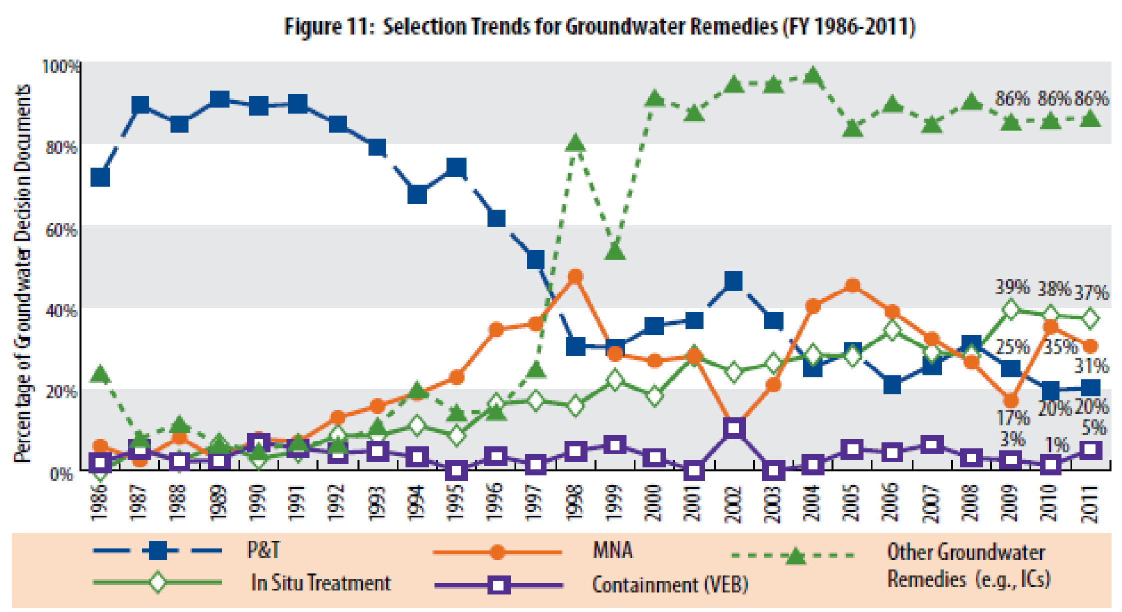
Monitoring wells yield a depth integrated flow weighted average







Mass Flux Distribution- And The Rise of In-Situ Remedies



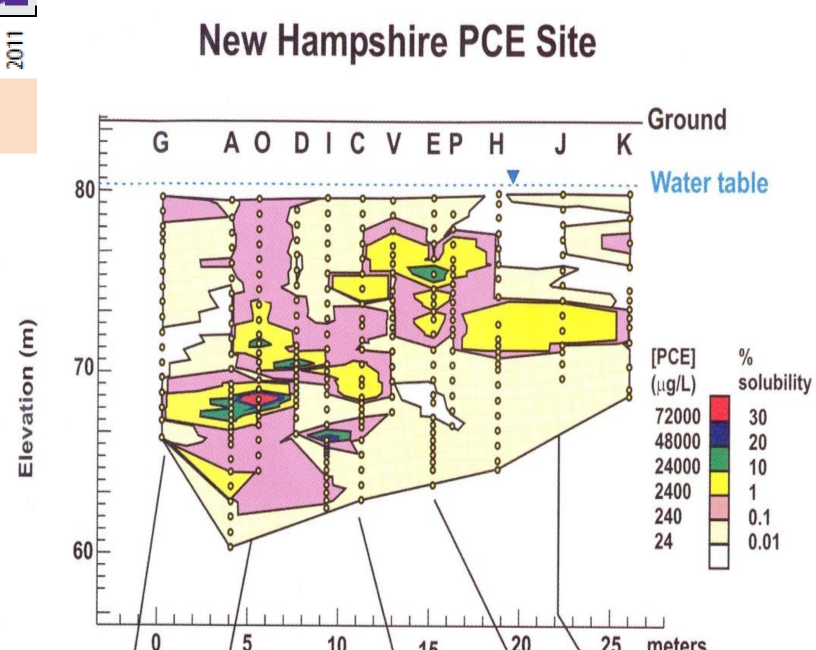
Superfund Remedy Report 14th edition

- **1980's- Pump and Treat 90% of GW remedies, no in-situ remedies**
- **2011- Pump and Treat 30%, In-situ almost 40%**

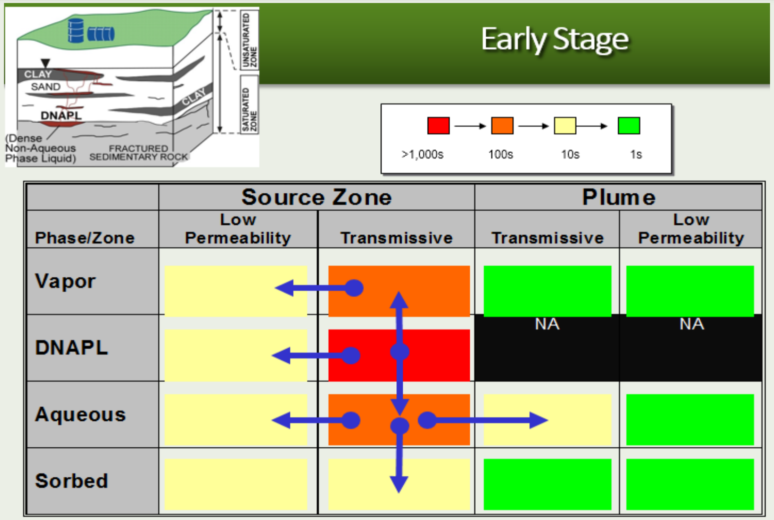
Guilbeault et al., 2005

75% of mass discharge occurs through 5% to 10% of the plume cross sectional area

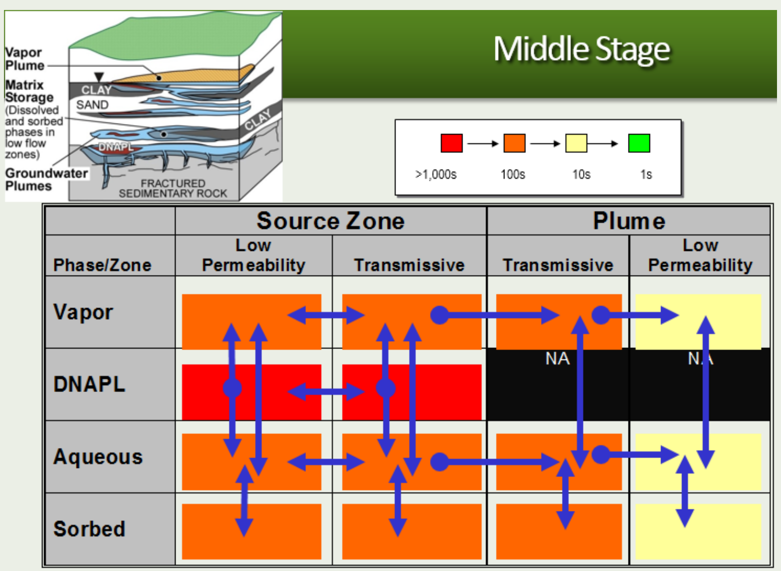
Optimal Spacing is ~0.5 m



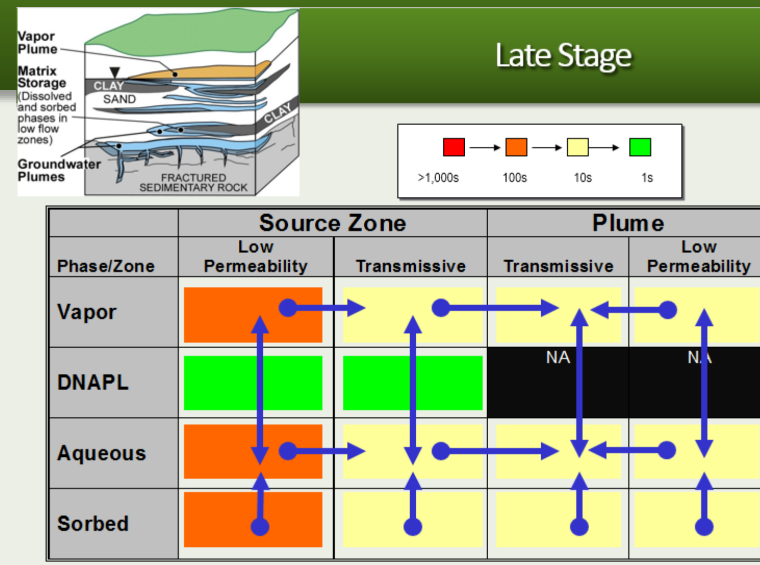
Spatial Variability In Flux…… But Also Temporal



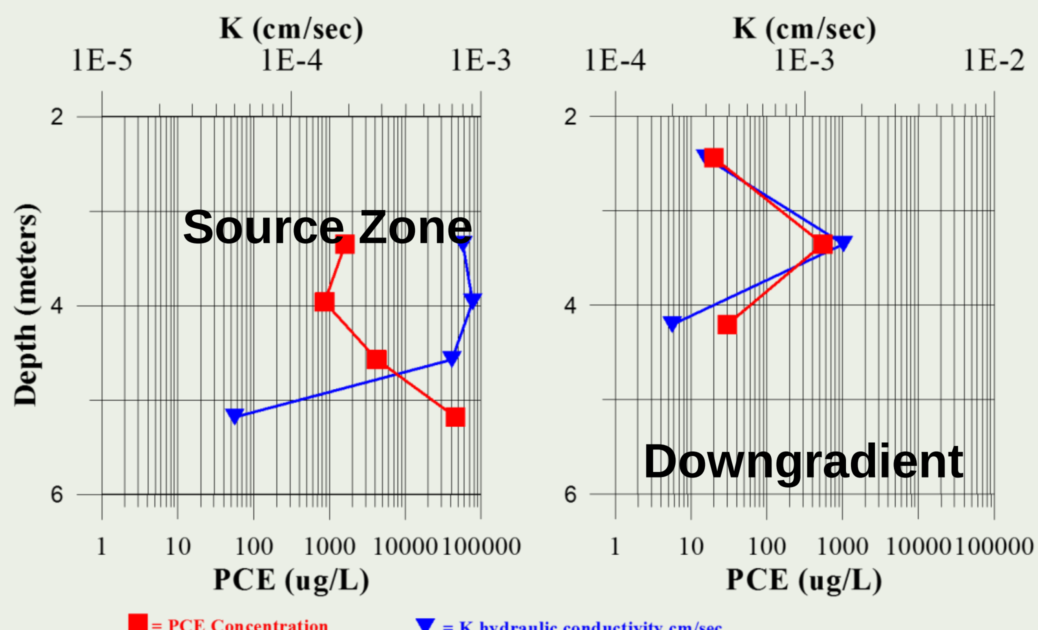
Tom Sale and Chuck Newell



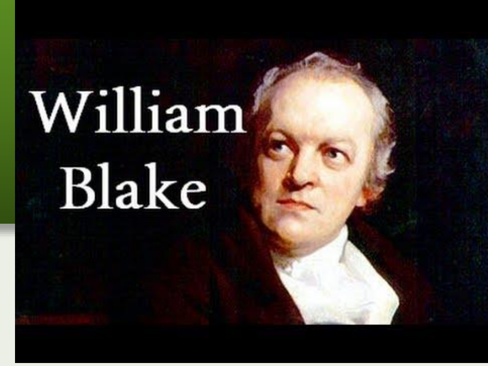
Tom Sale and Chuck Newell



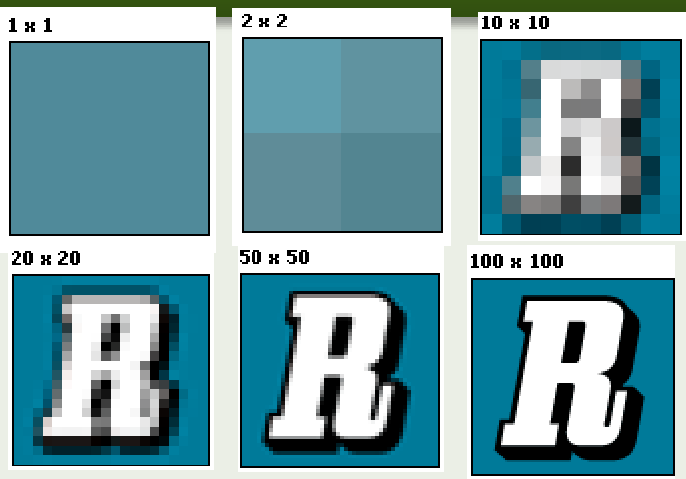
Tom Sale and Chuck Newell



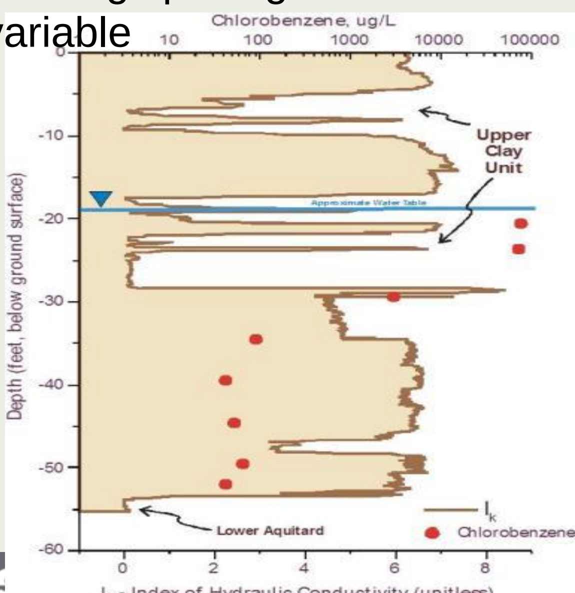
How Much is Enough?



"You never know what is enough unless you know what is more than enough!"



With real-time or direct sensing spacing can be variable



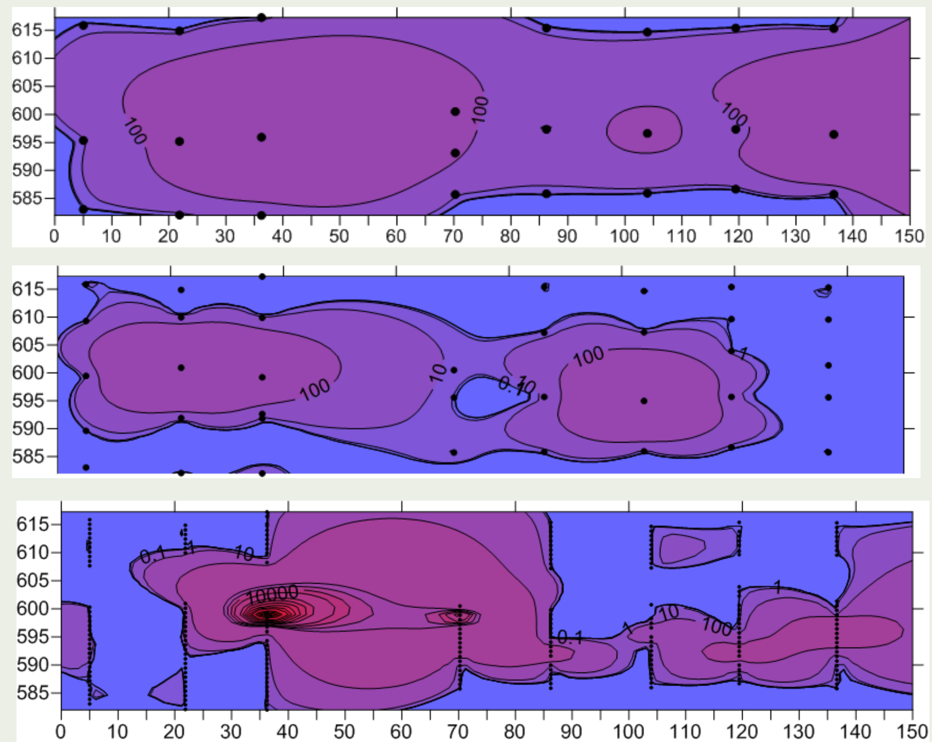
Multi-Level Sampling Transect

PCE in a Sandy Aquifer

Shallow, medium, deep

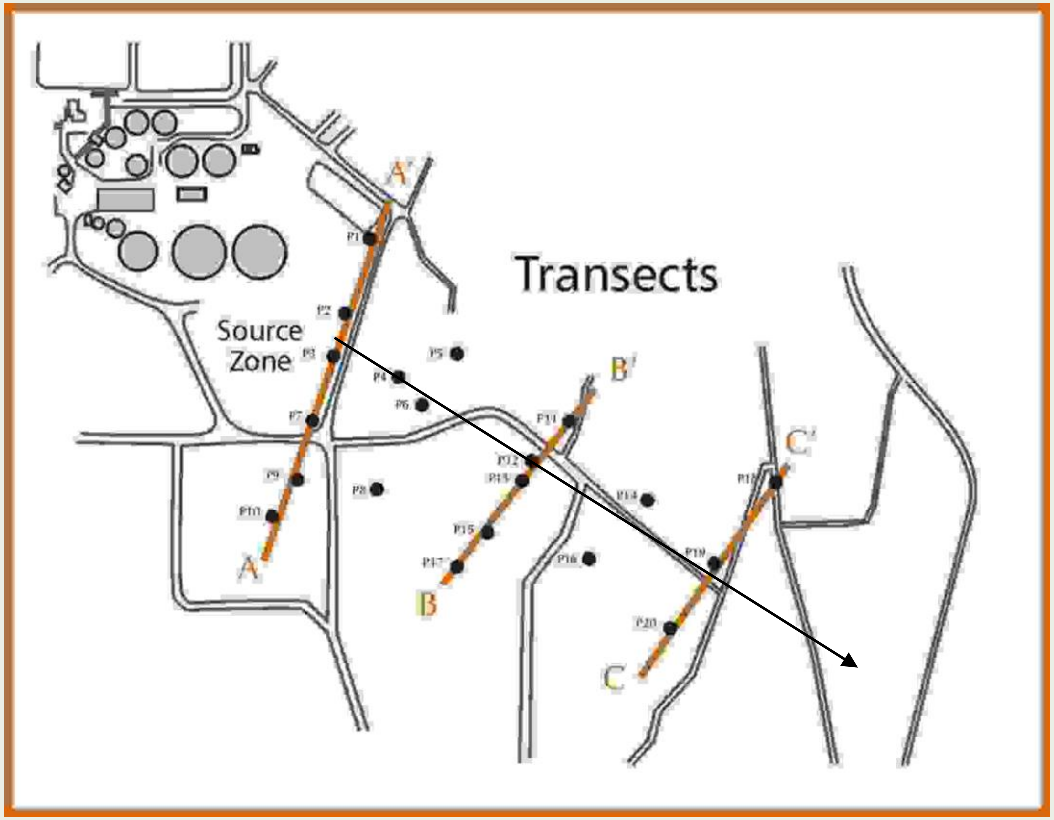
10-ft vertical spacing

0.8-ft vertical spacing

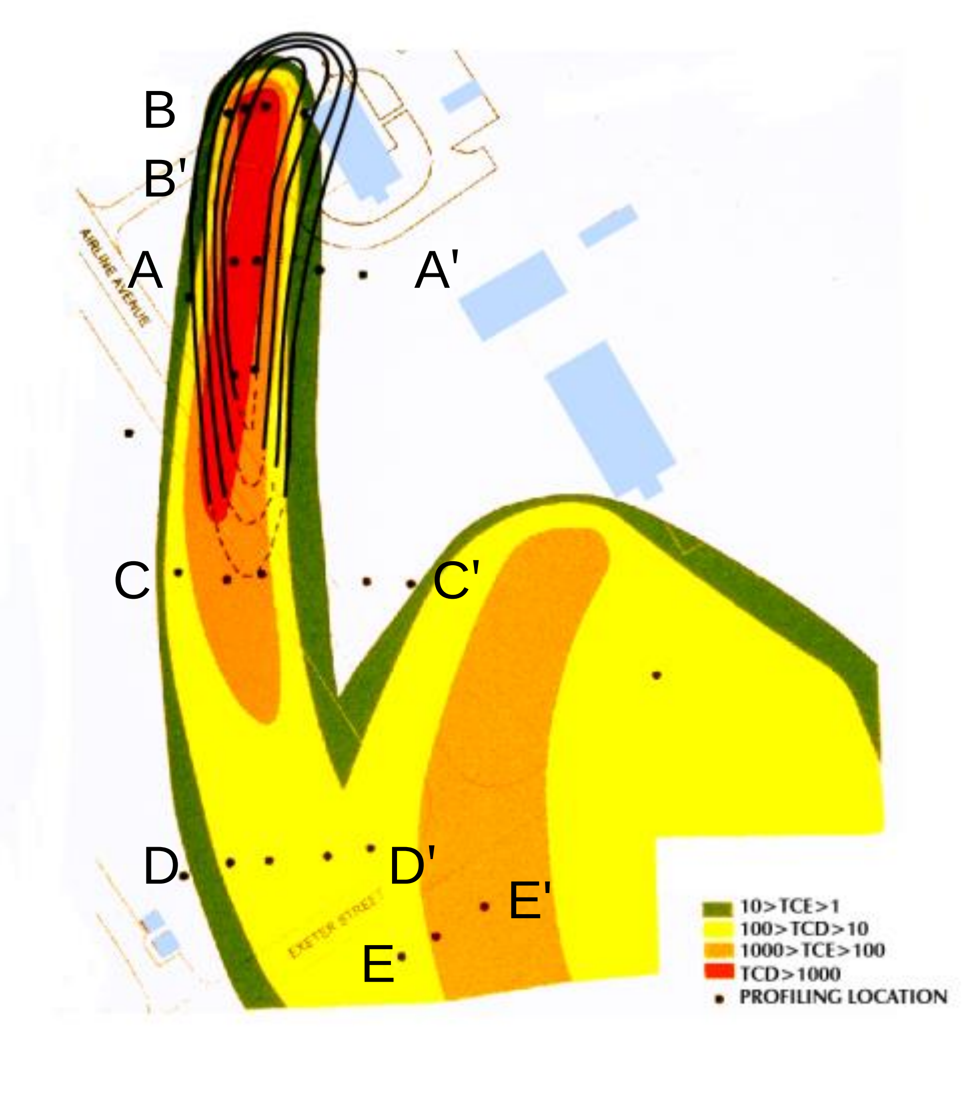


Site Scale and Transect-Based Profiling Approach

- **<u>Transect</u>: Line of vertical profiles oriented normal to the direction of the hydraulic gradient (groundwater flow)**
- **<u>Sample Interval</u>: Vertical dimension of the sampled portion of the aquifer**
- **<u>Sample Spacing</u>: Vertical distance between samples**

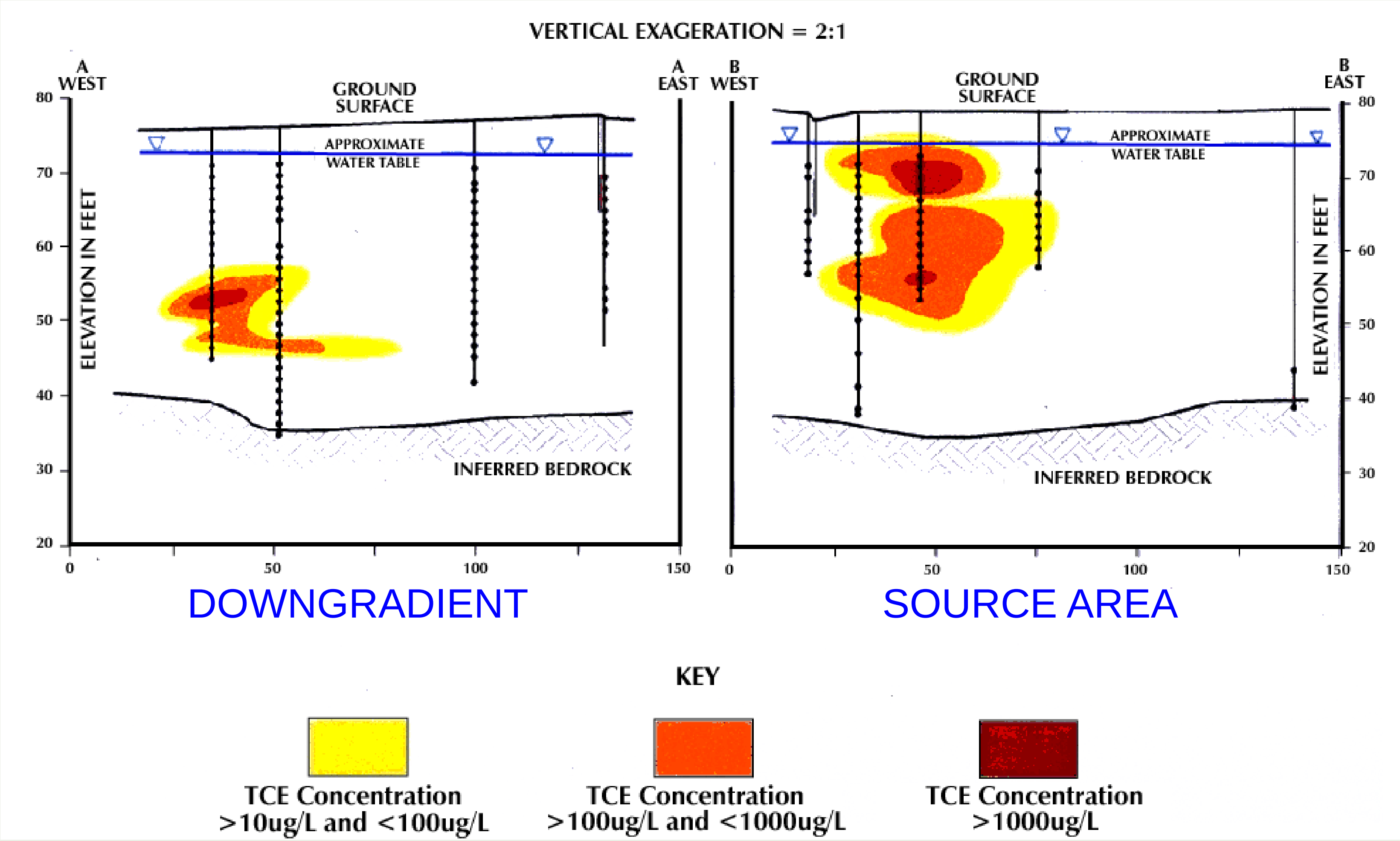


Transect Case Study: Secondary Groundwater Plume Characterization, Pease AFB, NH

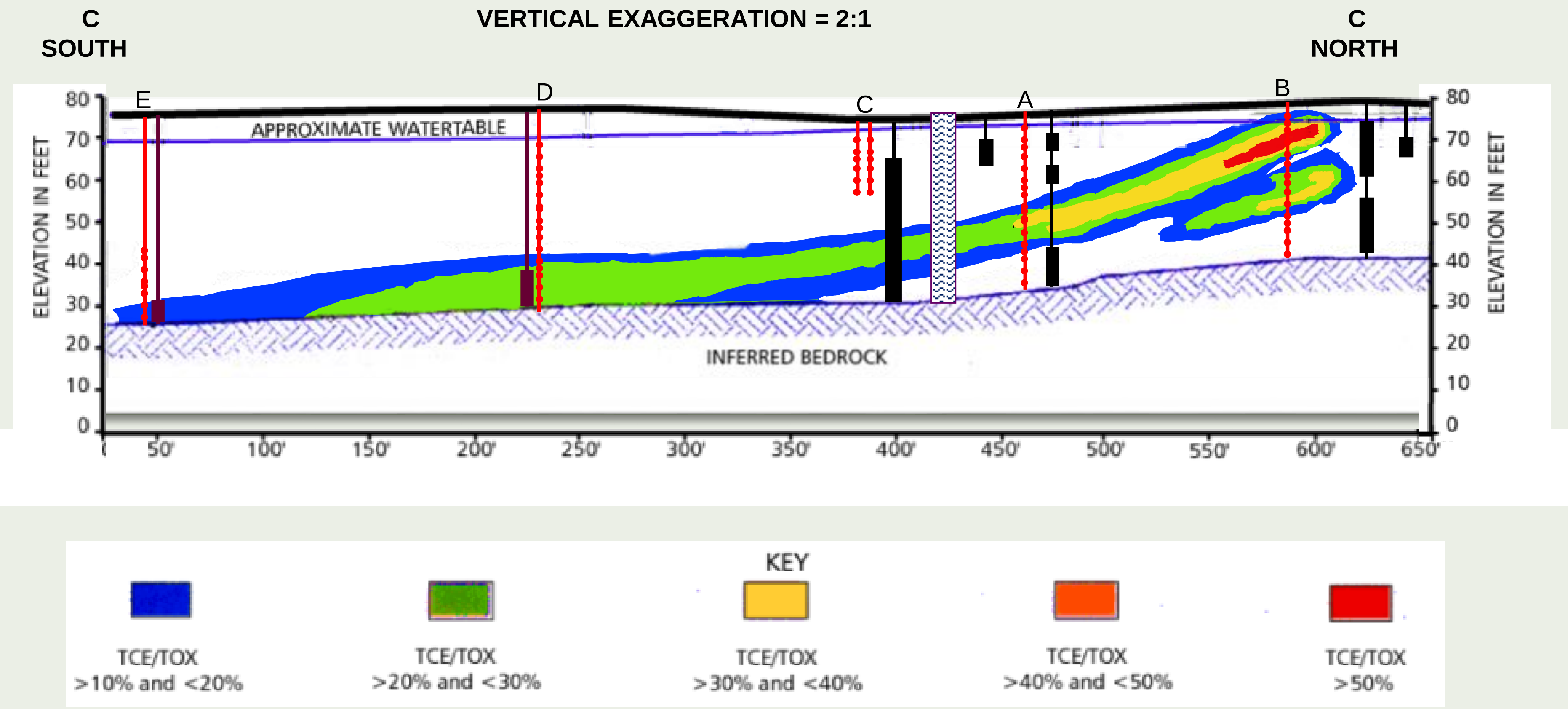


- **VOC and POL release site**
- **VOCs potentially affecting two bedrock supply wells**
  - » Concern over DNAPL in bedrock
- **Prior monitoring well investigation did not accurately characterize the plume**
  - » Defined as “short plume”
- **5 Modified Waterloo Profiler transects performed normal to plume axis**
  - » A - A’ = Downgradient of source
  - » B - B’ = Through source area
  - » C - C’ / D - D’ / E - E = Downgradient plume delineation

Profiler Cross Sections Showed VOC Plume was Sinking with Distance from Source (vs. "short plume")

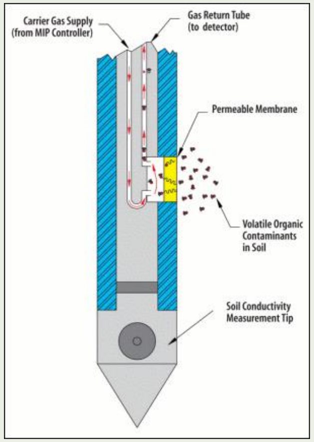


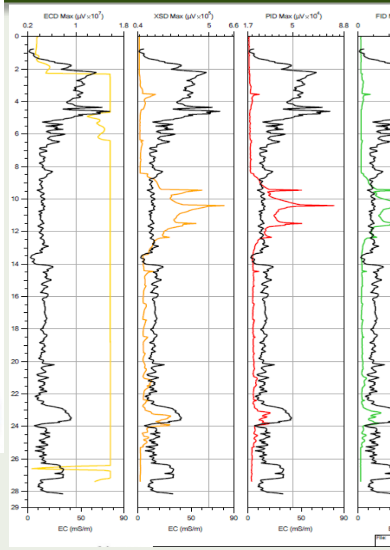
Plume Anatomy Characterization & Remediation: Vertical Profiling vs. Monitoring Well

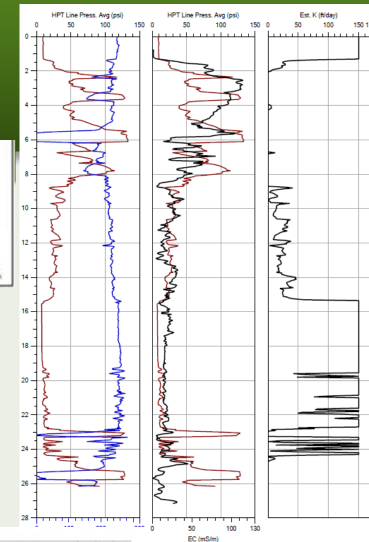


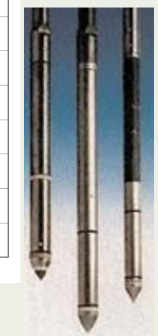
Prior Investigation Monitoring Well Stone Profile Stone Monitoring Well

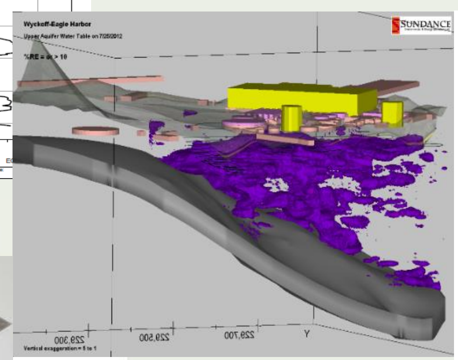
HRSC- Profound Effect on CSMs
Many Advances in Tools- Just A Few Examples

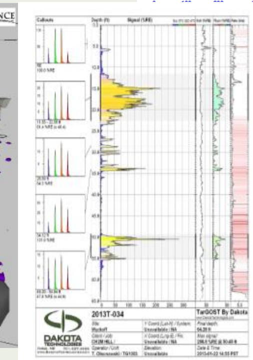


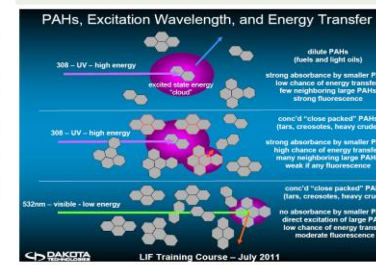




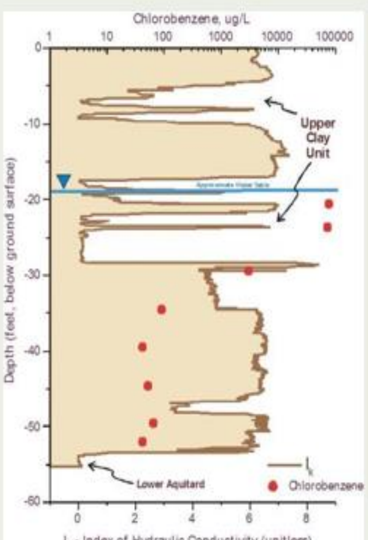




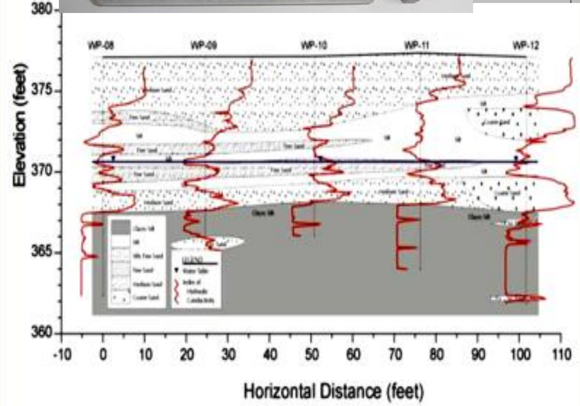


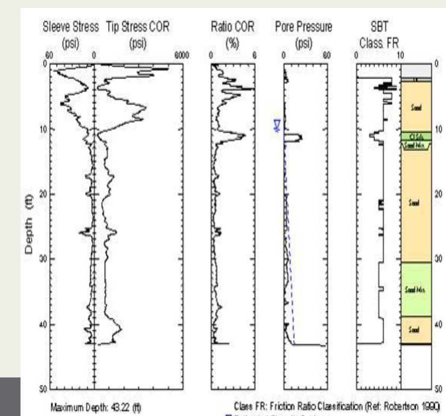


Sample depth selection

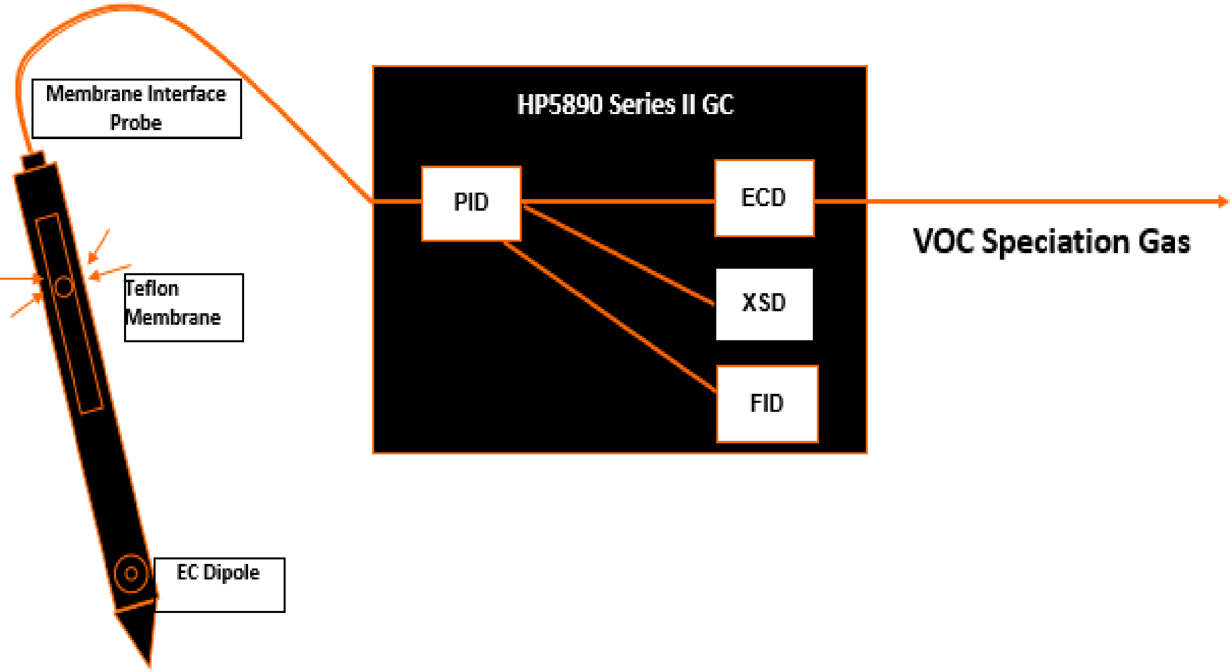


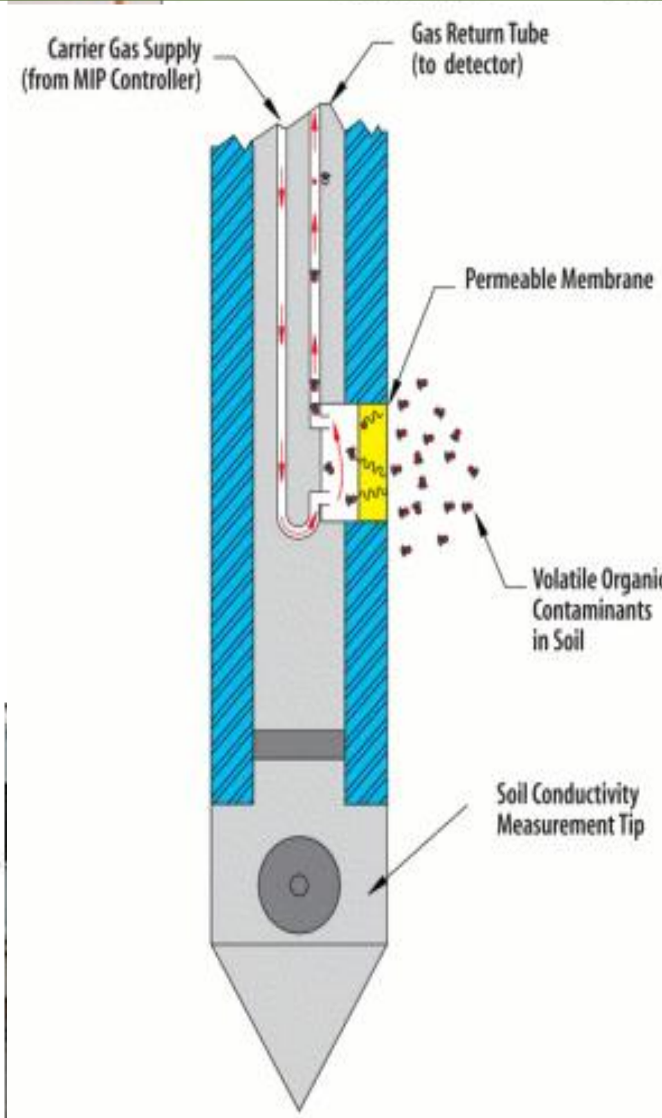
Stratigraphic Interpretation





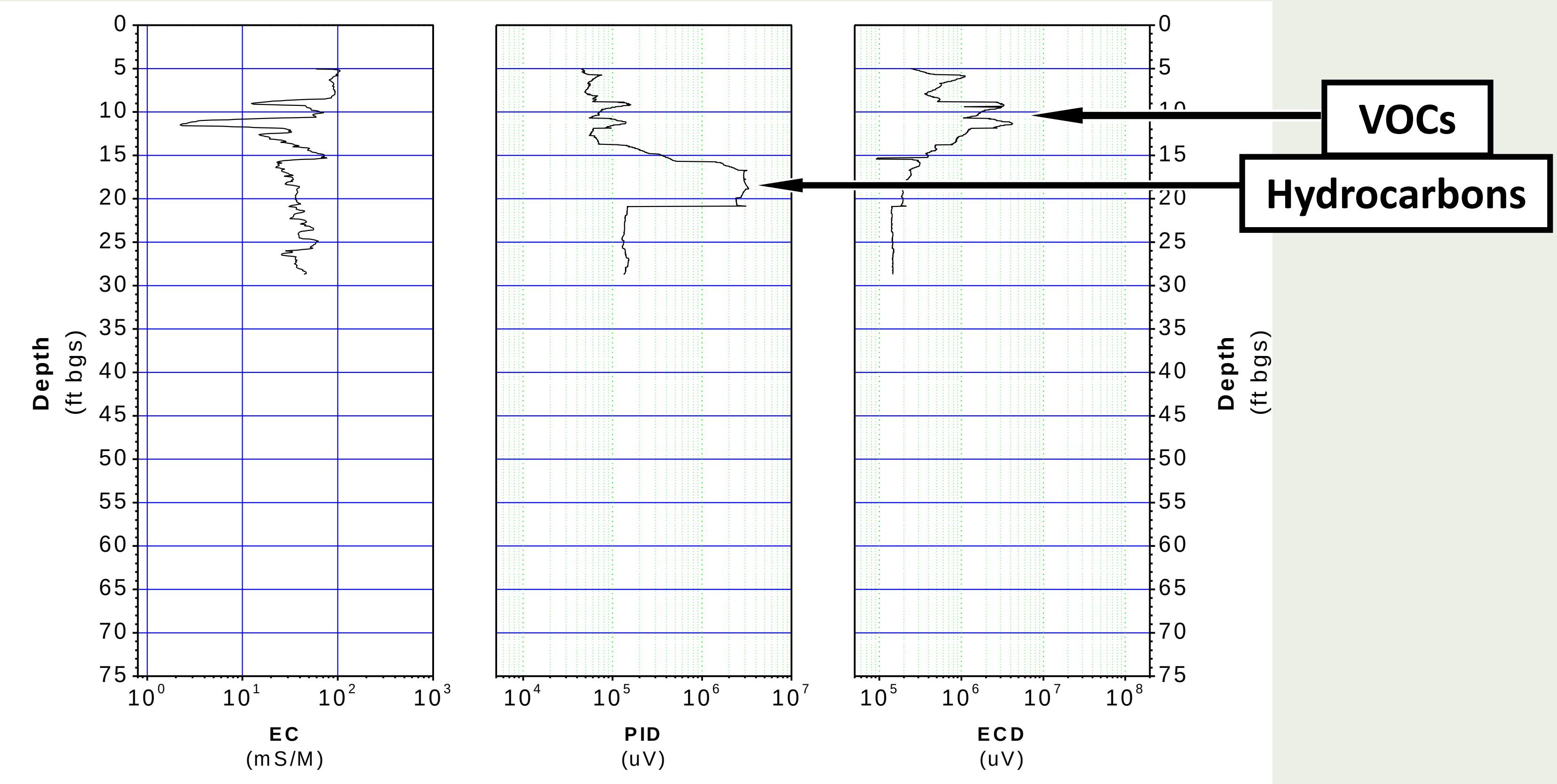
Membrane Interface Probe- MIP





Case Example – Real-Time MIP

With onsite VOC vapor speciation



LOC	DEPTH	Trans 1,2-DCE	1,1-DCA	Cis 1,2-DCE	TCA	TCE	PCE	TCE:THOC	Presence of Hydrocarbons
MIP-13	11	0	0	120	624	5,035	0	0.87	NO
MIP-13	18	0	0	1,645	0	365	672*	0.18	YES

STONE ENVIRONMENTAL INC

Recent Study Confirms MIP is Only a Qualitative Screening Tool

MIP works well for rapid location of relative high concentration zones such as plume cores or source areas.

MIP does not work well for estimating contaminant concentrations or mass.

Groundwater

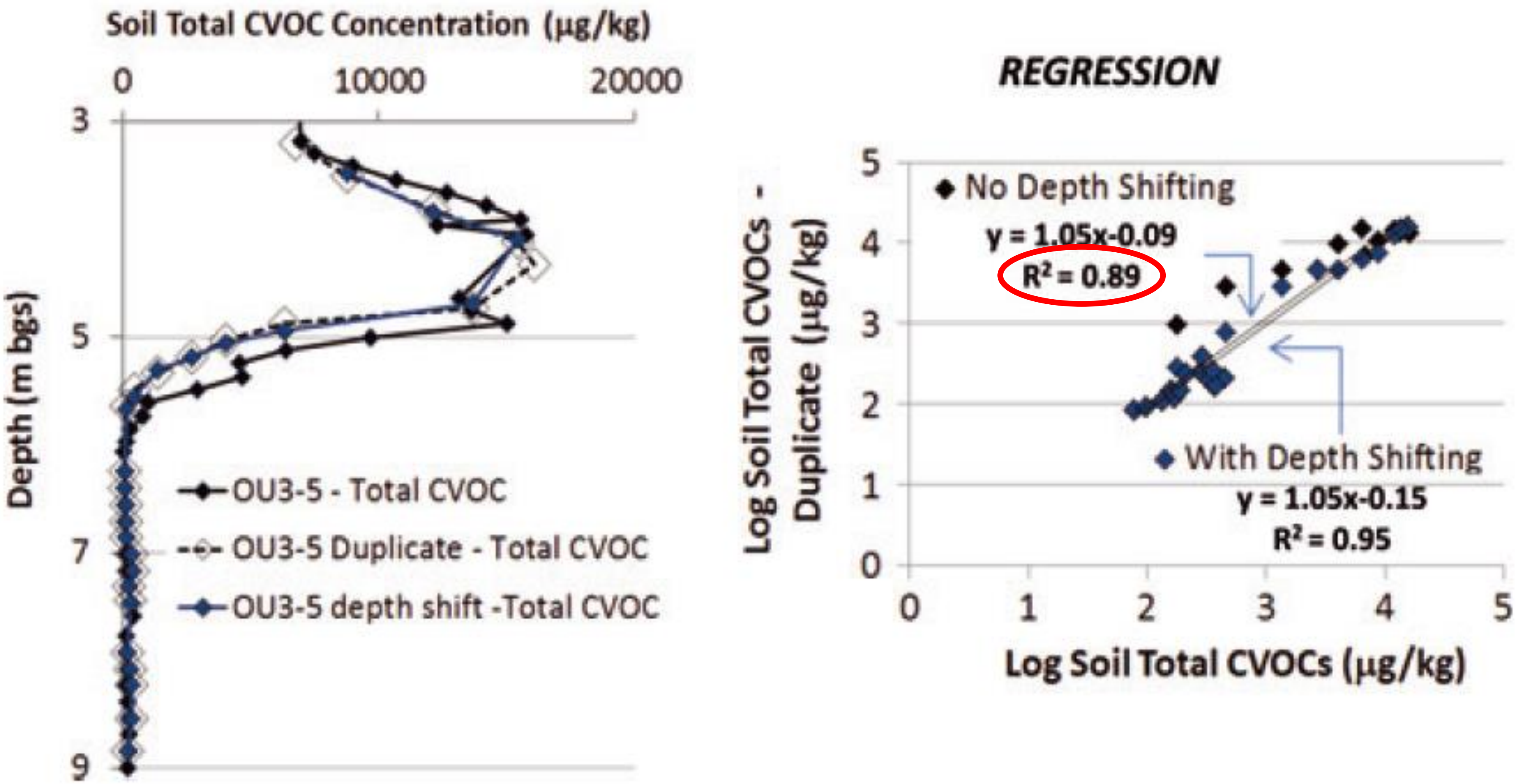
Membrane Interface Probe Protocol for Contaminants in Low-Permeability Zones

by David T. Adamson[1], Steven Chapman[2], Nicholas Mahler[3], Charles Newell[3], Beth Parker[2], Seth Pitkin[4], Michael Rossi[4], and Mike Singletary[5]

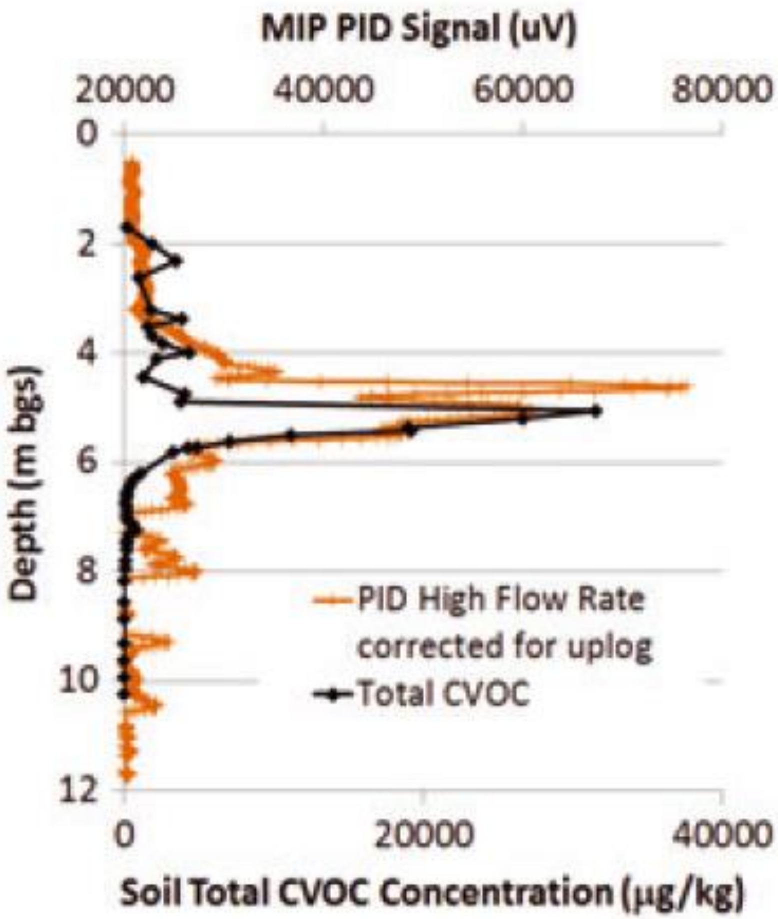
Abstract

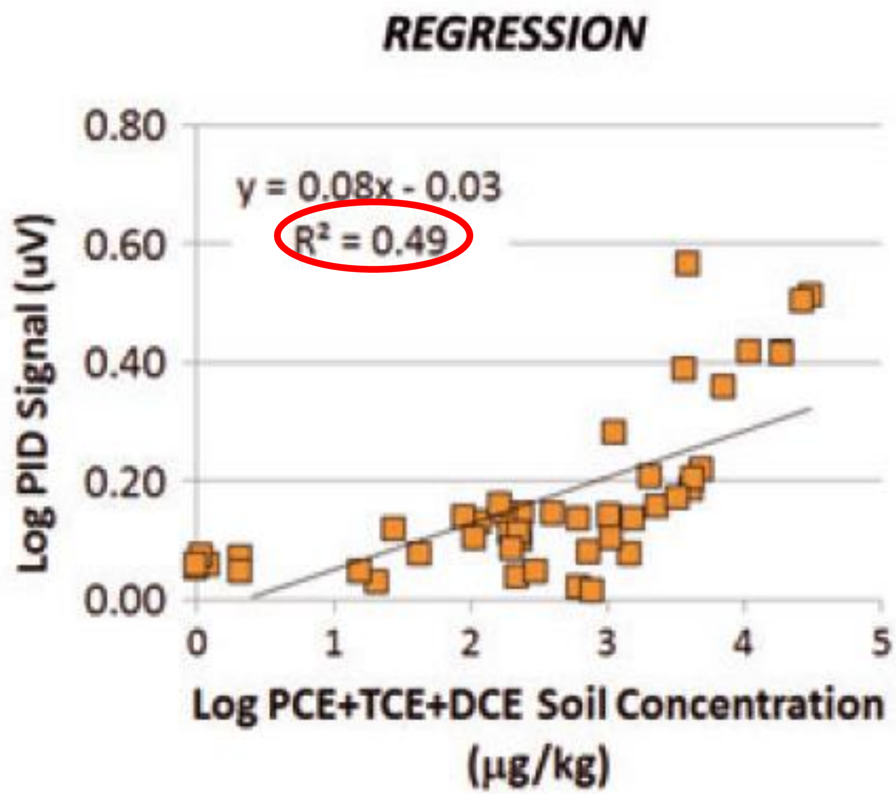
Accurate characterization of contaminant mass in zones of low hydraulic conductivity (low k) is essential for site management because this difficult-to-treat mass can be a long-term secondary source. This study developed a protocol for the membrane interface probe (MIP) as a low-cost, rapid data-acquisition tool for qualitatively evaluating the location and relative distribution of mass in low-k zones. MIP operating parameters were varied systematically at high and low concentration locations at a contaminated site to evaluate the impact of the parameters on data quality relative to a detailed adjacent profile of soil concentrations. Evaluation of the relative location of maximum concentrations and the shape of the MIP vs. soil profiles led to a standard operating procedure (SOP) for the MIP to delineate contamination in low-k zones. This includes recommendations for: (1) preferred detector (ECD for low concentration zones, PID or ECD for higher concentration zones); (2) combining downlogged and uplogged data to reduce carryover; and (3) higher carrier gas flow rate in high concentration zones. Linear regression indicated scatter in all MIP-to-soil comparisons, including R^2 values using the SOP of 0.32 in the low concentration boring and 0.49 in the high concentration boring. In contrast, a control dataset with soil-to-soil correlations from borings 1-m apart exhibited an R^2 of $\geq$0.88, highlighting the uncertainty in predicting soil concentrations using MIP data. This study demonstrates that the MIP provides lower-precision contaminant distribution and heterogeneity data compared to more intensive high-resolution characterization methods. This is consistent with its use as a complementary screening tool.

Analytical Results from 2 Adjacent Soil Cores: Good Correlation

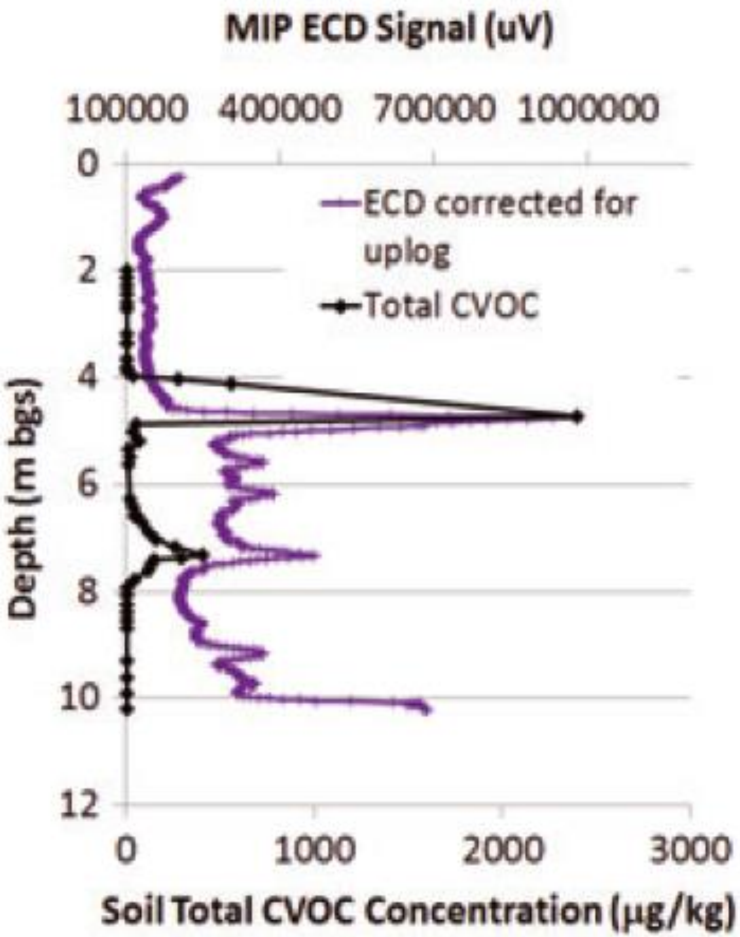


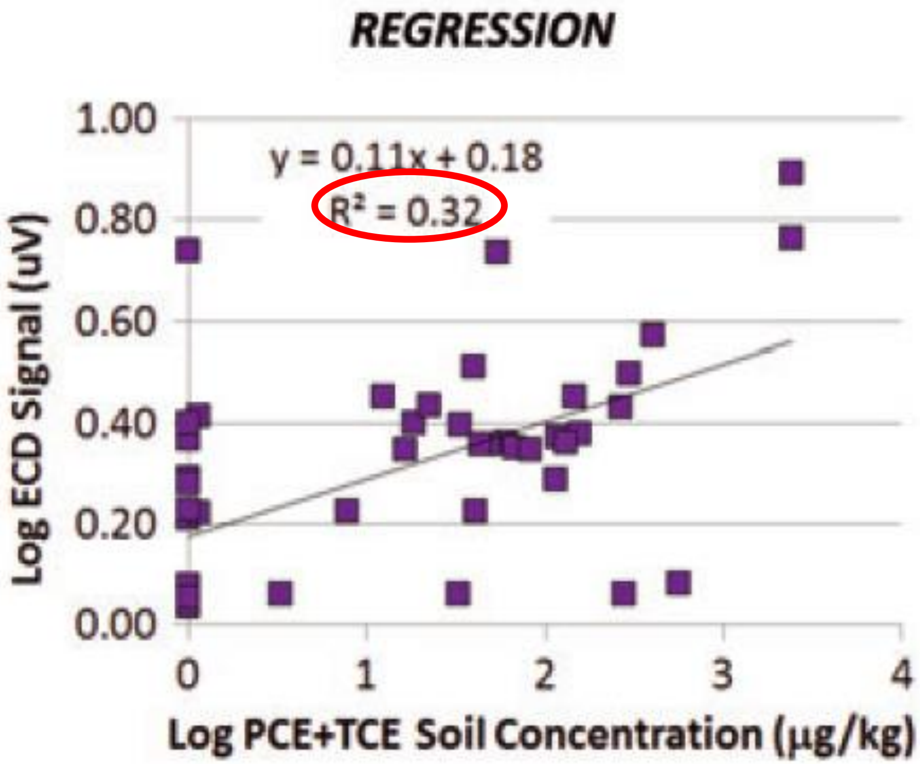
MIP and Soil Core High Conc. Location: Reasonably Good ID of Plume Location – Poor Concentration Correlation



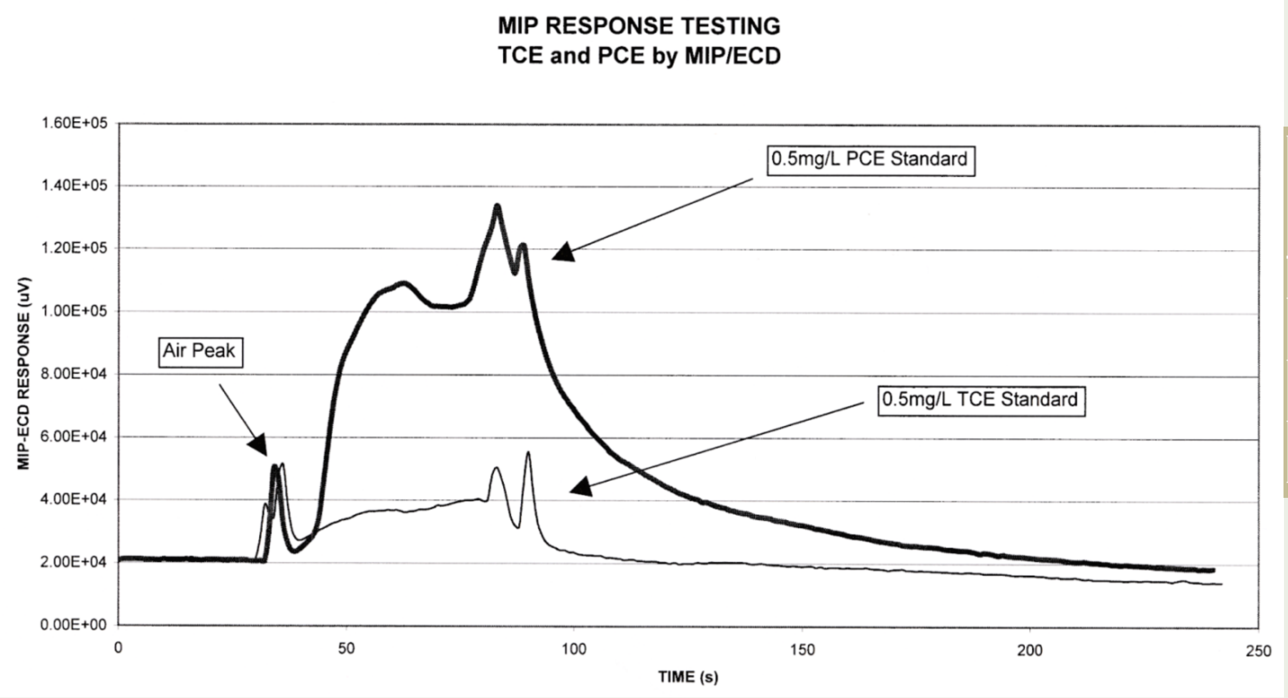


MIP and Soil Core Low Conc. Location: Reasonably Good ID of Plume Location – Poor Connection Correlation





Variability in ECD Detector Response



Response Test Results: ECD & PID with PCE, TCE and c-DCE

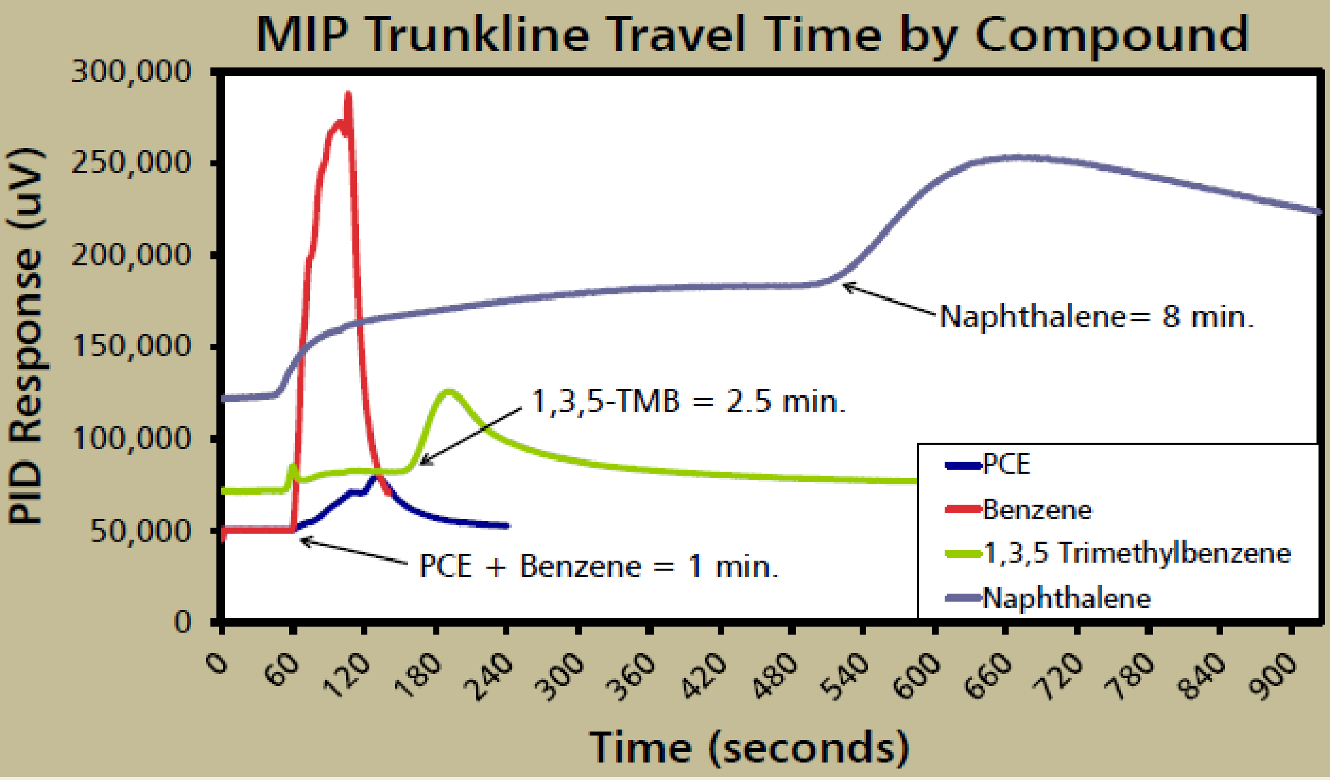
Compound	ECD Response, mV	PID Response, mV
PCE	1800	16
TCE	690	23
C-DCE	22	19

ECD Response: Dramatic Decrease
PID Response: No Significant Change

XSD, PID and FID RFs much more uniform

Factors Impacting MIP Performance

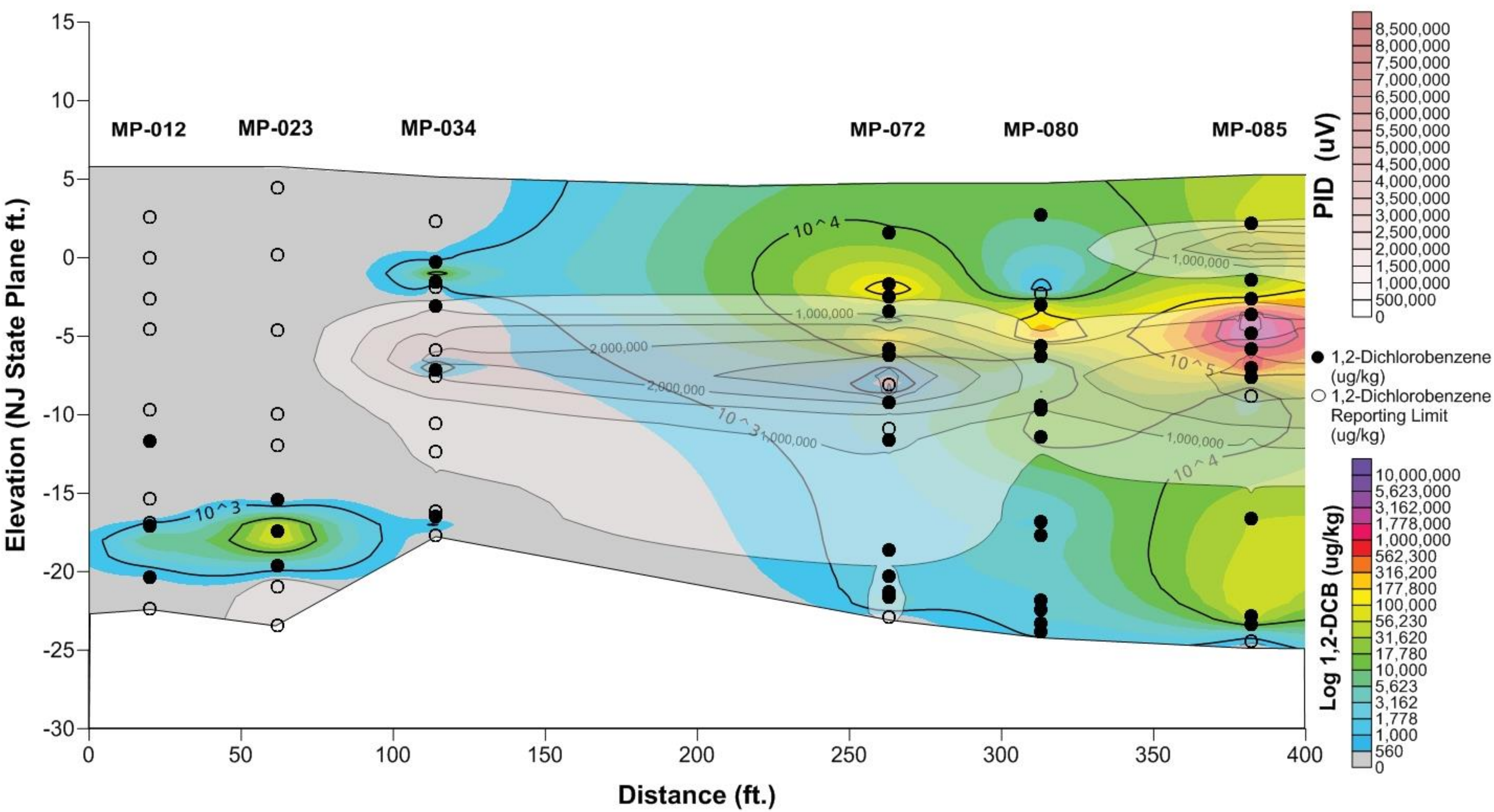
Trip Time Disparity



- Different compounds travel at different rates, causing potential inaccuracies in contaminant distribution

Correlations and Complex Mixtures

Trip Time Disparity



Select BTSC Technical Support Projects

Petroleum Brownfields Focus

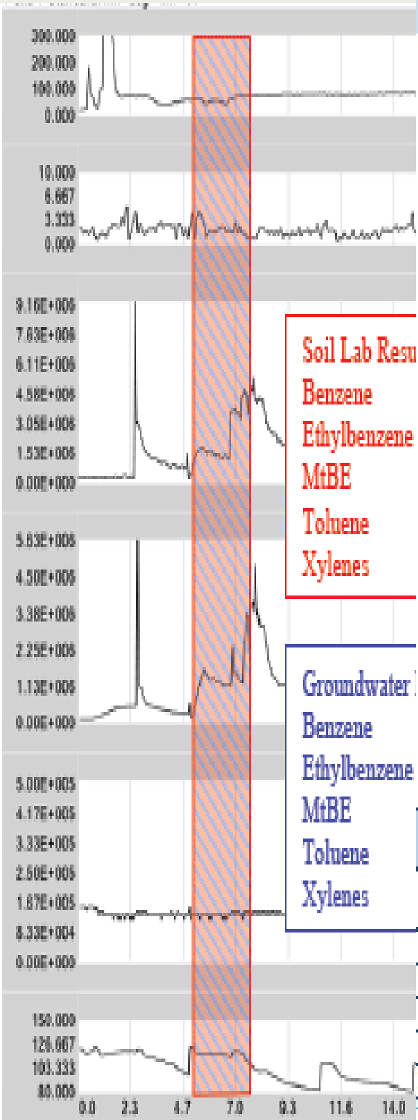


Table 2 – Traditional Screening/Sampling vs. Real-Time Measurements

Traditional Screening/Sampling (Hypothetical)

Site	No. of Conventional Borings	Total No. of Feet	Total No.of Data Points[1]
Steve's Amoco	27	726	291
T&T Standard	23	641	257
Severson's Service	30	644	259
DM&E Railroad	31	883	354
Former Husky Oil	22	601	241
TOTAL	**133**	**3,495**	**1,403**

[1] Consists of 1 data point per 2.5 foot interval using a PID, and one data point for 1 soil sample analyzed in a fixed laboratory.

VS.

Real-Time Measurements (Actual)

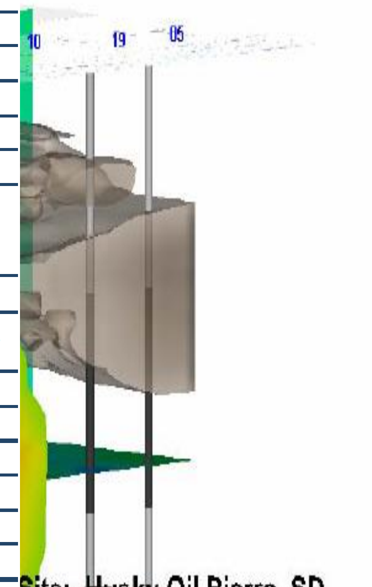
Site	No. of MIP Borings	Total No. of Feet of Data	Total No.of Data Points
Steve's Amoco	27	726	72,600
T&T Standard	23	641	64,100
Severson's Service	30	644	64,400
DM&E Railroad	31	883	88,300
Former Husky Oil	22	601	60,100
TOTAL	**133**	**3,495**	**349,500**

[1] Consists of 20 data points/instrument/ per foot. Instruments include Conductivity, PID, FID, ECD, and Temp.

Table 3 – Cost Reduction Using Triad Study

Site	Previous Assessments	Triad Assessment	% Reduction
Steve's Amoco	$0.00	$32,220.63	0.00%
T&T Standard	$62,837.06	$30,574.07	51.34%
Severson's Service	$103,044.38	$30,997.17[1]	69.92%
DM&E Railroad	$34,763.29	$29,937.93	13.88%
Former Husky's	$0.00	$25,312.17[1]	0.00%

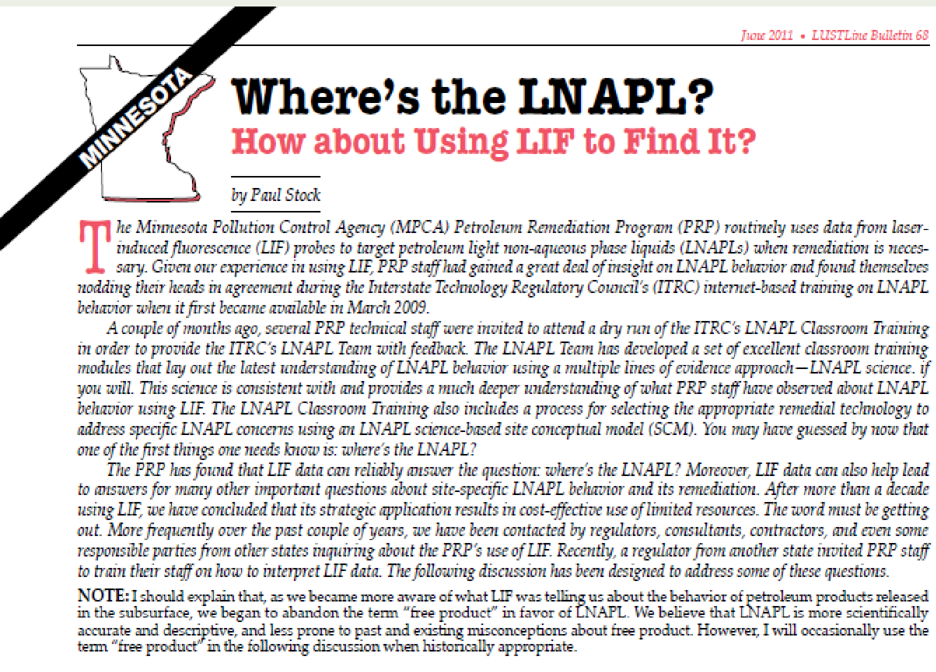
[1] Invoices for work have not yet been received, therefore, costs are estimated.



Site: Husky Oil Pierre, SD
Survey Date: Dec 2004
MIP Borings: 1-22
View: From NW
Horiz Slice: 18 ft
Vert Slice: Ctr of Pump Island
Detector: PID (uV)
Conductivity > 100 mS/m
COLUMBIA Technologies
SmartData Solutions

Laser Induced Fluorescence

- ***'Immediately obvious that LNAPL does not float on the water table… majority mass of LNAPL below water table… profound implications for remediation'***
- ***'Allowed us to confidently target LNAPL remediation efforts with almost surgical precision… SVE would not have significantly affected submerged LNAPL'***
- ***'We assumed that free product would simply follow the water table gradient... LIF data showed us that this is rarely the case; rather, migrating LNAPL follows the path of least resistance… including opposite the hydraulic gradient'***



June 2011 • LUSTLine Bulletin 68

MINNESOTA

Where's the LNAPL?
How about Using LIF to Find It?

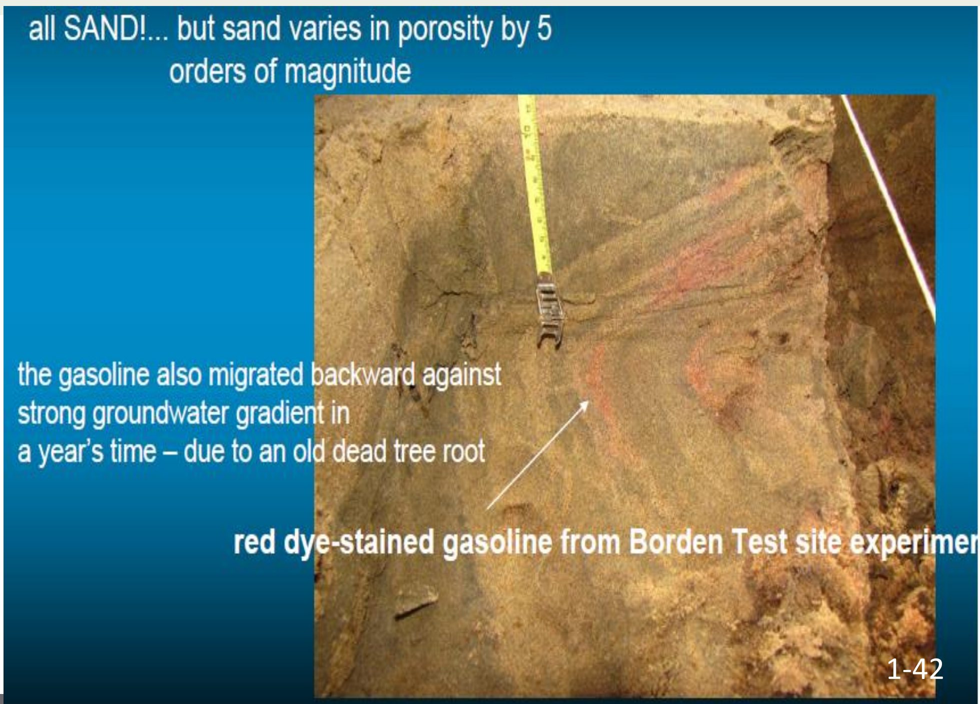
by Paul Stock

The Minnesota Pollution Control Agency (MPCA) Petroleum Remediation Program (PRP) routinely uses data from laser-induced fluorescence (LIF) probes to target petroleum light non-aqueous phase liquids (LNAPLs) when remediation is necessary. Given our experience in using LIF, PRP staff had gained a great deal of insight on LNAPL behavior and found themselves nodding their heads in agreement during the Interstate Technology Regulatory Council's (ITRC) internet-based training on LNAPL behavior when it first became available in March 2009.

A couple of months ago, several PRP technical staff were invited to attend a dry run of the ITRC's LNAPL Classroom Training in order to provide the ITRC's LNAPL Team with feedback. The LNAPL Team has developed a set of excellent classroom training modules that lay out the latest understanding of LNAPL behavior using a multiple lines of evidence approach—LNAPL science. if you will. This science is consistent with and provides a much deeper understanding of what PRP staff have observed about LNAPL behavior using LIF. The LNAPL Classroom Training also includes a process for selecting the appropriate remedial technology to address specific LNAPL concerns using an LNAPL science-based site conceptual model (SCM). You may have guessed by now that one of the first things one needs know is: where's the LNAPL?

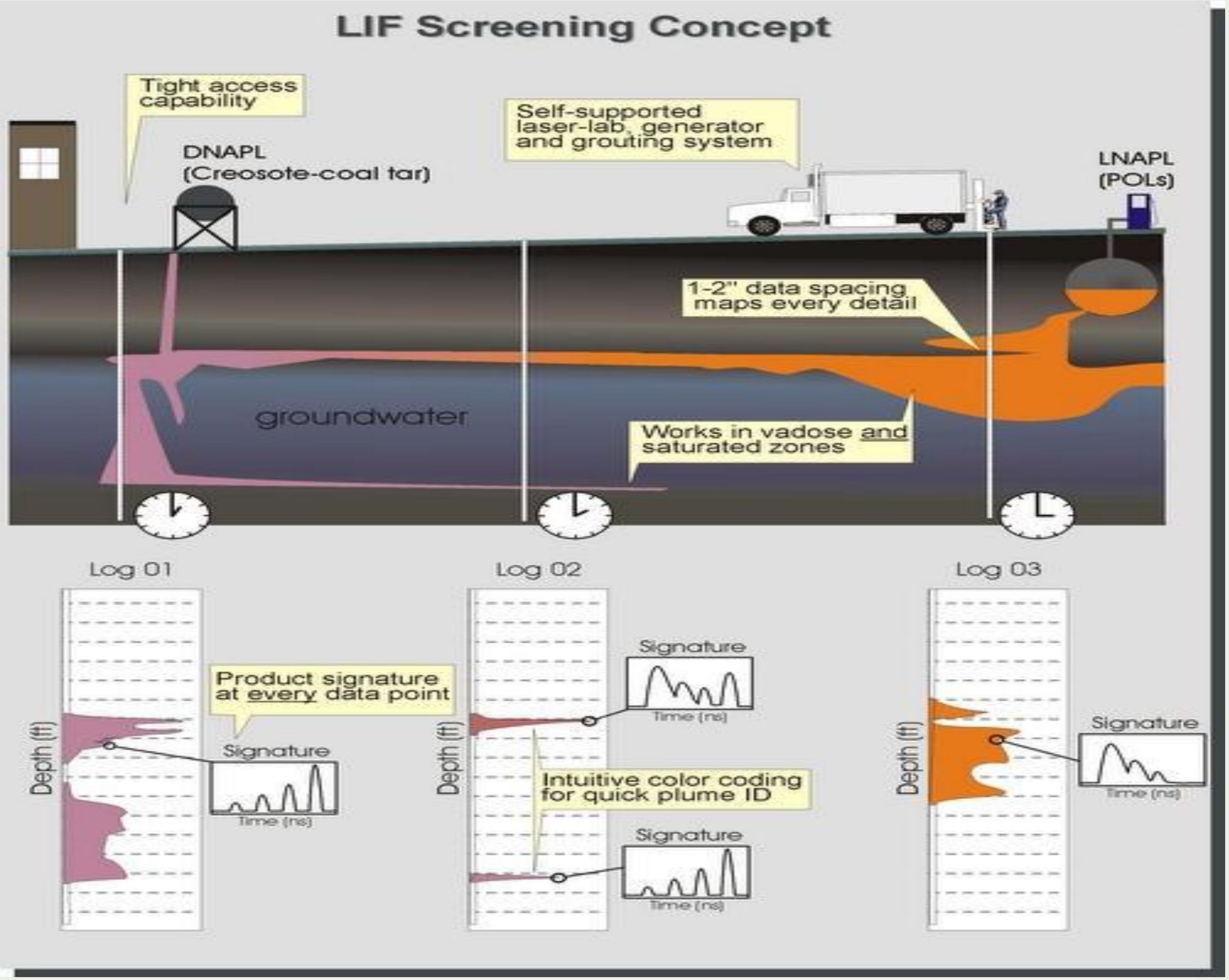
The PRP has found that LIF data can reliably answer the question: where's the LNAPL? Moreover, LIF data can also help lead to answers for many other important questions about site-specific LNAPL behavior and its remediation. After more than a decade using LIF, we have concluded that its strategic application results in cost-effective use of limited resources. The word must be getting out. More frequently over the past couple of years, we have been contacted by regulators, consultants, contractors, and even some responsible parties from other states inquiring about the PRP's use of LIF. Recently, a regulator from another state invited PRP staff to train their staff on how to interpret LIF data. The following discussion has been designed to address some of these questions.

NOTE: I should explain that, as we became more aware of what LIF was telling us about the behavior of petroleum products released in the subsurface, we began to abandon the term "free product" in favor of LNAPL. We believe that LNAPL is more scientifically accurate and descriptive, and less prone to past and existing misconceptions about free product. However, I will occasionally use the term "free product" in the following discussion when historically appropriate.



Laser Induced Fluorescence (LIF) – Basics of Optical Screening Tools

- **Work for Aromatic Compounds (PAH)**
- **Detect NAPL**
- **Employ sapphire-windows**
- **Direct push**
- **Log of depth vs. fluorescence**

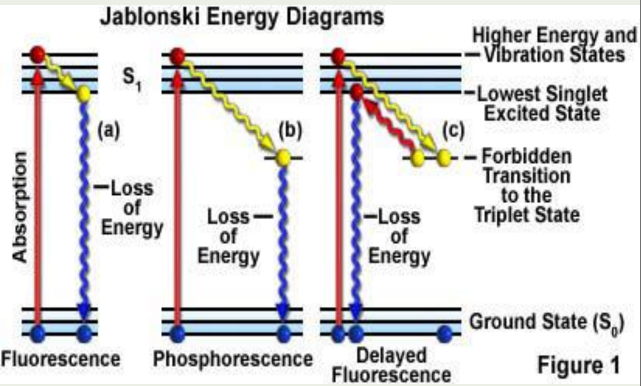


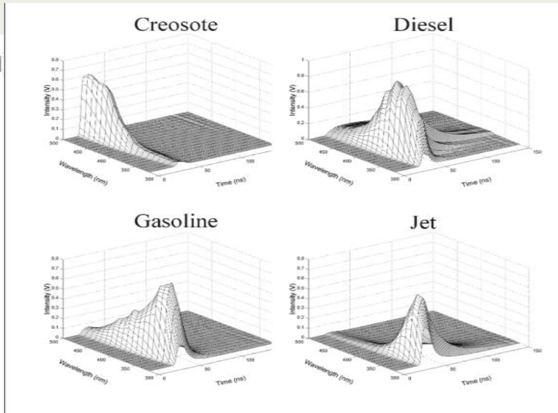
Dakota Technologies, Inc.

LIF – UVOST and TARGOST

- **Ultra Violet Optical Screening Tools (UVOST)**
  - Gasoline, diesel, jet (kerosene), motor oil, cutting fluids and hydraulic fluid
  - Does not see PCBs and straight chain halogenated compounds
  - Can give product class information though use of waveform evaluations
  - 10-500 ppm DLs - From “sheen to neat” – might not see dissolved phase PAHs
  - Best for use where presence of NAPL is driver for investigation
  - Matrix effects from soil particle size and color and other things that might be found in soils (sea shells, peat, calcite and calcareous sands)
- **Tar Specific Green Optical TARGOST**
  - Coal tar (MGP waste) and creosote and pentachlorophenol (wood treatment)

How LIF Works – Some Limitations

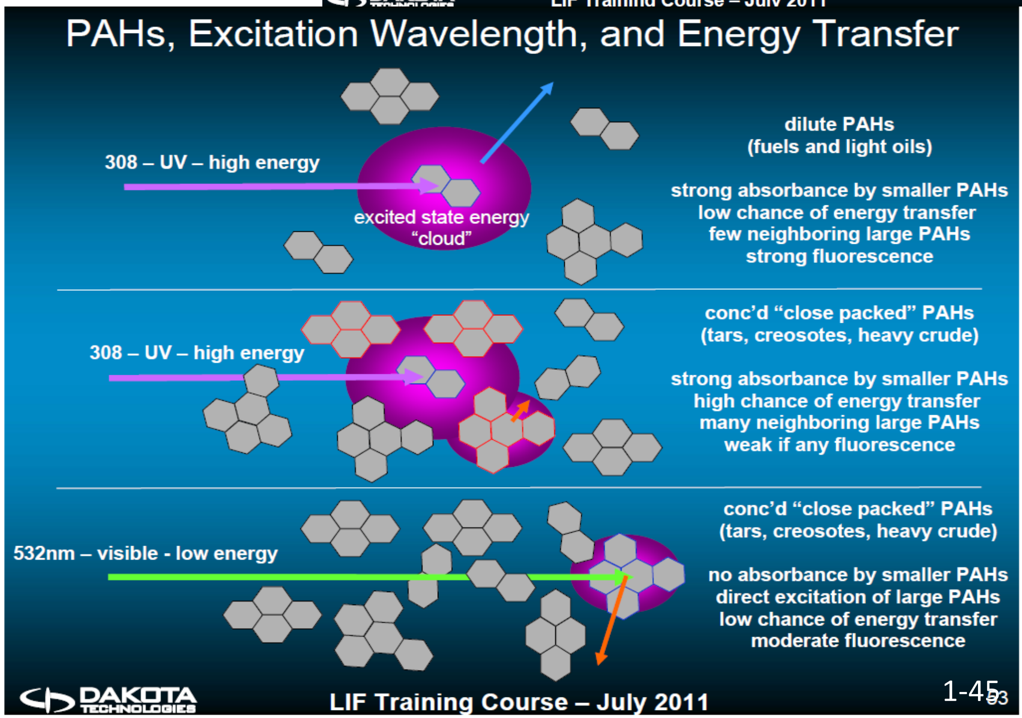




Model	Manufacturer / Providers	Technology / Deployment	Target
NA	SCAPS (Army/Navy/AF) gov't use	nitrogen laser-337 nm OMA detector CPT only	fuels/oils (poor jet fuel response)
FFD – Fuel Fluorescence Detector	Vertek mfct'd offered by numerous field service providers	CW Hg Lamp - 254.7 nm LEDs (?nm) PMT CPT only	fuels/oils containing low to moderate PAH
ROST - Rapid Optical Screening Tool	Dakota Fugro exclusively	dye laser - 290nm spectral/temporal hybrid CPT only	fuels/oils containing low to moderate PAH
UVOST - Ultra-Violet Optical Screening Tool	Dakota offered by numerous field service providers	XeCl laser - 308nm spectral/temporal Percussion & CPT	fuels/oils containing low to moderate PAH
TarGOST – Tar-specific Green Optical Screening Tool	Dakota Dakota exclusively	Nd:YAG laser - 532nm spectral/temporal Percussion & CPT	coal tars/creosotes containing moderate to heavy PAH
Soil Color	Dakota mfct'd offered by Dakota and available to providers	broadband white light reflectance Percussion & CPT	Munsell soil color, soil class, ???

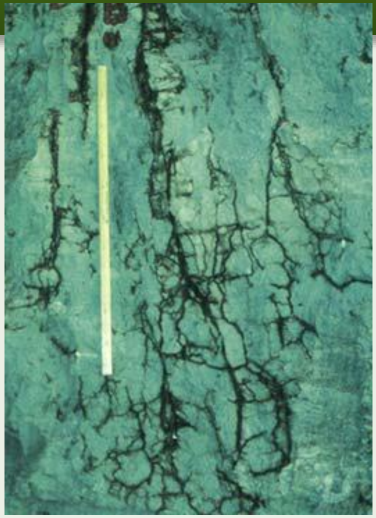
DAKOTA LIF Training Course – July 2011

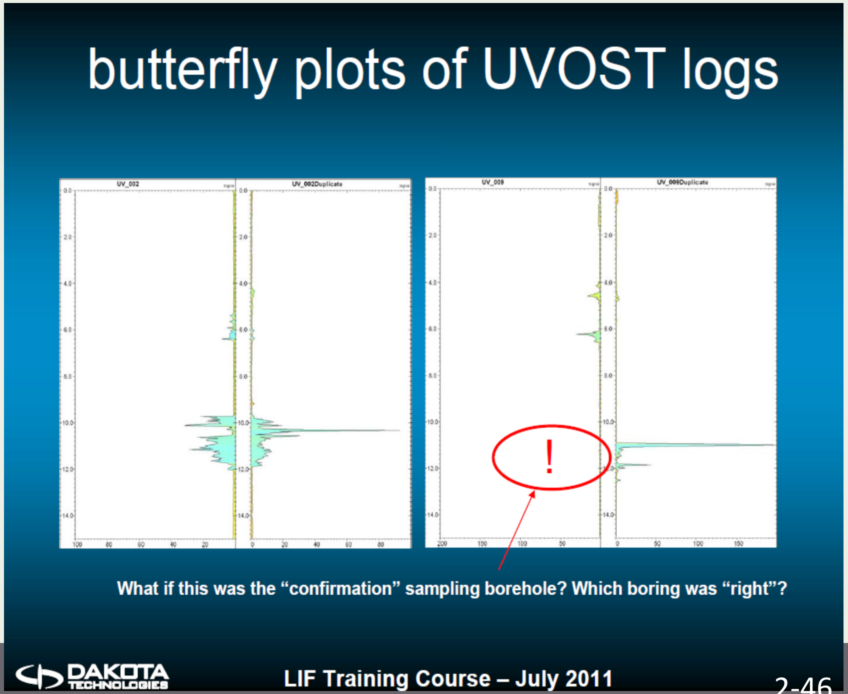
- Fancy quantum mechanics "stuff" determines behavior
- Molecules absorb light – might shed that energy by emitting light
- Aromatic (ring-shaped) molecules excel at this
- Note to "brainiacs": See Joseph R. Lakowicz' "Principles of Fluorescence Spectroscopy", 3rd Edition"



LIF Quality Control

- **Single point calibration with known reference**
  - » Like PID calibration with 100 ppm isobutylene
- **Reference emitter (RE) - known NAPL mixture is placed on window before each push**
- **Subsequent readings normalized by RE response; data ultimately displayed as %RE**
- **Corrects for change in optics, laser energy drift, window, mirror, etc.**
  - » RE approach used by all ROST and UVOST providers in U.S. and E.U.
- **Correct shape of waveform also QA's the qualitative aspect of the fluorescence**

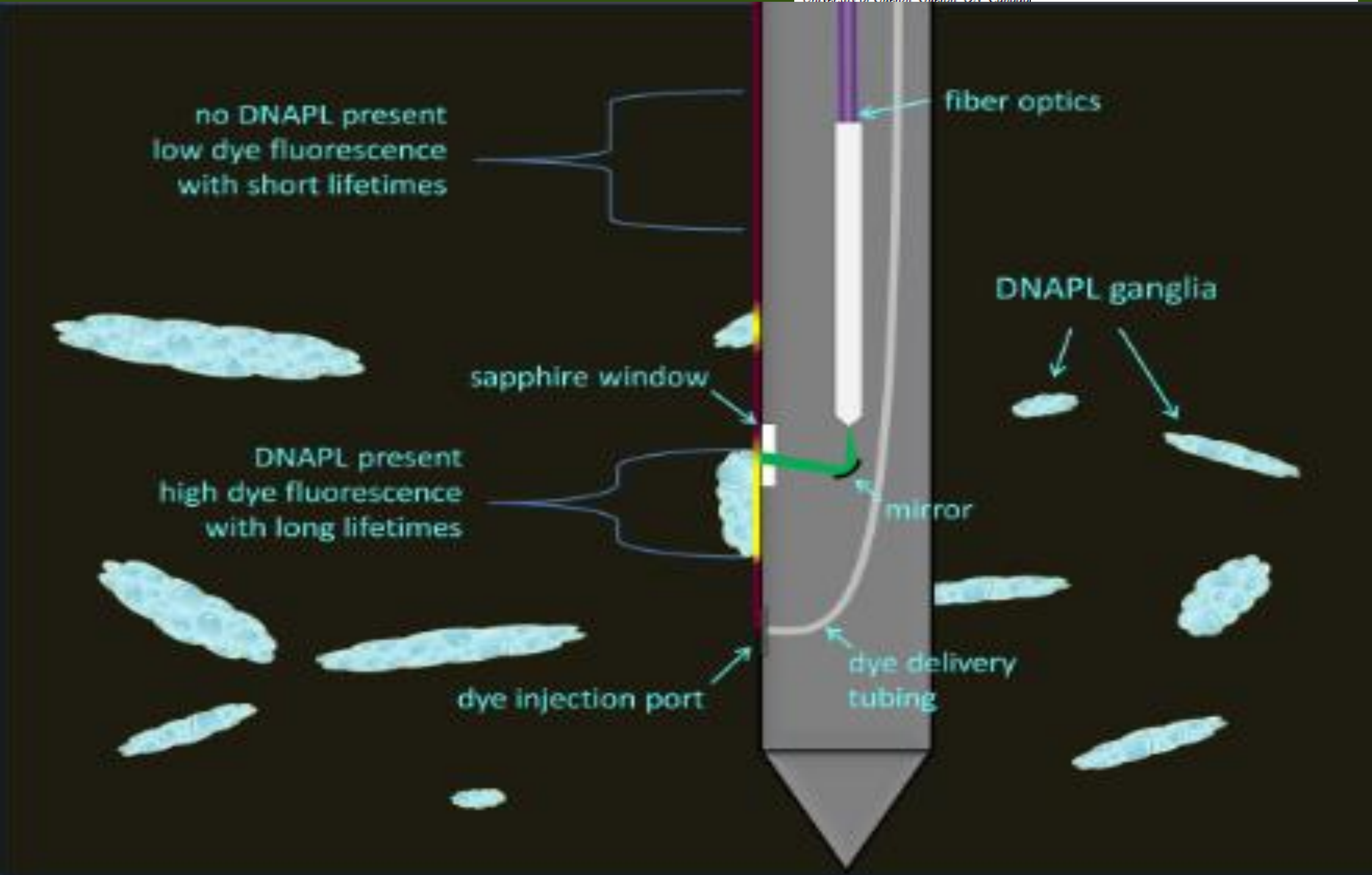




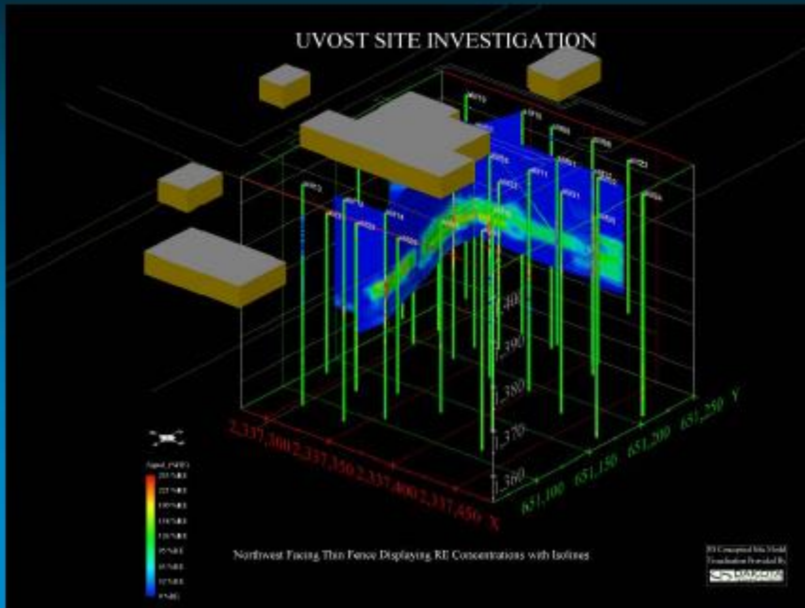
LIF – The Newest Frontier

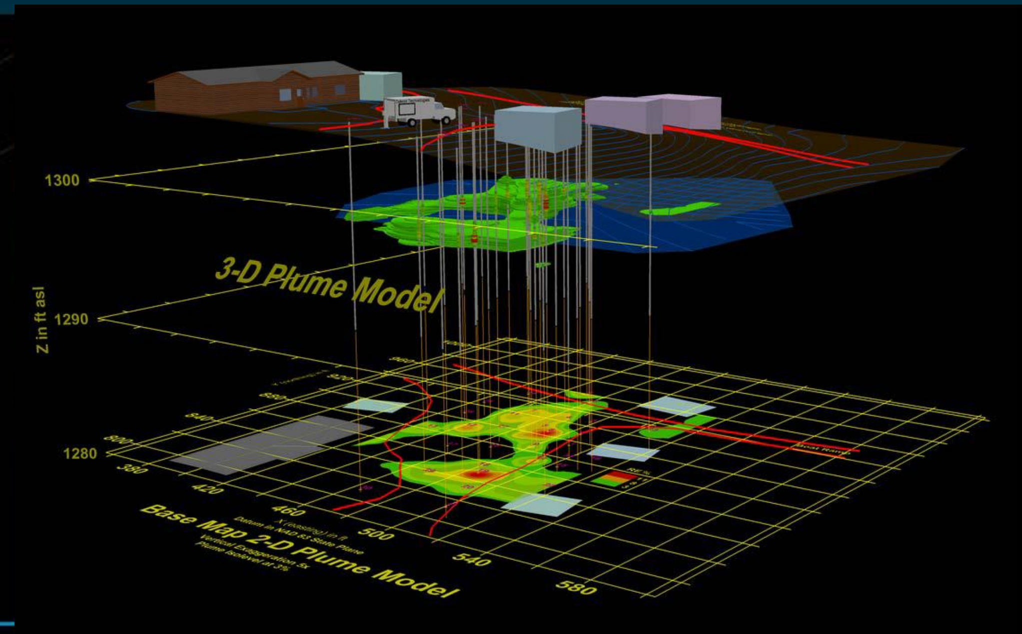
Dye based laser-induced fluorescence sensing of chlorinated solvent DNAPLs

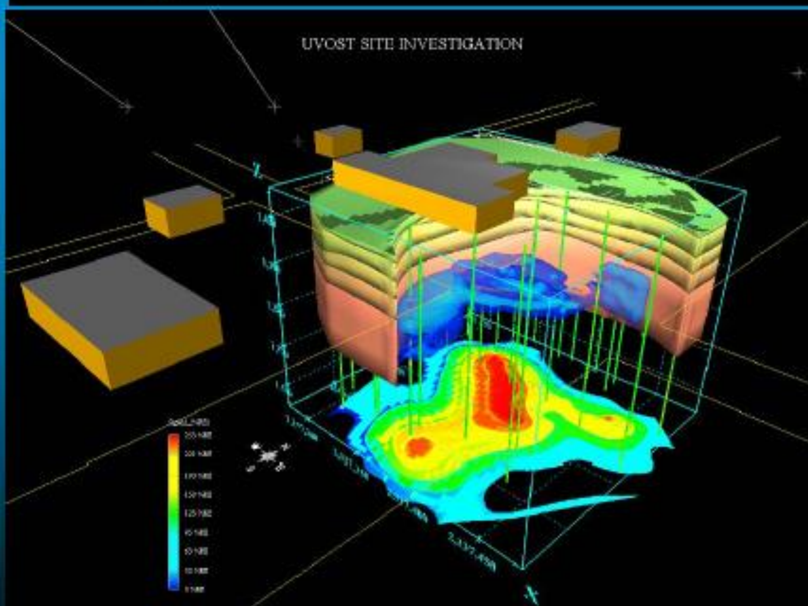
R.W. St. Germain
Dakota Technologies, Inc., Fargo, ND, USA
M.D. Einarson & A. Fure
Haley & Aldrich, Oakland, CA & Indianapolis, IN, USA
S. Chapman & B. Parker
University of Guelph, Guelph, ON, Canada

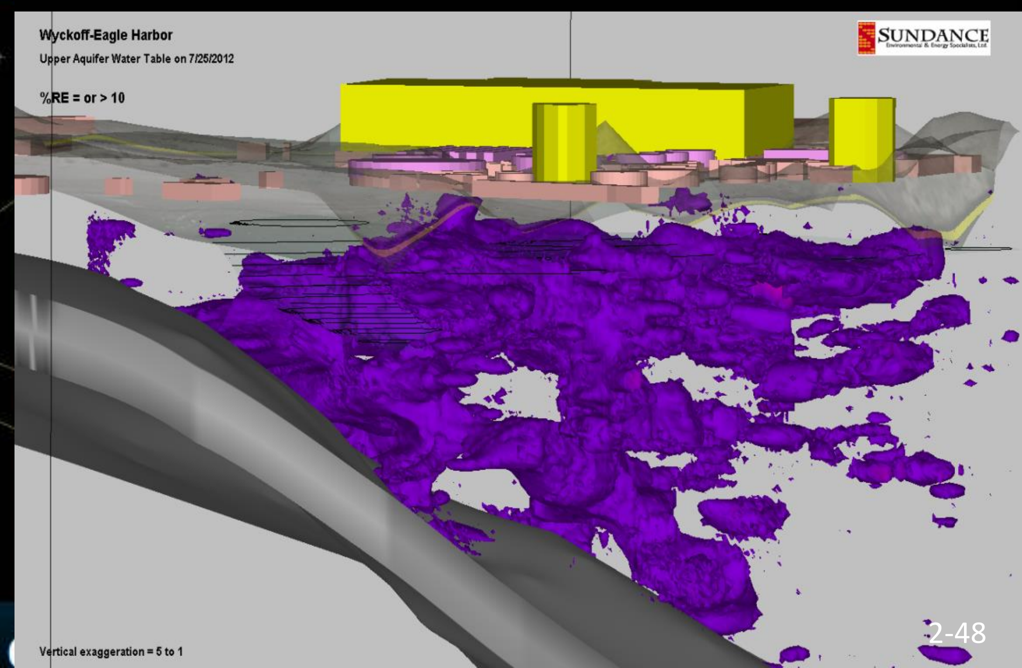


3D UVOST Field Data CSMs





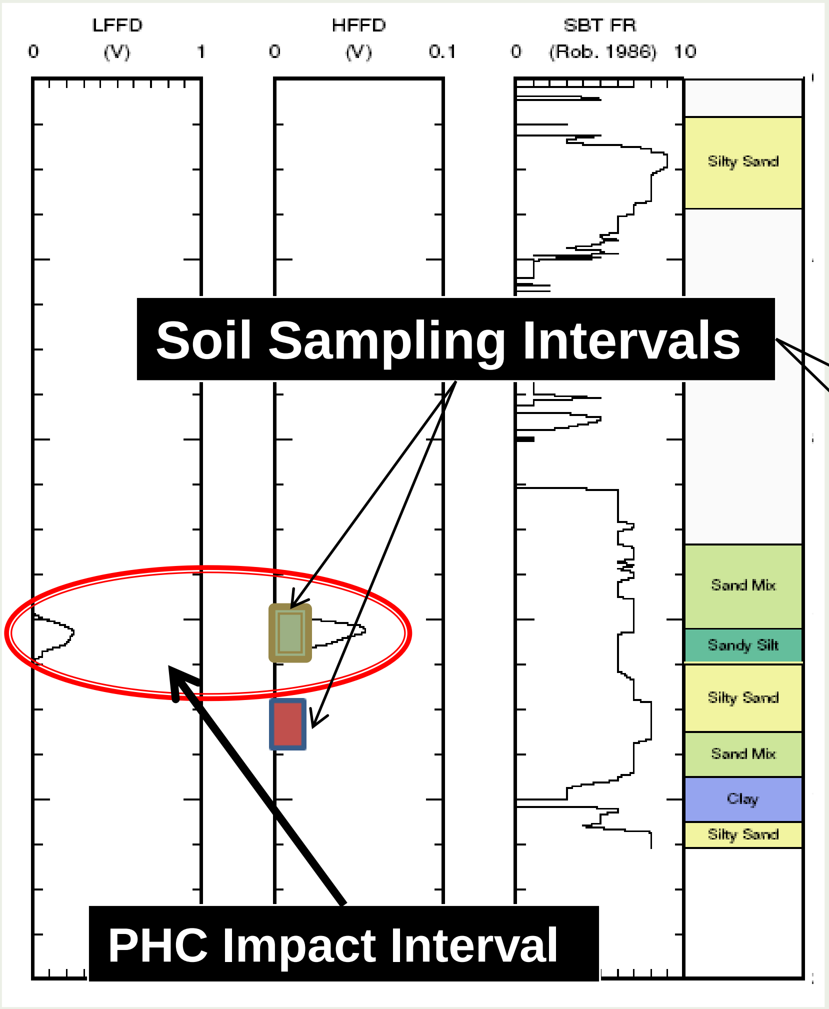


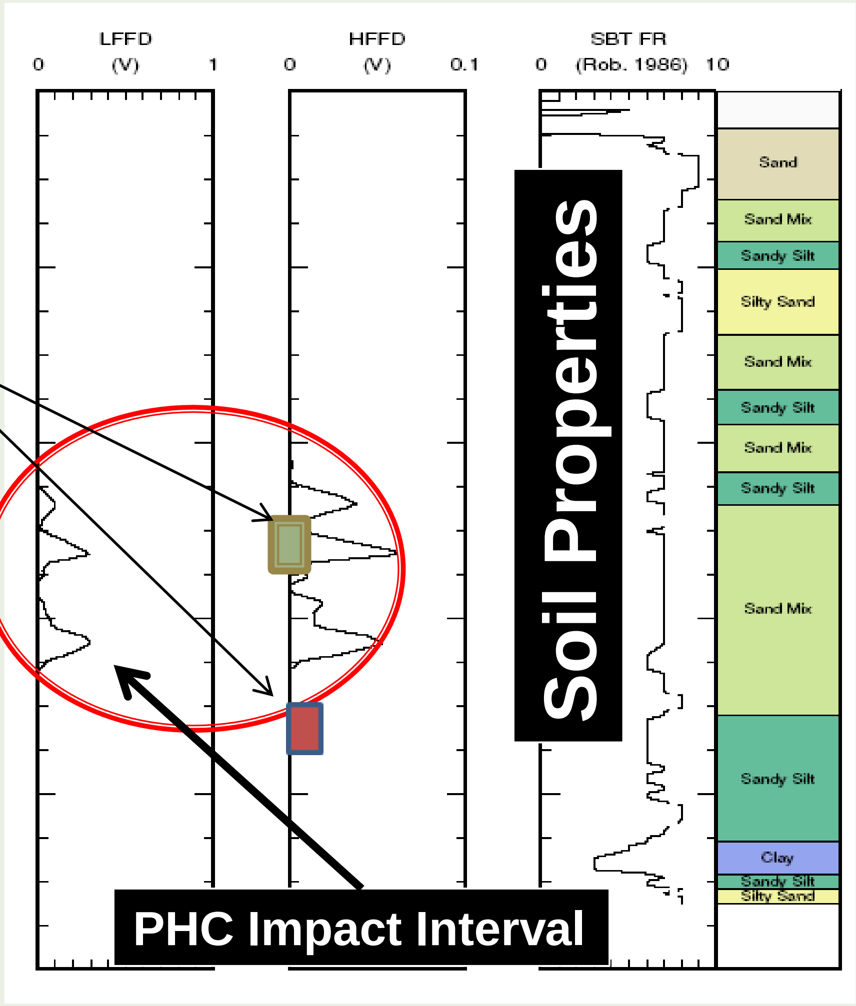


Fuel Fluorescence Detector- FFD

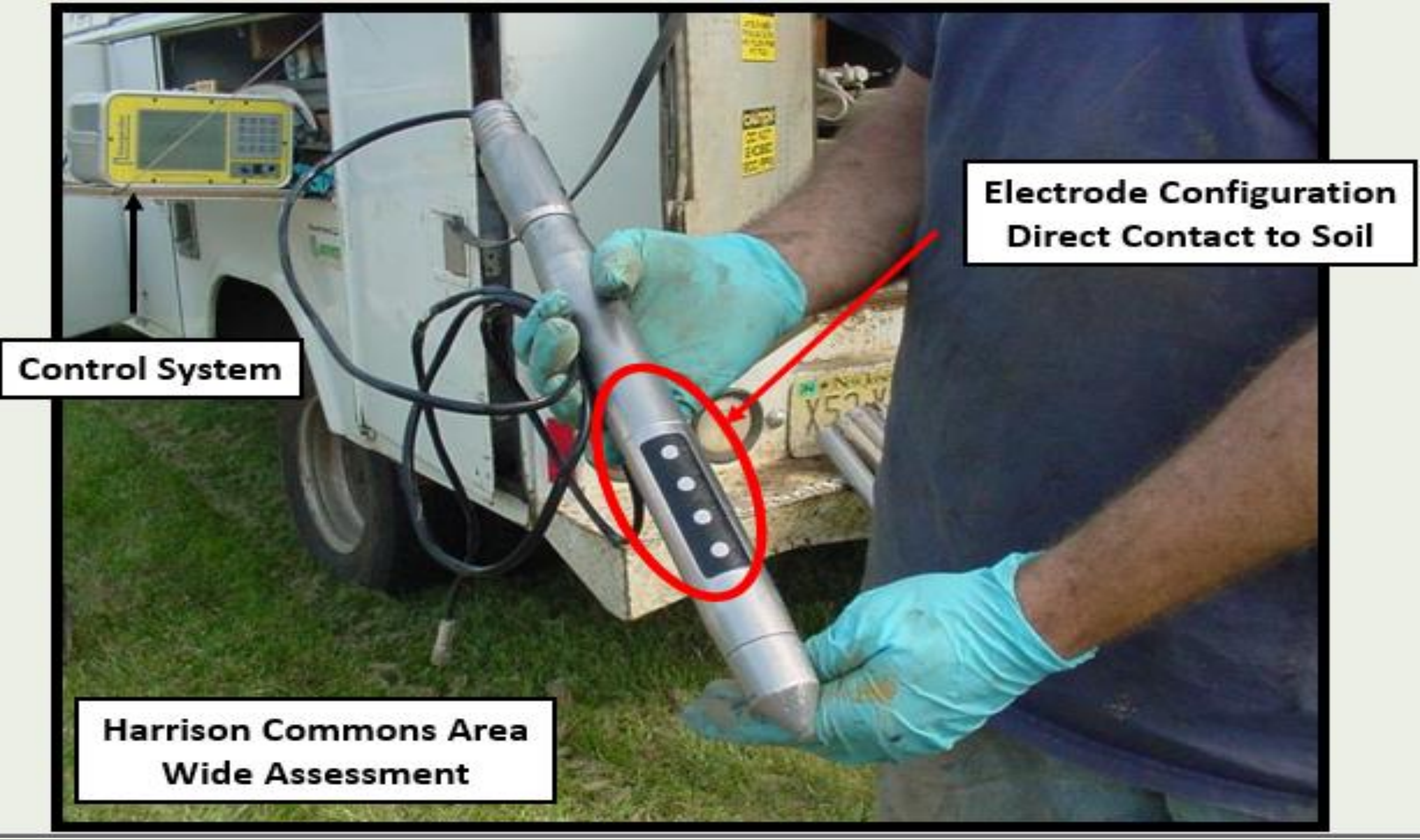
- Primarily for petroleum hydrocarbon delineation
- Direct push UVF probe (push only)
- UV lamp in probe causes hydrocarbons to fluoresce
- Fluorescence captured by probe and converted to electronic signal
- Continuous log of electronic signal created
- Signal strength corresponds to concentration and can be imported to ArcGIS
- Impact area can be imaged by classifying according to signal strength

Example FFD Logs



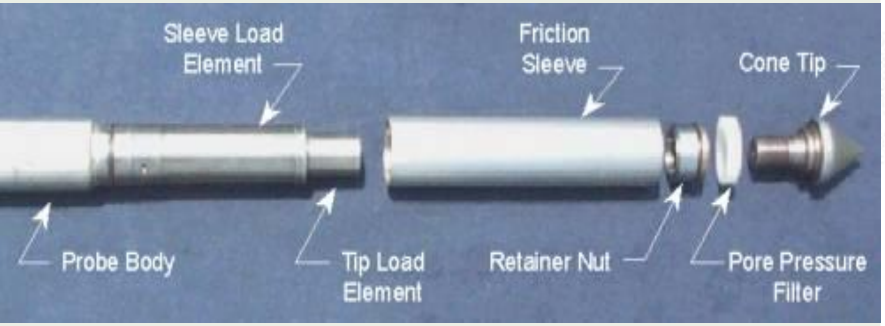


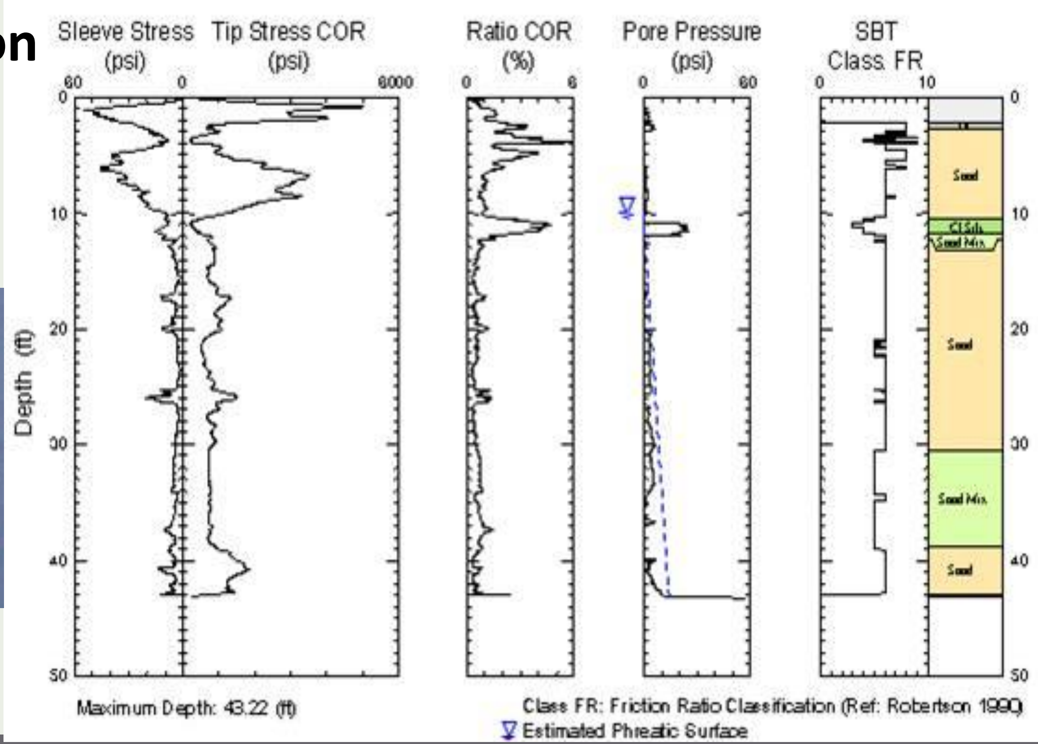
Electrical Conductivity- EC



Cone Penetrometer Testing (CPT) and Piezocone

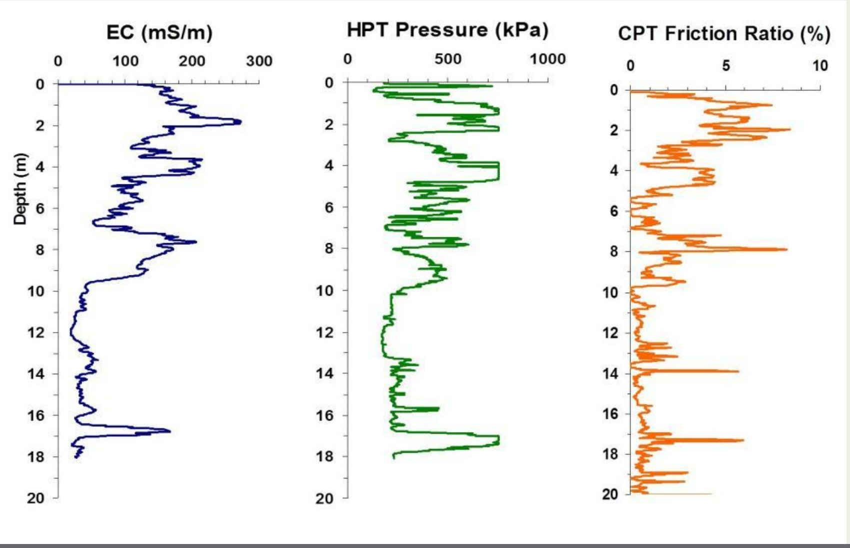
- **Static push (no percussion or vibration)**
- **Large heavy trucks**
- **Real-time data from *in situ* sensors**
- **Variety of sensors- high resolution piezocone**

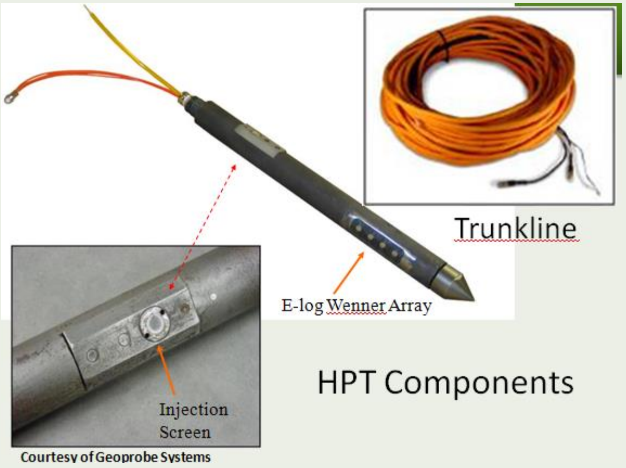




Geoprobe Hydraulic Profiling Tool (HPT)

- Continuous hydrostratigraphic data profiling
- Describes hydrostratigraphy on the basis of the flow of water into the formation
- Real-time data generation
- Direct push (percussion and vibration or static push)





HPT Components

Geophysical Surveys

http://water.usgs.gov/ogw/bgas/frgt/

FRGT METHOD SELECTION TOOL

Fill in cells shaded aqua-blue (in column C). All other cells will be automatically updated.

🟢 indicates method is potentially suitable
🔴 indicates method is likely not suitable
● indicates method is likely appropriate/effective
○ indicates method is not likely appropriate/effective

Project and site parameters	
1. What is the depth to bedrock (m)?	15
2. What is the electrical resistivity of bedrock (ohm-m)?	100
3. What is the minimum spacing between wells (m)?	4
4. What is the well casing?	Open
5. What is the vertical extent of open holes (m)?	40
6. Is borehole fluid turbid/ muddy (opaque)?	Yes
7. Borehole diameter (inches)	6
8. Cultural EM interference? (utilities, pipes, etc.)	Yes
9. Is it possible to disturb the ground for electrodes or geop	Yes
10. What is native groundwater conductivity (micro-S/cm)?	150
11. What is the project cost threshold for a given method?	High

Goals	
A. Identify discrete fracture network characteristics	Yes
B. Identify lithologic contacts	Yes
C. Map depth to bedrock	No
D. Understand large-scale anisotropy, average fracture orie	No
E. Estimate discrete fracture hydraulic properties	Yes
F. Estimate small-scale effective hydraulic properties	Yes
G. Estimate large scale hydraulic properties	Yes
H. Identify interwell hydraulic connections	Yes
I. Time-lapse snapshots of amendment delivery	Yes
J. Continuous monitoring of degradation	No
K. Screening for iron minerals	No

Assumptions

Comments

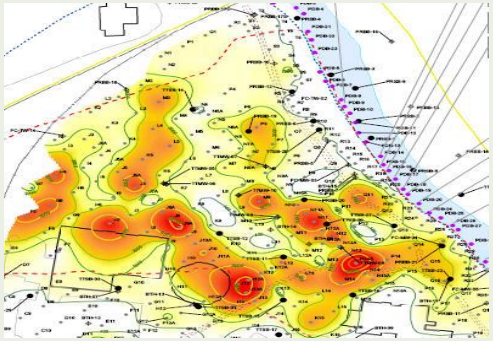
Methods		Appropriate for goals	Effectiveness at site	Relative cost
Surface methods				
1. EM terrain conductivity (induction)	🔴	●	○	Low
2. ERT	🟢	●	●	Low
3. GPR	🔴	●	○	Low
4. Resistivity - azimuthal	🔴	○	●	Low
5. SP - azimuthal	🔴	○	●	Low
6. Seismic refraction	🟢	●	●	Low
7. Seismic reflection	🟢	●	●	Medium
8. Time domain EM	🔴	●	○	Low
Cross-hole methods				
9. ERT	🟢	●	●	Medium
10. GPR	🔴	●	○	High
11. IP	🟢	●	●	Medium
12. Seismic	🟢	●	●	High
Borehole methods				
13. ATV	🟢	●	●	Low
14. Caliper	🟢	●	●	Low
15. EM Induction	🟢	●	●	Low
16. Flowmeter (single hole)	🟢	●	●	Low
17. Flowmeter (cross-hole)	🟢	●	●	Low
18. Gamma	🟢	●	●	Low
19. IP and Normal Resistivity	🟢	●	●	Low
20. Magnetic susceptibility	🟢	●	●	Low
21. NMR	🟢	●	●	Medium
22. OTV	🔴	●	○	Low
23. Radar (borehole GPR)	🔴	●	○	Medium
24. Video camera	🔴	●	○	Low
Hydrologic tests				
25. Dilution/fluid replacement	🟢	●	●	High
26. Focused packer testing	🟢	●	●	High
27. Fluid resistivity & temperature	🟢	●	●	Low
28. High resolution temperature	🟢	●	●	High
29. Open-hole hydraulic tests	🟢	●	●	Medium
30. Tracer tests	🟢	●	●	High

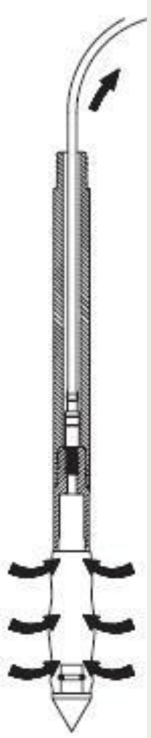
Methods	Method contributes to goal: A	B	C	D	E	F	G	H	I	J	K	Made infeasible by site parameter: 1	2	3	4	5	6	7	8	9	10	11
Surface methods																						
1. EM terrain conductivity (induction)		✔																	✖			
2. ERT		✔							✔													
3. GPR		✔										✖	✖						✖			
4. Resistivity - azimuthal																						
5. SP - azimuthal																						
6. Seismic refraction		✔																				
7. Seismic reflection		✔																				
8. Time domain EM		✔																	✖			
Cross-hole methods																						
9. ERT		✔						✔	✔													
10. GPR		✔						✔	✔				✖									
11. IP		✔						✔	✔													
12. Seismic		✔						✔														
Borehole methods																						
13. ATV	✔	✔																				
14. Caliper	✔	✔																				
15. EM Induction		✔																				
16. Flowmeter (single hole)					✔	✔																
17. Flowmeter (cross-hole)					✔	✔		✔	✔													
18. Gamma		✔																				
19. IP and Normal Resistivity		✔																				
20. Magnetic susceptibility		✔																				
21. NMR		✔				✔																
22. OTV	✔	✔															✖					
23. Radar (borehole GPR)		✔											✖									
24. Video camera	✔	✔															✖					
Hydrologic tests																						
25. Dilution/fluid replacement					✔	✔																
26. Focused packer testing					✔	✔	✔															
27. Fluid resistivity & temperature					✔	✔		✔														
28. High resolution temperature					✔	✔																
29. Open-hole hydraulic tests							✔															
30. Tracer tests					✔	✔	✔															

This FRGT utility is intended to help select methods and to assess their appropriateness and the potential for success given the goals of your investigation. Actual performance of the geophysical and hydraulic tools may vary depending on the specific tool used and acquisition settings.

Passive/Active Soil Gas

- **Passive soil gas**
  - Adsorbent placed in shallow subsurface
  - Easy to install, inexpensive, provide good site coverage
- **Active soil gas**
  - Hand drive points or direct push deployment
  - Depth discrete, can have lower DLs





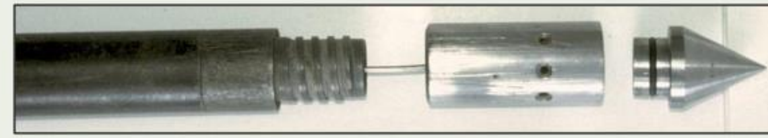
- **GC/MS analysis of VOCs (SW-846, TO methods)**
- **High density**
- **Define areas of concern, refine CSM, optimize drilling programs, locate source areas, optimize sample collection (location, depth),**
- **Gas stations, dry cleaners, solvent plumes**
- **Decisions include: optimized collaborative data locations, identify potential VI issues, revise site boundaries, update CSM, well placement/screen intervals, pathway determinations, etc.**

Waterloo APS™
ADVANCED PROFILING SYSTEM

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

Profiler Hardware and Tip Modifications

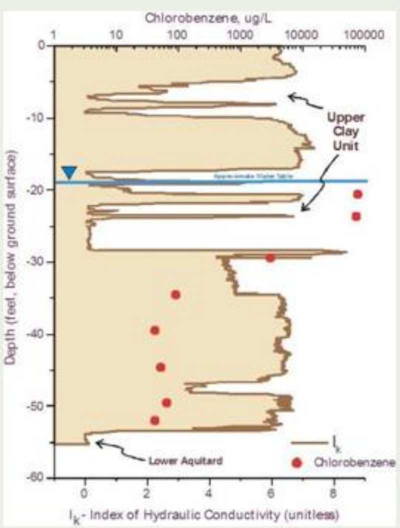
1994 Waterloo Profiler



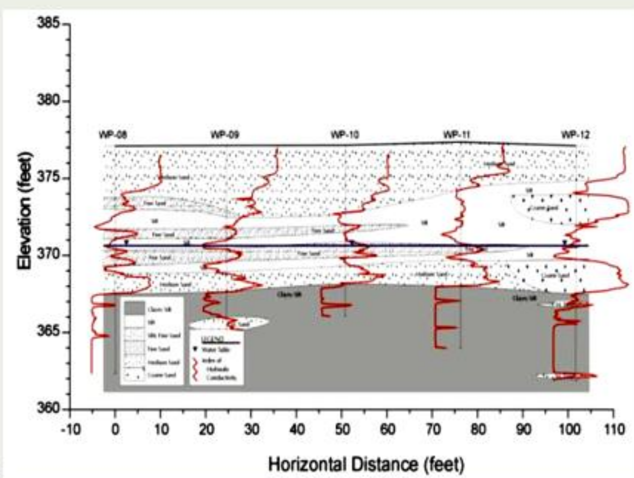
Waterloo Advanced Profiling System (Waterloo$^{APS™}$)

Two Uses of I_K Data

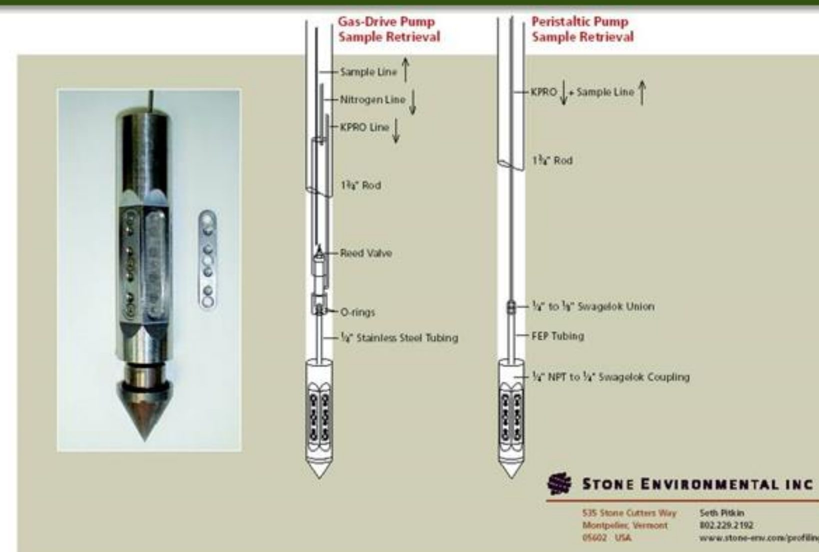
Sample depth selection



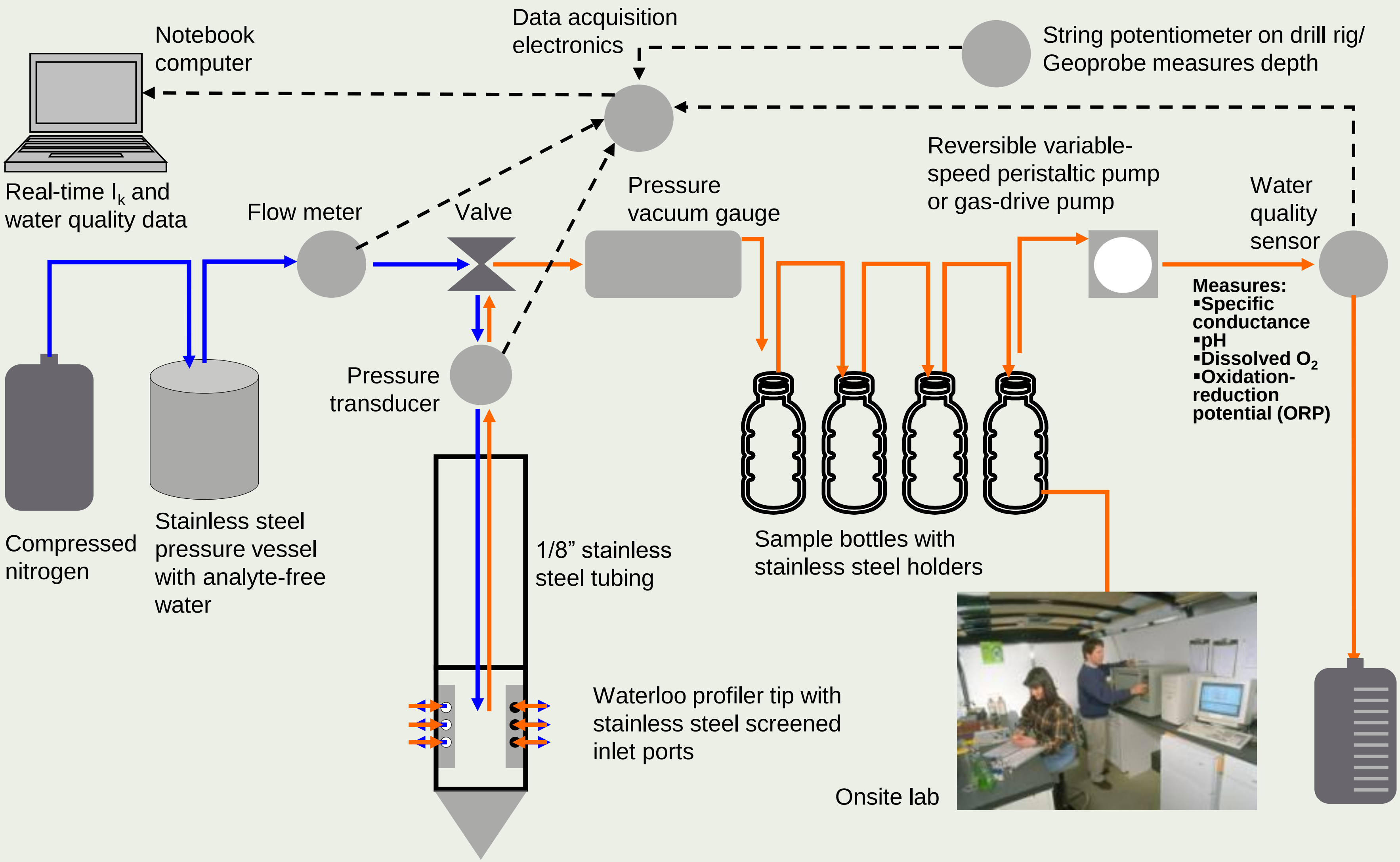
Stratigraphic Interpretation



Waterloo^{APS} Sampling Configurations

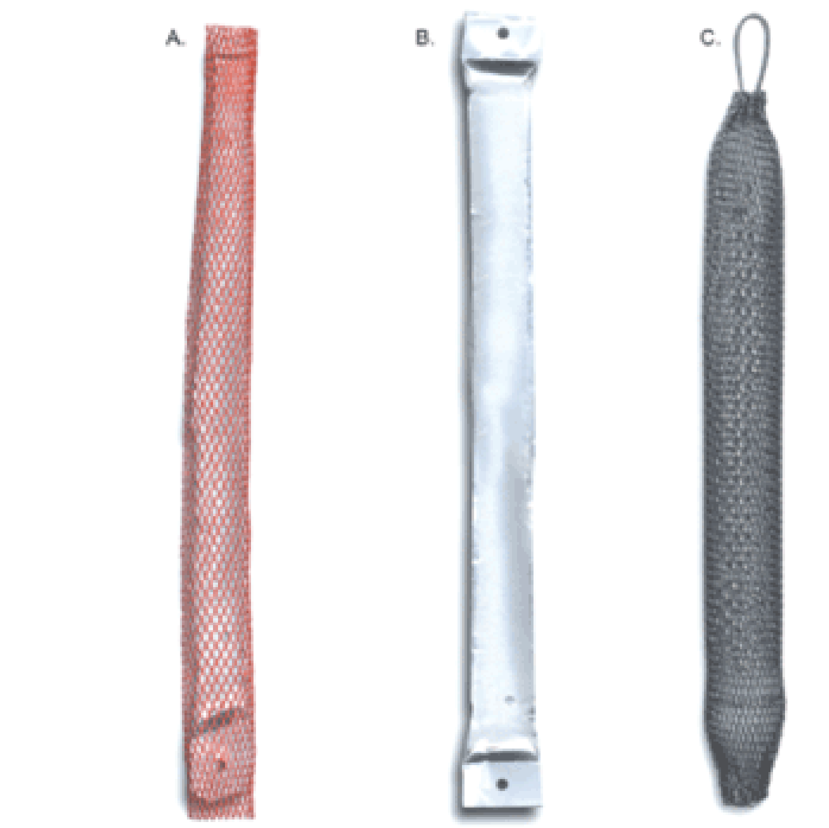


Waterloo^{APS} Data Acquisition Configuration and Process



Polyethylene Diffusion Bag Samplers

- ♦ **Uses**
- ♦ **Advantages**
- ♦ **Disadvantages**



A: Diffusion Bag with Polyethylene Mesh
B: Diffusion Bag Without Mesh
C: Diffusion Bag and Mesh Attached to Bailer Bottom

Pushpoint Sampler

2 **Pushpoint Sampling for Defining Spatial and Temporal Variations in Contaminant Concentrations in Sediment Pore Water**

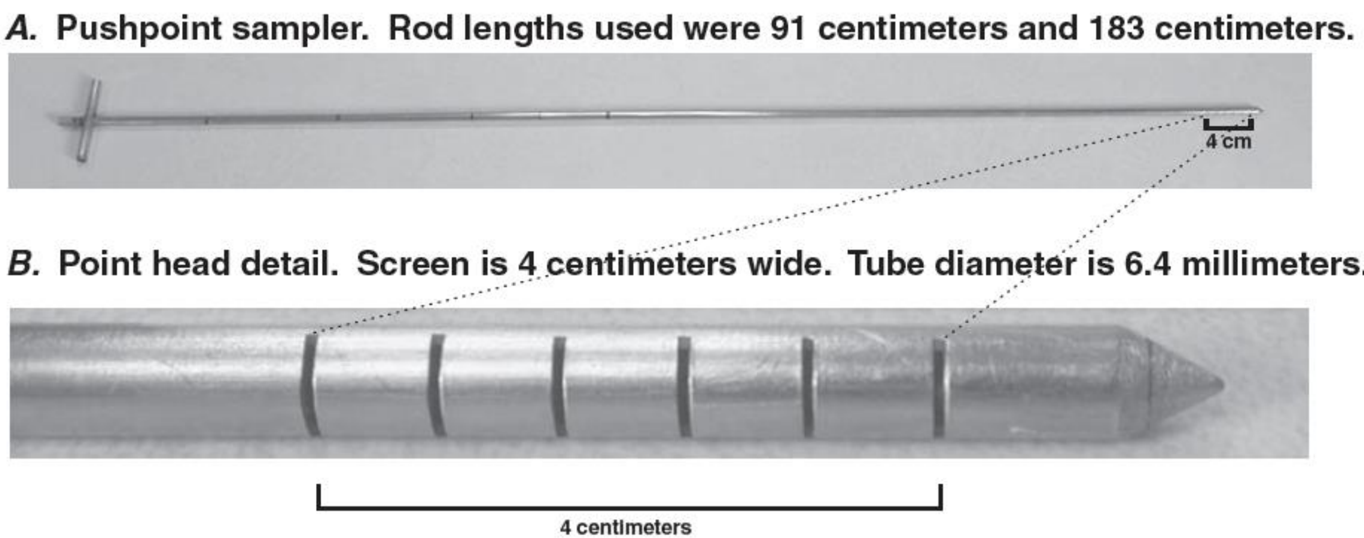


Figure 1. *A*, the 91-centimeter-long PushPoint Extreme Sampler, and *B*, closeup of the slotted screen at the tip.

Source: Zimmerman and others, 2005

Groundwater plume discharge into surface water is spatially complex

Available online at www.sciencedirect.com
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ELSEVIER
Journal of Contaminant Hydrology 73 (2004) 249–279
JOURNAL OF Contaminant Hydrology
www.elsevier.com/locate/jconhyd

A PCE groundwater plume discharging to a river: influence of the streambed and near-river zone on contaminant distributions

Brewster Conant Jr.*, John A. Cherry, Robert W. Gillham

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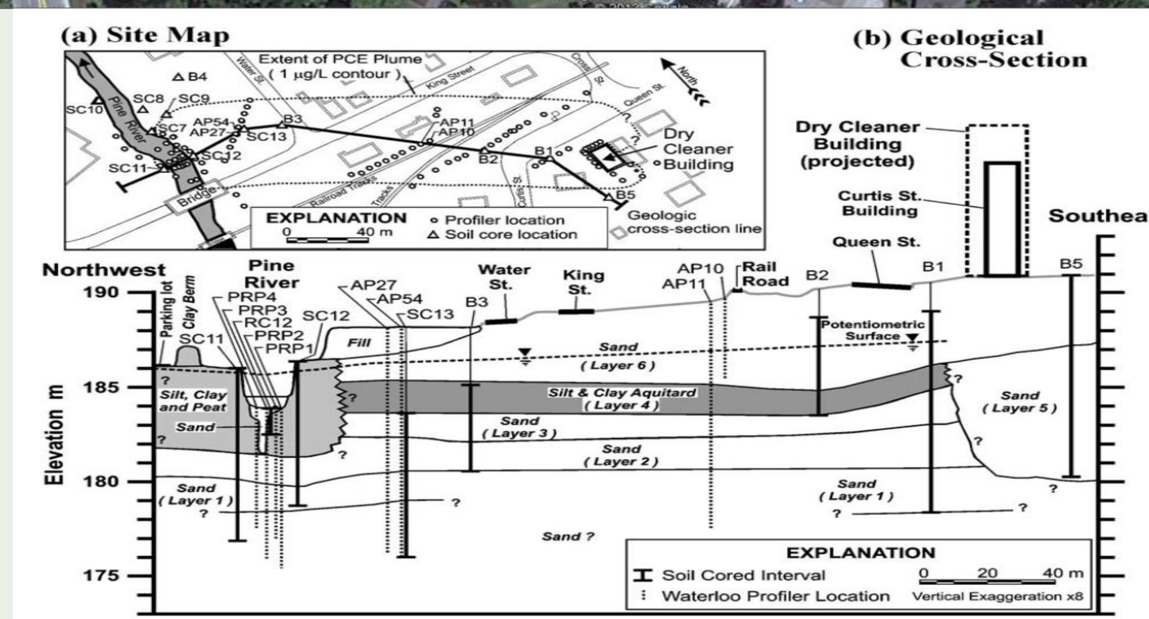
Received 6 November 2003; received in revised form 1 April 2004; accepted 1 April 2004

Abstract

An investigation of a tetrachloroethene (PCE) groundwater plume originating at a dry cleaning facility on a sand aquifer and discharging to a river showed that the near-river zone strongly modified the distribution, concentration, and composition of the plume prior to discharging into the surface water. The plume, streambed concentration, and hydrogeology were extensively characterized using the Waterloo profiler, mini-profiler, conventional and driveable multilevel samplers (MLS), Ground Penetrating Radar (GPR) surveys, streambed temperature mapping (to identify discharge zones), drivepoint piezometers, and soil coring and testing. The plume observed in the shallow streambed deposits was significantly different from what would have been predicted based on the characteristics of the upgradient plume. Spatial and temporal variations in the plume entering the near-river zone contributed to the complex contaminant distribution observed in the streambed where concentrations varied by factors of 100 to 5000 over lateral distances of less than 1 to 3.5 m. Low hydraulic conductivity semi-confining deposits and geological heterogeneities at depth below the streambed controlled the pattern of groundwater discharge through the streambed and influenced where the plume discharged into the river (even causing the plume to spread out over the full width of the streambed at some locations). The most important effect of the near-river zone on the plume was the extensive anaerobic biodegradation that occurred in the top 2.5 m of the streambed, even though essentially no biodegradation of the PCE plume was observed in the upgradient aquifer. Approximately 54% of the area of the plume in the streambed consisted solely of PCE transformation products, primarily *cis*-1,2-dichloroethene (cDCE) and vinyl chloride (VC). High concentrations in the interstitial water of the streambed did not correspond to high groundwater-discharge zones, but instead occurred in low discharge zones and are likely sorbed or retarded remnants of past high-concentration plume discharges. The high-concentration areas (up to 5529 μg/



Brewster Conant Jr., John A. Cherry, Robert W. Gillham*
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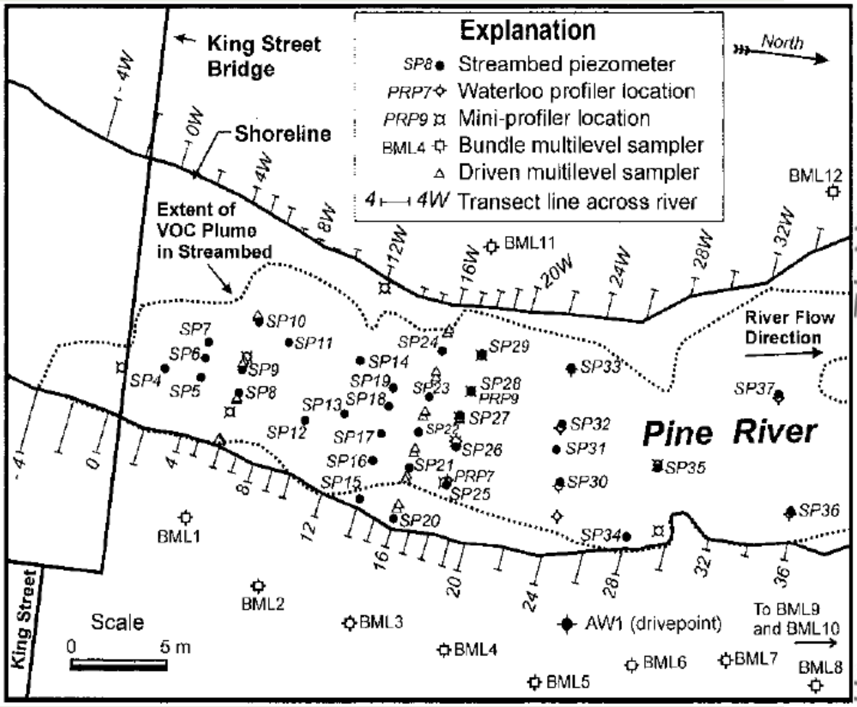
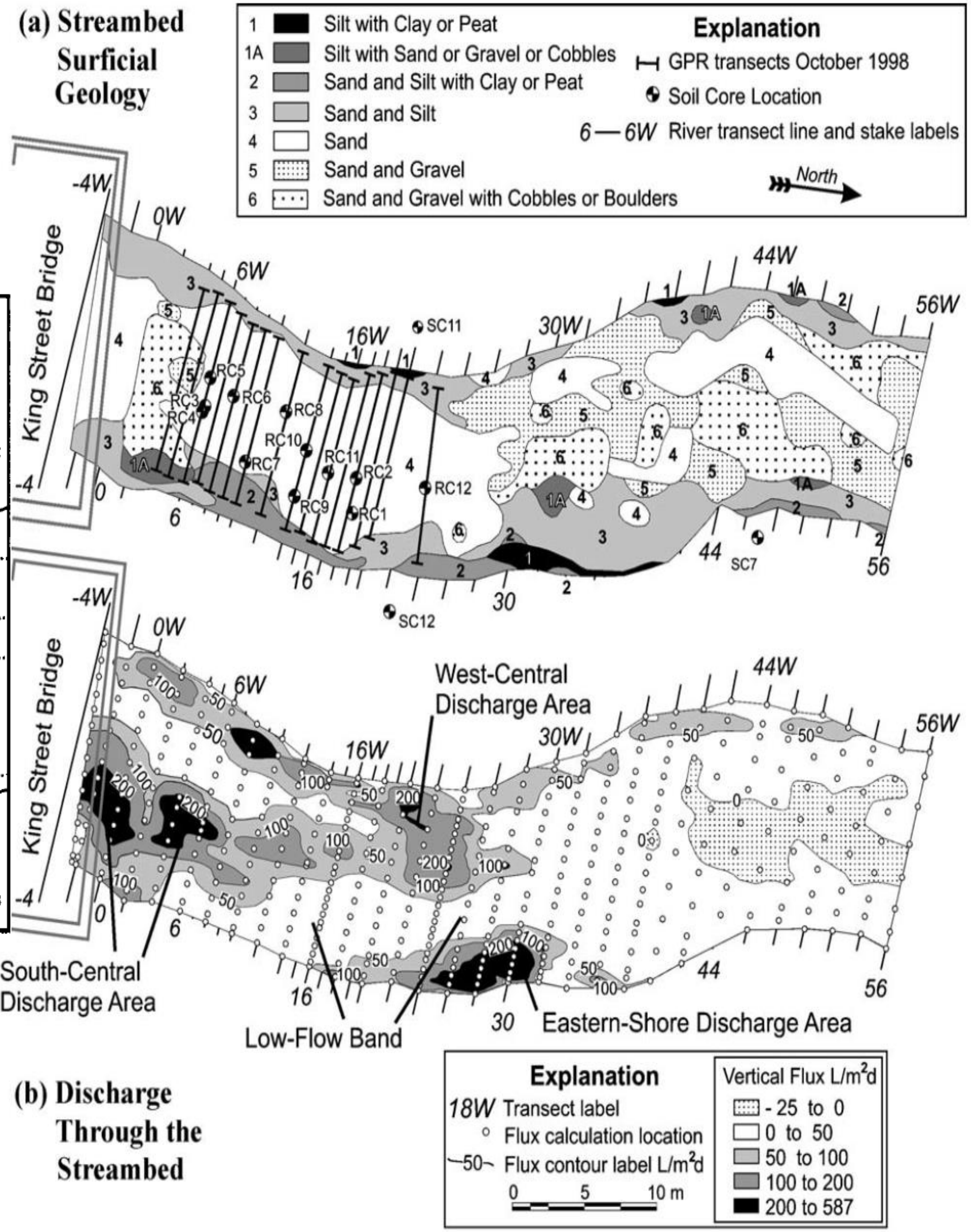
Pine River Research Site





Conant et al., 2004

Distribution of Streambed Temperature

B. Conant Jr.
GROUND WATER
42, no. 2: 243-257

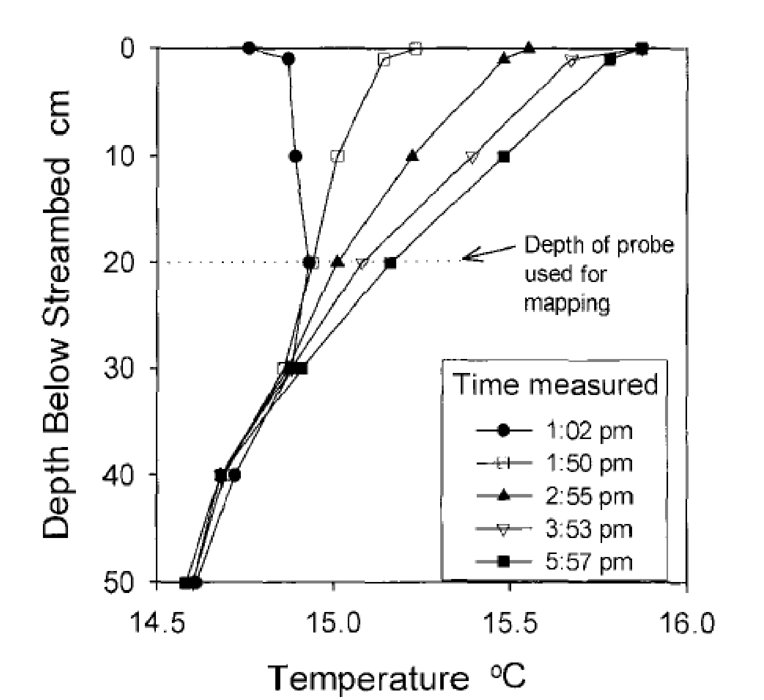
ground water

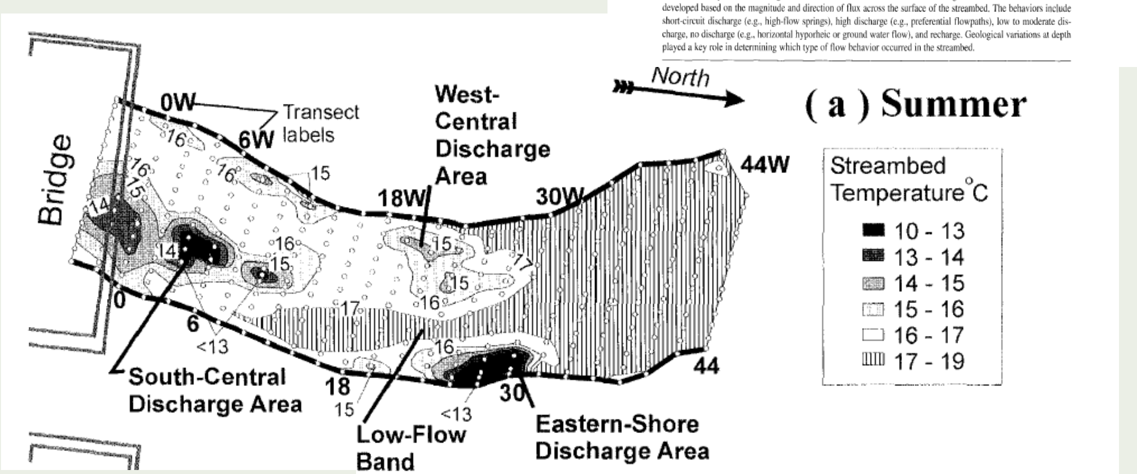
Delineating and Quantifying Ground Water Discharge Zones Using Streambed Temperatures

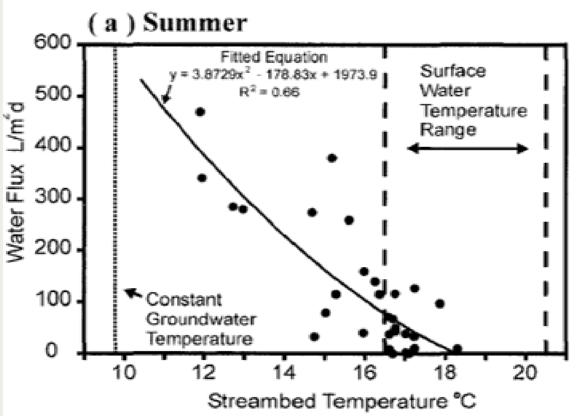
by Brewster Conant Jr.[1]

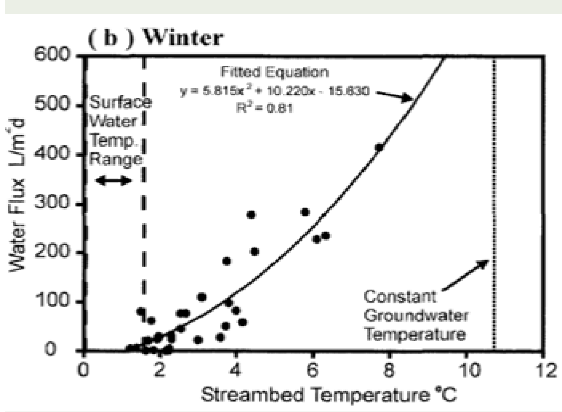
Abstract

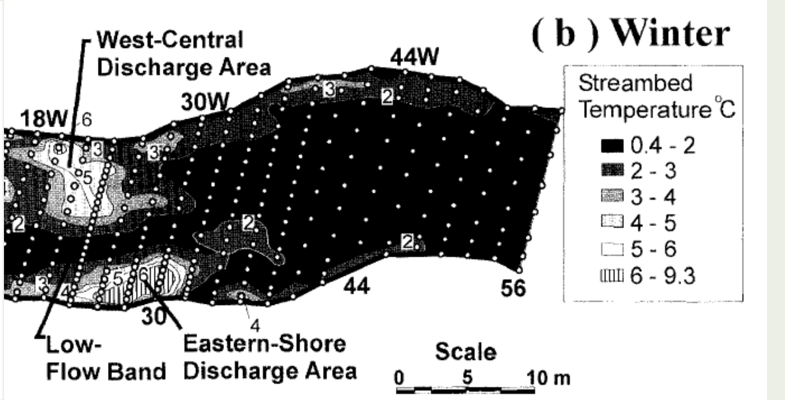
Streambed temperature mapping, hydraulic testing using minipiezometers, and geochemical analyses of interstitial water of the streambed were used to delineate the pattern of ground water discharge in a sandy streambed and to develop a flux-based conceptual model for ground water/surface water interactions. A new and simple empirical method was used to relate fluxes obtained from minipiezometer data to streambed temperatures. The relationship allowed flux to be calculated at locations where only streambed temperature measurements were made. Slug testing and potentiomanometer measurements at 34 piezometers indicated ground water discharge ranged from 0.03 to 446 L/m²/day (and possibly as high as 7060 L/m²/day) along a 60 m long by 11 to 14 m wide reach of river. Complex but similar plan-view patterns of flux were calculated for both summer and winter using hundreds of streambed temperatures measured on a 1 by 2 m grid. The reach was dominated by ground water discharge and 5% to 7% of the area accounted for ~20% to 24% of the total discharge. < 12% of the total area consisted of recharge zones or no-discharge zones. A conceptual model for ground water/surface water interactions consisting of five different behaviors was developed based on the magnitude and direction of flux across the surface of the streambed. The behaviors include short-circuit discharge (e.g., high-flow springs), high discharge (e.g., preferential flowpaths), low to moderate discharge, no discharge (e.g., horizontal hyporheic or ground water flow), and recharge. Geological variations at depth played a key role in determining which type of flow behavior occurred in the streambed.











Key Findings

- "the near-river zone strongly modified the distribution, concentration, and composition of the plume prior to discharging into the surface water."
- "Spatial and temporal variations in the plume entering the near-river zone contributed to the complex contaminant distribution observed in the streambed where concentrations varied by factors of 100 to 5,000 over lateral distances of less than 1 to 3.5 m."
- "…geological heterogeneities at depth below the streambed controlled the pattern of groundwater discharge through the streambed and influenced where the plume discharged into the river (even causing the plume to spread out over the full width of the streambed at some locations)."
- "…essentially no biodegradation of the PCE plume was observed in the upgradient aquifer. Approximately 54% of the area of the plume in the streambed consisted solely of PCE transformation products, primarily cis-1,2-dichloroethene (cDCE) and vinyl chloride (VC)."

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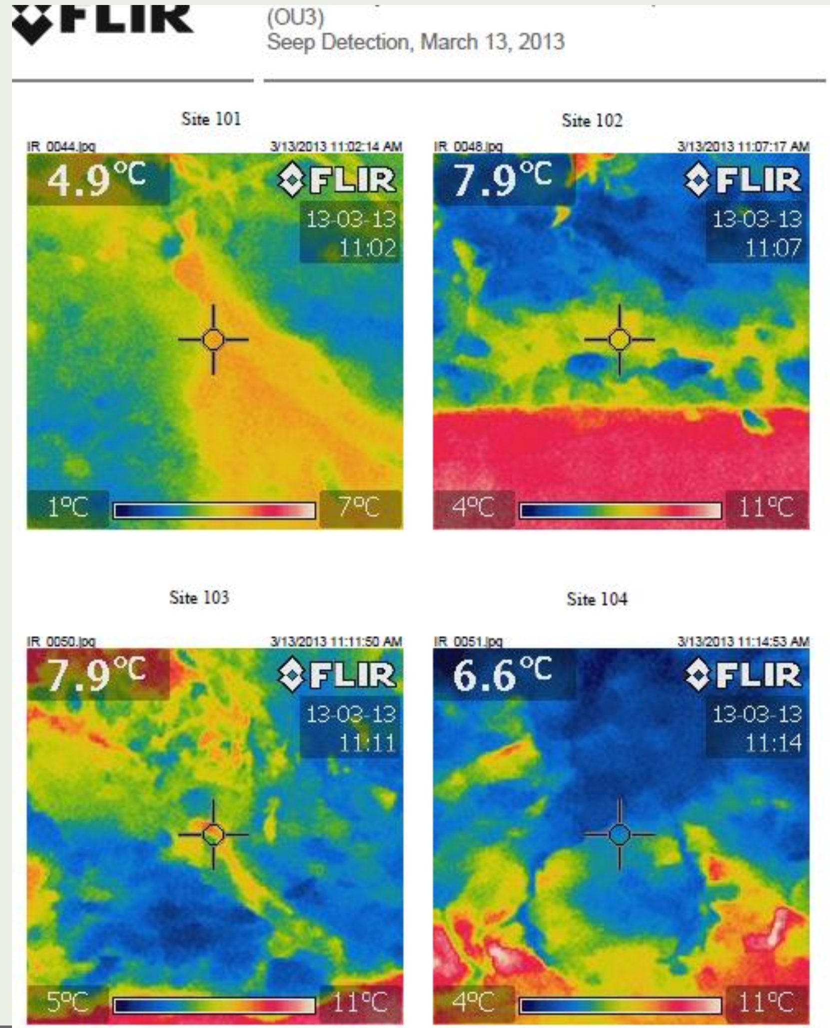
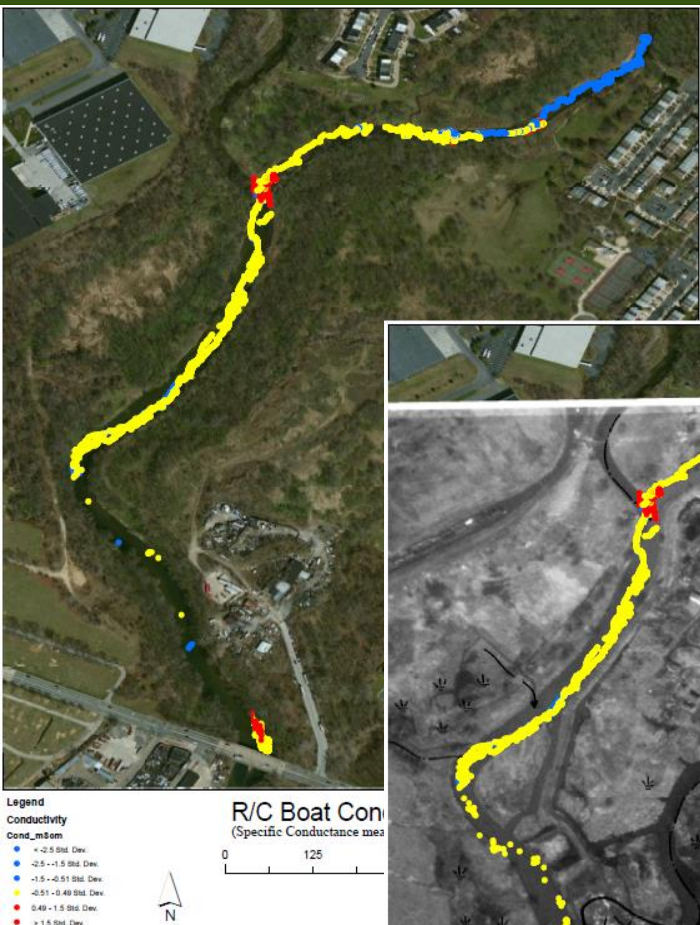
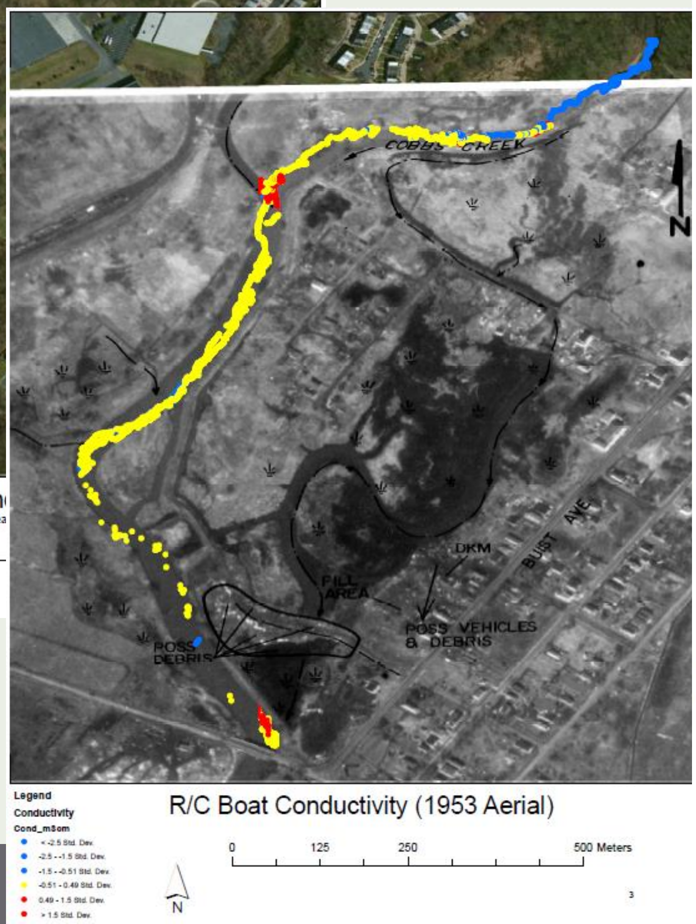
Thermal Imaging

- **IR Camera detects variations in temperature at a moment in time**



Specific Conductance Survey – Surface Water and Sediment



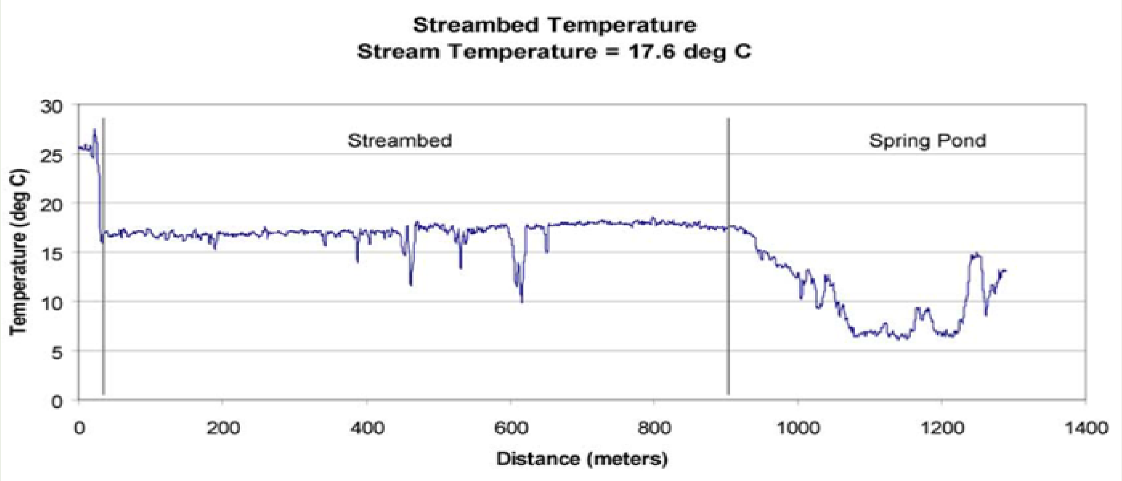


Distributed Temperature Sensor

- Distributed Temperature Sensing Systems (DTS) measure temperatures using fiber optics as linear sensors
- Temperatures are recorded along the optical sensor cable, in continuous profile
- High accuracy of temperature measurement is achieved over great distances
- Continuous measurement over kilometers
- 30 kilometers for each channel (some systems)
- Spatial resolution of about 1 meter (depends on configuration)
- Thermal resolution of about 0.01 degree Celsius (depends on configuration)
- Temporal resolution of seconds to hours depending on the desired thermal precision

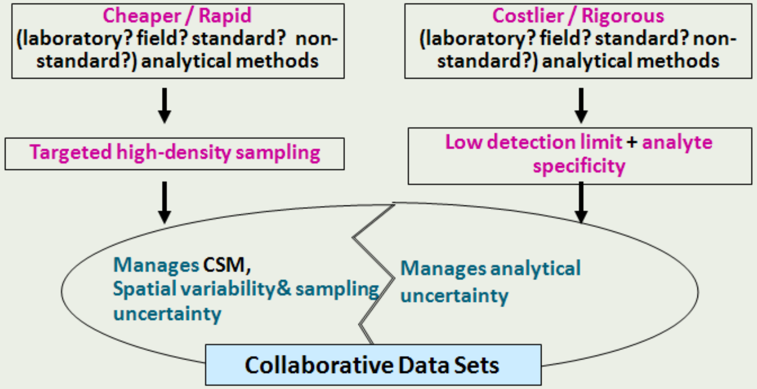
http://water.usgs.gov/ogw/bgas/fiber-optics/

Temperature Profile Along Stream Reach



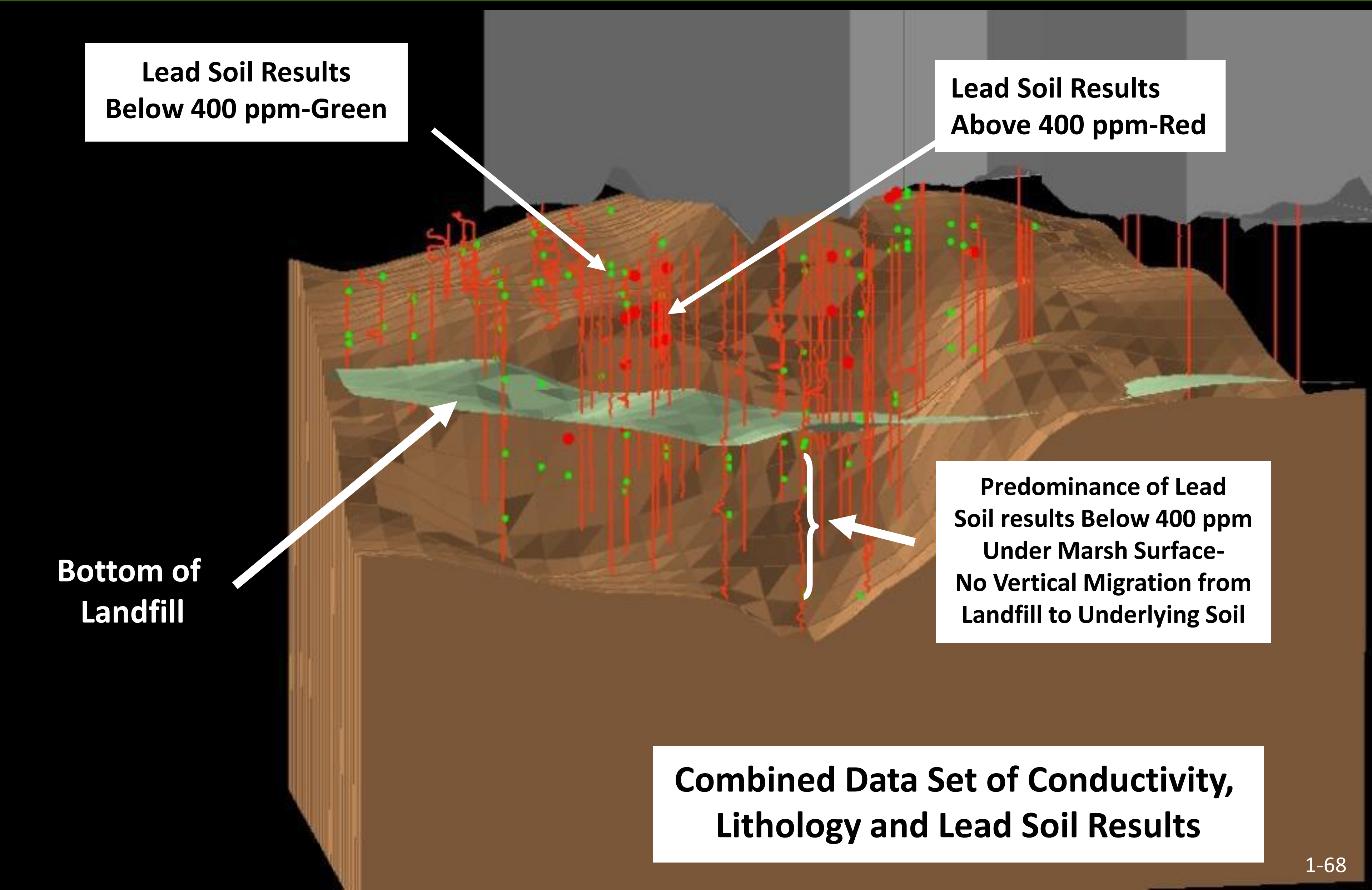
Identifying spatial variability of groundwater discharge in a wetland stream using a distributed temperature sensor. *Christopher S. Lowry, John F. Walker, Randall J. Hunt, and Mary P. Anderson. WATER RESOURCES RESEARCH, VOL. 43. 2007*

Collaborative Data-
Examples of Other Tools



- **Different methods for same analyte or suite of analytes**
- **Multiple lines of evidence = “weight of evidence”**
  - Control project and site decision uncertainties
  - Revises decision criteria in response to data
- **One method provides information for when another is required or beneficial**
- **Control multiple error sources**
  - Sampling design, matrix, prep, analytical
- **Result: increased confidence in the CSM; better decisions, better remedy implementation**
  - Characterization of chemistry and physical attributes with adequate data density

Example of Collaborative Data Set

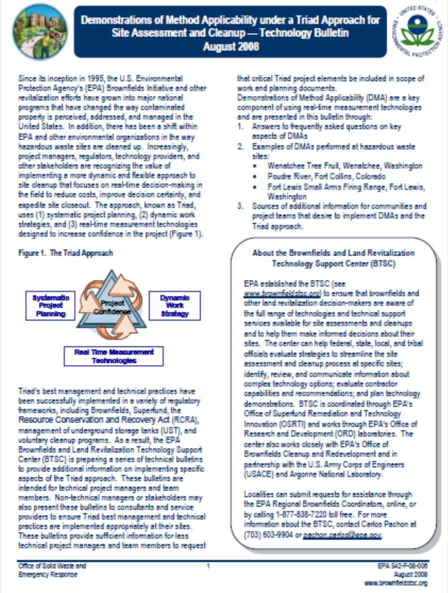


Managing Tools- DMA

Initial site-specific performance evaluation for a wide range of sampling, testing, and data management tools

- **Performed early in program, though not always appropriate**
- **Establishes that proposed technologies and strategies**
  - provide information appropriate to meet project decision criteria
  - perform as advertised by the vendor
- **Assesses performance of field analytical technology compared to fixed-base laboratory**
- **Highlights laboratory and field method advantages and challenges**
- **Provides initial look at CSM assumptions; augments planned data collection and CSM development**
- **Develops relations between visual observations and direct sensing tools**
- **Provides flexibility to change tactics based on DMA rather than full implementation**
- **Optimizes sequencing, staffing, load balance, unitizing costs**

http://brownfieldstsc.org/pdfs/Demonstrations_of_Methods_Applicability.pdf



Demonstrations of Method Applicability under a Triad Approach for Site Assessment and Cleanup — Technology Bulletin
August 2008

Since its inception in 1995, the U.S. Environmental Protection Agency's (EPA) Brownfields Initiative and other revitalization efforts have grown into major national programs that have changed the way contaminated property is perceived, addressed, and managed in the United States. In addition, there has been a shift within EPA and other environmental organizations in the way hazardous waste sites are cleaned up. Increasingly, project managers, regulators, technology providers, and other stakeholders are recognizing the value of implementing a more dynamic and flexible approach to site cleanup that focuses on real-time decision-making in the field to reduce costs, improve decision certainty, and expedite site closeout. The approach, known as Triad, uses (1) systematic project planning, (2) dynamic work strategies, and (3) real-time measurement technologies designed to increase confidence in the project (Figure 1).

Figure 1. The Triad Approach

Triad's best management and technical practices have been successfully implemented in a variety of regulatory frameworks, including Brownfields, Superfund, the Resource Conservation and Recovery Act (RCRA), management of underground storage tanks (UST), and voluntary cleanup programs. As a result, the EPA Brownfields and Land Revitalization Technology Support Center (BTSC) is preparing a series of technical bulletins to provide additional information on implementing specific aspects of the Triad approach. These bulletins are intended for technical project managers and team members. Non-technical managers or stakeholders may also present these bulletins to consultants and service providers to ensure Triad best management and technical practices are implemented appropriately at their sites. These bulletins provide sufficient information for less technical project managers and team members to request that critical Triad project elements be included in scope of work and planning documents.

Demonstrations of Method Applicability (DMA) are a key component of using real-time measurement technologies and are presented in this bulletin through:

1. Answers to frequently asked questions on key aspects of DMAs
2. Examples of DMAs performed at hazardous waste sites:
   - Wenatchee Tree Fruit, Wenatchee, Washington
   - Poudre River, Fort Collins, Colorado
   - Fort Lewis Small Arms Firing Range, Fort Lewis, Washington
3. Sources of additional information for communities and project teams that desire to implement DMAs and the Triad approach.

About the Brownfields and Land Revitalization Technology Support Center (BTSC)

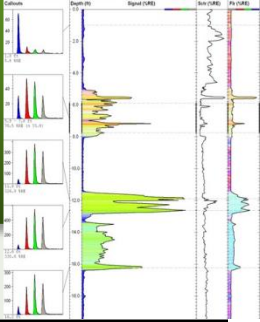
EPA established the BTSC (see www.brownfieldstsc.org) to ensure that brownfields and other land revitalization decision-makers are aware of the full range of technologies and technical support services available for site assessments and cleanups and to help them make informed decisions about their sites. The center can help federal, state, local, and tribal officials evaluate strategies to streamline the site assessment and cleanup process at specific sites; identify, review, and communicate information about complex technology options; evaluate contractor capabilities and recommendations; and plan technology demonstrations. BTSC is coordinated through EPA's Office of Superfund Remediation and Technology Innovation (OSRTI) and works through EPA's Office of Research and Development (ORD) laboratories. The center also works closely with EPA's Office of Brownfields Cleanup and Redevelopment and in partnership with the U.S. Army Corps of Engineers (USACE) and Argonne National Laboratory.

Localities can submit requests for assistance through the EPA Regional Brownfields Coordinators, online, or by calling 1-877-838-7220 toll free. For more information about the BTSC, contact Carlos Pachon at (703) 603-9904 or pachon.carlos@epa.gov.

Office of Solid Waste and Emergency Response 1 EPA 542-F-08-006 August 2008 www.brownfieldstsc.org

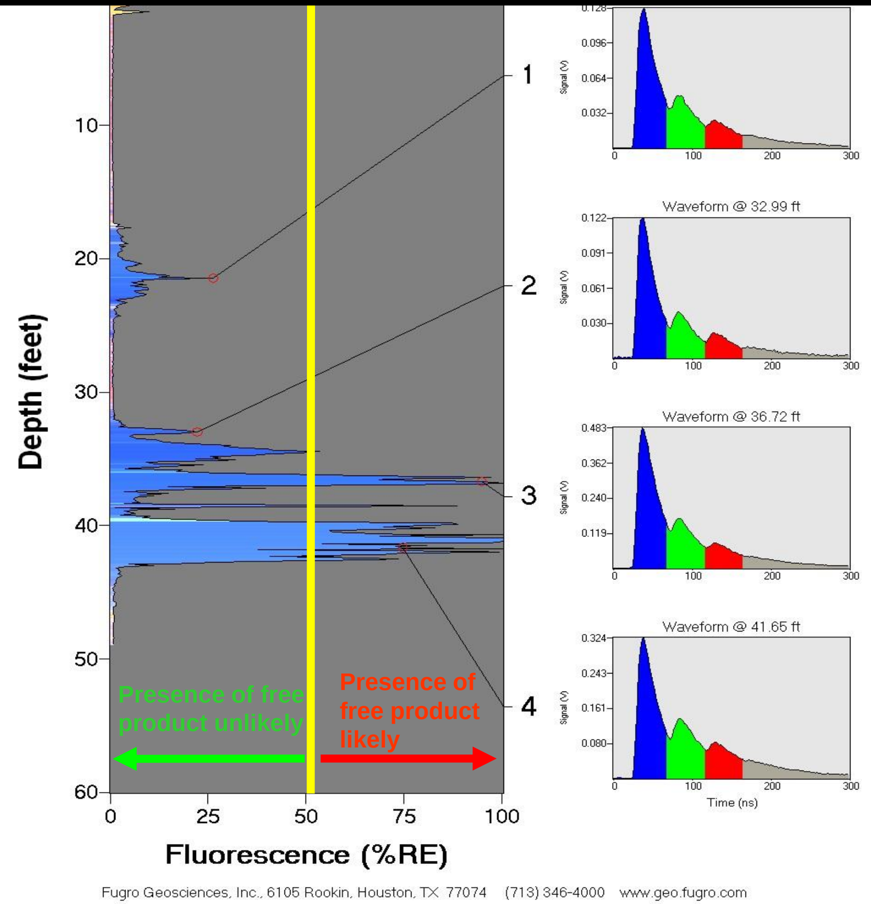
Example DMA Output

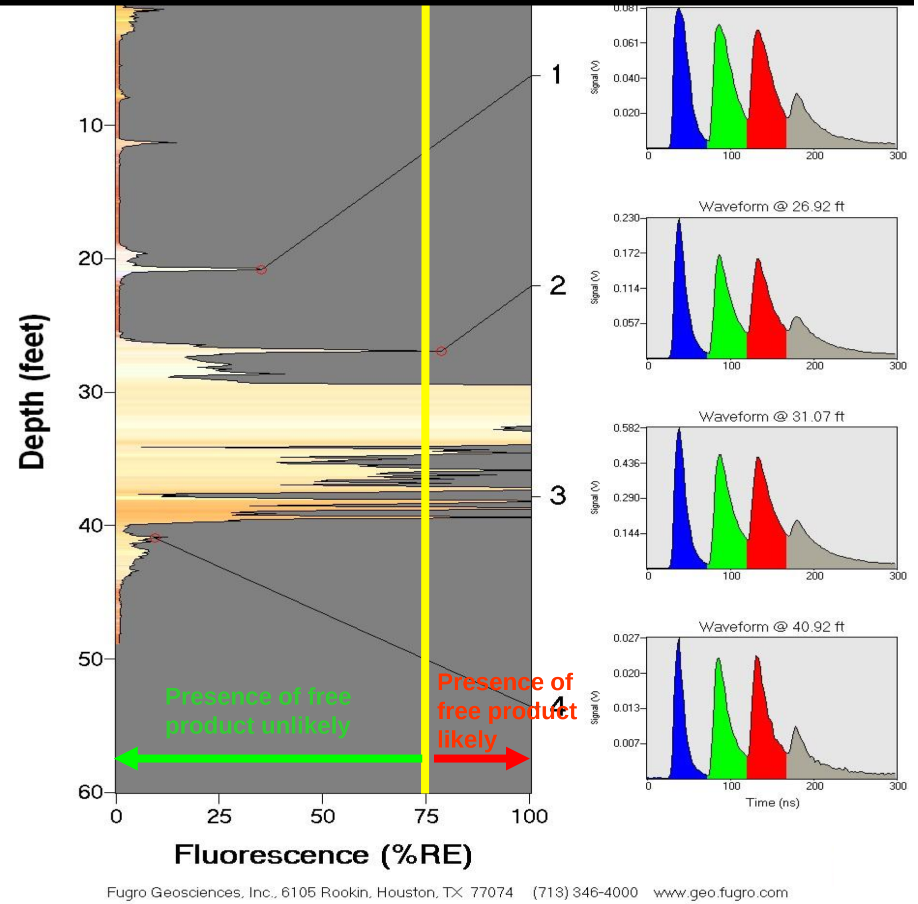
http://brownfieldstsc.org/pdfs/Demonstrations_of_Methods_Applicability.pdf



Free Product At >50% Relative Fluorescence for Gasoline

Free Product At >75% Relative Fluorescence for Oil





Case Studies of Interest

Innovations in Site Characterization

Case Study: The Role of a Conceptual Site Model for Expedited Site Characterization Using the Triad Approach at the Poudre River Site, Fort Collins, Colorado

U.S. Environmental Protection Agency
Office of Superfund Remediation and Technology Innovation
Brownfields Technology Support Center
Washington D.C. 20460

Prepared by:

The Brownfields and Land Revitalization Technical Support Center

In cooperation with:
U.S. Environmental Protection Agency Region 8

United States Environmental Protection Agency

Office of Solid Waste and Emergency Response (5102G)

EPA 542-R-06-007
November 2006
www.epa.gov
clu-in.org

United States Environmental Protection Agency

Office of Solid Waste and Emergency Response (5102G)

September 2010
www.epa.gov
www.clu-in.org
542-R-10-006

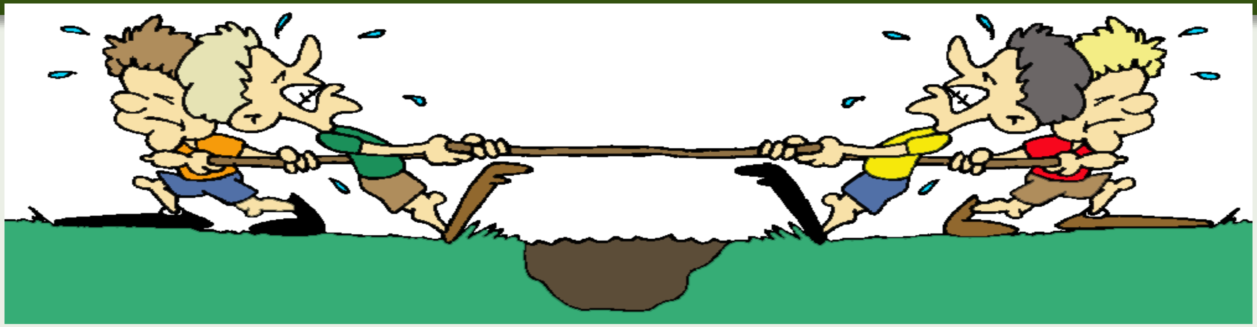
Innovations in Site Characterization

Streamlining Cleanup at Vapor Intrusion and Product Removal Sites Using the Triad Approach:
Hartford Plume Site, Hartford, Illinois

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF SUPERFUND REMEDIATION AND TECHNOLOGY INNOVATION
SUPERFUND TECHNOLOGY SUPPORT CENTER
WASHINGTON, D.C. 20460

Now Let's Look at Soil

Incremental Soil Sampling vs. HRSC in Groundwater



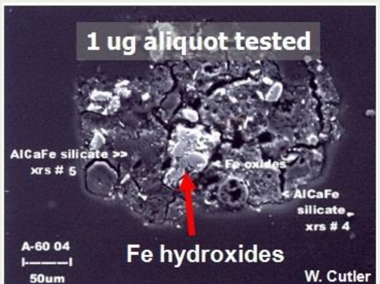
Soil	Matrix Property	Groundwater
1. High	1. Variability	1. High
2. Static, Lower spatial correlation	2. Contamination distribution	2. Dynamic, higher spatial correlation
3. Low	3. Mass transfer and storage	3. High
4. Low	4. Cost of obtaining samples	4. High
5. Decision Unit	5. Typical exposure scenarios	5. Variable
6. Lower cost/shorter cleanups= blunt force	6. Remediation applications	6. High cost/long cleanups= finesse,

The Nature of Soil

- **Variability in Soil Matrices- 3 scales of importance**

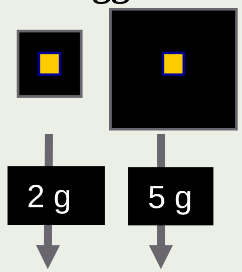
Micro-scale

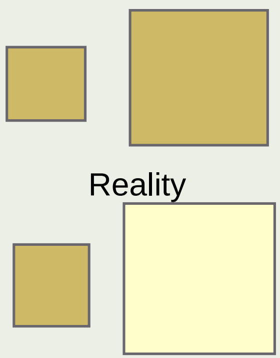
Particle Size Effects

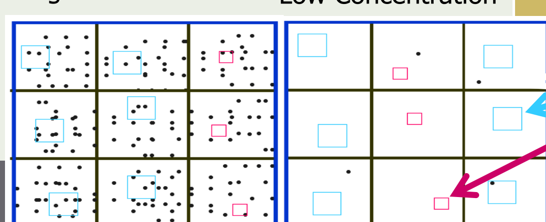


Firing Range Soil Grain Size (Std Sieve Mesh Size)	Pb Concentration in fraction by AA (mg/kg)
Greater than 3/8" (0.375")	10
Between 3/8" and 4-mesh	50
Between 4- and 10-mesh	108
Between 10- and 50-mesh	165
Between 50- and 200-mesh	836
Less than 200-mesh	1,970
Bulk Total	327 (wt-averaged)

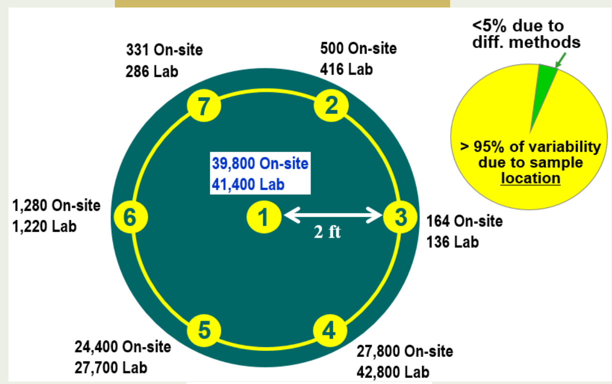
The Nugget Effect

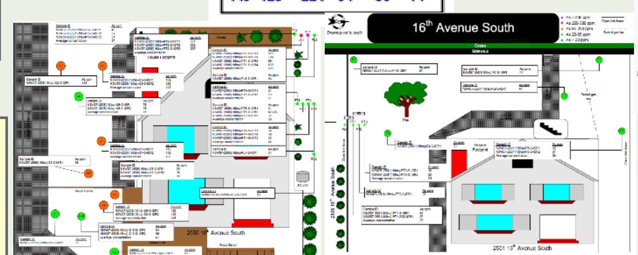




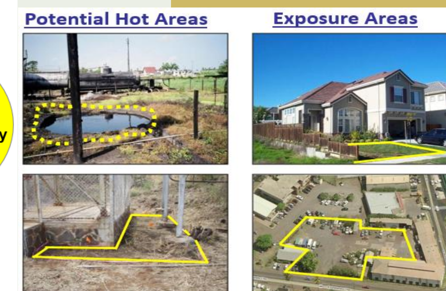


Short-scale

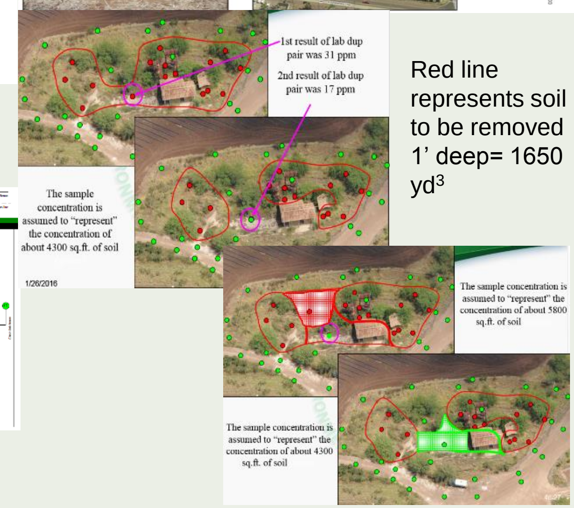




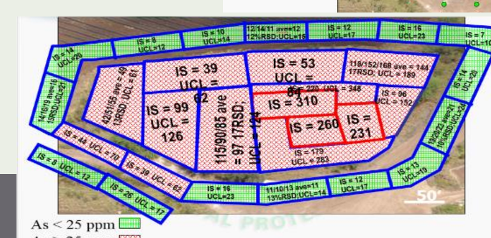
Long-scale



See ITRC, ISM-1 (www.itrcweb.org/ISM-1) Section 3.3 and ITRC ISM Internet Training archives: http://www.cluin.org/live/archive/ and search for "incremental"

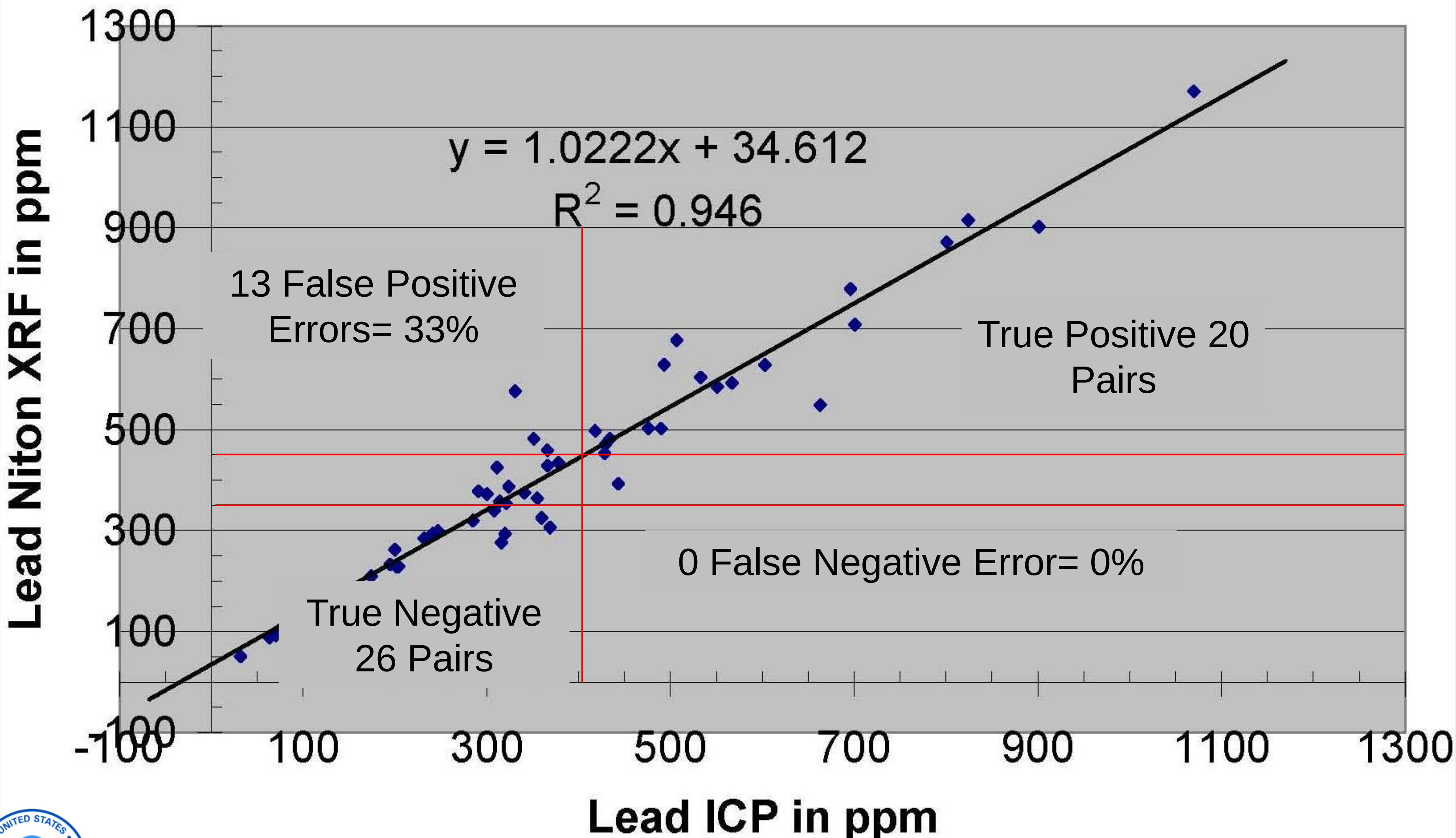


Red line represents soil to be removed 1' deep= 1650 yd^3

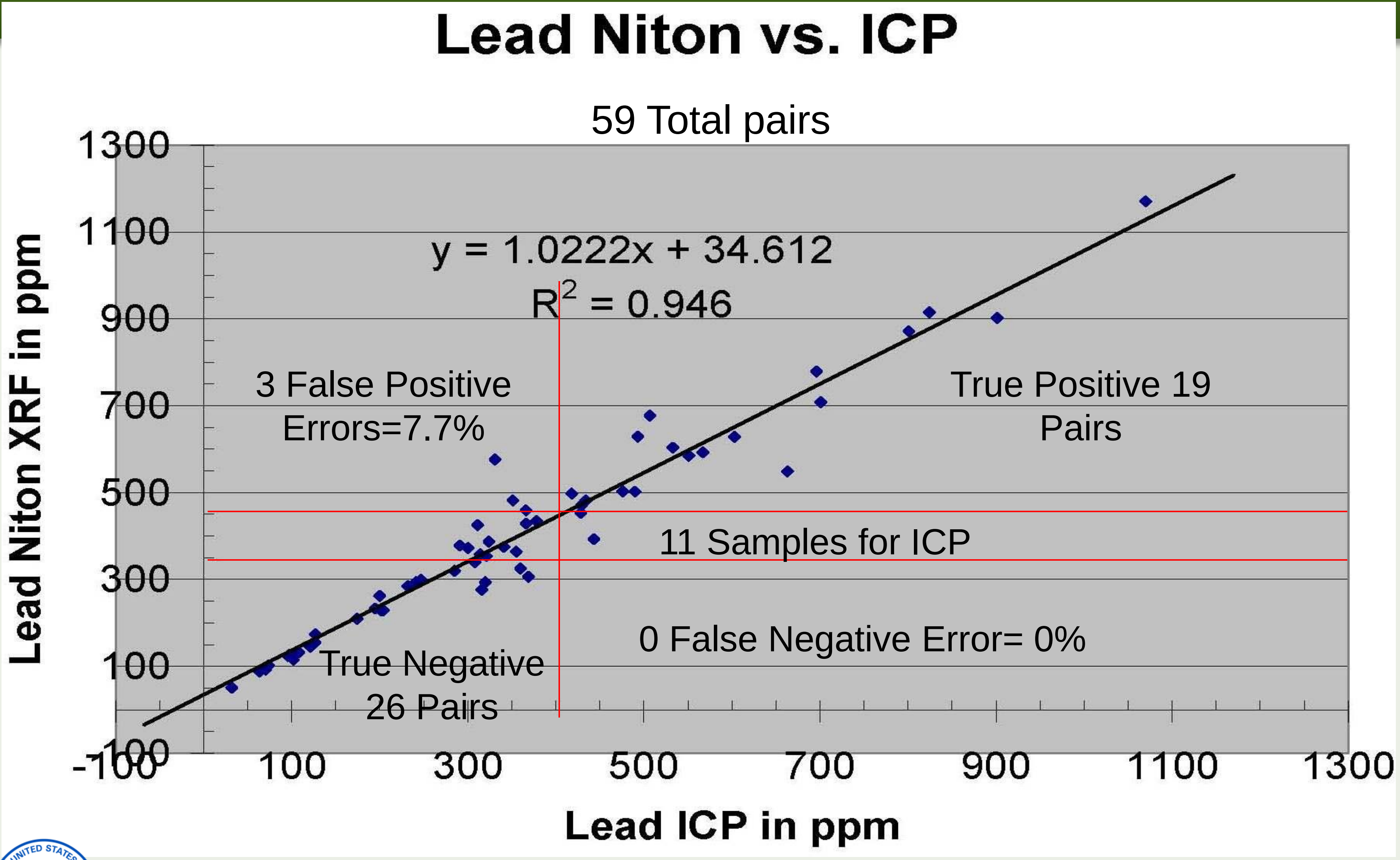


Lead Niton vs. ICP

59 Total pairs



3 Way Decision Structure With Region of Uncertainty



Example of Standardizing Core Descriptions

- ***No visible evidence*** – No visible evidence of oil on soil sample
- ***Sheen*** – Can be effective in detecting petroleum-based products in concentrations lower than regulatory cleanup guidelines. Sheens are classified as follows:
  - » *No Sheen (NS)* – No visible sheen on water surface
  - » *Slight Sheen (SS)* – Light colorless film; spotty to globular; spread is irregular, not rapid; areas of no sheen remain; film dissipates rapidly
  - » *Moderate Sheen (MS)* – Light to heavy film, may have some color or iridescence, globular to stringy, spread is irregular to flowing; few remaining areas of no sheen on water surface
  - » *Heavy Sheen (HS)* – Heavy colorful film with iridescence; stringy, spread is rapid; sheen flows off the sample; most of water surface may be covered with sheen
- ***Staining*** – Visible brown or black staining on soil. Can be visible as mottling or in bands. Typically associated with fine-grained soils.
- ***Coating*** – Visible brown or black oil coating soil grains. Typically associated with coarse-grained soils.
- ***Oil Wetted*** – Visible brown or black oil wetting the soil sample. Oil appears as a liquid and is not held by soil grains. Soils oozing petroleum typically contain approximately 2 to 3 percent petroleum.

Designating Decision Units (DUs)

- This is the most important design element!
  - Should seek stakeholder consensus during planning, NOT after the data have come in.
- Information used to develop DU dimensions and locations:
  - Are there likely "hot" areas present? Size DUs as small remedial units probably needing cleanup
    - Historical site use & aerial photos
    - Existing sampling data
    - Interviews with current or former site workers
  - Exposure DUs (for determining exposure risk)
    - Size the DUs based on current and future site use

Size, Shape and Type of DU

Potential Hot Areas

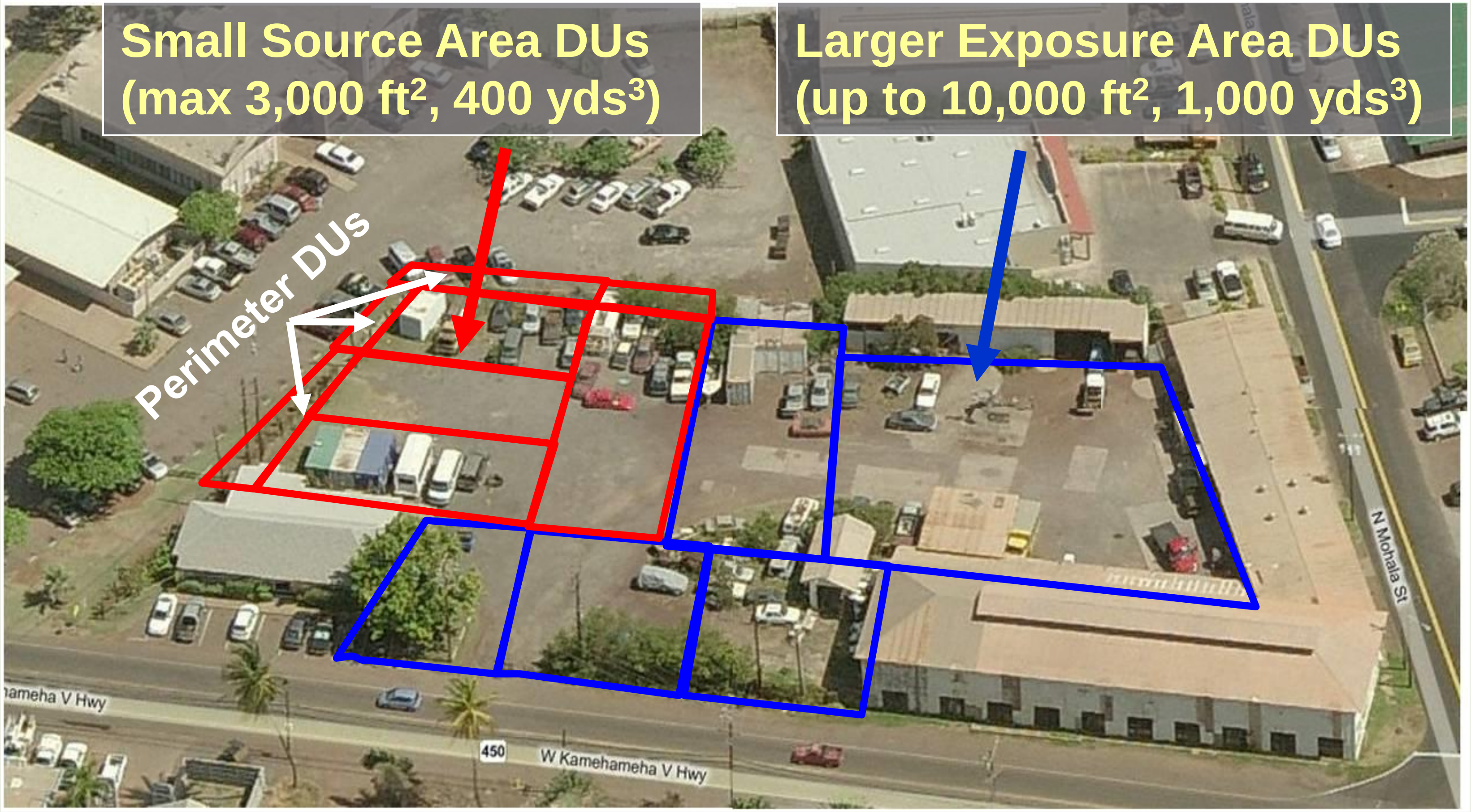
Exposure Areas

See ITRC, ISM-1 (www.itrcweb.org/ISM-1)
Section 3.3
and
ITRC ISM Internet Training archives:
http://www.cluin.org/live/archive/
and
search for
“incremental”

Former Power Plant
Proposed as a Community Center

Primary objective is to identify and delineate source area and extent of contamination that exceeds action levels.

Former Power Plant Decision Unit Designation

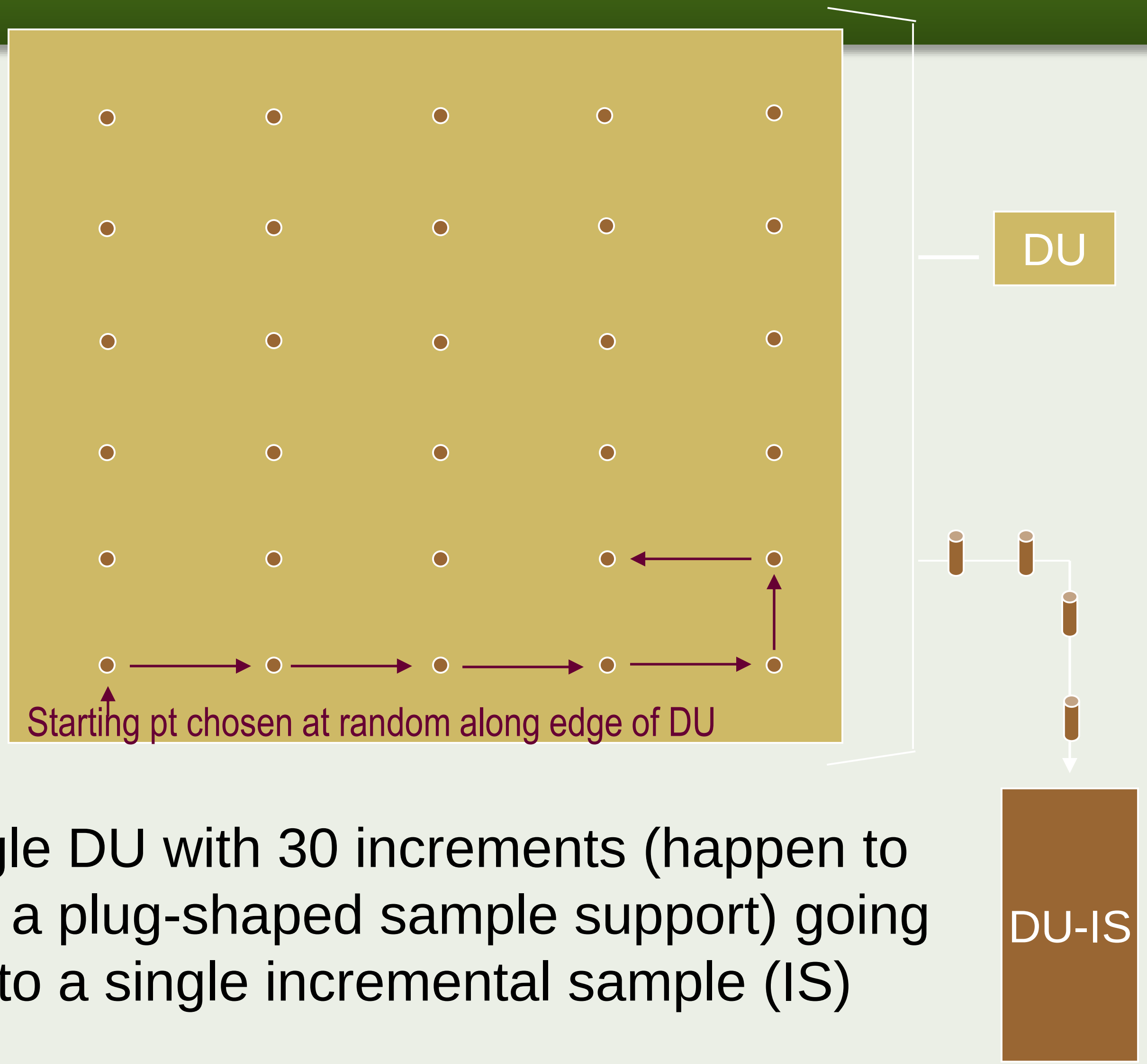


100′

Incremental Sampling Methodology (ISM)

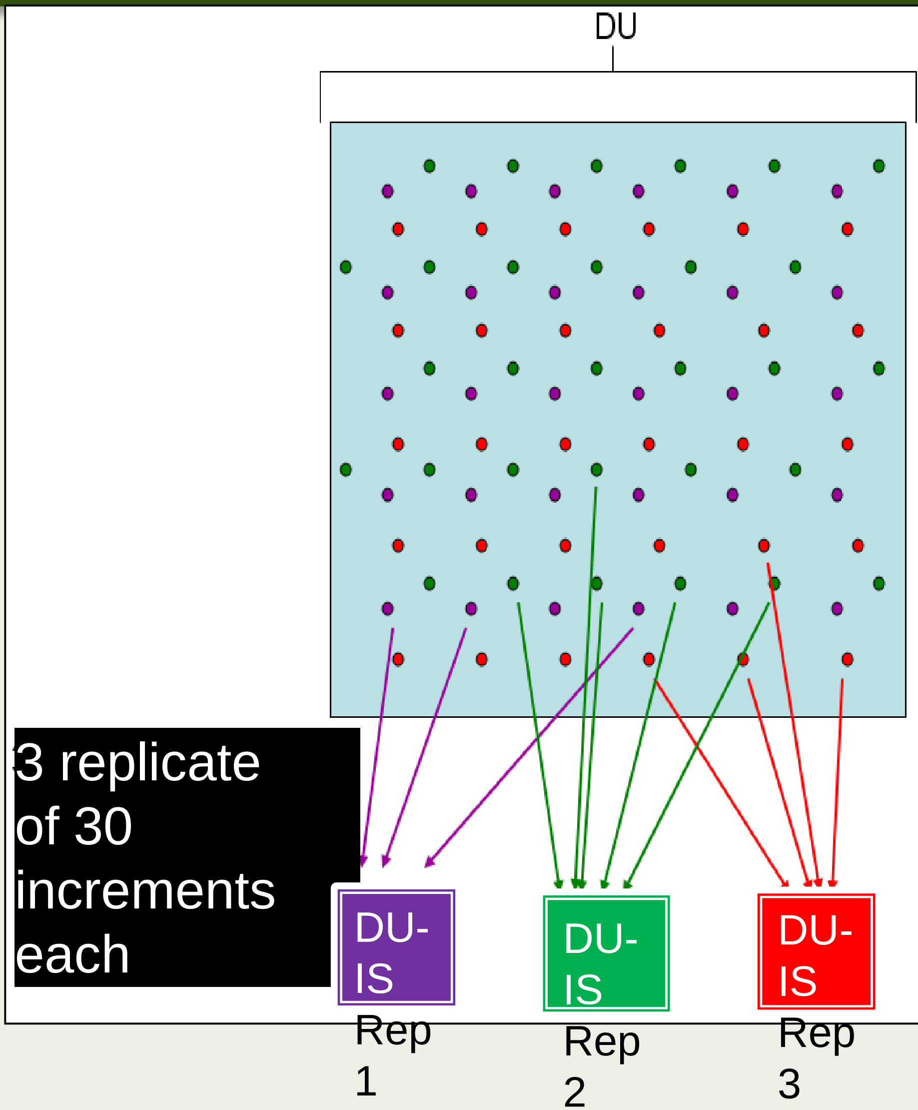
Single incremental sample (IS) covers a decision unit (DU)

Definitive guidance is the ITRC ISM Tech Reg web doc



Single DU with 30 increments (happen to have a plug-shaped sample support) going into a single incremental sample (IS)

Replicate Incremental Samples

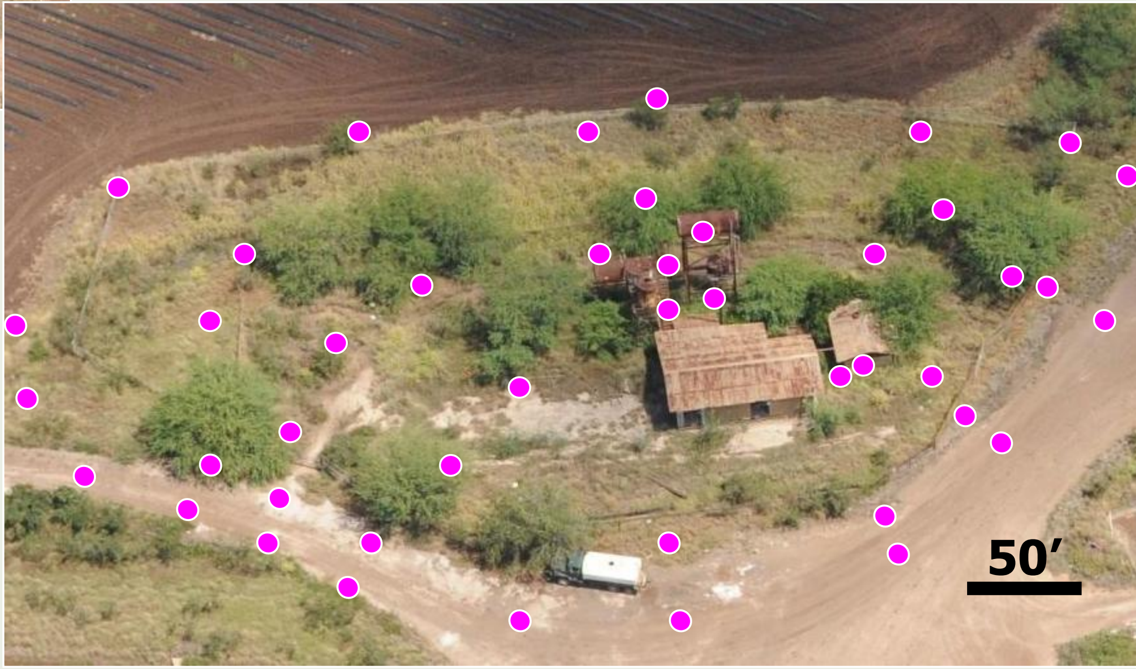


3 allows stats- mean, UCL

What About In Soil?

High Density, High/Low Resolution

- Arsenical pesticide mixing area in Hawaii
- Residential redevelopement
- This parcel is 3 acres
- As cleanup level = 25 ppm



- 44 grab samples (judgemental or random) collected for lab analysis.
- Sampling density of 15 samples per acre.

Results Mapped

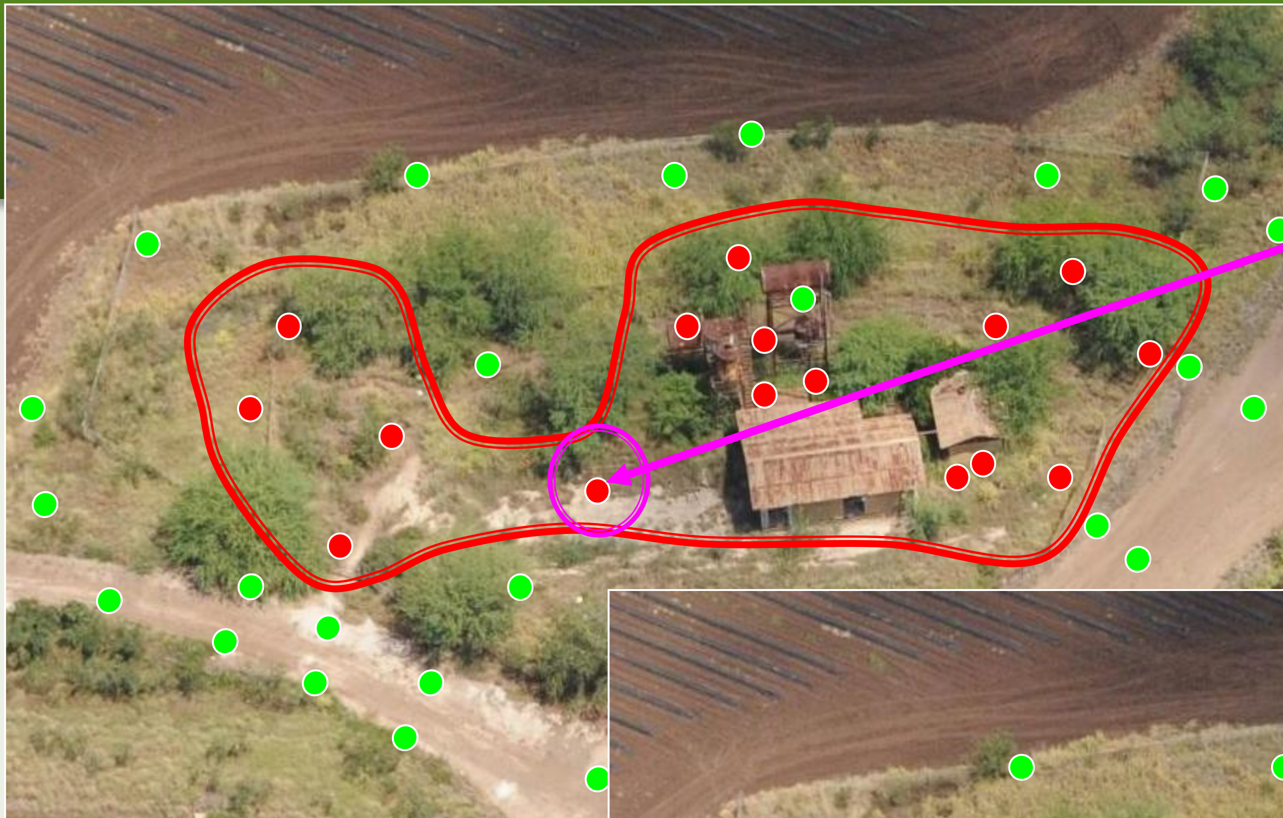
Red line represents soil to removed 1' deep= 1650 yd³

Dear Developer,

Please fund the removal and disposal of 1,650 yd^3 of arsenic-contaminated soil. Oh, and by the way, there is about a 50:50 chance that this cleanup footprint is incorrect. The actual volume needing removal could be

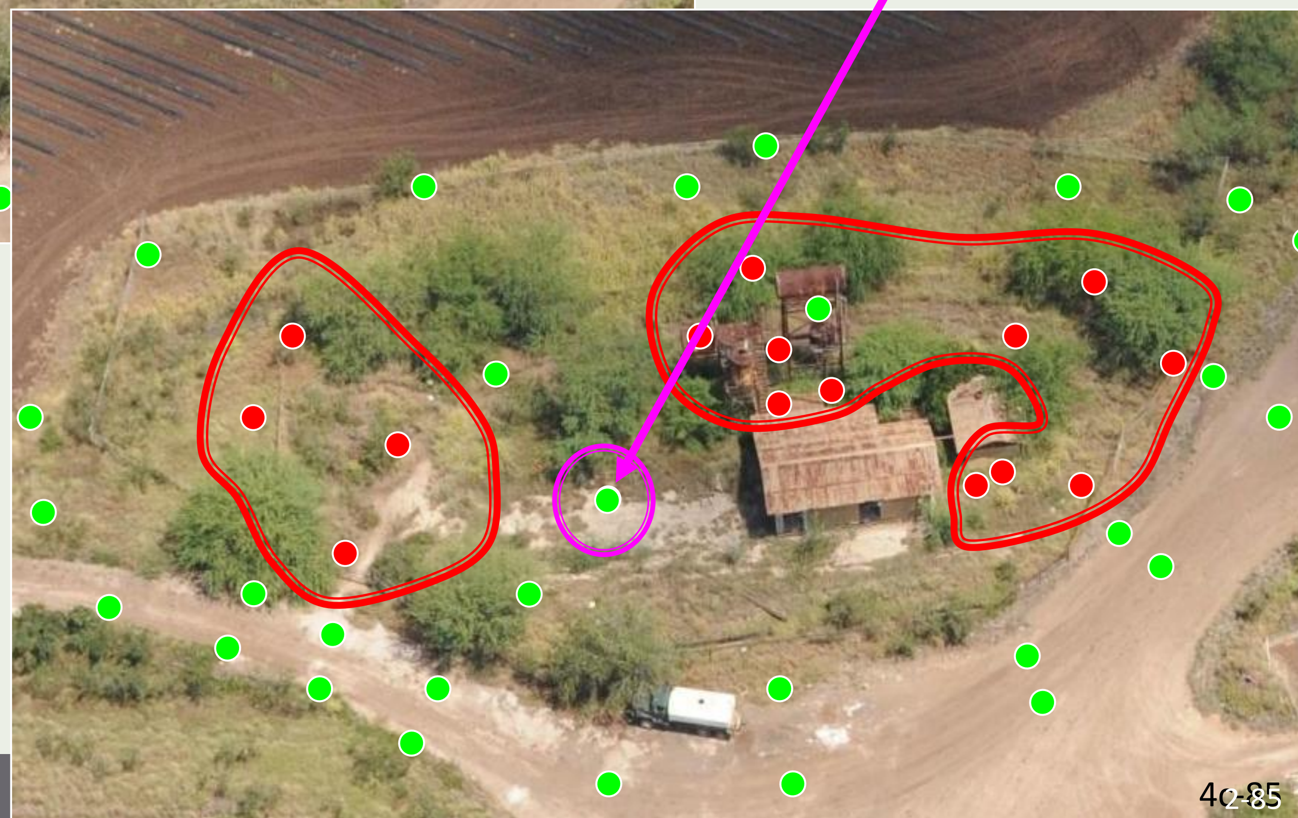
1) more than this;
2) less than this; and/or
3) the footprint could be in the wrong place.

So, after confirmation sampling, I may be asking you for more money to do this all over again. But it will be the data's fault, not mine.

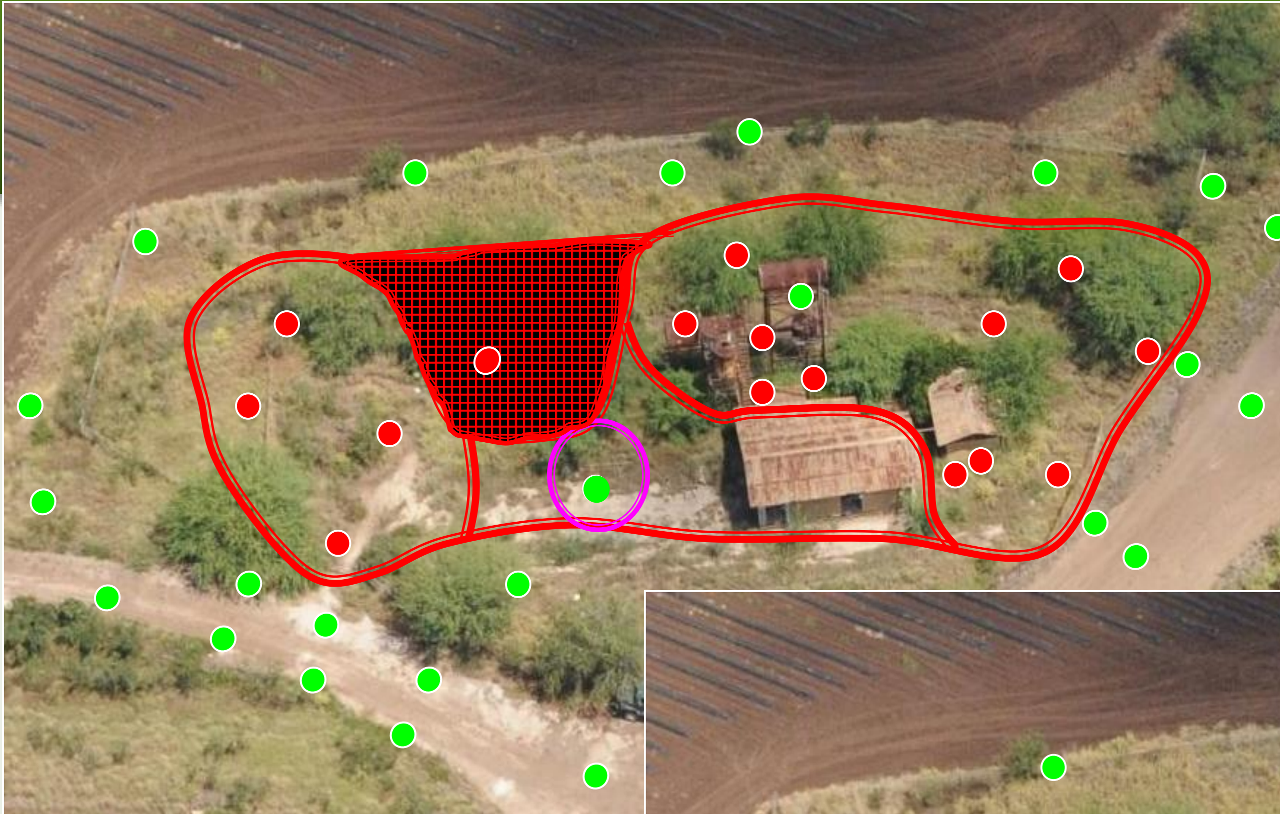


1st result of lab dup pair was 31 ppm

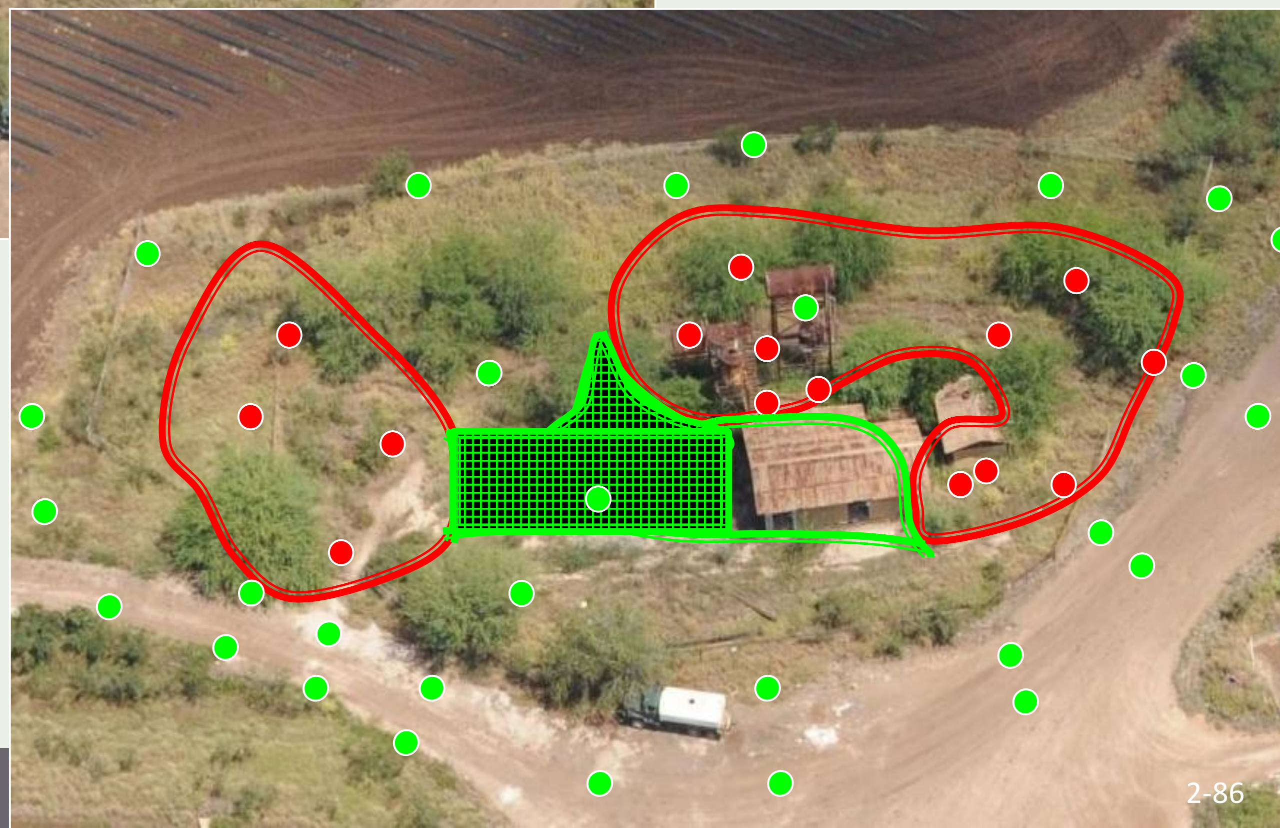
2nd result of lab dup pair was 17 ppm



The sample concentration is assumed to “represent” the concentration of about 4300 sq.ft. of soil (green)



The sample concentration is assumed to “represent” the concentration of about 5800 sq.ft. of soil (green)

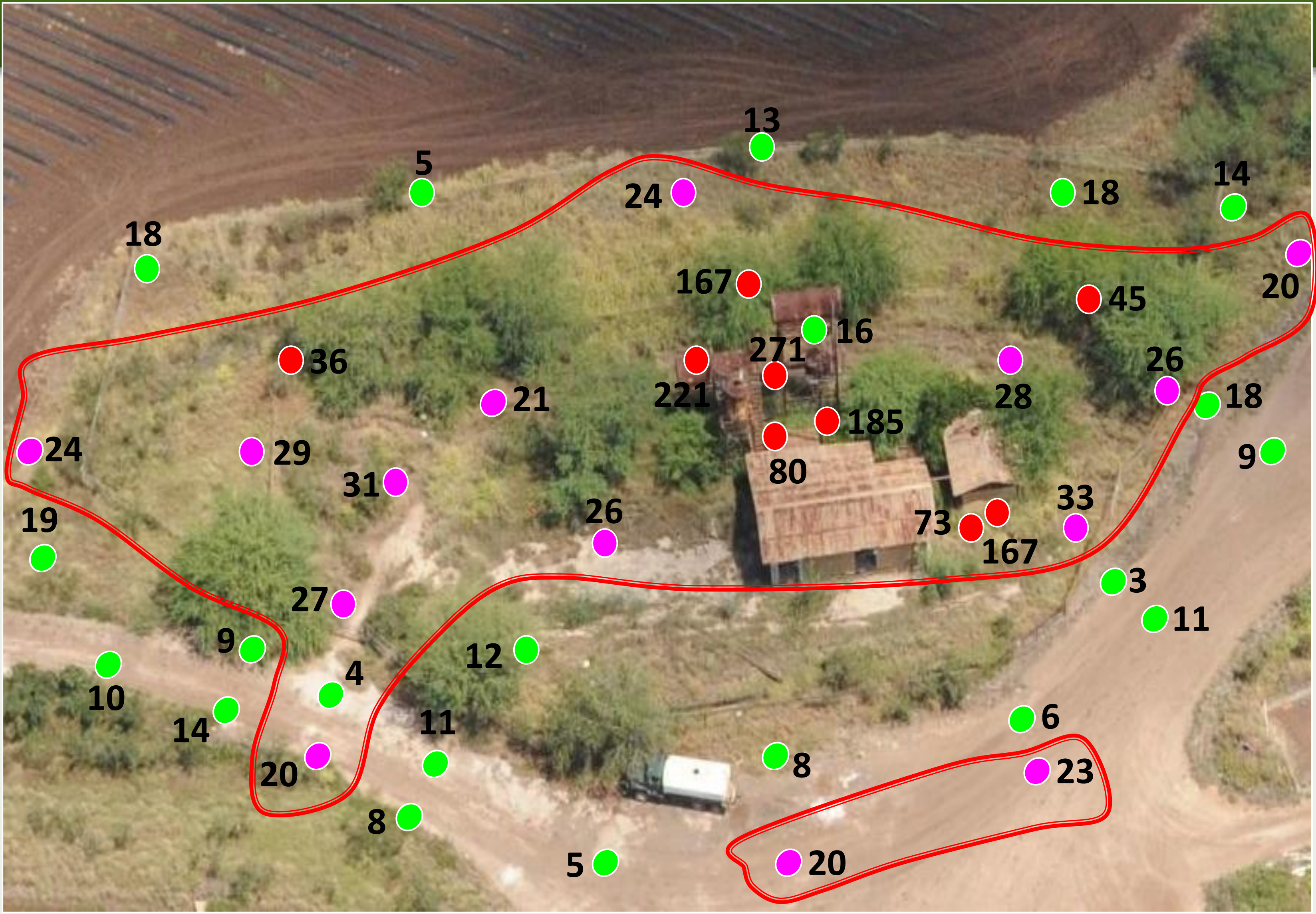


The sample concentration is assumed to “represent” the concentration of about 4300 sq.ft. of soil (green)

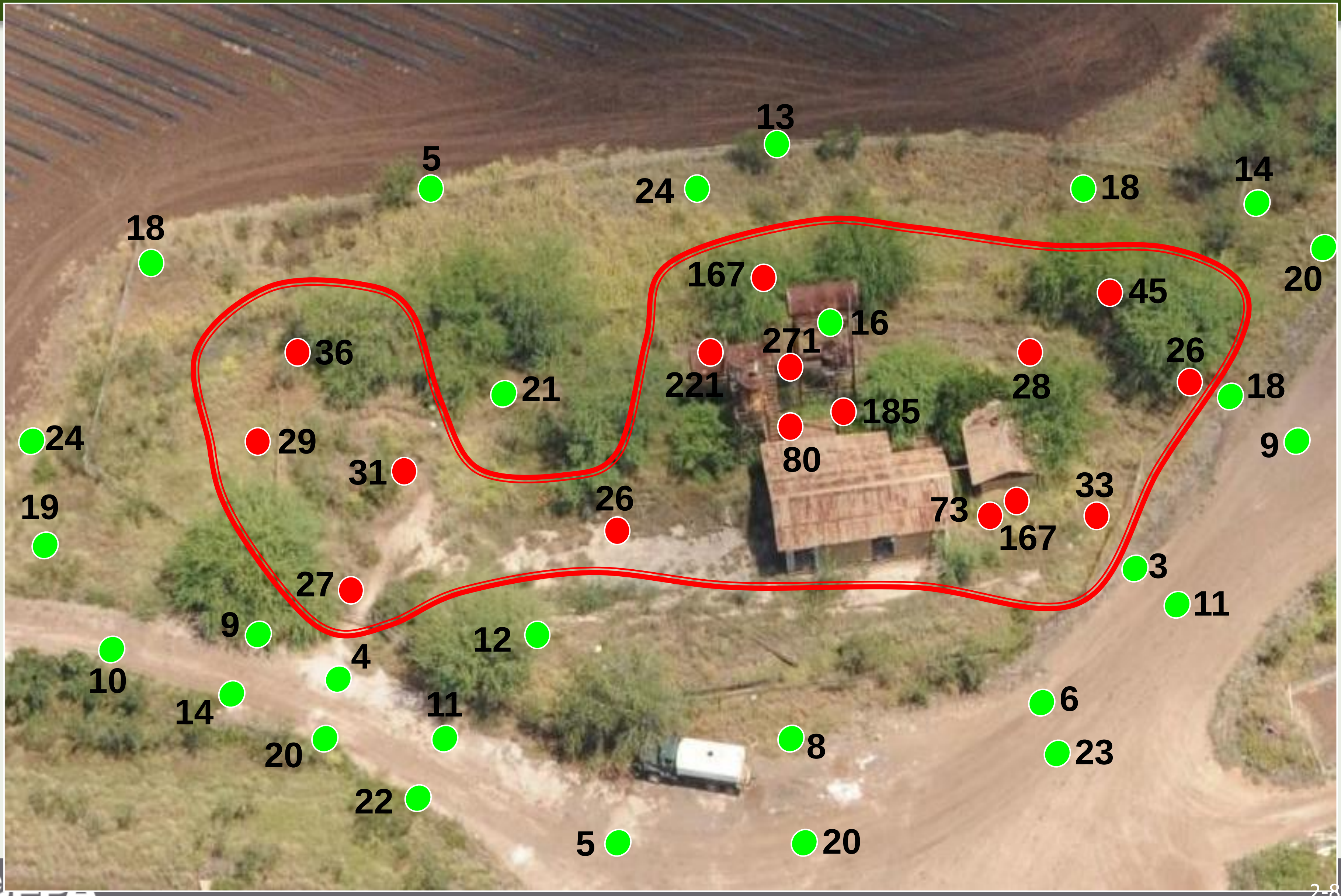
How Much Confidence Do You Need?

Using total data imprecision: everything within the red boundary (3,450 cu. yd.) would need to be removed to have 95% confidence the site is clean.

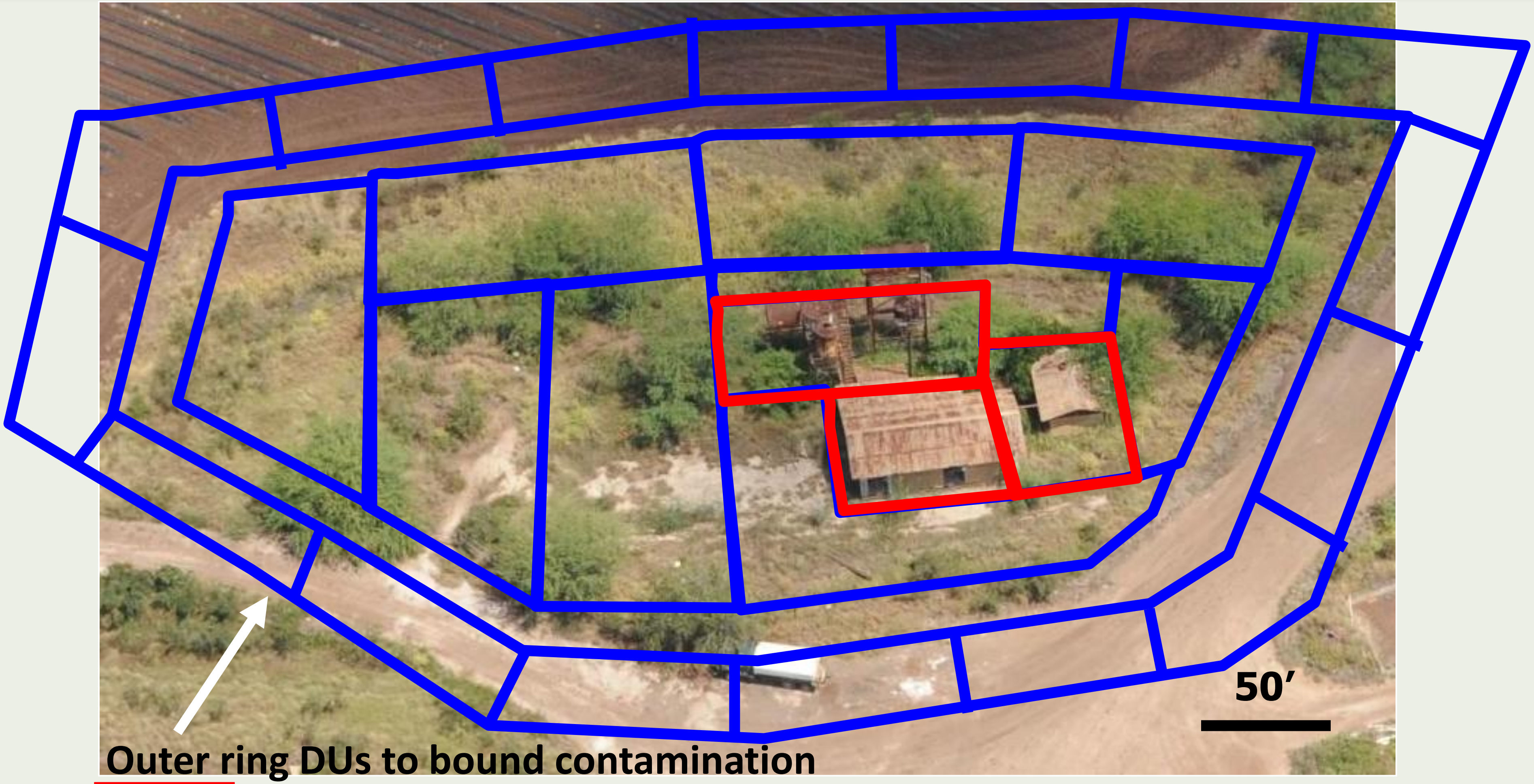
Settling for 75% decision confidence means removing only 2,650 cu. yd.



Or, again, you can flip a coin to decide whether this cleanup footprint (1,650 cu. yd.) is correct.



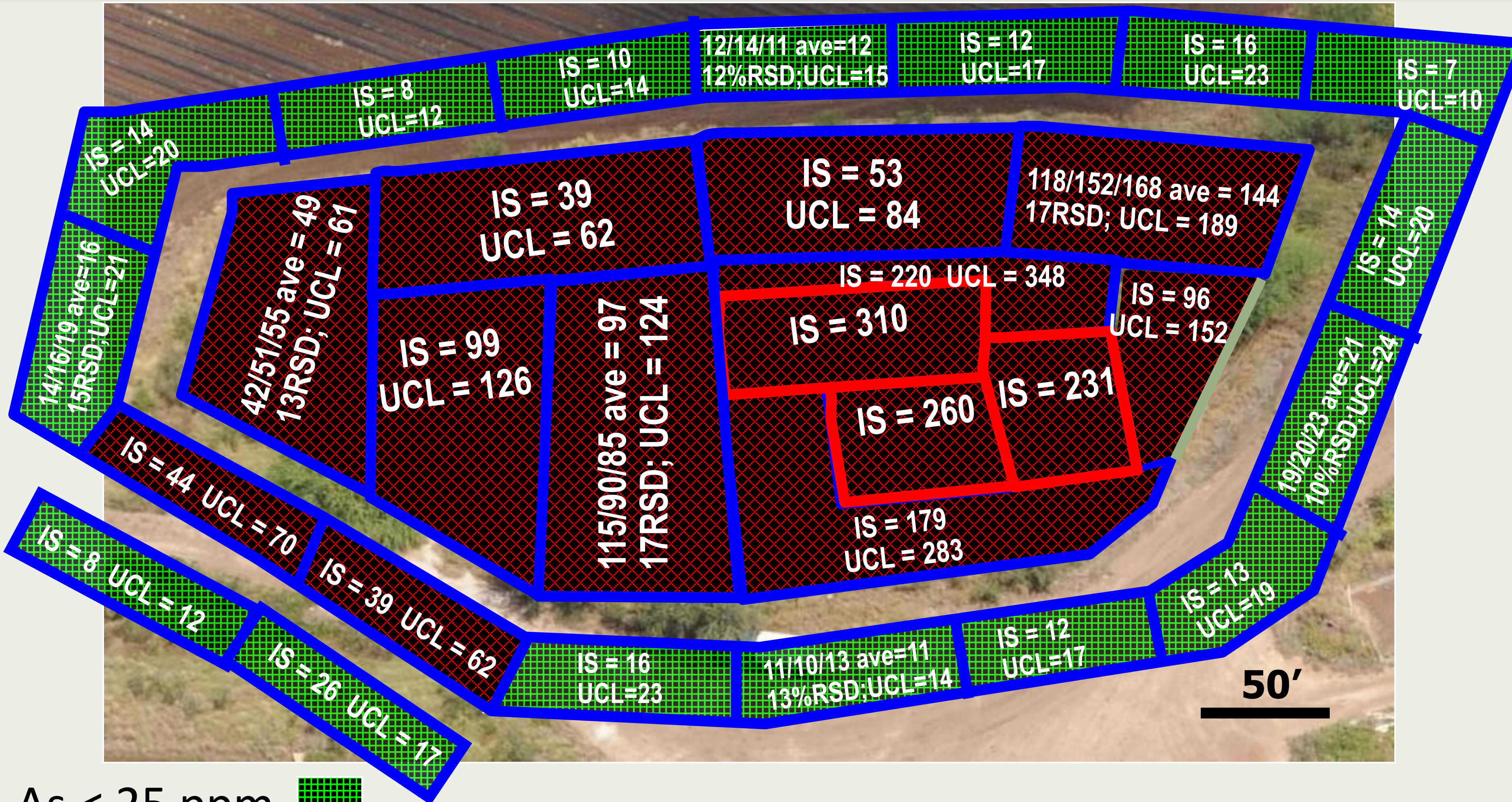
Decision Unit Designation for Incremental Sampling



Spill Area DUs: Heavy contamination

Direct Exposure DUs: Maximum 5,000 ft^2

Results

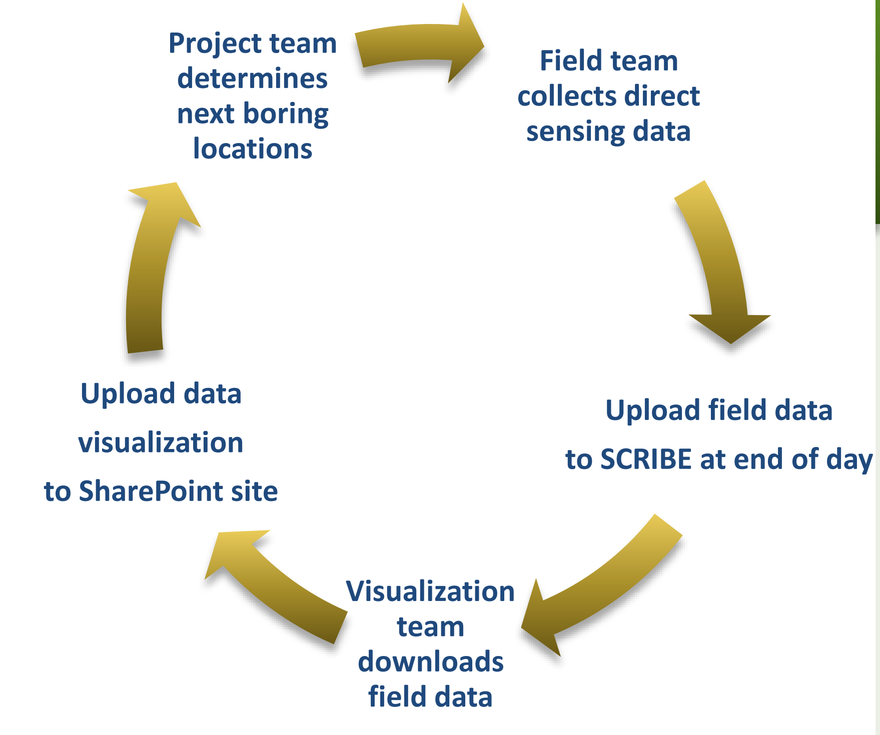


As < 25 ppm

As ≥ 25 ppm

Putting It All Together

Real-Time Direct Sensing and CSM Updates



- **Forces data interpretation … not just presentation**
- **Includes all site decision-makers in the process**
  - Builds consensus; streamlines decision process
- **Saves time and expense**
  - Reduces repeat mobilizations; flags data collection errors immediately
- **Keeps focus on root causes, not symptoms**
  - High mass footprint (where to remediate)
  - Matrix distribution (how to remediate)
- **Pushes the decision process forward**

Conclusions

HRSC and Incremental Sampling Translated for Remedial Designs

- **In Groundwater**
  - Limit large scale averaging, use scale appropriate measurements
  - Use transects and multi-level sampling
  - Use direct sensing and collaborative data sets
- **In Soil**
  - Use incremental and compositing techniques to control matrix variability, reasonably represent exposure and decision units
  - Many increments and replicate samples provide- good estimate of mean, and ability to calculate UCL/LCL and statistical confidence
- **Real-time CSM Updates/Data Visualization**
  - Forces interpretation not just presentation
  - Includes all decision makers in the process- consensus, streamline
  - Save time and money- fewer repeat mobilizations, early ID of data collection errors
  - Keeps focus on root causes not symptoms- High mass footprint (where to remediate), Matrix distribution (how to remediate)