High Resolution Site Characterization (HRSC)

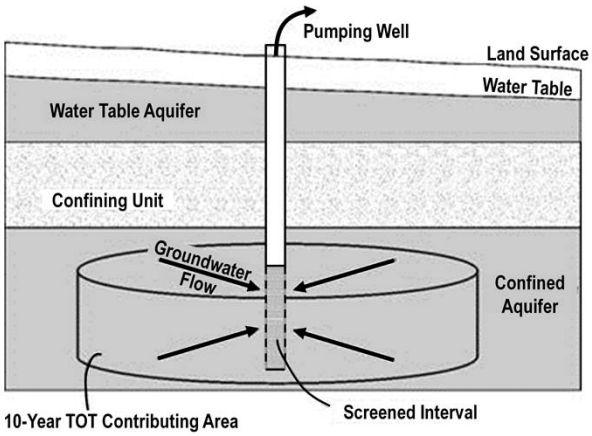
Presentation Overview

► Introduction

- What is High Resolution Site Characterization (HRSC)?
- Scientific Basis for HRSC
- Why Do HRSC?
- Implementation of HRSC
- HRSC Tools and Approaches
- Case Study – Naval Air Station Jacksonville
- Wrap Up

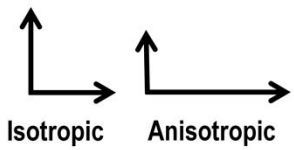
History and Development of HRSC

Historical Perspective – Water Supply

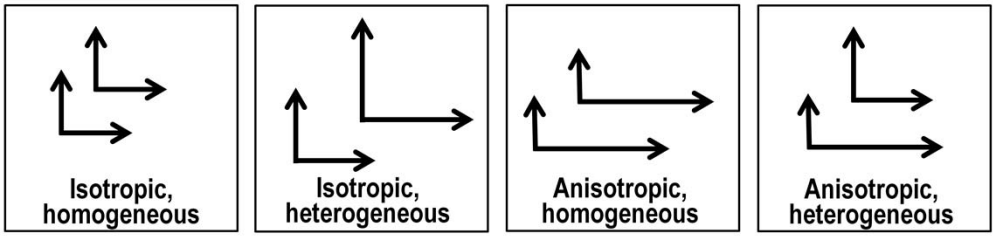


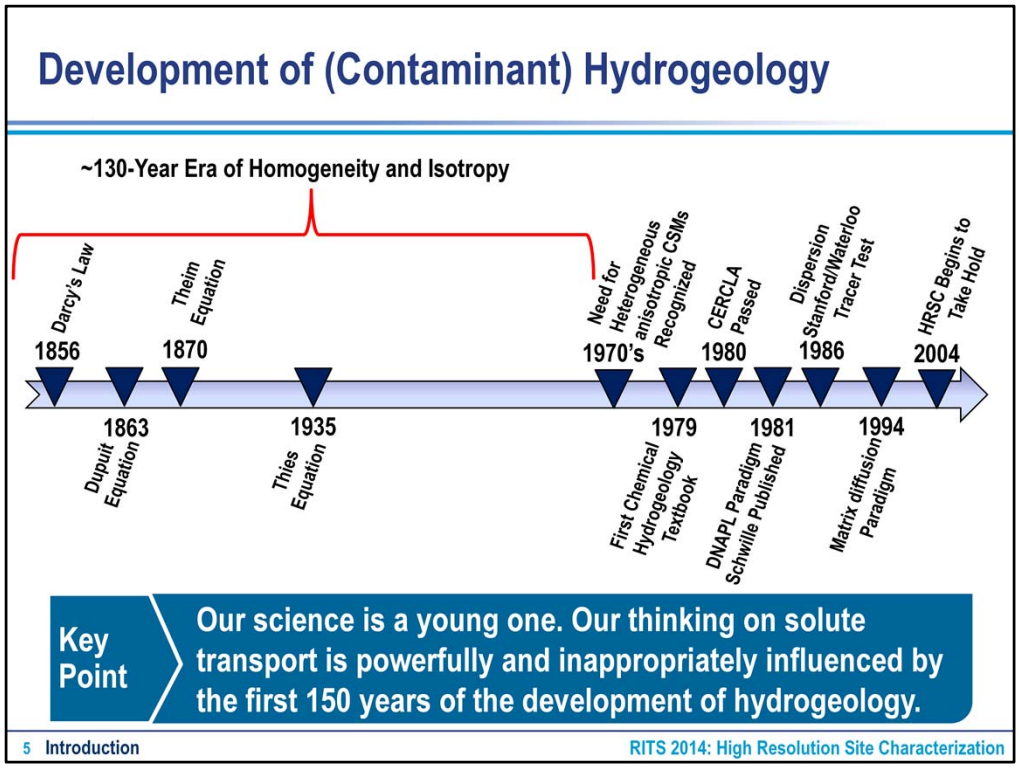
- Aquifers are:
  - Homogeneous
  - Isotropic
  - Infinite extent
- Treated as a single bulk entity
  - T
  - S
  - How much water can we get out of it?

Definitions: Isotropy and Homogeneity



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




Development of (Contaminant) Hydrogeology
~130-Year Era of Homogeneity and Isotropy
1856
Darcy's Law
1863
Dupuit Equation
1870
Theim Equation
1935
Thies Equation
1970's
Need for Heterogeneous anisotropic CSMs Recognized
1979
First Chemical Hydrogeology Textbook
1980
CERCLA Passed
1981
DNAPL Paradigm Schwille Published
1986
Dispersion Stanford/Waterloo Tracer Test
1994
Matrix diffusion Paradigm
2004
HRSC Begins to Take Hold
Key Point
Our science is a young one. Our thinking on solute transport is powerfully and inappropriately influenced by the first 150 years of the development of hydrogeology.
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Development of (Contaminant) Hydrogeology

Charles V. Theis

C.V. Theis – 1967 "I consider it certain that we need a new conceptual model, containing the known heterogeneities of natural aquifers, to explain the phenomenon of transport in groundwater."

Key Point

Our science is a young one. Our thinking on solute transport is powerfully and inappropriately influenced by the first 150 years of the development of hydrogeology.

Development of (Contaminant) Hydrogeology

John Cherry – 1981

"In the early nineteen seventies, it became apparent that … the approach used in the evaluation of contaminant migration in groundwater… involved direct adaptations of …monitoring methods and …models of the type traditionally used in groundwater resource studies. …the behavior of groundwater flow systems is … such that these direct adaptations are unsuitable or misleading because of the heterogeneous character of the geological deposits and/or the geochemical nature of the contaminant species."

Key Point

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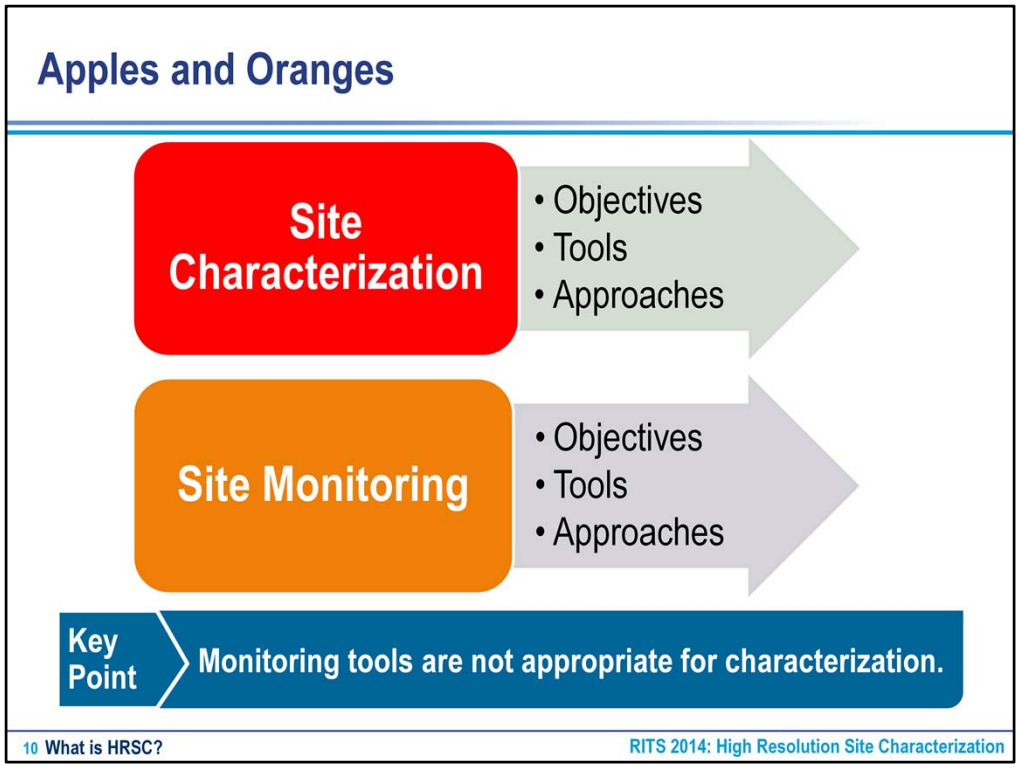
What is HRSC ?

Subsurface investigation appropriate to the scale of heterogeneities in the subsurface which control contaminant distribution, transport, and fate, at the required degree of detail

- **Spatial structure of hydrogeologic variables controlling contamination distribution, transport, and fate is on the centimeter scale**
- **Remedies involving injection/extraction of fluids are controlled by the same variables at the same scales**


Apples and Oranges
Site Characterization
• Objectives
• Tools
• Approaches
Site Monitoring
• Objectives
• Tools
• Approaches
Key Point
Monitoring tools are not appropriate for characterization.
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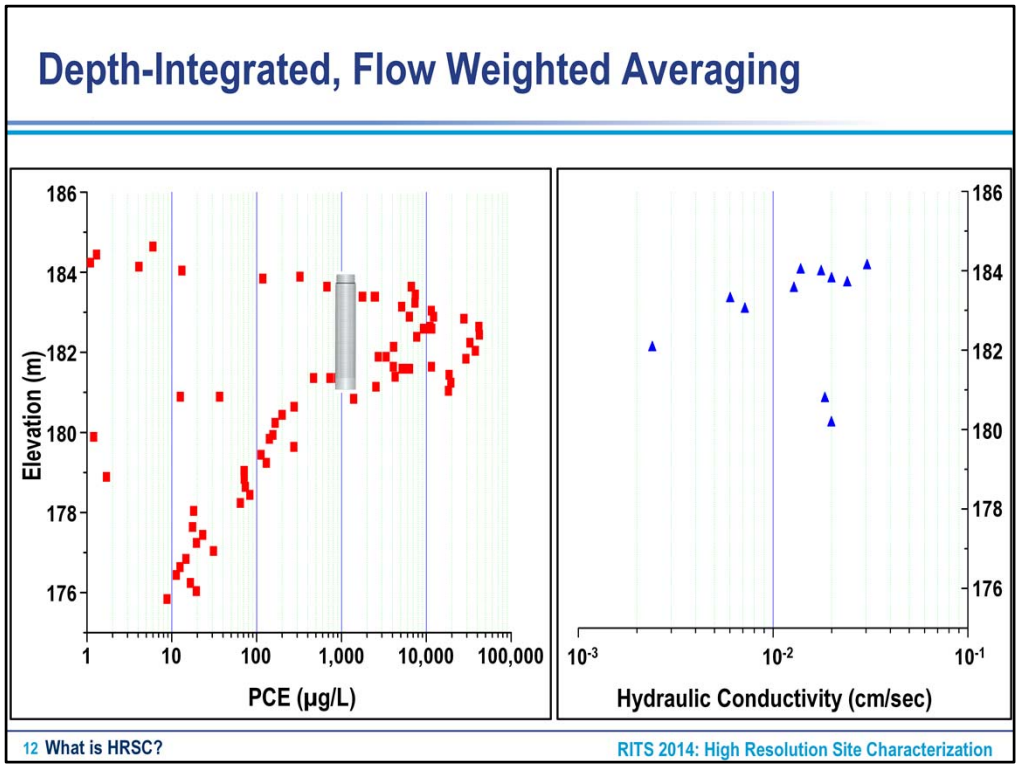
How "Well" Do You Understand Your Site Conditions?

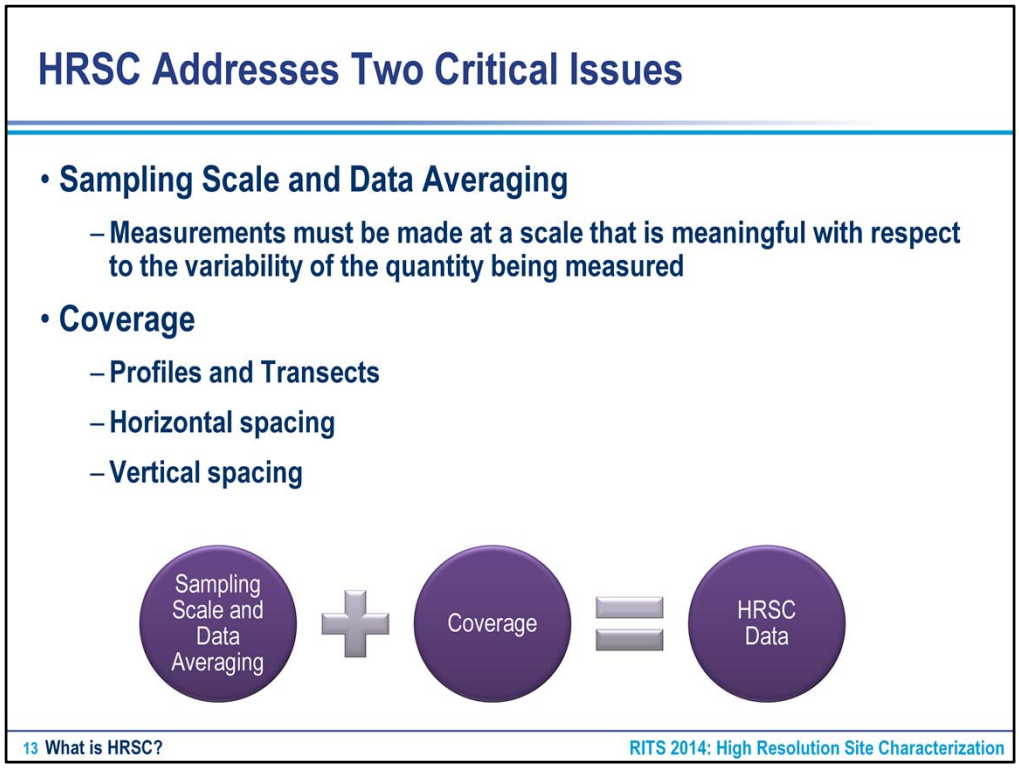
- Technology used influences the understanding you develop
- The scale of measurement must be appropriate for the scale of the heterogeneity
  - Variability of hydraulic conductivity and other parameters
  - Weak transverse hydrodynamic dispersion
  - Heterogeneous distribution of DNAPL sources
- Conventional 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



The profile in red is the vertical distribution of PCE at a location just downgradient of a dry cleaning establishment in Angus, Ontario. The profile was produced using an early version of the profiler with a vertical sample interval of approximately 6 mm (1/4 inch). Approximately 100 mL of water was pumped prior to sample collection. The vertical sample spacing is 20 cm. The concentrations are shown in log scale and range from non detect to 42,000 ug/kg over approximately 2 meters. Order of magnitude changes in concentration occur over as little as 20 cm. These steep concentration gradients are a result of the weak nature of vertical transverse hydrodynamic dispersion, which is common in porous media.

Once the distribution of the PCE concentrations were understood, Pitkin installed a conventional 2-inch diameter PVC monitoring well with a sand pack extending 1 foot above the screen and a bentonite pellet plug above the sand pack. The length of the screened interval was 5 ft. The well was sampled following purging of 3 well volumes. The concentration obtained from the well was 1,007 ug/L compared with the peak concentration of 42,000 ug/L in the profiler.

The reason for the disparity in concentrations is the depth integrated flow weighted averaging caused by the monitoring well. The distribution of hydraulic conductivity along the well screen interval is shown on the right. Hydraulic conductivities range from the low end of the 10-3 cm/sec range to the middle of the 10-2 cm/sec range. The lowest K values are found in the middle of the well screen interval where the concentrations are highest. The fastest flow zones are at the top of the well screen interval where concentrations are lowest. Thus when the well is pumped for sampling, most of the water that enters the well comes from the low concentration zones and relatively little enters the well from the high concentration zone in the middle. The resulting sample is weighted toward the low concentrations.



"High resolution" is achieved by addressing these two key issues: (1) sample scale/data averaging and (2) having the samples be spaced appropriately in three dimensions.

Sample size must be such that averaging of properties over the scale of the sample does not obscure important information that resides in the region being sampled. Subsurface geologic heterogeneity is such that the values of most key variables change profoundly over very short distance scales. For a groundwater sample, key sample size issues include the length of the vertical sample interval as well as how much water is pumped in order to obtain the sample. Increasing the volume of water pumped increased the volume of aquifer sampled and results in decreased resolution.

Horizontal and vertical spacing of sampling points must be small enough that important information (such as high concentration zones) are not missed, but not so small that the cost increases beyond the value obtained from it.

High Resolution (more pixels): Sampling Scale and Averaging

- Understanding a plume or source area through a sampling program is analogous to trying to discern the information in a pixelated image
  - Most of us understand that the more pixels an image is broken into, the higher the resolution is and the clearer the image is
  - If we just have one large pixel (or sample), the information in the image is averaged over the area of the single pixel and we can learn little about the image
  - With 4 pixels, each a quarter of the size of the first, there is some variability present in our image but we still are not getting very much of the information
  - By the time we increase the number of pixels (samples) to 100 and reduce the size of each pixel, we can begin to see the image
- The image becomes clearer and sharper with the increasing number of pixels and the reduced size of the pixels. Somewhere along the way we have a resolution that is adequate to our particular purpose
  - It may be at 400 pixels or it may be at 10,000 pixels or somewhere in between
  - When the sample volume is too large, the information is averaged to a point that it is not available to us
  - If the number of samples is too small, we can not see the complete picture

Sampling Coverage and Density:
HRSC Wisdom Through the Ages

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

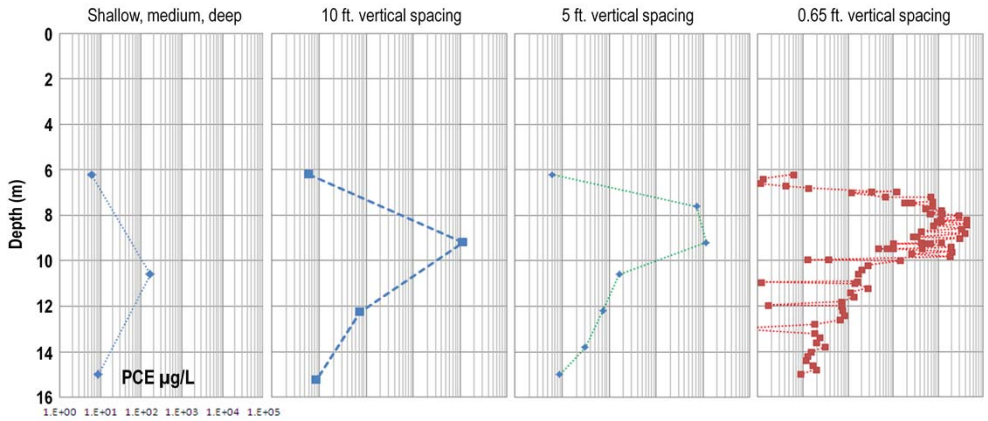
William Blake

Key Point The only way to know what degree of resolution you need is to look at a high level of resolution.

How Much is Enough?

What is Right Vertical Spacing?

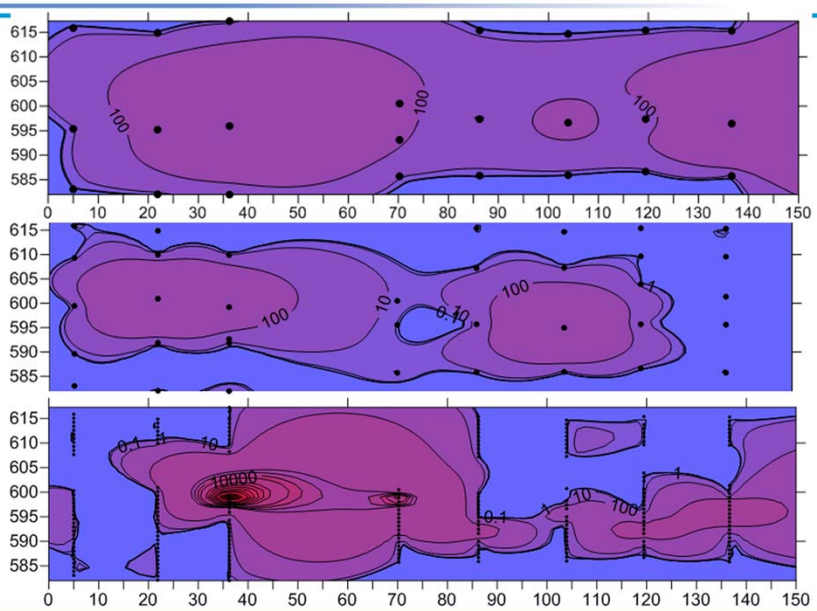
A Profile Through PCE Plume in Sandy Aquifer



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



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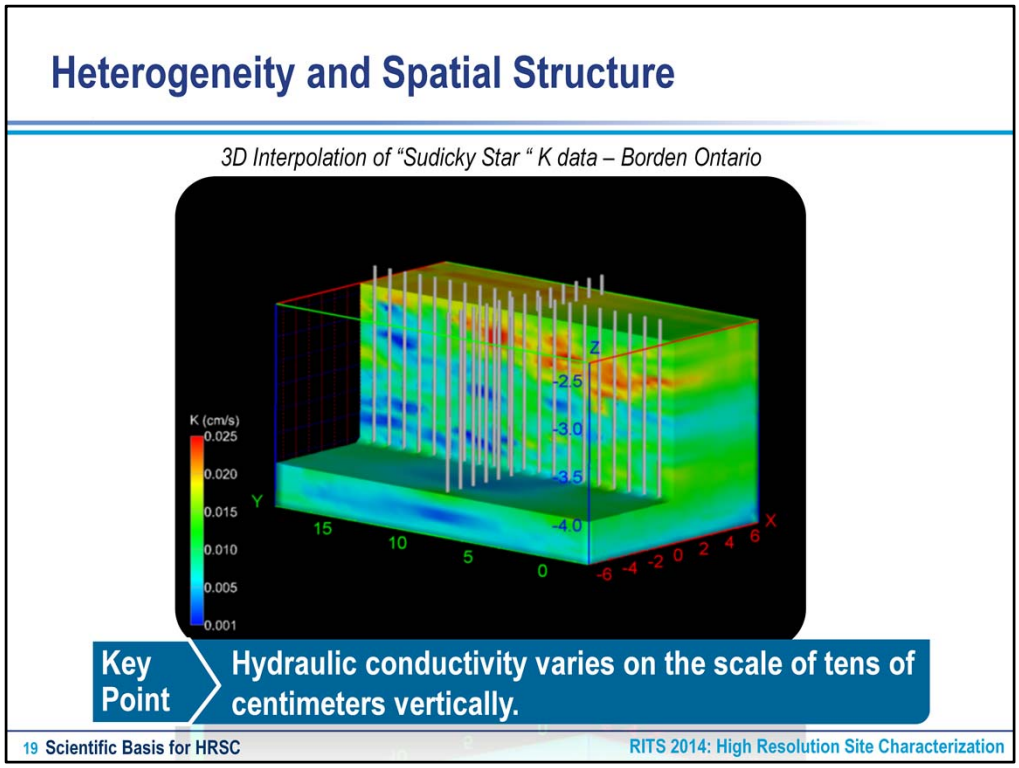
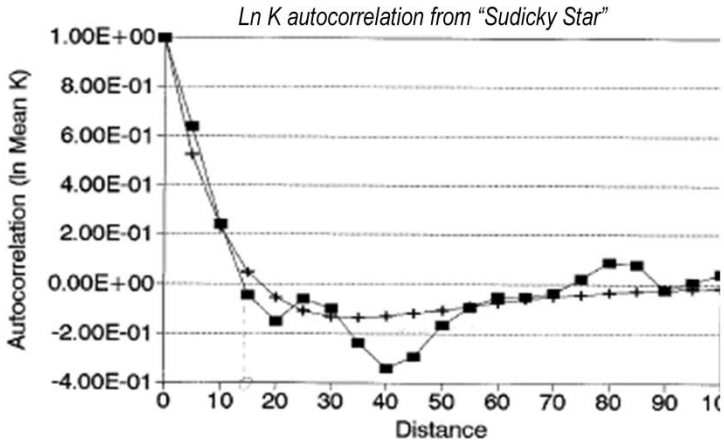


The simplifying assumption of homogeneity implicit in much of the classical hydrogeological applications leads us to speak of the hydraulic conductivity of an aquifer. However, aquifers have many different zones of many different hydraulic conductivity values. It is the spatial distribution of these values that determines the paths that groundwater actually follows and the routes by which contaminants are transported. The spatial structure of hydraulic conductivity is closely related to the nature and degree of hydrodynamic dispersion in aquifers.

This image shows the results of work done by Ed Sudicky at the University of Waterloo at the time of the Stanford-Waterloo Natural Gradient Tracer Test at Canadian Forces Base Borden in Ontario, Canada. (the interpolation and visualization in this image was done by Seth Pitkin using Ed's data). Ed collected a series of 2 meter long cores spaced 1 meter apart horizontally in a cross pattern. He then chopped the cores into 5 cm thick chunks and ran permeameter tests on each chunk, resulting in 1,279 measurements of hydraulic conductivity. The Borden aquifer is commonly referred to as relatively homogeneous in appearance and is in a sand deposited beach environment. This image shows the distribution of the K values in 3 dimensions. Note that there is a substantial vertical exaggeration in the image. The spatial structure of hydraulic conductivity is such that there are thin zones of high K material adjacent to thin zones of lower K material.

Heterogeneity and Spatial Structure

Seth's Homework circa 1992
Ln K autocorrelation from "Sudicky Star"



Key Point Hydraulic conductivity varies on the scale of tens of centimeters vertically.

Hydraulic Conductivity Correlation Lengths

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.* (1992)
Aefligan	15 – 20	0.05	Hess *et al.* (1992)
Chalk River, Ontario	1.5	0.47	Indelman *et al.* (1999)

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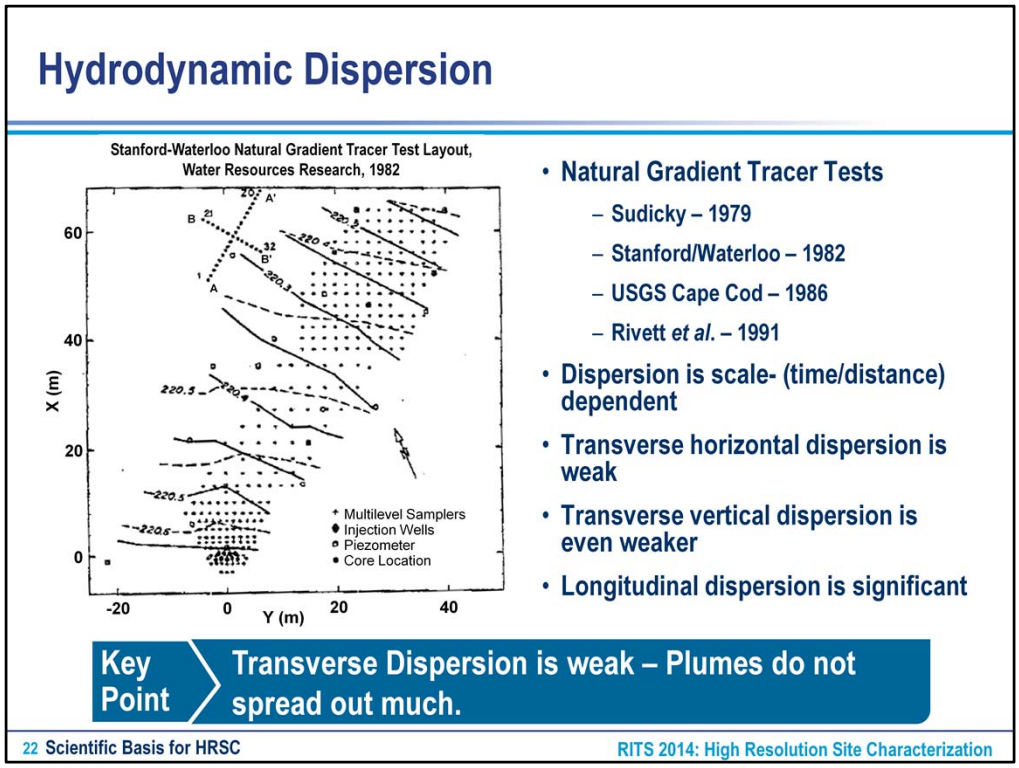
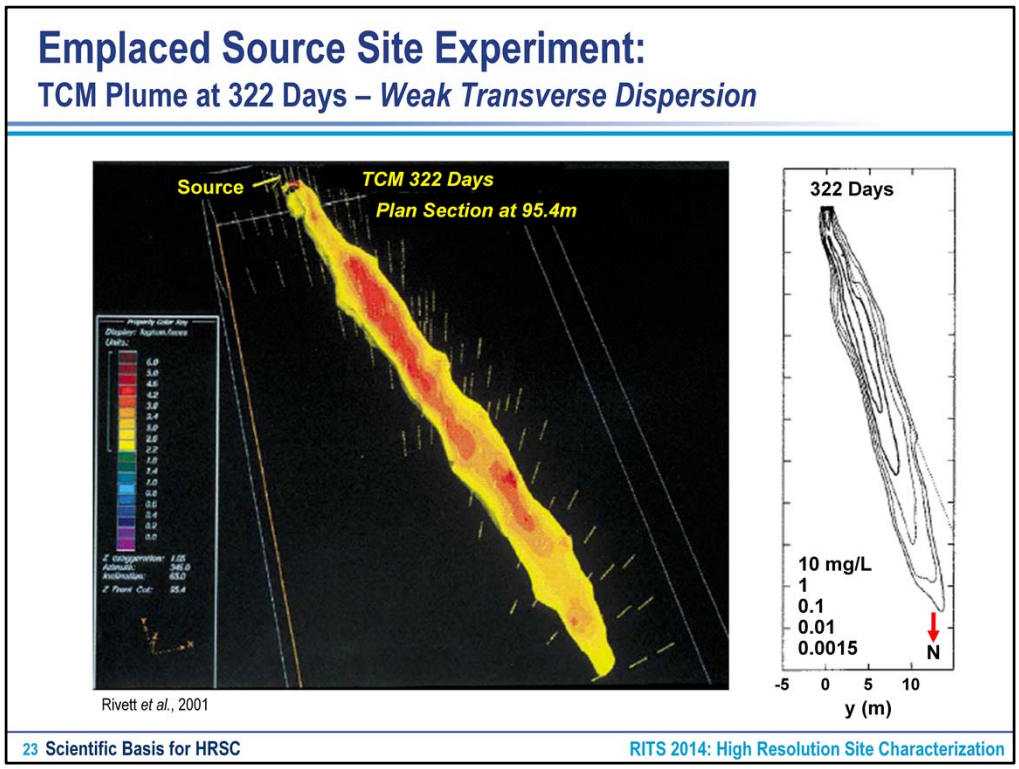
Other investigators have since performed similar studies and have found similar results. With the exception of Columbus AFB, all of the investigators have found vertical correlation lengths in the centimeter scale with horizontal correlation lengths in the meter to a few tens of meters.



In the 1970s and early 1980s, it was thought that hydrodynamic dispersion was a relatively strong process and that it resulted in fan shaped plumes with fairly low concentration gradients and significant dilution.

However, work beginning with Ed Sudicky's Ph.D. thesis at the University of Waterloo in 1979 raised doubt about this view of dispersion. The Stanford Waterloo natural gradient tracer test was a seminal event in contaminant hydrogeology, published in Water Resources Research in 1982. This large scale, rigorous and robust study indicated that transverse (at right angles to the principal direction of flow) dispersion was a weak process. Vertical transverse dispersion was found to be very weak, essentially on the order of molecular diffusion. Similar work by other researchers followed, including a large scale test conducted by the USGS at the Massachusetts Military Reservation on Cape Cod, verifying the results of the Stanford Waterloo experiment. These tracer tests used conservative tracers such as chloride to assess transport. Later experiments such as those by Mike Rivett and others used reactive contaminants such as chlorinated solvents to assess transport and further confirmed the results of the conservative tracer tests.

Note the location of the "Sudicky Star" on the plan view diagram of the Stanford Waterloo Tracer test at CFB Borden. The Sudicky Star is the location of the study of hydraulic conductivity distributions that was shown earlier.



This is a view of the trichloromethane plume emanating from the "emplaced source" at CFB Borden. The results of this experiment, carried out by Rivett et. al. illustrates the effects of weak transverse hydrodynamic dispersion. Plumes tend to be long and narrow with very steep concentration gradients. This means that not only do hydraulic conductivity measurements, porosity measurements, and hydraulic gradient measurements vary significantly over short distances, but contaminant concentrations are expected to vary by orders of magnitude over short distances transverse to the direction of transport. Plumes, particularly plume cores, are expected to have widths similar to the width of the source.

DNAPL Distribution

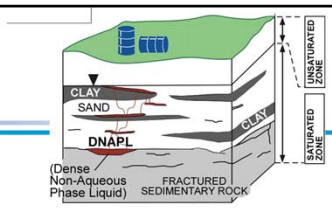
- Test pit at an experimental release site at Canadian Forces Base Borden
- Two releases of the same volume of PCE were staged at adjacent locations
- PCE (dyed red with Sudan IV) was released at the surface
  - In the first case the DNAPL was released all at once
  - In the second release a Marriott bottle was used to simulate a drip release over time
- Once both releases had occurred and sufficient time had passed for the DNAPL to come to rest, the sites were excavated and the distribution of the PCE was mapped
- The distribution of the DNAPL is controlled by subtle soil textural changes at the millimeter scale. It does not take a clay contact to direct DNAPL flow; variability in sand grain size distribution can do it.

Key Point DNAPL distribution is controlled by capillary pressures that vary at the mm scale. Distribution is very complex.

Dual Porosity Systems and Diffusion

- Systems in which there are (relatively) high and low permeability units
- Nearly all advective flow takes place through the pores in the high permeability materials (mobile porosity)
- Water in the saturated pore spaces in the low permeability materials (immobile porosity) is dominated by diffusive, rather than advective flux
- Pore water in the low permeability materials essentially serves as storage for solutes

Dual Porosity Systems:
17 Potentially Relevant Fluxes



Phase/Zone	Source Zone: Low Permeability	Source Zone: Transmissive	Plume: Transmissive	Plume: Low Permeability
Vapor				
DNAPL			NA	NA
Aqueous				
Sorbed				

Dual Porosity Systems

Sand Aquifer with Clay Lenses and Underlying Aquitard

Key Point

Solute mass diffuses into low-K zones in the source area and throughout the dissolved plume.

Persistent Plume after Source Isolation due to Back Diffusion

Key Point

Solutes diffuse back out of low-K zones following source area isolation/remediation. The whole dissolved plume footprint becomes the source.

Where the Mass Is

Key Point

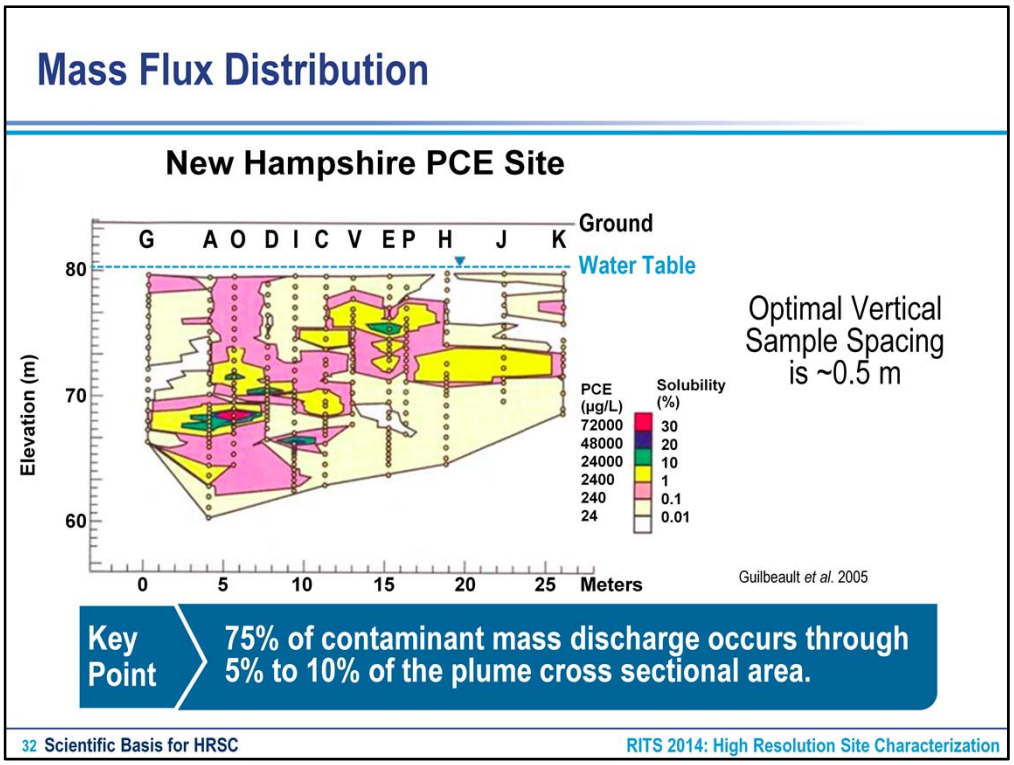
Contaminant mass mostly in low-K layers creates thin plumes in high-K layers throughout the dissolved plume.

The Matrix Diffusion Challenge

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

Developing Approaches to Mass in Low-K Units

- **Molecular Biological Techniques**
  - Used to establish microbial activity and presence and nature of biodegradation in the immobile porosity (low-K zones)
- **Remedial Techniques for Low-K units**
  - Thermal methods (*e.g.*, electrical resistance heating)
  - Electrokinetics rapid transport of remedial agents into low-K layers (to be discussed in the Case Study)



Martin Guilbeault, Beth Parker and John Cherry were the first to report (at least in a peer reviewed format) the finding that the vast majority of contaminant mass discharge occurs through a very small percentage of the overall cross sectional area of the plume. This is a logical consequence of the weak nature of transverse hydrodynamic dispersion and the discrete and complex distribution of many source materials (particularly DNAPLs).
Guilbeault et al (2005) used very closely (15 cm) spaced groundwater samples to define the solute distributions at three sites around North America. The finding that 75% of the mass discharge occurs through only 5 to 10% of the plume cross sectional area has profound implications for how sites need to be investigated and how remedies need to be focused.

The authors also found that the optimal vertical sample spacing based on their work at the three sites was approximately 45 cm. This is a very close spacing and the cost of investigating sites by collecting and analyzing samples at such a close spacing would be prohibitive. This issue can be overcome through the use of collaborative data (*e.g.* screening with a MIP or LIF) followed by targeted sampling at the required spacing only in key portions of the profile (and plume). The use of onsite labs can also reduce the amount of sampling required by providing near real-time feedback on the spatial structure of contaminant distributions (in particular, when you are sampling outside of the 5% to 10% of the cross sectional area through which the vast majority of the flux occurs.

Nature of Plumes

- Multiple high concentration plume cores
- Long narrow plumes
- Majority of mass flux through small portion of cross sectional area of plume

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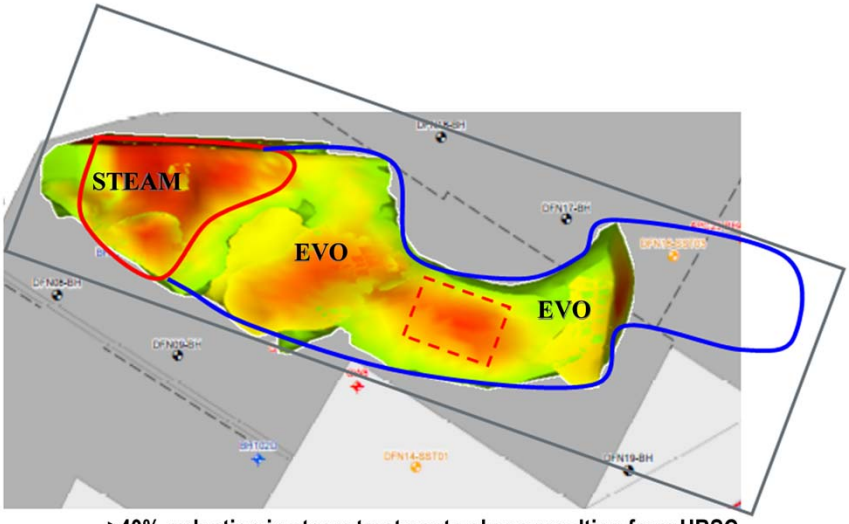
HRSC Increases Remedy Cost Effectiveness

- HRSC increases remedy effectiveness by providing a more accurate and realistic Conceptual Site Model (CSM)
  - Identify/delineate source zones (NAPL, matrix diffusion, *etc.*)
  - Identify plume cores
  - Identify mass flux distribution
  - Understand transport pathways and mass storage of contaminants in the subsurface
- A detailed and more realistic CSM allows for efficient and effective targeted *in situ* remedies

HRSC → Targeted Remedies → Cost Savings



>40% reduction in steam treatment volume resulting from HRSC

Halifax, UK

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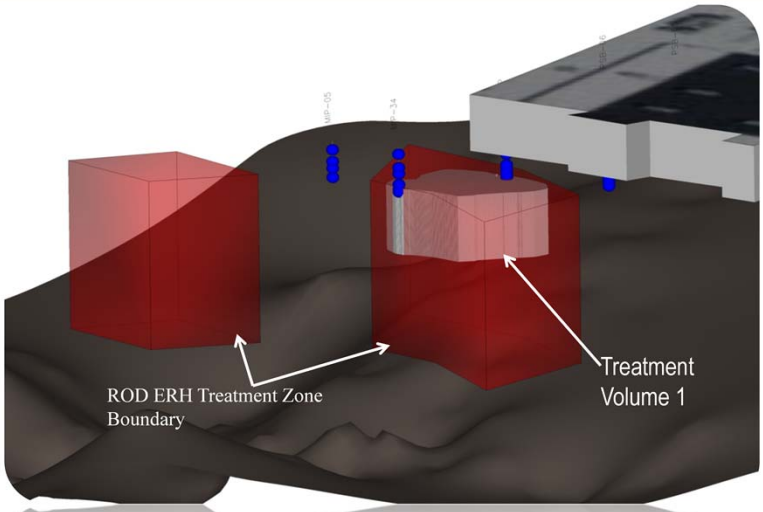
HRSC → Targeted Remedies → Cost Savings



>75% reduction in ERH treatment volume resulting from HRSC

New Hampshire, U.S.

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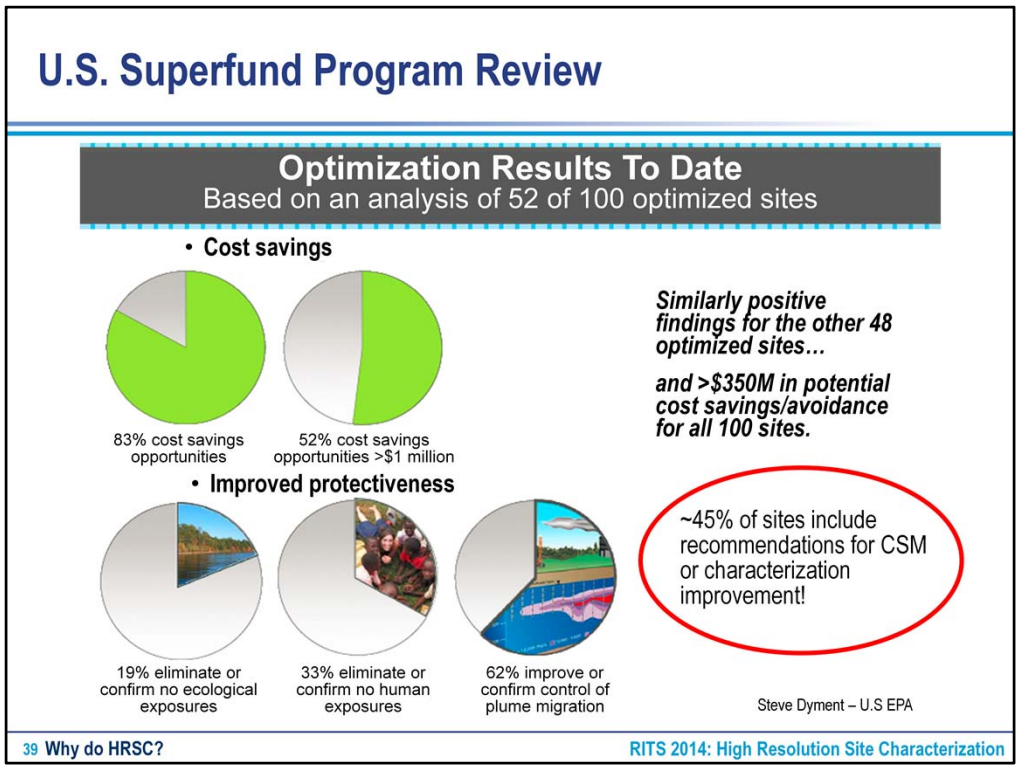
Cost of Remedies vs. Cost of Characterization

- Remedies based on a flawed CSM may not perform as expected, increasing the time it takes to achieve remedial action objectives, and the overall cost
- HRSC makes the investment upfront to obtain a more complete and realistic CSM
- Pay a little more now to avoid paying a lot more later
  - Until the CSM reflects reality, investigation and cleanup will be costly – pay the costs upfront and get the CSM right the first time in order to avoid paying more later


U.S. Superfund Program Review
Optimization Results To Date
Based on an analysis of 52 of 100 optimized sites
• Cost savings
83% cost savings opportunities
52% cost savings opportunities >$1 million
• Improved protectiveness
19% eliminate or confirm no ecological exposures
33% eliminate or confirm no human exposures
62% improve or confirm control of plume migration
Similarly positive findings for the other 48 optimized sites…
and >$350M in potential cost savings/avoidance for all 100 sites.
~45% of sites include recommendations for CSM or characterization improvement!
Steve Dyment – U.S EPA
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HRSC Provides a "Return on Investigation" (ROI)

- Higher initial investigation costs
- Fewer mobilizations and shorter period to completion
- Focused "surgical" remedy design and implementation
- Lower overall program costs

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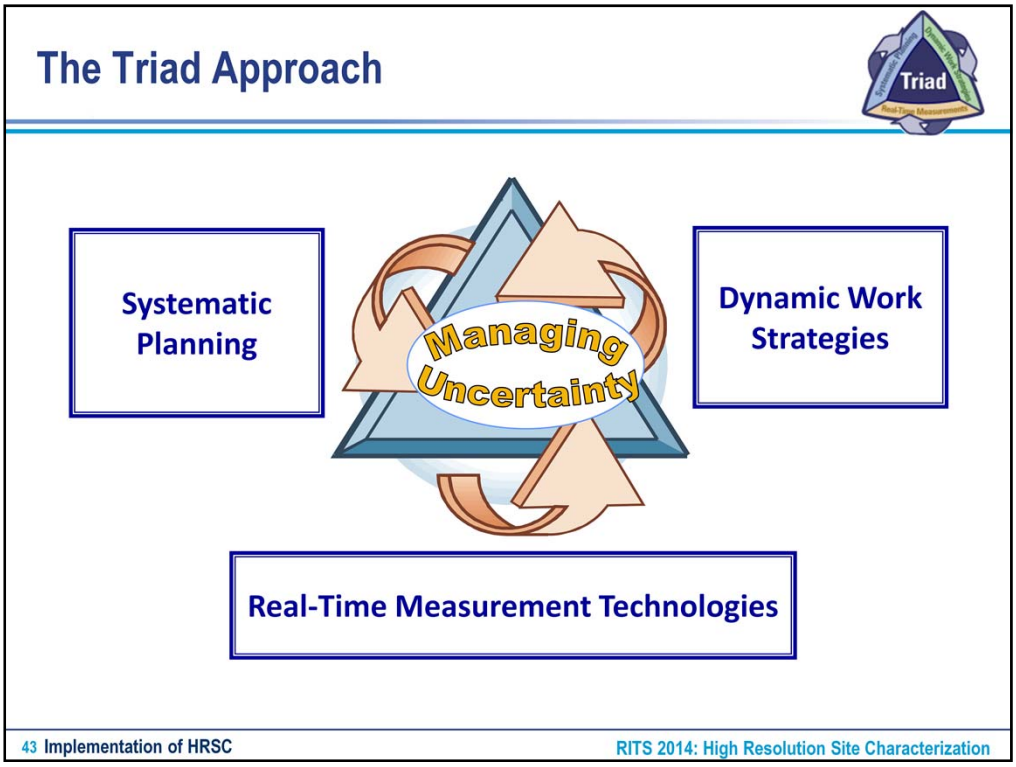
Transect Approach for Groundwater Contaminant Plumes

- **Profiles**
  - Close vertical spacing of sampling points/measurements at a single location
  - Small volume of sample/measurement
  - Vertical spacing?
- **Transects**
  - Series of profiles along a line oriented at a right angle to the direction of transport
  - Horizontal spacing?
- **Not longitudinal sections**

The use of vertical profiles provides excellent information on the vertical distribution of variables at a given location. Organizing these profiles along lines transverse to the direction of transport (or along transects) provides a comprehensive view of the plume anatomy. Such an approach is also well suited to providing a flux-based view of plumes. A transect can be thought of as a movie screen upon which the projector casts an image of the source material located upgradient. Thus when a transect is completed downgradient of the source area, people commonly refer to “back projecting” the locations of the source material from the “hot spots” on the transect.


The Triad Approach
Triad
Systematic Planning
Managing Uncertainty
Dynamic Work Strategies
Real-Time Measurement Technologies
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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
  - Screening tools for rapid reconnaissance of source zones, plume cores, hot spots (*e.g.*, MIP)
  - Groundwater sample profiling of permeable zones (mobile porosity)
  - Soil coring and profile sampling for low-K zones (immobile porosity)

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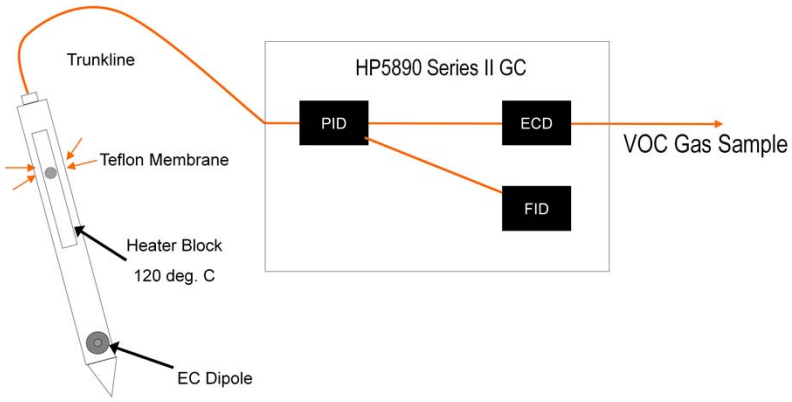
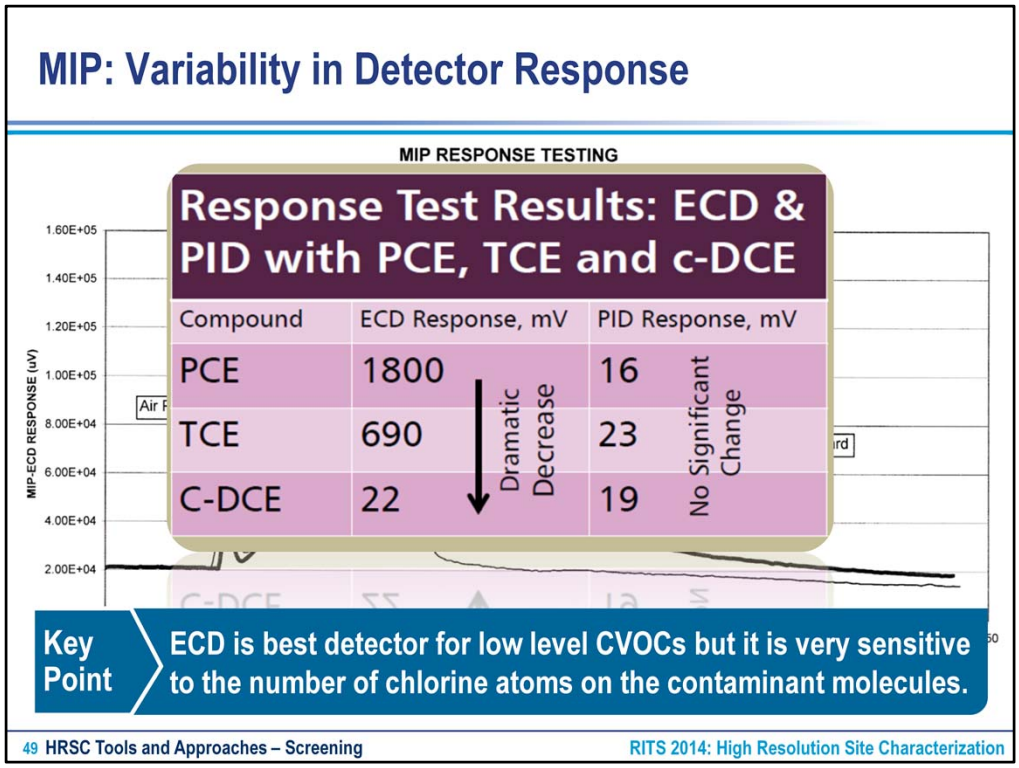
Membrane Interface Probe (MIP) Screening Tool

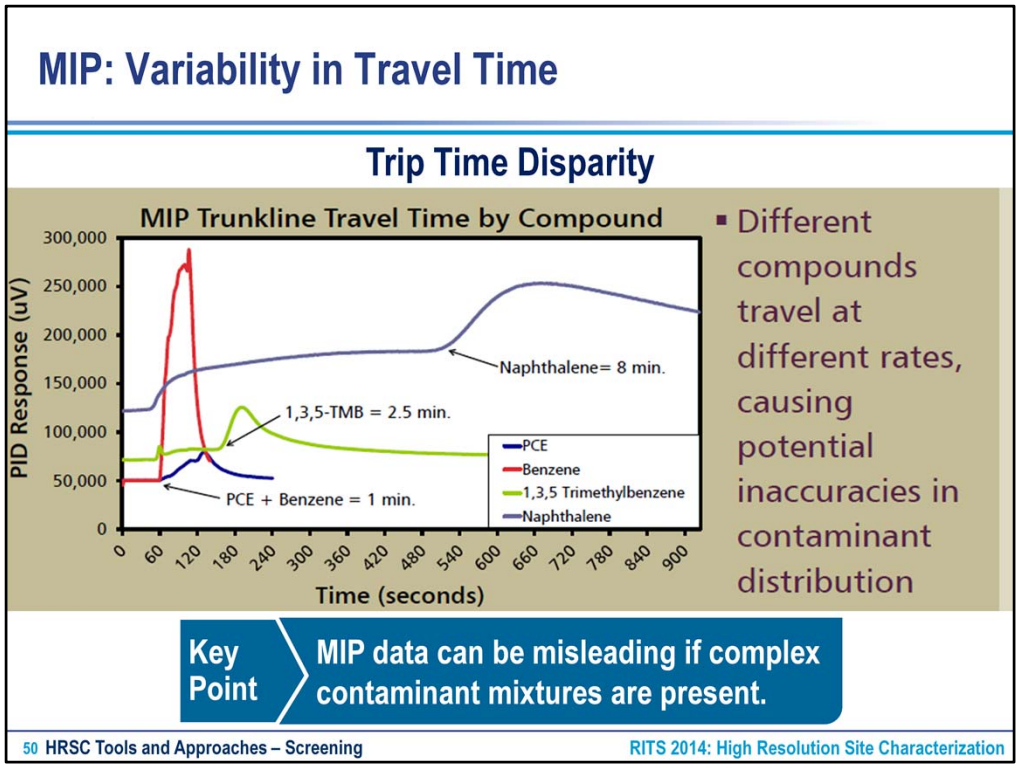


MIP Screening Tool (cont.)

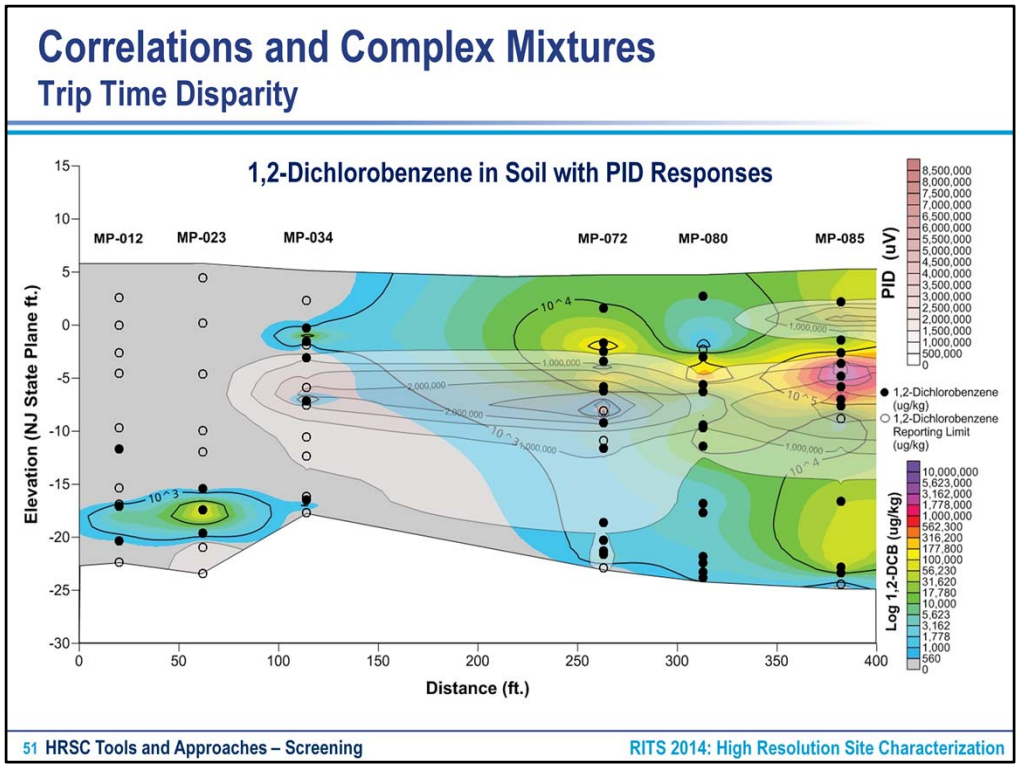
- Strengths
  - Vertically continuous, real-time data
  - Can typically complete 150 to 250 linear feet of exploration per day
  - Ideal for locating source areas and plume cores
- Limitations
  - Limited depth penetration
  - Units (volts) not the same as with soil or water concentration
  - Correlations with soil/water concentrations problematic
  - Generally does not distinguish between analytes
  - Apparent "dragdown" of contamination



The ECD is the most sensitive detector for chlorinated compounds used in MIP logging. One limitation of the ECD is that the sensitivity of the detector to specific compounds varies strongly with the number of chlorine atoms on the molecule. Approximately an order of magnitude of signal is lost with each chlorine atom. In the plot above, the response test curves are shown for 0.5 mg/L PCE and TCE standards. The response of the 0.5 mg/L PCE standard (upper curve) is much stronger than that for the TCE standard (lower curve). Thus, if the makeup of the plume changes spatially (*i.e.*, the ratio of PCE:TCE changes) then the detector response will change significantly even if the overall mass per volume concentration is the same. The travel time for the two compounds is the same.



In the last slide we saw that the travel time (from membrane, through the trunkline to the detector) was the same for PCE and TCE. However, for more dissimilar compounds, the travel times can be very different. The plot above shows the travel times for PCE; benzene; 1,3,5-TMB; and naphthalene. The travel times vary from 1 minute for PCE and benzene to 8 minutes for naphthalene. Since the depth at which the contamination was encountered is determined in the MIP software on the basis of a single travel time based on a response test, the presence of multiple compounds with different travel times will result in peaks showing up at different depths, when, in fact they all originated at the same depth.



This image is from a transect at a chemical plant in New Jersey. The colored image represents 1,2-dichlorobenzene concentrations in soil with each black dot showing the location of a soil sample. The ghosted image shows the MIP PID response (in micro volts). It is clear that the zones at which the MIP shows peak concentrations are shifted downward relative to the locations of those peak zones as determined by soil sampling. This downward shift is the result of the long travel times of 1,2-DCB relative to the travel times determined during the response test using TCE. In sites with complex mixtures of contaminants, the MIP data may be hard to decipher and can cause some confusion.

MiHPT – Combined MIP and HPT

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  - Soil Coring
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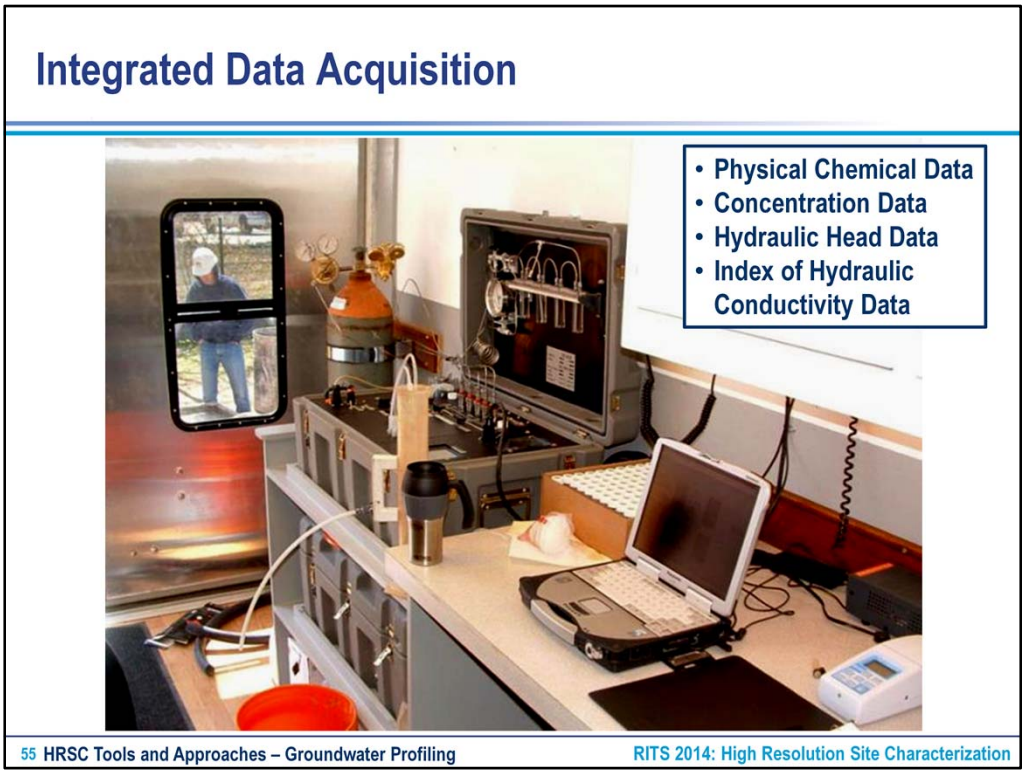
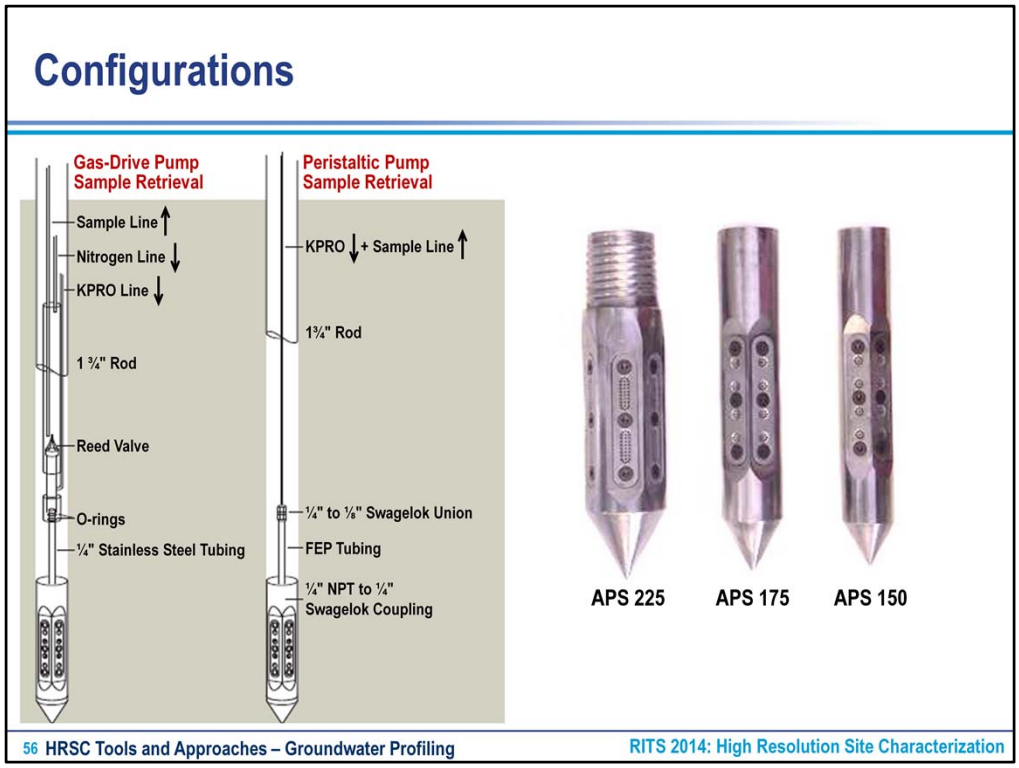
Direct Push Groundwater Sampling Tools

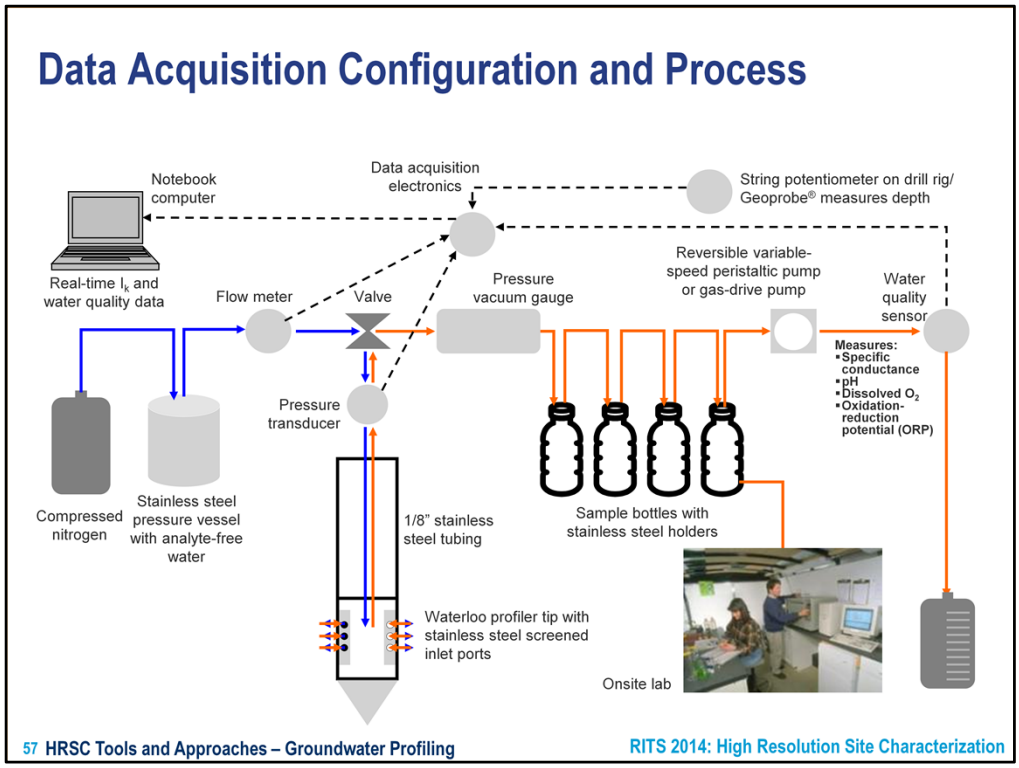
- Probes
  - Small diameter
  - Variable screen length
- Removed (tripped) following collection of each sample
- Piezometers
  - Left in Place
  - Fast, low material cost



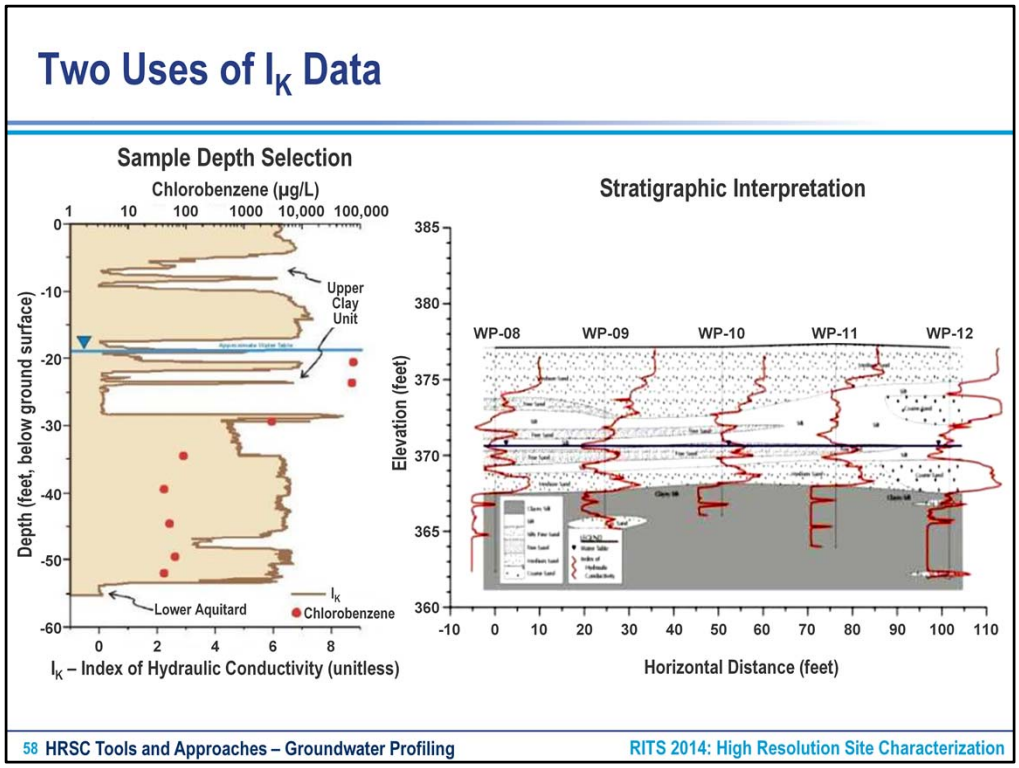
The profiler has been modified to allow for the collection of detailed data relative to contaminant concentrations, the distribution of hydraulic conductivity and hydraulic head as well as pH, specific conductance, dissolved oxygen and oxidation reduction potential in a single push.



Two options for pumping of formation water. On the left is a schematic diagram of a positive displacement nitrogen gas drive pump, which pushes that water up from the bottom of the drill string. On the right is a schematic of a version of the tool used with a peristaltic pump located uphole.



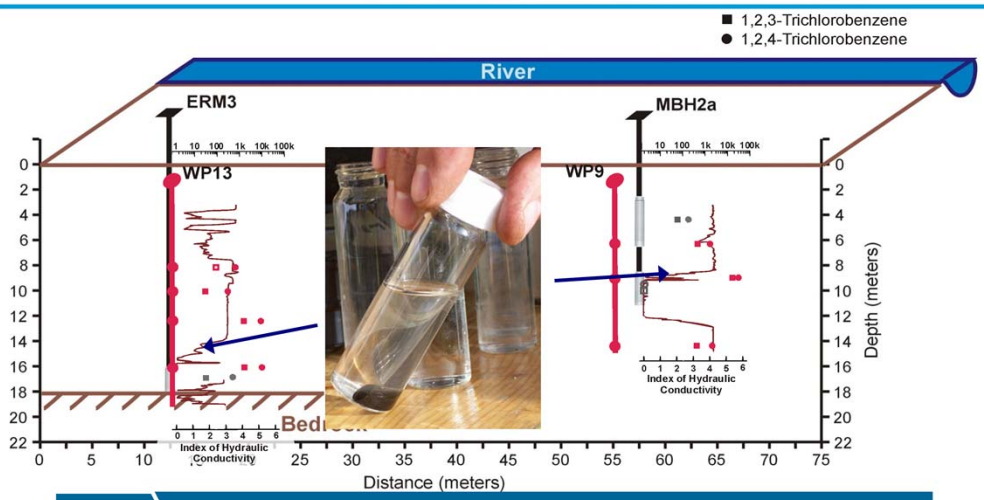
This diagram illustrates how the data acquisition system works. Compressed nitrogen pressurizes a stainless steel container filled with analyte-free water. The pressure pushes the water past an electronic flow meter and pressure transducer and down the hole inside a small diameter stainless steel tube. The water is forced out the ports and into the formation. A string potentiometer on the rig tracks the depth of the tool. All of the data are routed to the data acquisition electronics in the control box. Once a desired sampling depth is reached, the flow of water is shut off and purging begins. Water is pumped from the formation until the geochemical parameters measured in the flow cell reach approximate equilibration. Then the samples are collected and taken to the onsite lab. The total quantity of water purged is recorded along with the equilibrium parameters.



In the diagram at the left the brown line shows a continuous record of the index of hydraulic conductivity versus depth. Clay layers are seen at 7’, 9’ and 19’ bgs. The clay layer between 19 and 28 ft bgs is interbedded with significant sand layers. Once below the water table, the investigators stopped driving upon encountering the first sand layer and collected a sample. The sample had a concentration of approximately 70,000 ug/L of chlorobenzene. The tool was driven a little deeper and a second sand unit was encountered. Again, a sample was collected which had a very similar chlorobenzene concentration as the first sample. The tool was driven below the clay layer and a sample was collected from the aquifer upon exiting the clay. This sample had a concentration an order of magnitude lower than those within the clay unit. The samples throughout the aquifer proper were two and a half orders of magnitude lower. The Ik recorded is very useful for making real-time decisions about depths from which to collect samples.

The second use of the IK data is to infer sitewide stratigraphy by interpolating the data or interpreting the geology based on the IK records.

Post-Remedy Investigation Northern England



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

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Essential Information from Cores

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

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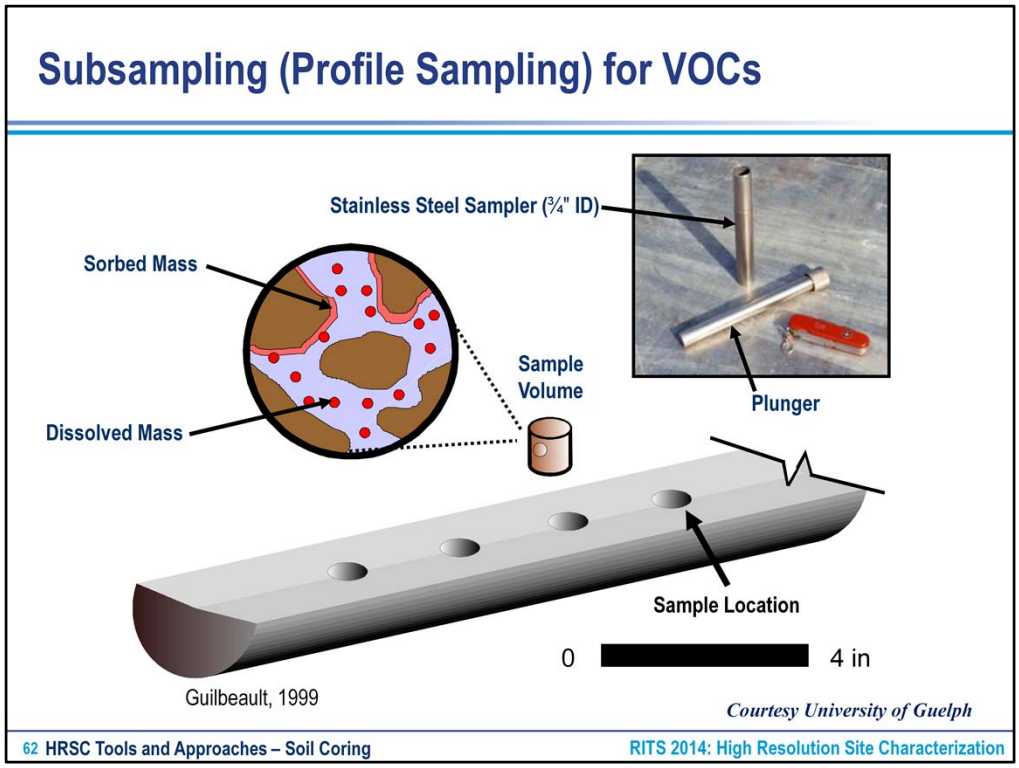
There are many reasons for obtaining high quality cores, including: an understanding of the detailed microstratigraphy that controls NAPL and solute migration; the provision of samples from which accurate physical, microbial, and chemical properties can be determined; a determination of contaminant mass distributions, particularly between high and low-K zones and including concentration gradients and contaminant flux between these zones; and finally, determining the effects of remedial actions on the subsurface.


Subsampling (Profile Sampling) for VOCs
Stainless Steel Sampler (¾" ID)
Sorbed Mass
Sample Volume
Plunger
Dissolved Mass
Sample Location
0
4 in
Guilbeault, 1999
Courtesy University of Guelph
62 HRSC Tools and Approaches – Soil Coring
RITS 2014: High Resolution Site Characterization

Molecular Biological Techniques (MBTs)

- Quantitative polymerase chain reaction (qPCR)
- Fingerprinting methods (DGGE, PLFA)
- Stable isotope probing (SIP)
- Microarrays
  - Fluorescence *in situ* hybridization (FISH)
  - Enzyme activity probes (EAPs)

Questions	CSIA	qPCR	RT-qPCR	Fingerprinting	Microarrays	SIP	EAP	FISH
Site Characterization								
A) Are contaminant-degrading microorganisms present?		X	X	X	X	X	X	X
B) Are contaminant-degrading microorganisms active?	X		X		X	X	X	X
C) Are the microorganisms capable of complete degradation?		X	X		X	X		X
D) Is biodegradation occurring?	X					X	X	
E) Is the contaminant attenuating abiotically?	X							
F) Are multiple sources contributing to the contamination?	X							
G) If there is a potential for multiple sources, can the sources be distinguished?	X							

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Groundwater

Membrane Interface Probe Protocol for Contaminants in Low-Permeability Zones

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 ≥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.
© 2013, National Ground Water Association.

NAS Jacksonville Investigations (July/August 2011)

OU3 Building 106

- Former dry cleaner (1962 – 1990)
- PCE and TCE released to shallow aquifer
- Building removed
- Interim remedies (AS, SVE) have been discontinued after 5-yr review (2005)
- Strong interest in evaluating MNA as long-term remedy

NAS Jacksonville: Characterization Methods

- Membrane Interface Probe (MIP) screening
  - Rapid lithology (EC) and contaminant (ECD, PID) delineation – qualitative
- Profiler system
  - Real-time hydrostratigraphy
  - Targeted groundwater sampling of higher K zones/interfaces
- Hydraulic profiling
  - Real time hydrostratigraphy
- Continuous cores
  - Detailed lithology delineation
  - Subsampling for mass distribution (targeted to lower K zones)

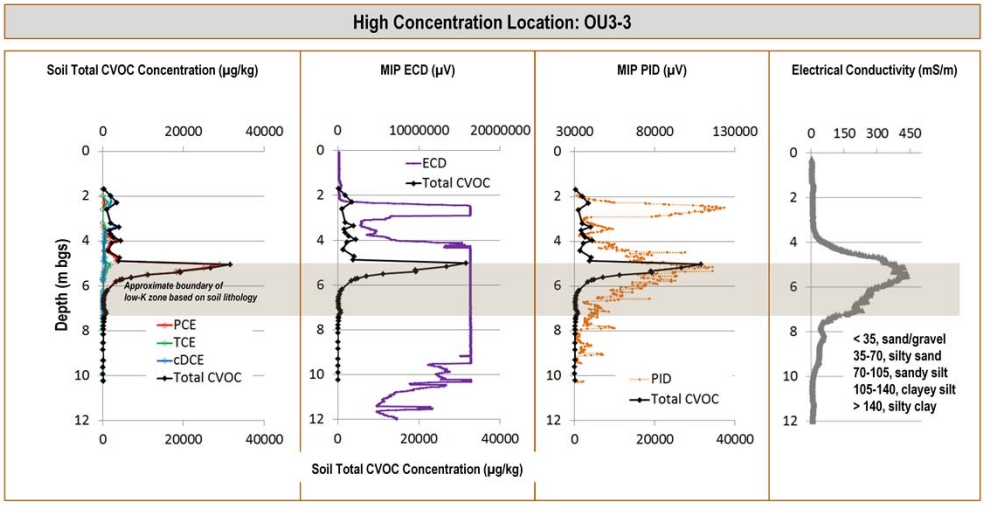
Soil Coring, Extraction, and Analysis: It Matters How You Do It

- Soil Core Profiling – close vertical spacing
- Soil samples collected into:
  - MeOH in vials
  - Enore samplers – *24-hr and 72-hr hold time in EnCore*
- Extractions
  - UG Shake Flask (2-week process)
  - Standard EPA 5035 Purge & Trap at Test America (2 week turnaround)
  - Onsite Lab Rapid Disaggregation and Suspension (1 hour)

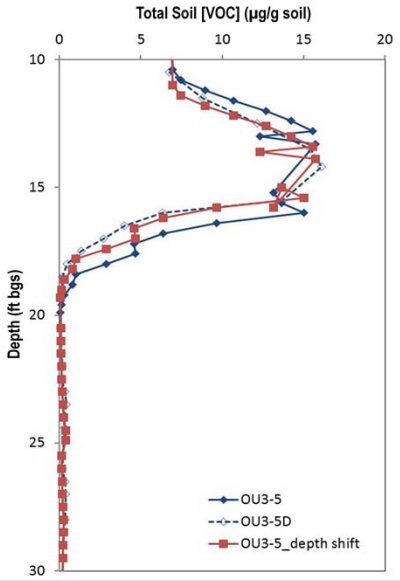
Key Point

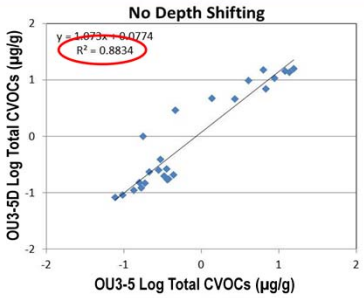
Commercial (*i.e.*, Standard) lab method provides incomplete extraction.

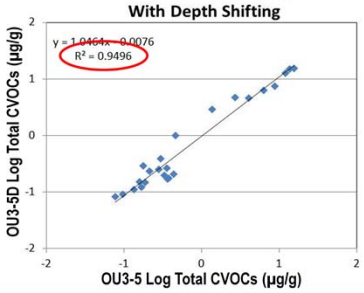
OU3-3: MIP (ECD and PID) and Soil Concentrations



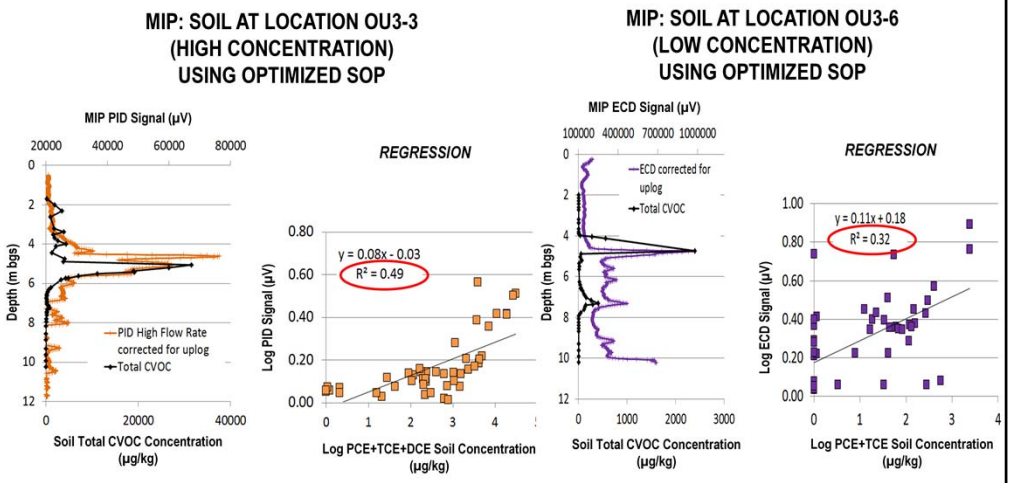
Collocated Soil Cores Demonstrate Good Correlation





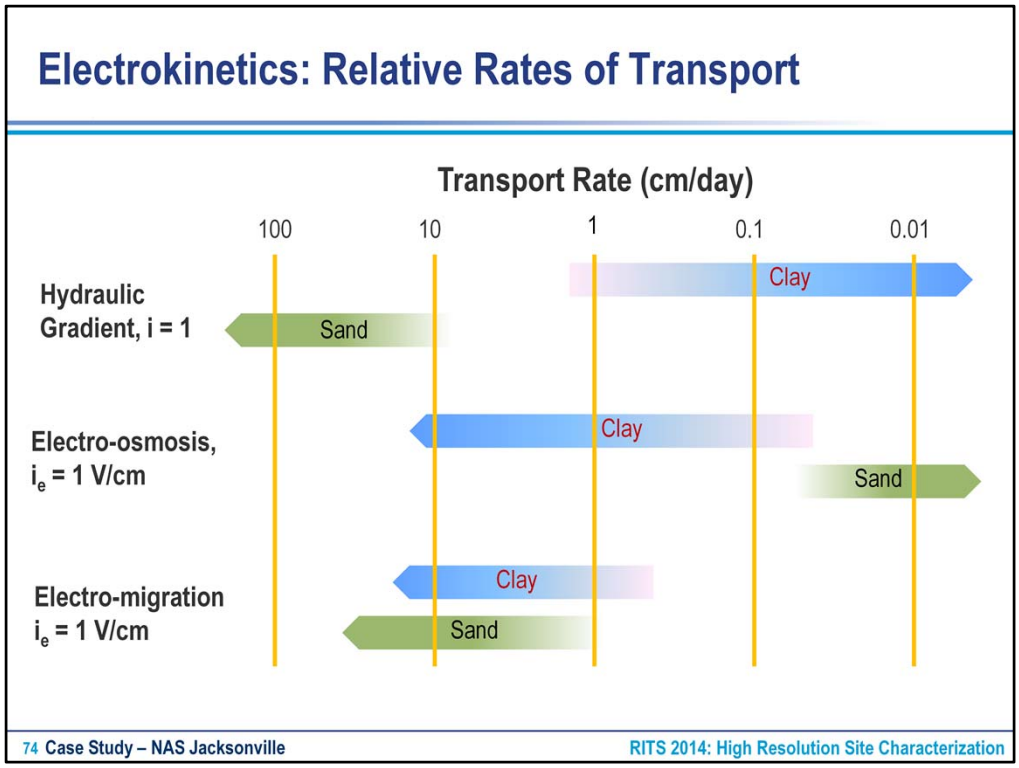


MIP Provides Mass Location But Not Concentration Correlation

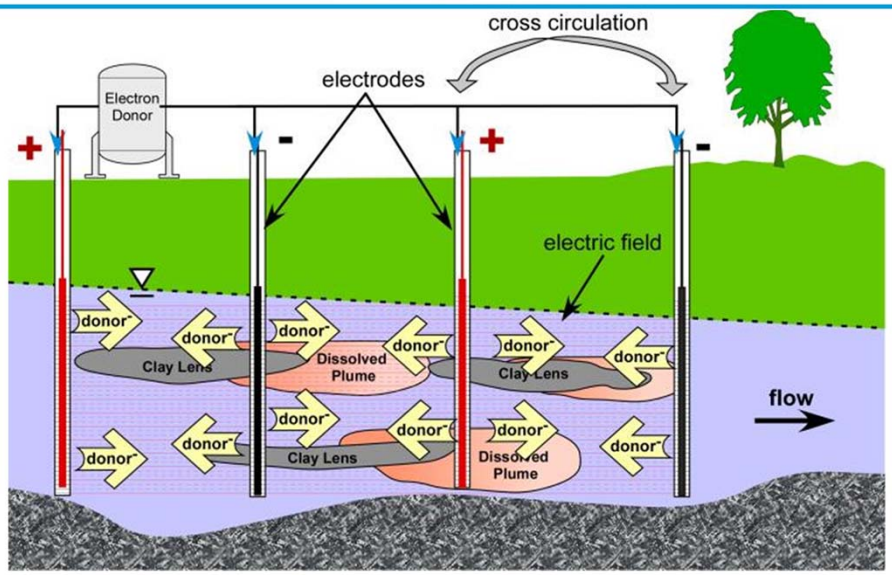


The Remediation Challenge

- Much of remaining contaminant mass is in low permeability layers
- Mass diffuses out slowly and represents a long term source of contamination
- Injections do not distribute remedial agents well in low permeability layers
- How to enhance biodegradation in low-K layers?


Electrokinetics: Relative Rates of Transport
Transport Rate (cm/day)
100
10
1
0.1
0.01
Hydraulic Gradient, i = 1
Sand
Clay
Electro-osmosis, i_e = 1 V/cm
Clay
Sand
Electro-migration i_e = 1 V/cm
Clay
Sand
74 Case Study – NAS Jacksonville
RITS 2014: High Resolution Site Characterization

Electrokinetic (EK)-Bio Field Application Concept



EK Treatability Testing at OU3

- DPT soil core from OU3
- Migrated lactate through core for 28 hours
- Thin-sectioned core, froze sections, analyzed for lactate
- Calculated lactate migration rate of 3 – 5 cm/day

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Key Points

- Successful remedies require site characterization data collected at a scale consistent with the spatial structure of the controlling variables
- Hydraulic conductivity often varies at the cm scale vertically and the meter scale horizontally
- DNAPL distributions are influenced by capillary pressure distributions that can vary at the mm scale
- Transverse hydrodynamic dispersion is weak (*i.e.*, plumes don't "spread out" much)
- 75% of mass flux occurs through only 5 to 10% of the plume's total cross sectional area

Key Points (cont.)

- Substantial contaminant mass may be present in low permeability zones due to diffusive flux and cause rebound following remediation
- HRSC is implemented using:
  - Transects (orthogonal to direction of transport) of profiles
  - The Triad Approach principles
- Monitoring wells provide depth-integrated, flow-weighted average data and may obscure important information

Key Points (cont.)

- **Multiple tools and methods are required**
  - *Screening tools can save time and money*
  - *Groundwater profiling and analysis in the more permeable zones*
  - *Soil core profiling and analysis in the low permeability zones*
- **Methods for low-K soil sample collection, preservation and extraction can have a significant effect on analytical results (purge & trap is not optimal)**
- **MIP provides high resolution screening data quickly and relatively inexpensively**
- **MIP data indicate where relatively high concentrations are located but MIP data are not strongly correlative with actual soil and groundwater concentrations**