ZEBRA

Direct Sensing Subsurface Investigation with

UVOST

Matt Ednie
ZEBRA Environmental

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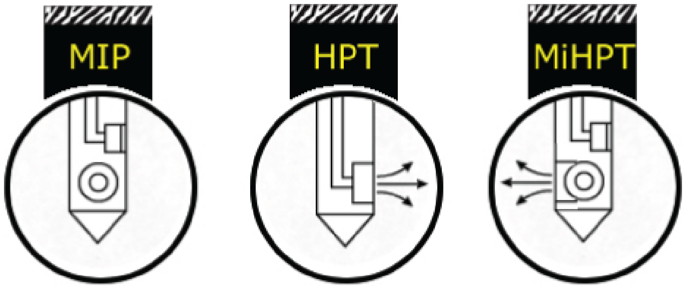
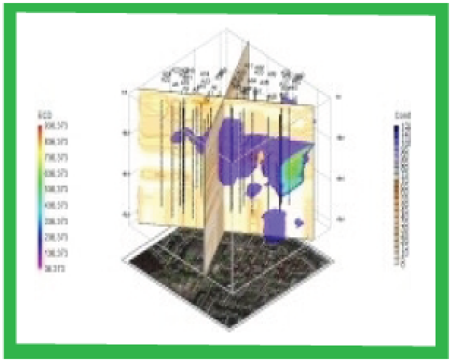
MIP HPT MiHPT EC LIF

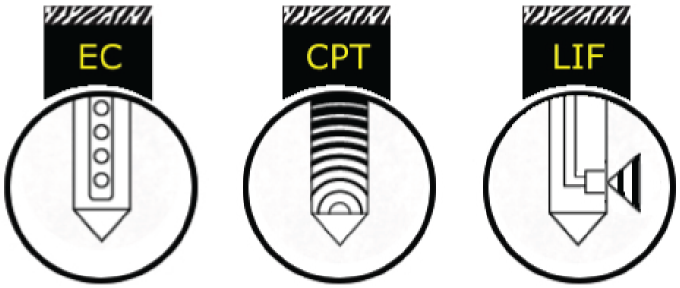
We're Not Your Typical Driller...We Carry a Different Tool Box

ZEBRA provides the widest range of Geoprobe®/ DPT services available anywhere, including a tool box full of **Injection** and **Direct Sensing** systems. For the past 20 years, ZEBRA has given you the best tools to investigate subsurface conditions at your site. Now we offer more options with the addition of the

NEW combined MIP & HPT probe = **MiHPT and the UVOST® system.**







ZEBRA is now offering UVOST® services along with **MIP, HPT, MiHPT, EC, CPT, MIP/CPT** ZEBRA offers the most complete array of **Direct Sensing** and **Optical Screening Tool** systems available on the **East Coast**.

*Trademarks of DAKOTA Technologies.

High Resolution Site Characterization
Applying Next Generation Tools

Strategies for Cost Effective Site Characterization

- Multiple lines of evidence (data)
  - Geologic
  - Hydrogeologic
  - Contaminant
- High density data sets
  - plan view and vertical
- Adaptive, flexible, dynamic…..
  sampling plan with clear DQOs
- On-site, real-time analysis
- On-site, real-time decisions
- Evolving conceptual site model

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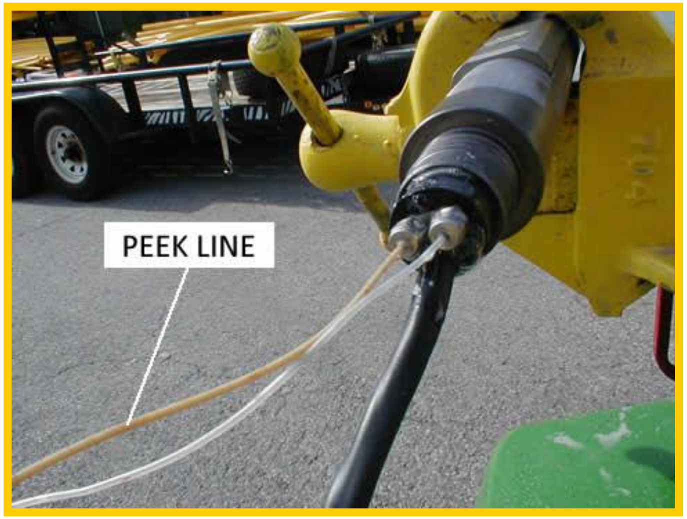
ZEBRA 7822 UNIT

Real Time Benefits

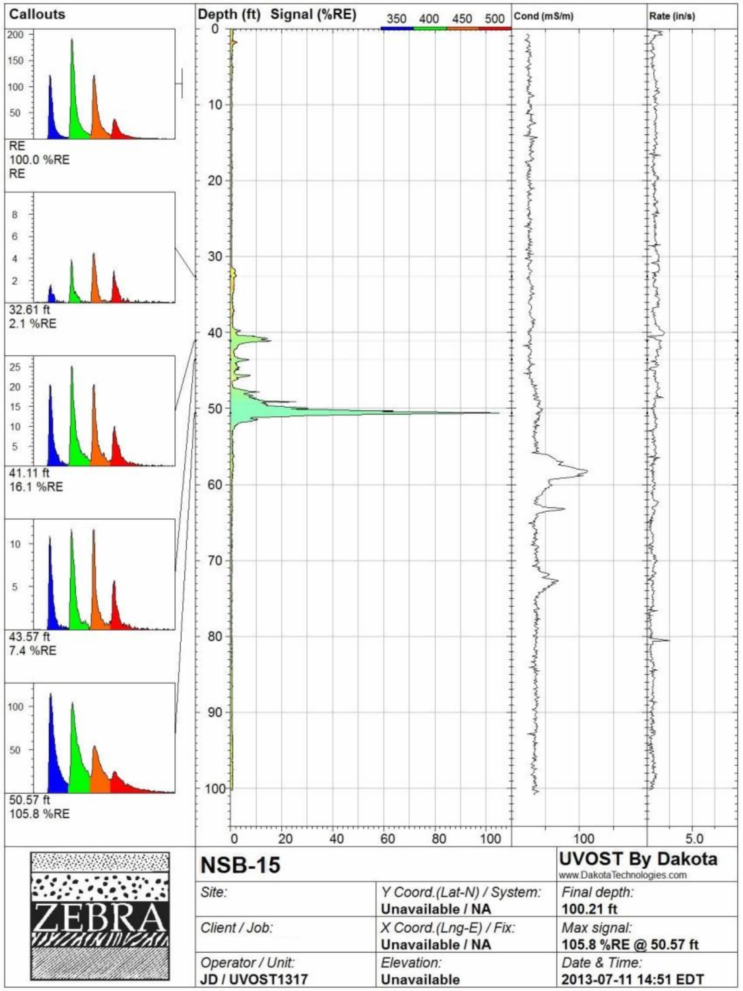
- Make decisions in the field.
- Collect higher density of data.
- Use of screening data to select laboratory samples.
- Accelerate project schedules
- Reduce overall project costs
- Improve project outcomes



ZEBRA ENVIRONMENTAL UVOST

Laser Induced Fluorescence (LIF)

- Laser Induced Fluorescence (LIF) investigation allows for rapid and highly adaptable assessment of NAPL impacts.
- Technology is based on fluorescent properties of polyaromatic hydrocarbon (PAH) compounds that are commonly found in gasoline and fuel oil.
- Can be used to delineate/define the extent of a wide range of petroleum products.
- Allows for very accurate vertical and horizontal characterization of NAPL impacts.



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LIF Detects PAH-containing NAPLs (Source Material)

Using UV excitation

- Gasoline
- Diesel fuel
- Jet fuel
- Hydraulic fluids
- Motor Oil
- Cutting Fluids
- Crude Oil

Never or Rarely used for

- PCBs
- Chlorinated Solvents
- Dissolved Phase PAHs

The fluorescence signal scales proportionally with NAPL concentration.

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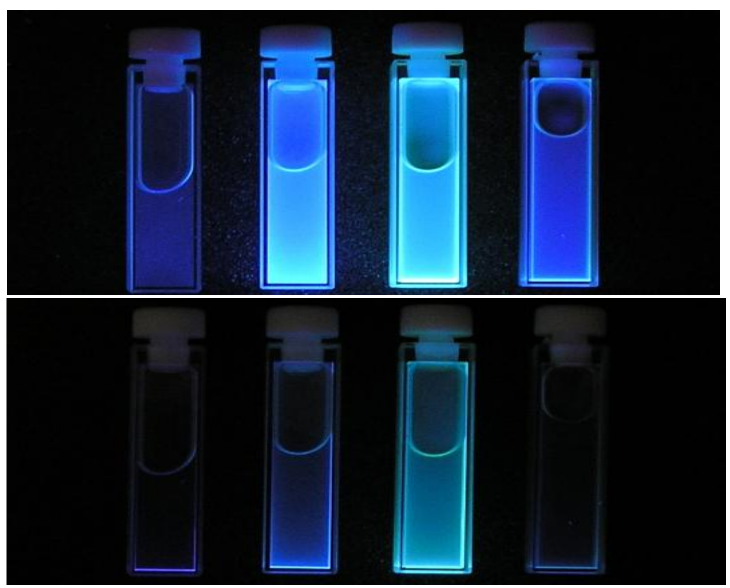
Fortunately all PAH non-aqueous phase liquids or NAPLs Fluoresce

PAH fluorescence is a way to detect them by their “glow”



Potential LIF Characterization Sites

Leaking Underground Storage Tanks

Pipelines

Refineries

Fueling Areas

Automobile Service Locations

Lagoons and Waste Ponds

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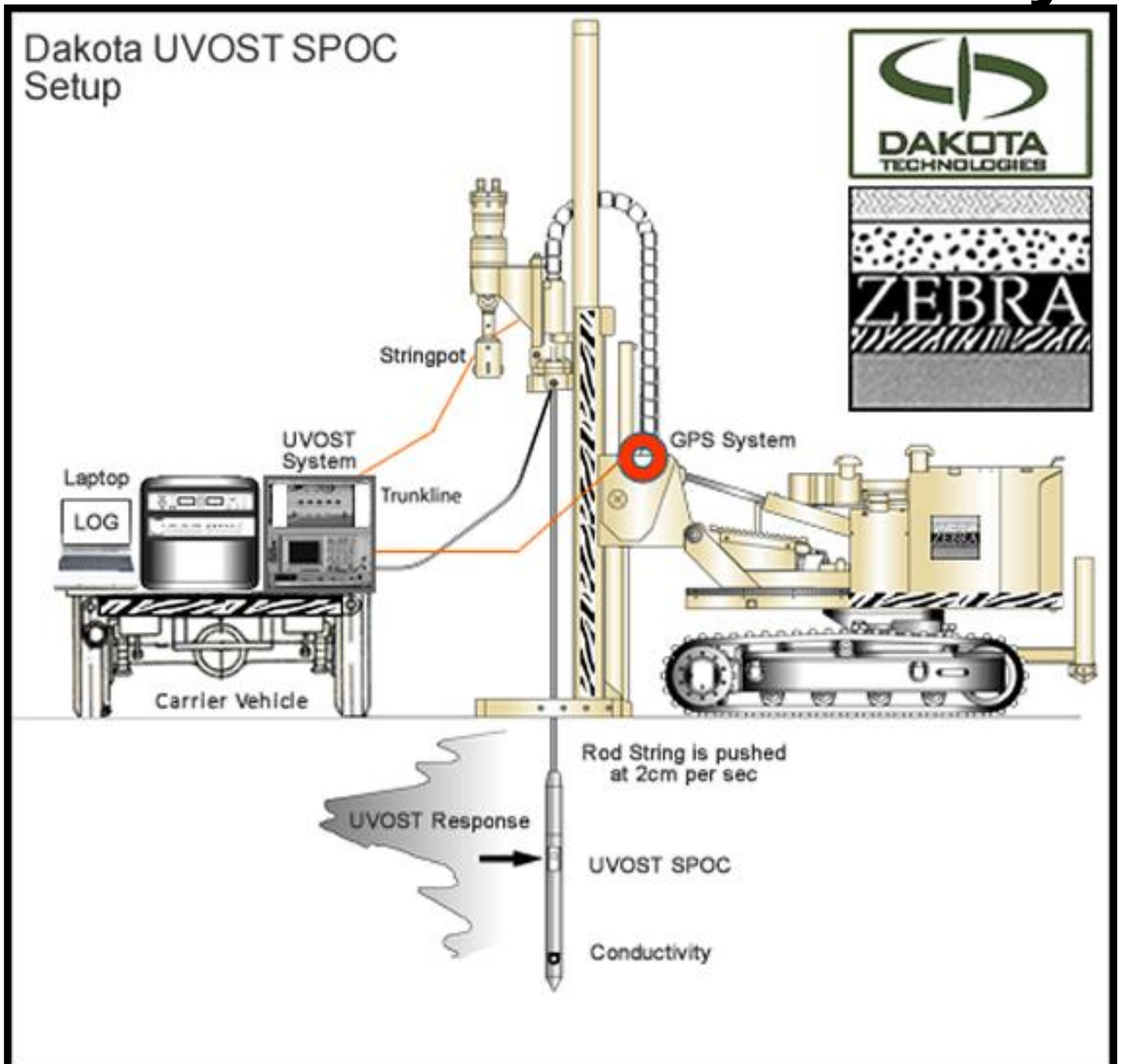
The UVOST System



UVOST SPOC

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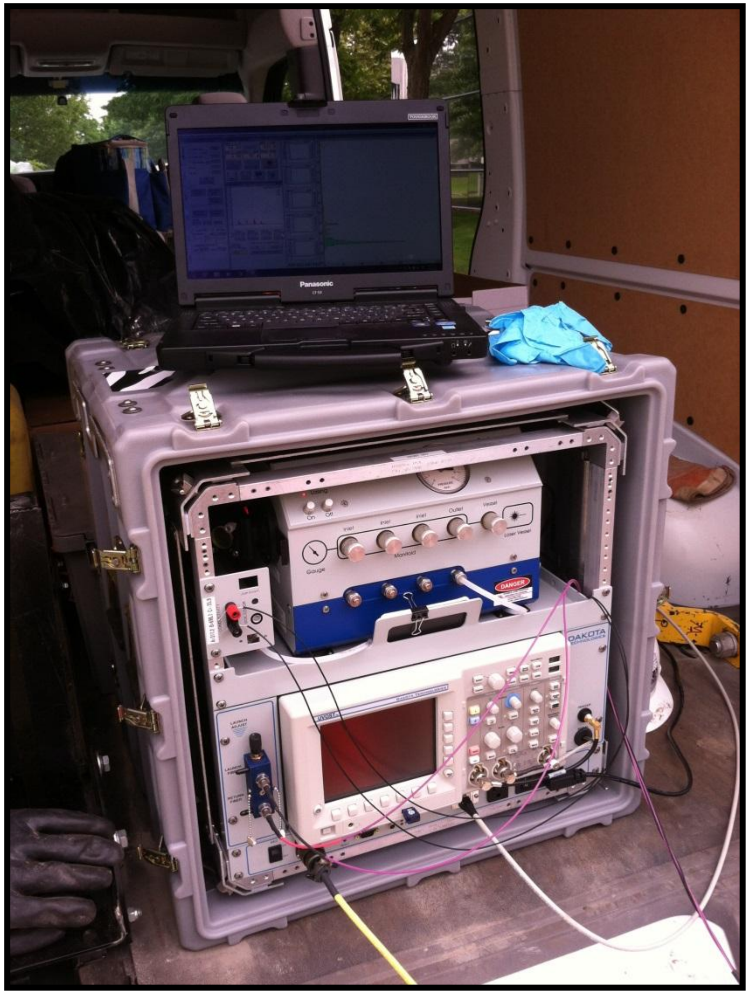
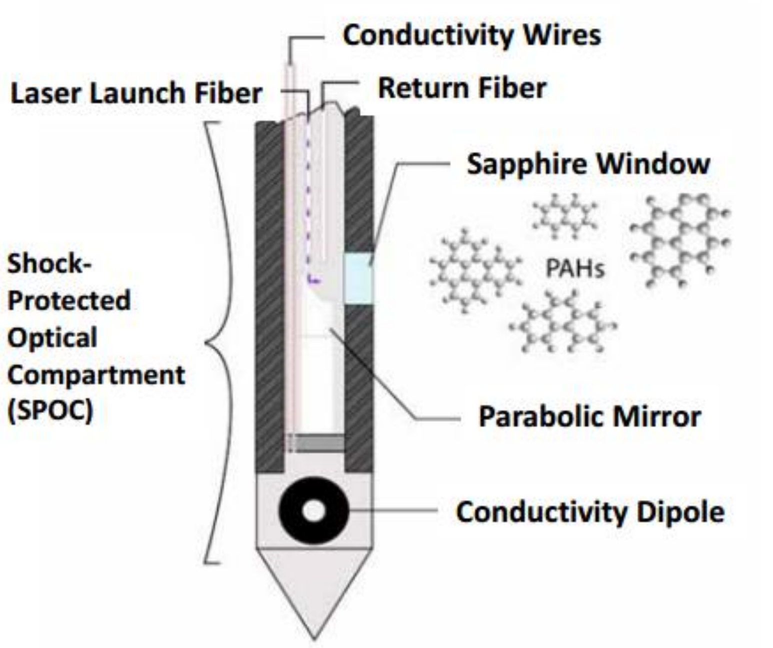
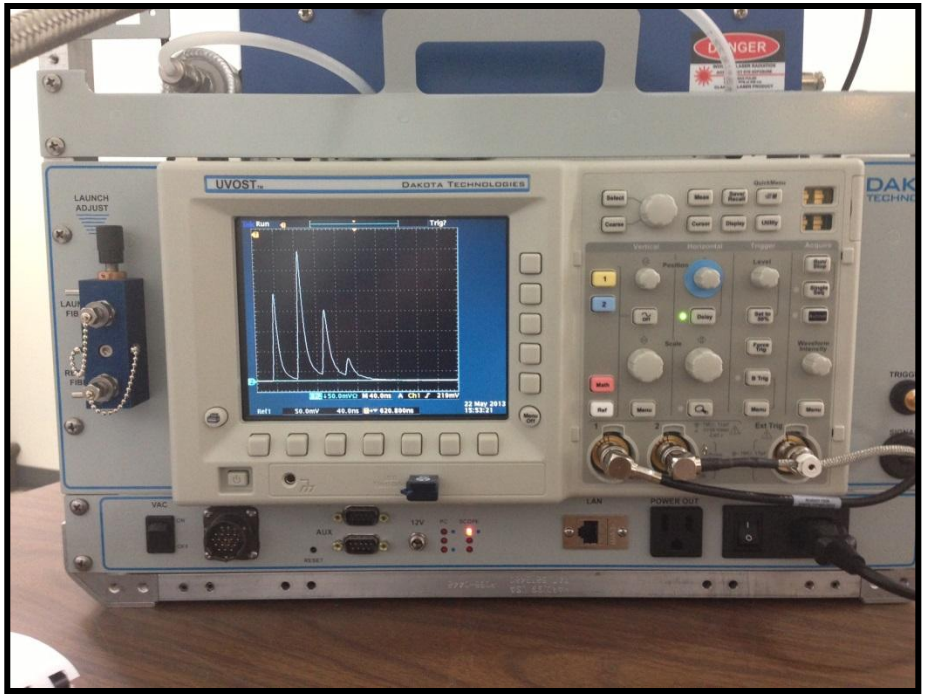
UVOST/LIF



UVOST/LIF



Shock-resistant and water-tight SPOC is advanced with direct-push equipment



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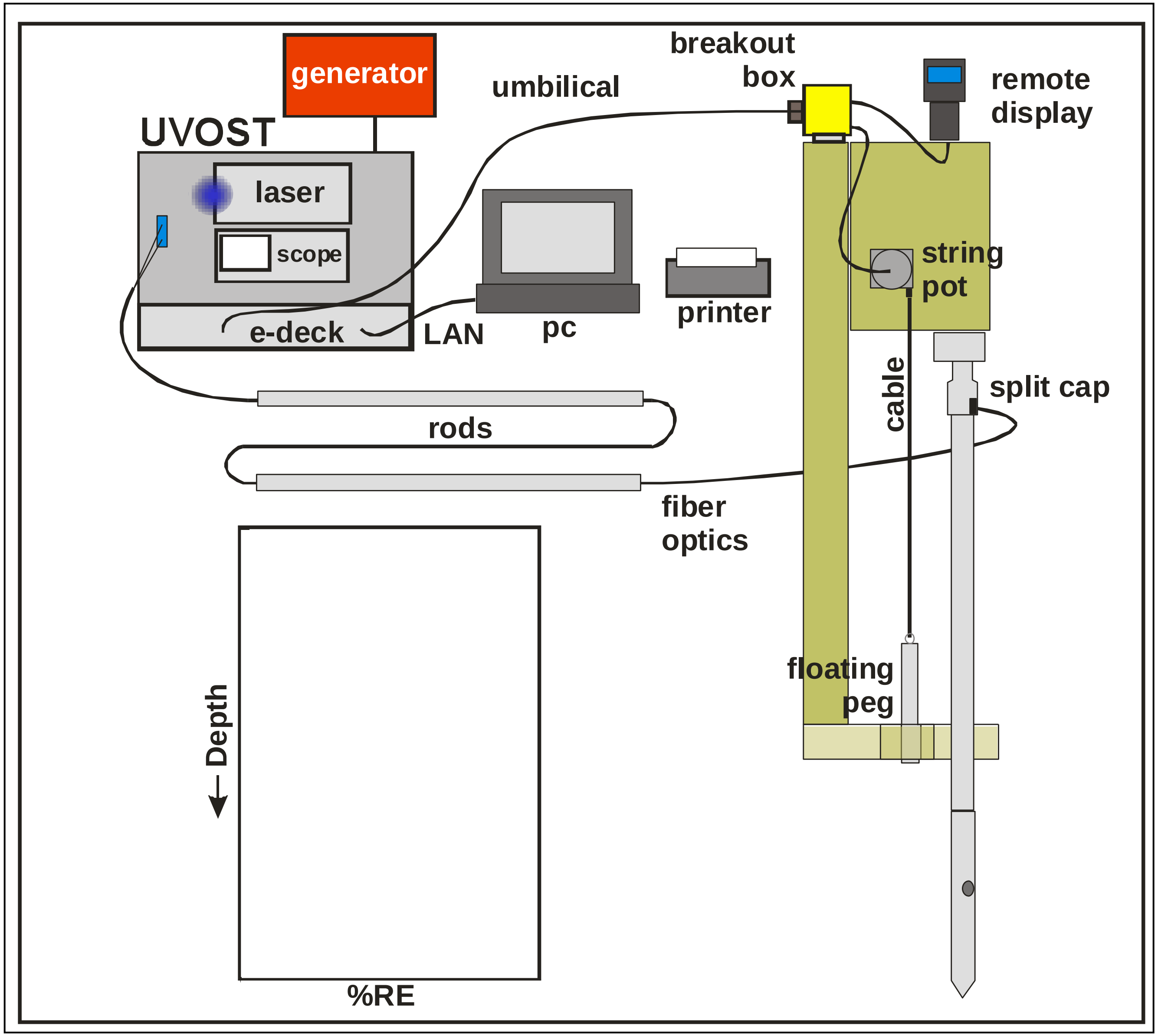
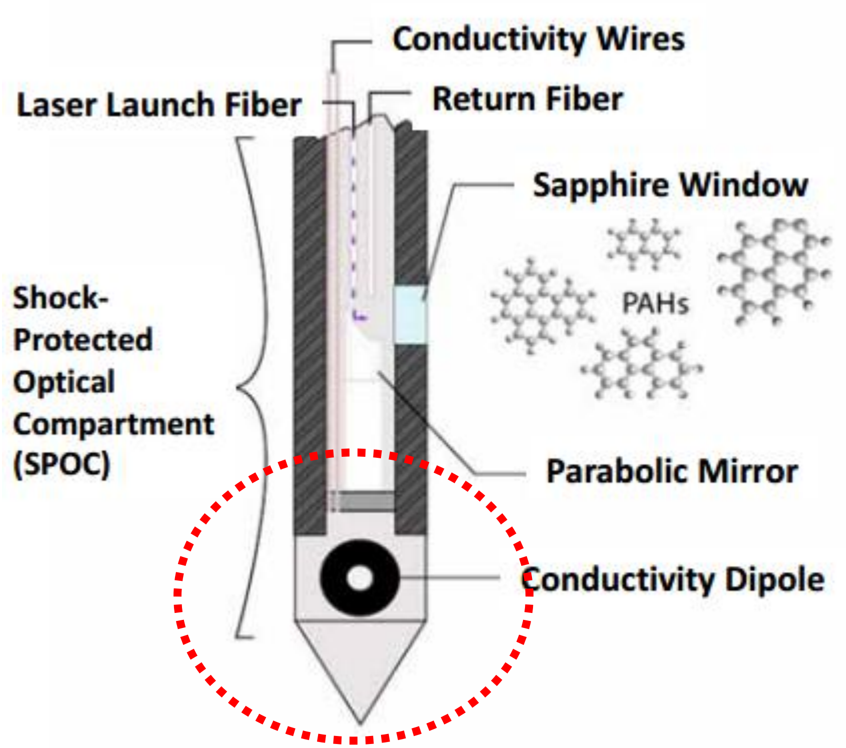


generator
UVOST
laser
scope
e-deck
LAN
pc
printer
umbilical
breakout box
remote display
string pot
cable
split cap
rods
fiber optics
floating peg
Depth
%RE

Conductivity Di-Pole



Shock-resistant and water-tight SPOC is advanced with direct-push equipment

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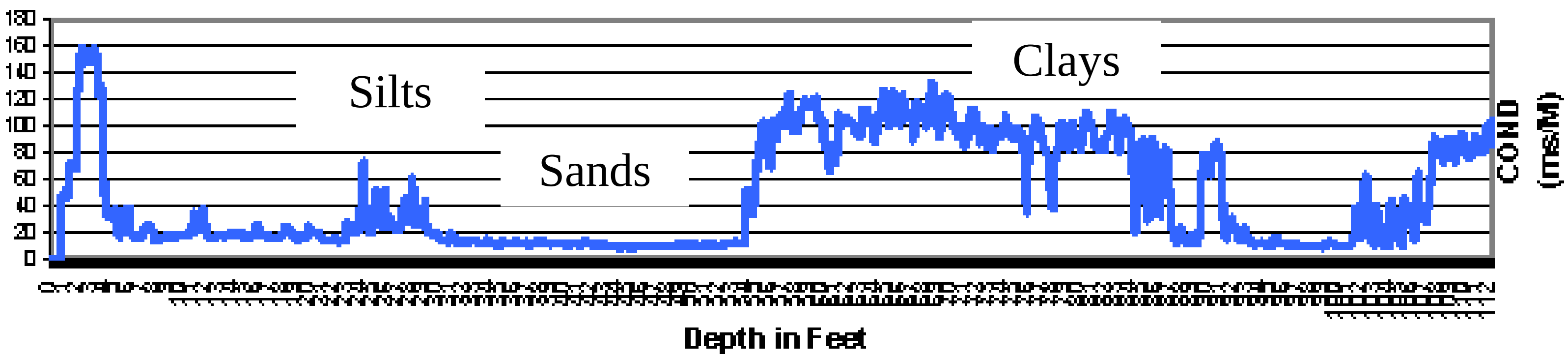
Changes in soil conductivity are indicative of:

- Changes in soil particle size
- Changes in the mineralogy
- Changes in the pore fluid
- Presence of ionic contaminants



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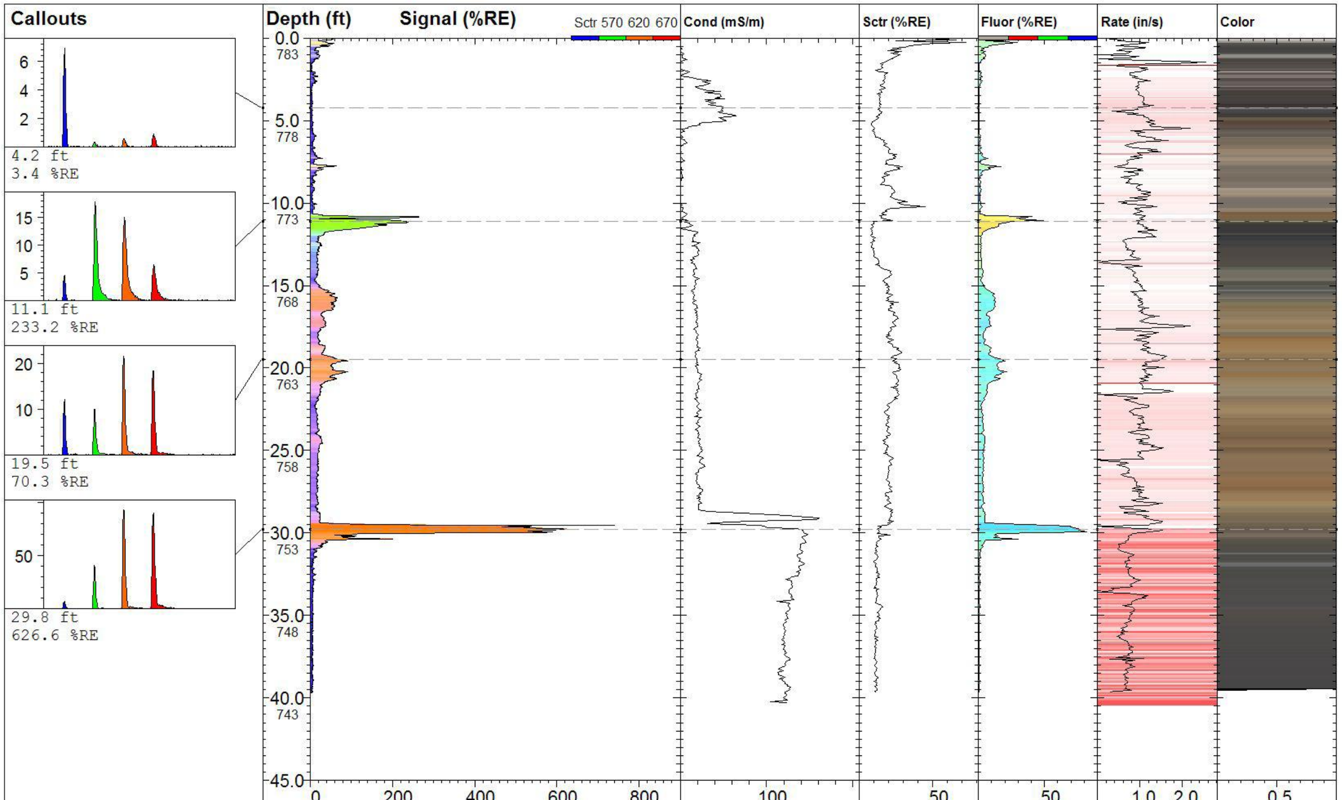

Sample Data		TarGOST By Dakota www.DakotaTechnologies.com
Site: **Fargo, ND**	*Latitude / Datum:* **46 54.430700 N / WGS-84**	*Final depth:* **39.68 ft**
Client / Job: **ABC Consulting**	*Longitude / Fix:* **096 47.753700 W / DG-3D**	*Max signal:* **758.3 %RE @ 29.54 ft**
Operator / Unit: **St. Germain / UVOST1000**	*Elevation:* **782.5 ft**	*Date & Time:* **2008-12-10 13:05 CST**

DAKOTA TECHNOLOGIES
Fargo, ND 701.237.4908
www.DakotaTechnologies.com

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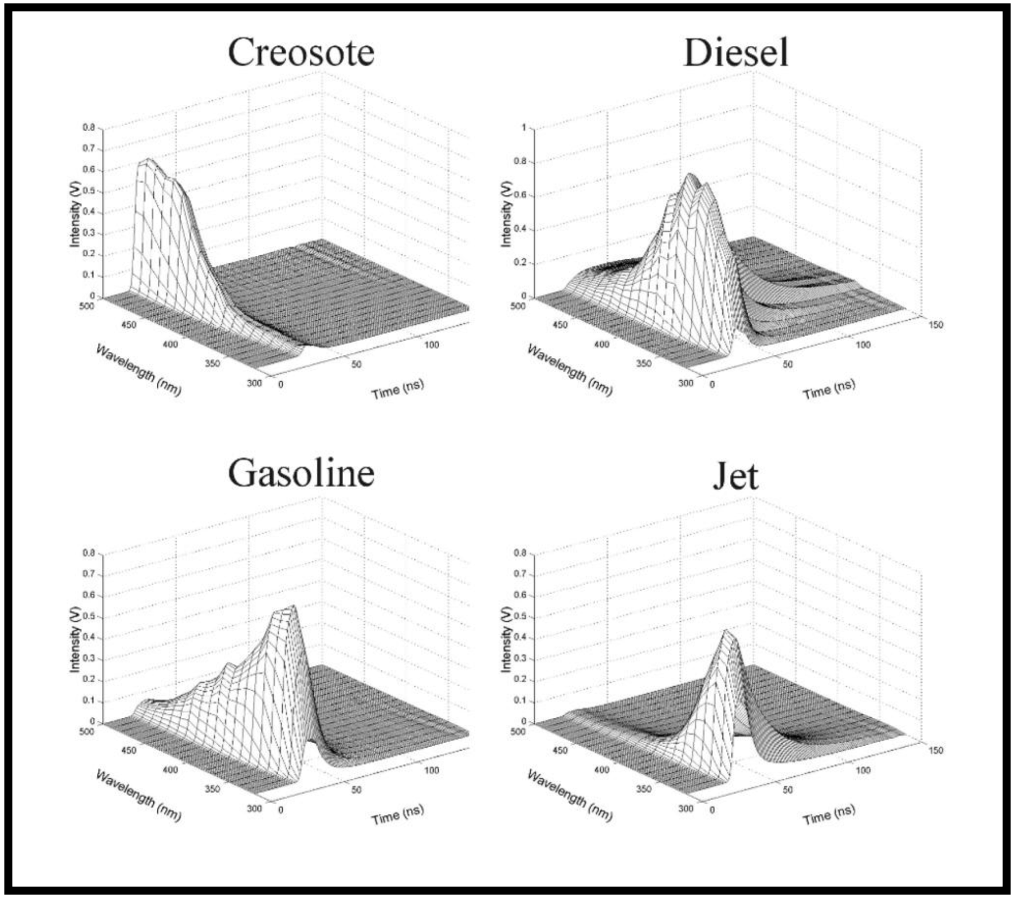
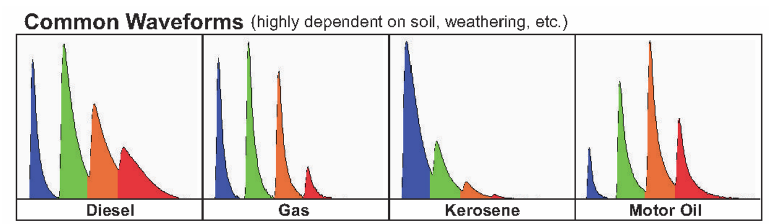
Laser Induced Fluorescence (LIF) Concepts

Each Aliphatic Solvent yield a fairly unique wavelength/time matrix (WTM)





Diesel

Gas

Jet

Motor Oil

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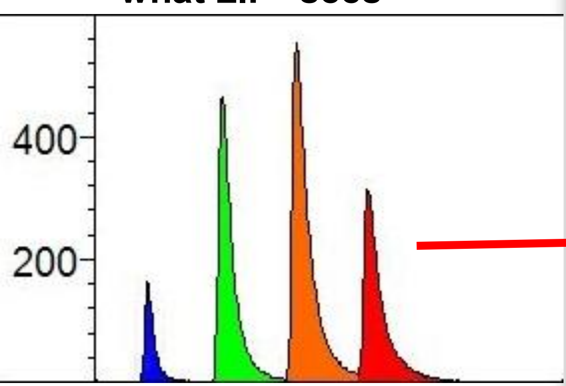
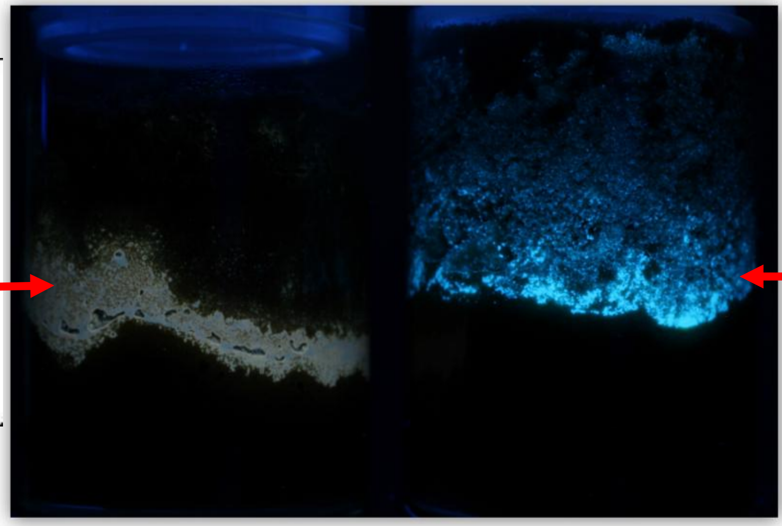
Fluorescence

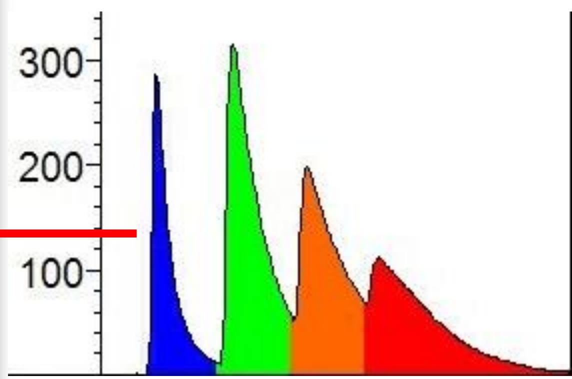
crude oil **diesel**

what LIF "sees"





what LIF "sees"



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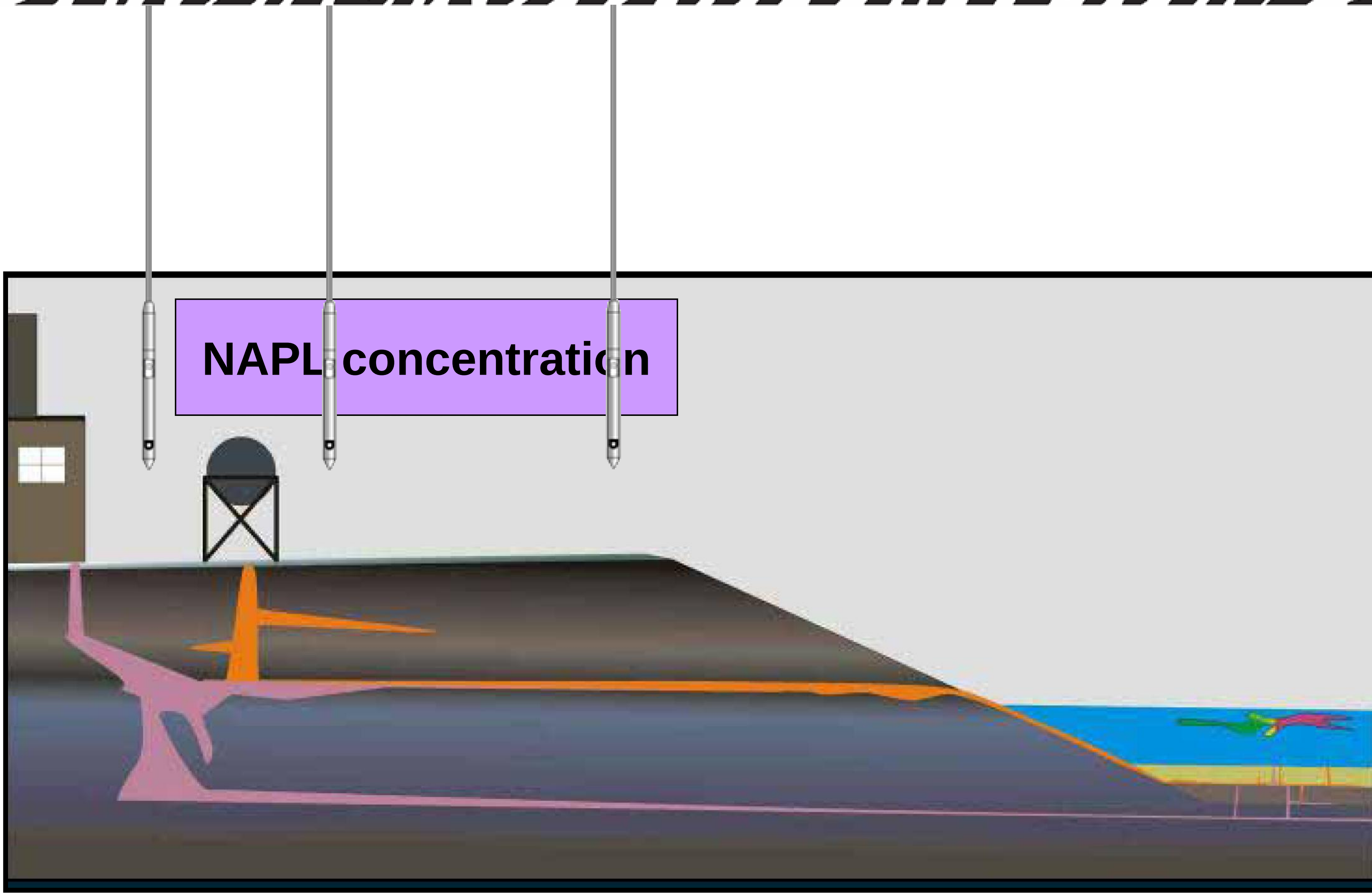

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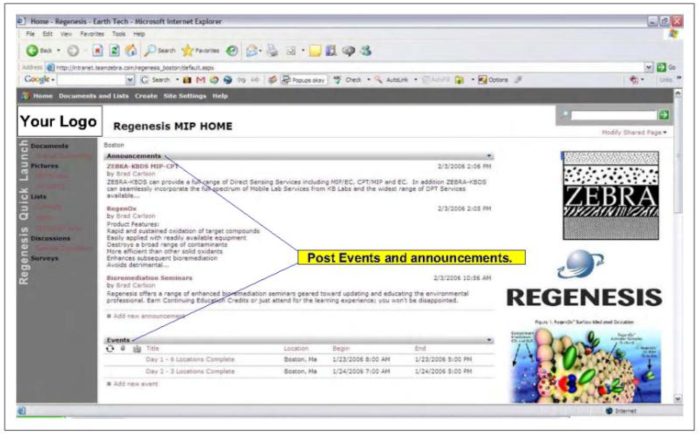
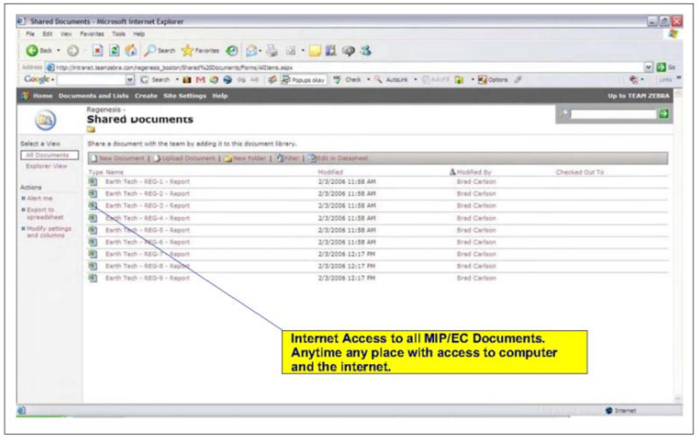
SHAREPOINT WEBSITE FOR LIF DATA SHARING

ZEBRA SharePoint Site

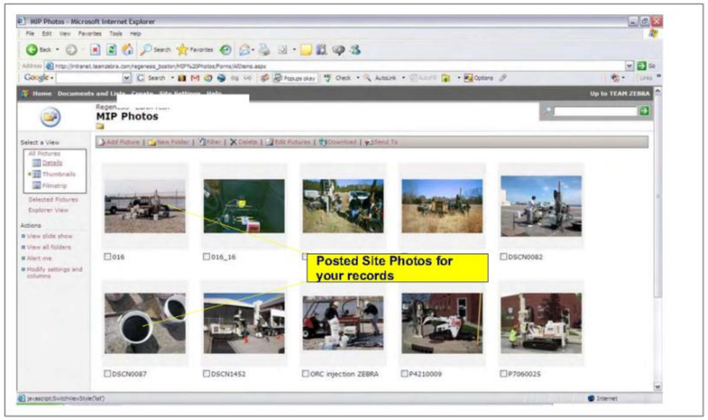
A custom web site for your Technical Documents

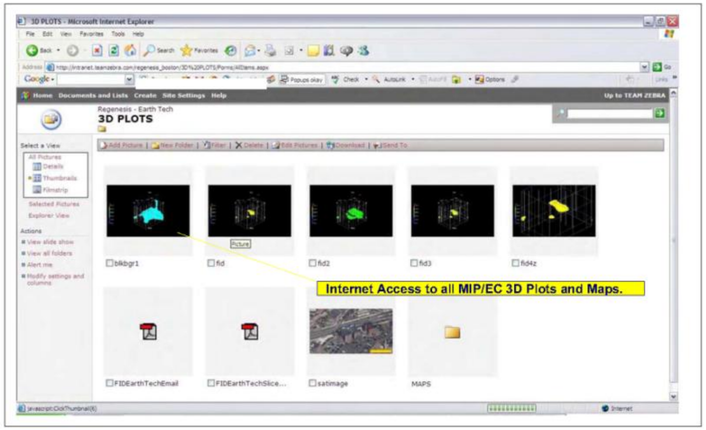




ZEBRA SharePoint Site

A custom web site for your Technical Documents





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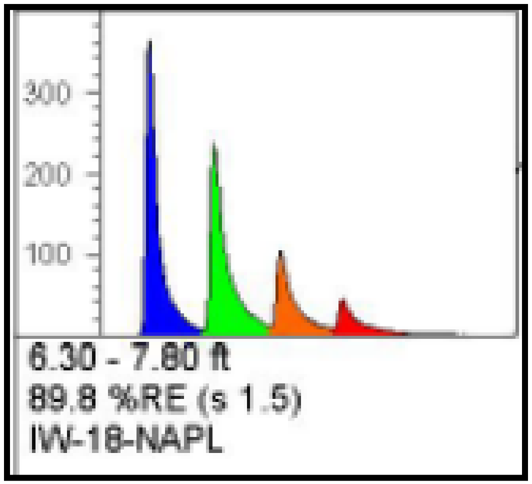
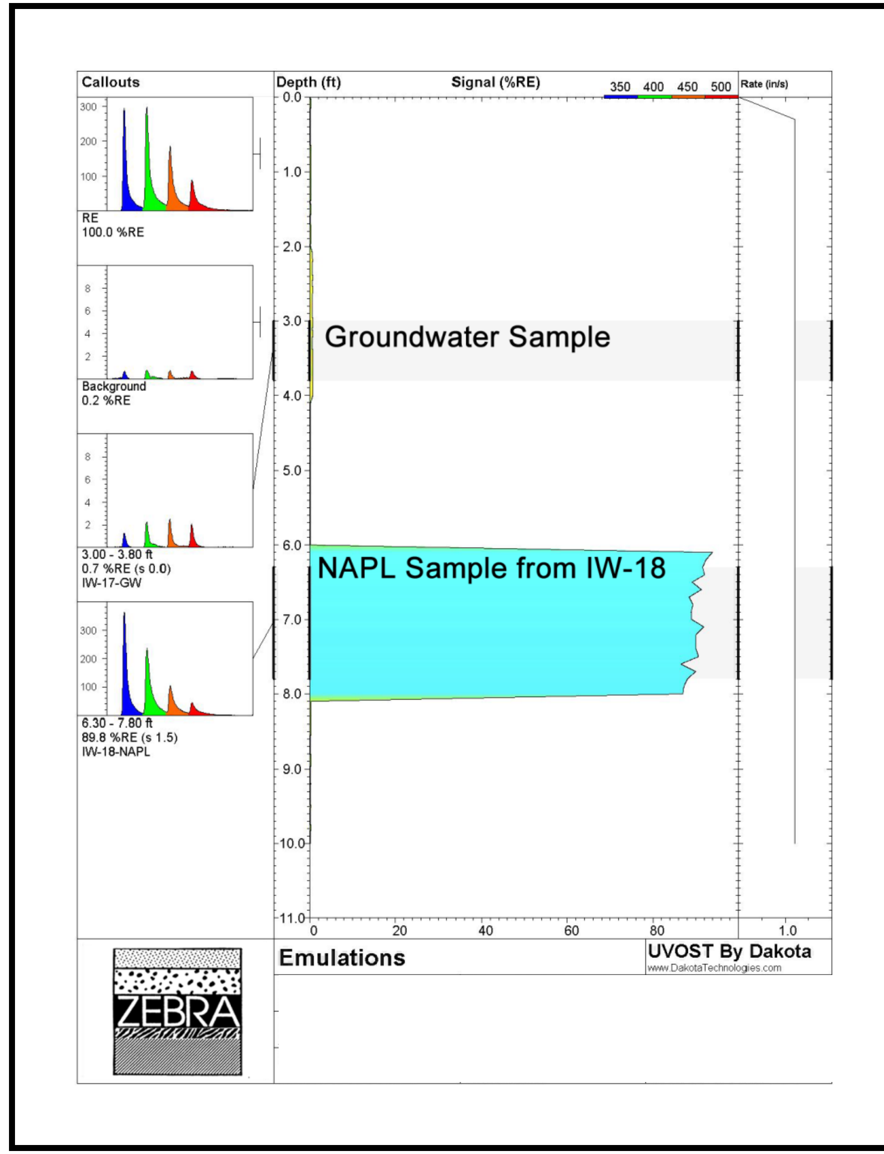
NAPL Pre-SAMPLE





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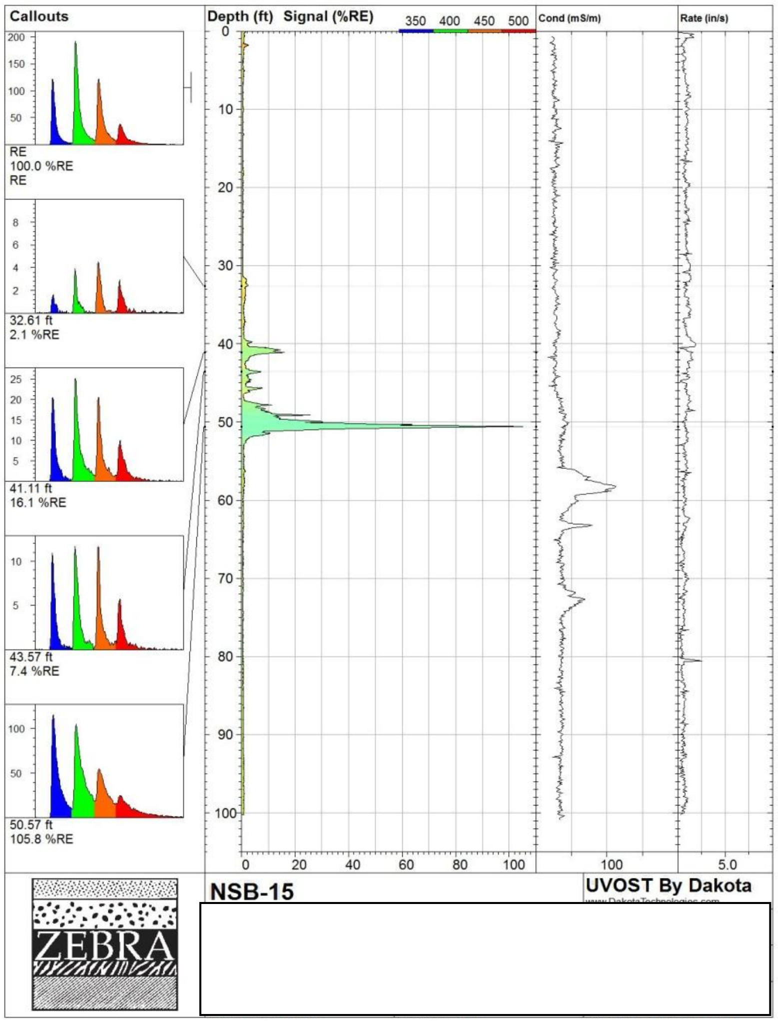
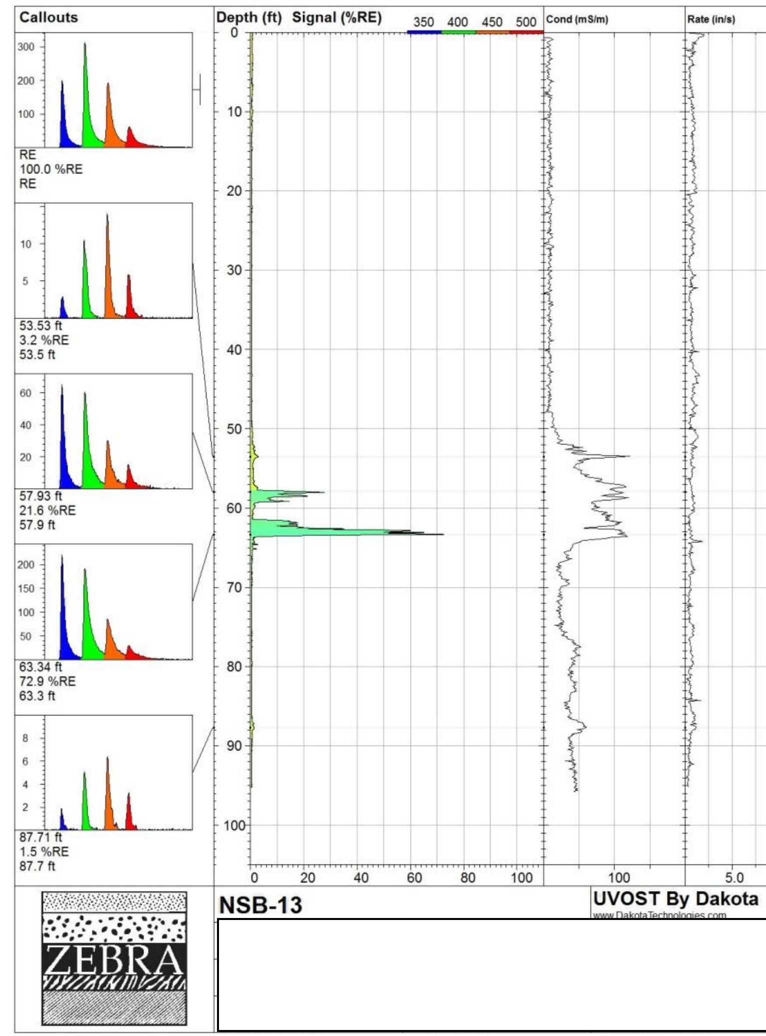

Callouts
Depth (ft) Signal (%RE)
350 400 450 500
Cond (mS/m)
Rate (in/s)
RE
100.0 %RE
RE
32.61 ft
2.1 %RE
41.11 ft
16.1 %RE
43.57 ft
7.4 %RE
50.57 ft
105.8 %RE
0 20 40 60 80 100
100
5.0
NSB-15
UVOST By Dakota
ZEBRA


Callouts
Depth (ft) Signal (%RE)
350 400 450 500
Cond (mS/m)
Rate (in/s)
RE
100.0 %RE
RE
53.53 ft
3.2 %RE
53.5 ft
57.93 ft
21.6 %RE
57.9 ft
63.34 ft
72.9 %RE
63.3 ft
87.71 ft
1.5 %RE
87.7 ft
0 20 40 60 80 100
100
5.0
NSB-13
UVOST By Dakota
www.DakotaTechnologies.com
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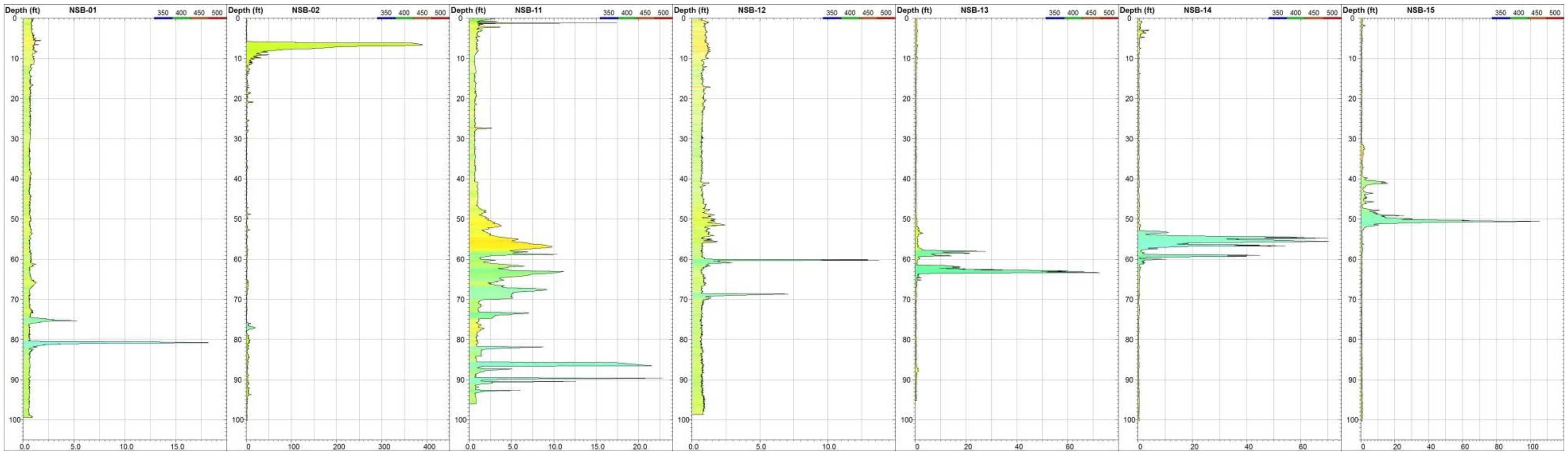
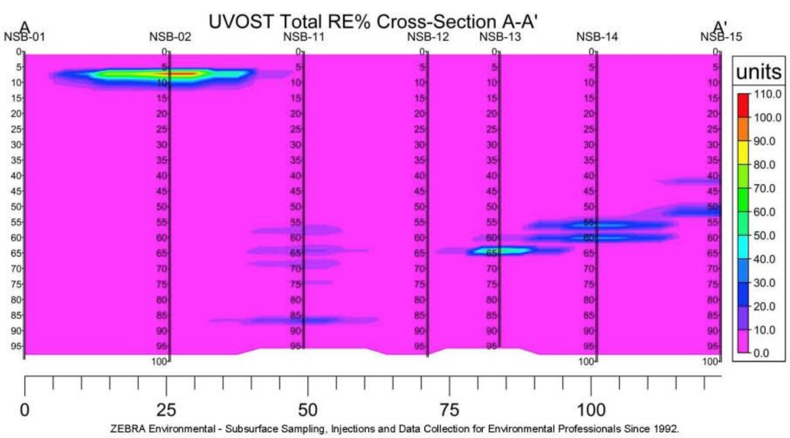
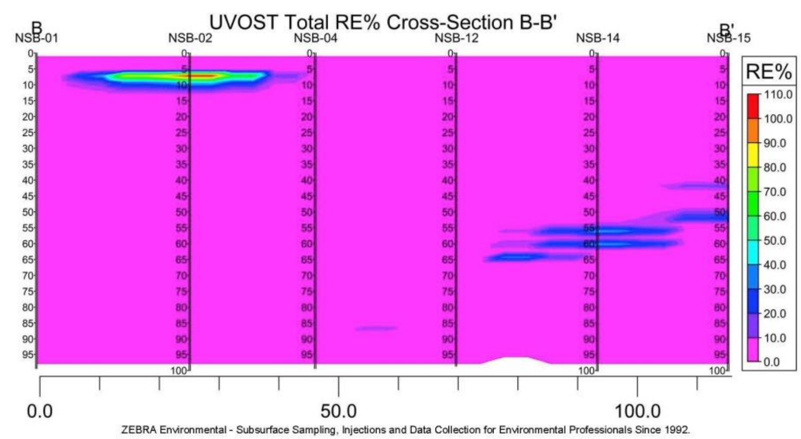

Depth (ft)
NSB-01
NSB-02
NSB-11
NSB-12
NSB-13
NSB-14
NSB-15
350 400 450 500


UVOST Total RE% Cross-Section A-A'
A
A'
NSB-01
NSB-02
NSB-11
NSB-12
NSB-13
NSB-14
NSB-15
units
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
25
50
75
100
ZEBRA Environmental - Subsurface Sampling, Injections and Data Collection for Environmental Professionals Since 1992.


UVOST Total RE% Cross-Section B-B'
B
B'
NSB-01
NSB-02
NSB-04
NSB-12
NSB-14
NSB-15
RE%
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
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0.0
0.0
50.0
100.0
ZEBRA Environmental - Subsurface Sampling, Injections and Data Collection for Environmental Professionals Since 1992.

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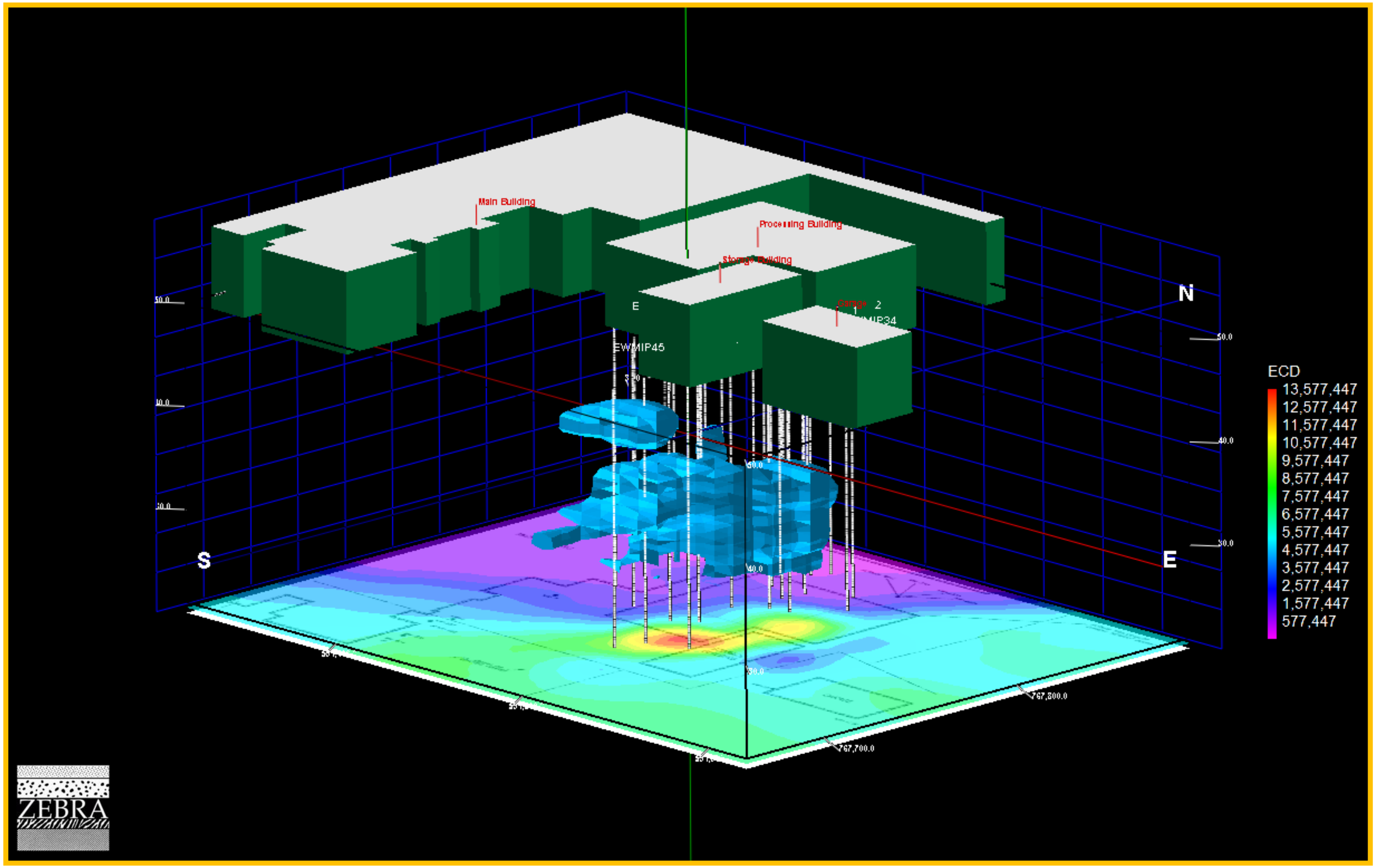

HRSC Solid Model with Surface Objects

For more information
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Potential LIF Characterization Sites

Consulting Engineers and Scientists

LSPA

LNAPL Laboratory Techniques for Evaluating Mobility

Brandon J. Fagan
LSP, PG

December 2013

Presentation Acknowledgments:

PTS Laboratories
Dakota Technologies

GEI Consultants

Overview: A brief discussion of various laboratory analyses that are used to determine the mobility of light non-aqueous phase liquid (LNAPL) in soil. The analysis includes methods to test LNAPL capillary pressure drainage, relative permeability in soil in the saturated zone (wetting fluid), and unsteady state conditions and water flood pore volume exchange. These methods are used to develop remedial strategies to recover LNAPL, reduce dissolve phase concentrations, and support risk characterization assessments.

LNAPL Mobility Evaluation

- LNAPL - Screening & Analytical Methods
  - Property Index Tests for Models
  - Photography
  - Laser Induced Fluorescence
  - LNAPL Saturation Analysis
- Laboratory Test Methods
  - Residual Saturation Analysis
  - Capillary Pressure Test
  - Unsteady State Relative Permeability Test
  - Pore Volume Analysis

Index Property Tests (Modeling Parameters)

LNAPL Properties	ASTM D445, ASTM D971, ASTM D1331, ASTM D1298, ASTM D 2983	LNAPL Porosity, Interfacial tension, Surface Tension, and Specific gravity are a key mobility parameter performed at a specific temperature (field conditions) Source: STL Laboratories, Inc.	

Inputs	**Porosity**	**0.26 (gravel)**
	Specific Gravity	**0.883**
	LNAPL/Water Interfacial Tension	**26.3**
	Air/LNAPL Surface Tension	**36**
	Residual LNAPL Saturation	**10.9 %**
	LNAPL Saturation	**7%**

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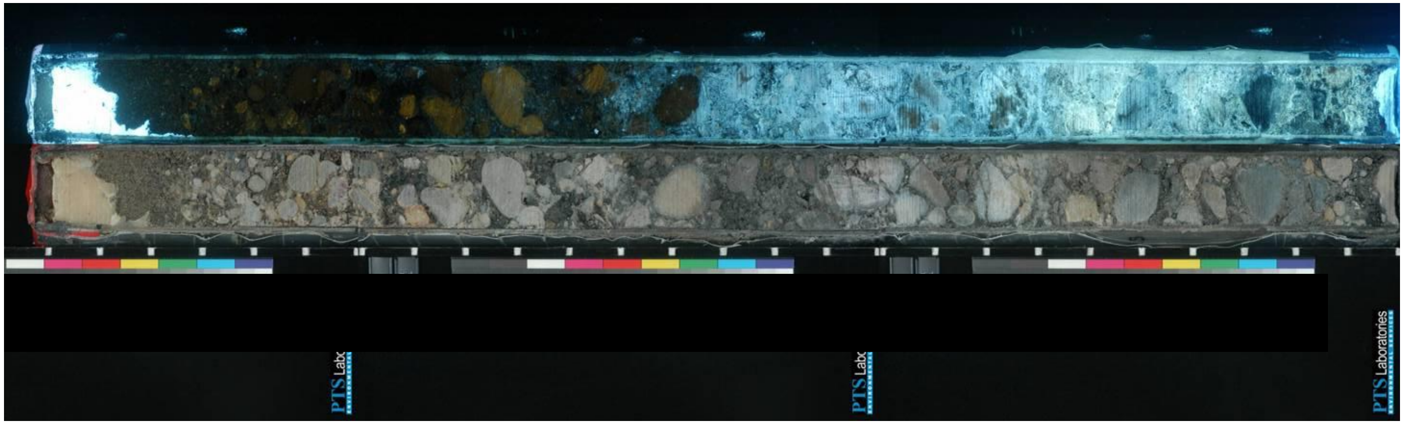
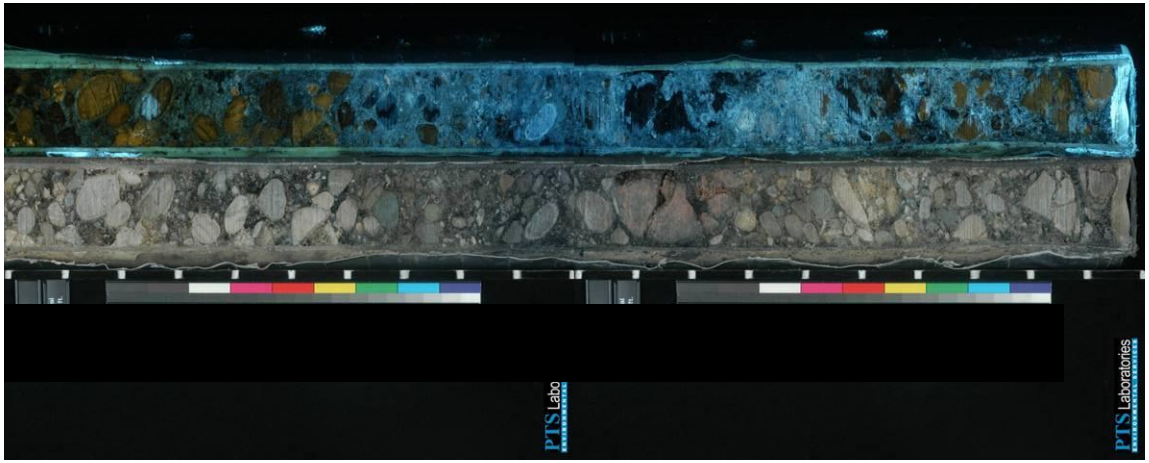
CORE White Light & UVL Photography





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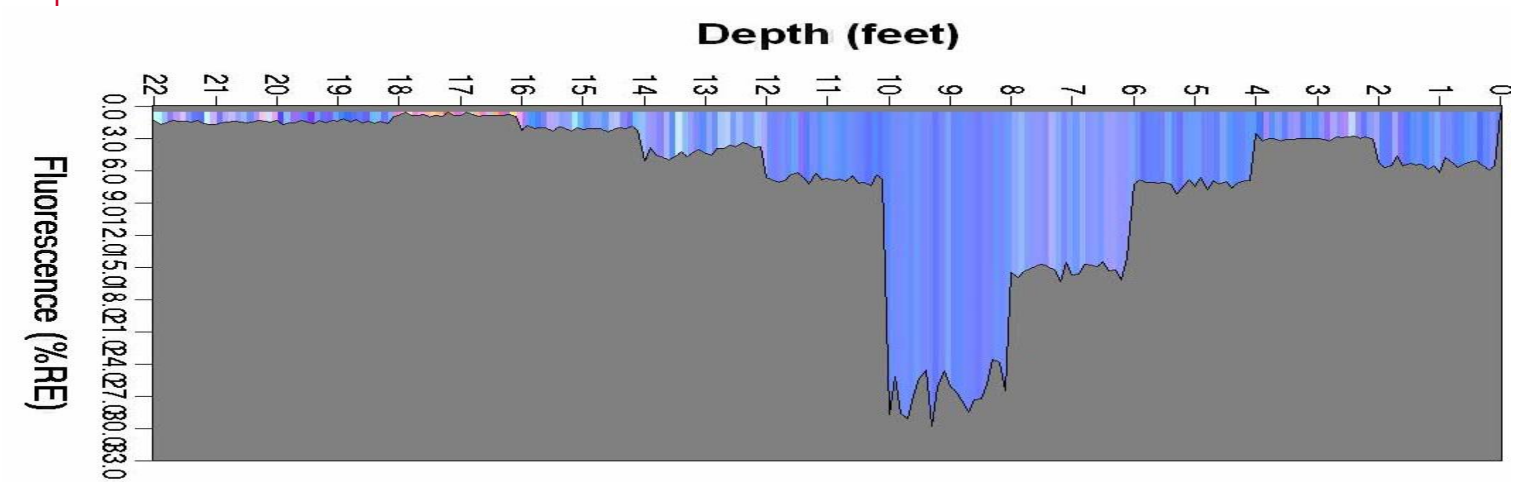
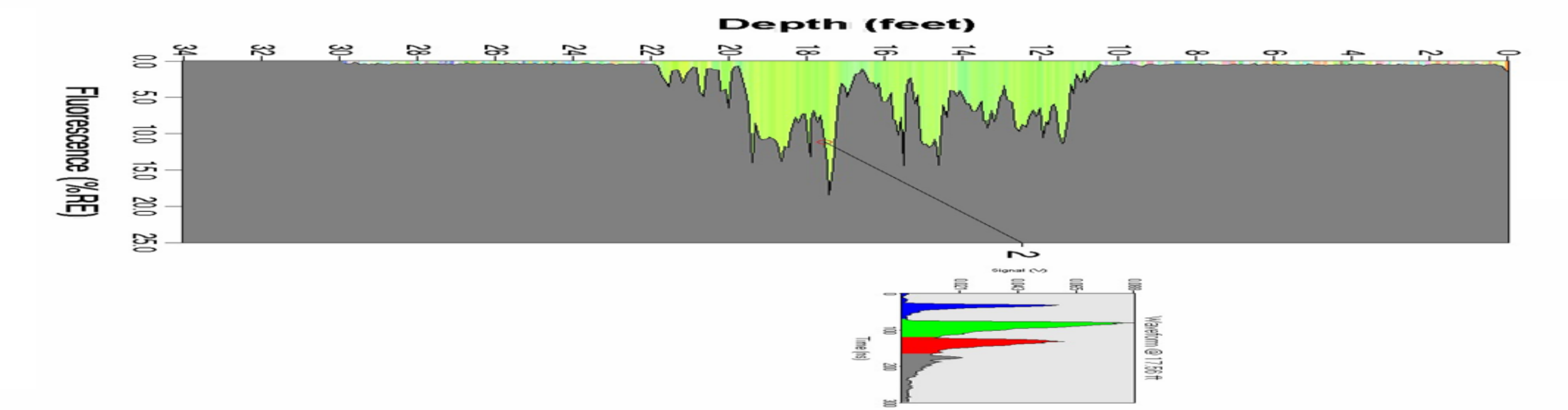
LIF Fluorescence Relationship to PAH Saturation



Profile of LIF collected from PAH absorption to Poly-di-methyl-siloxane tubing



Profile of LIF collected using Geoprobe LIF Tool (UVOST/ROST/TarGOST)

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Mobility & Residual Saturation Analysis

LNAPL Mobility Testing Laboratory Information (Direct Tests)

Table 1
Comparison of Methods for Mobility / Residual Saturations

Test Description	Residual Saturation Method	Cost (1)	Duration (2)	Advantage	Limitation
Steady-State Relative Permeability	CT Scanning	High	8-10 wks	Direct saturation and permeability measurements	Cost, duration, non-native fluids
Unsteady-State Relative Permeability	Dynamic displacement	High	4-6 wks	Native site fluids, well established method. Can use field gradients.	Large volumes of field fluids required. Indirect saturations
Capillary Pressure	Curve Fitting	Moderate	3-4 wks	Rapid; multiple samples per run	Residual saturation dependant on curve fit routine
Nuclear Magnetic Resonance	Magnetic Field	Moderate	2-3 wks	Multiple parameter generation	Specific soil type; new method and may be difficult to defend
ASTM D-425M (Centrifuge)	Dean-Stark Extraction	Low	1-2 wks	Rapid, low cost screening. Multiple samples per run	Sample preservation is critical.
Literature Values	Look-up Tables	Low	Varies	Low cost	Non-Site Specific data. Difficult to defend

(1) Low: $200-300/sample; Moderate: $500-750/sample; High: $950-3000/sample.
(2) Typically multiple samples are run in series.

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LNAPL Soil Saturation Analysis

Test	Reference	Purpose and Description	Cost
Dean-Stark Extraction	ASTM D95 API RP 40	Percentage of LNAPL and water by volume, i.e. Fluid Saturation A method for the measurement of fluid saturations in a core sample by distillation extraction. The water in the sample is vaporized by boiling solvent, then condensed and collected in a calibrated trap. This gives the volume of water in the sample. The solvent is also condensed, then flows back over the sample and extracts the oil. Extraction continues for a minimum of two days until the extracted solvent is clean or the sample shows no more fluorescence. The weight of the sample is measured before and after extraction. Then the volume of oil is calculated from the loss in weight of the sample minus the weight of the water removed from it. Saturations are calculated from the volumes. Information includes fluid saturations (LNAPL, water, air) , total porosity, air-filled porosity, grain density, dry bulk density, and moisture content. Source: Schlumberger Oilfield Glossary www.glossary.oilfield.slb.com	$90 to $150

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Residual Saturation Analysis

Test	Reference	Purpose and Description	Cost
Screening Method for Determining Free Product Mobility - Capillary Pressure Drainage Test (Centrifuge Method)	ASTM D425M API RP 40	Single point quantification of residual saturation and LNAPL drainage. Provides a conservative estimate of residual saturation under gravity drainage by applying centrifugal force at 1000 times gravity for one hour to demonstrate product mobility equal to 1G for 1000 hours. Includes initial and residual pore fluid saturations, total porosity, dry bulk density and LNAPL Drainage observations (greater/less than residual where product mobilizes or does not mobilize from the sample) Source: PTS Laboratories www.ptslabs.com	$345

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Water/LNAPL Imbibition Capillary Pressure Tests

Test	Reference	Purpose and Description	Cost
Water/LNAPL Imbibition Capillary Pressure Test (Centrifugal Method)	ASTM D6836 API RP 40 EPA 9110	Develop curve of capillary pressure vs. LNAPL saturation/production/loss by initially saturating a sample in the laboratory with LNAPL,, then introducing water as the permeant. increasing pressure incrementally. Measure fluid drainage out of the sample as LNAPL drainage changes to water and LNAPL production stops. Plot saturation vs. capillary pressure. Includes initial fluid saturations, LNAPL imbibition saturation, saturation change & drainage endpoints, hydraulic conductivity, specific permeability (relative permeability) to LNAPL	$450 to $700

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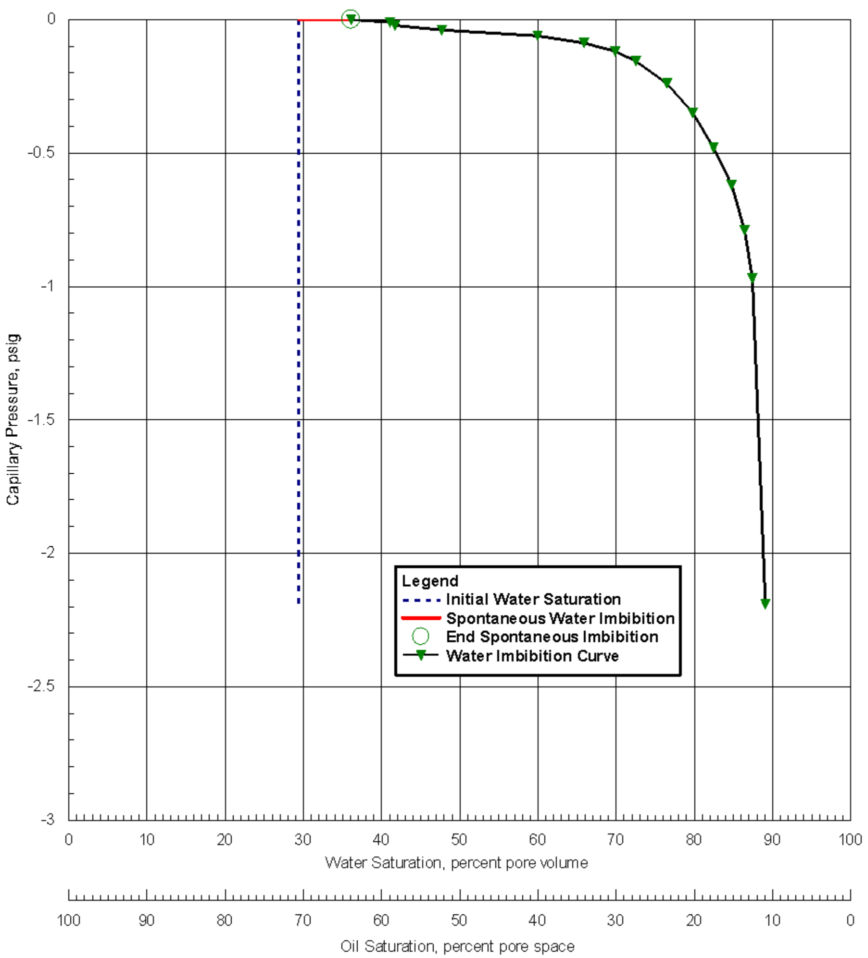
Capillary Pressure Test: Centrifugal Method

- **Capillary Pressure tests demonstrate that at 2 psig or ~4.5-ft of head, LNAPL has little potential mobility based on saturation relationships to existing conditions.**
  - Very low gradient across site, approx. 0.001 ft/ft
  - Under maximum LNAPL thickness scenario and average seasonal head, product in the source area is relatively immobile.

Capillary Pressure Centrifugal Method

Oil/Water Imbibition



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Unsteady State Relative Permeability Test

Test	Reference	Purpose and Description	Cost
Unsteady State Relative Permeability Test Dynamic Displacement	Triaxial Shear Cell Or Core Holder	Using changing gradients, develop curves of water saturation vs. LNAPL saturation/production/ loss by saturating a soil sample in a core holder or cell. with water as the wetting fluid Then, either imbibe LNAPL or a ratio of LNAPL to the water through one end of the soil core at a constant ratio of LNAPL and water . The pressure gradient across the core is measured, and the fluids leaving the soil core are collected with changing gradients and LNAPL to water ratios to develop relative permeability curves. Results include initial fluid saturations, LNAPL imbibition saturation, saturation change & drainage endpoints, hydraulic conductivity, specific permeability (relative permeability) to LNAPL RTDF "The Basics : Presentation 2005"	$650 to $1500

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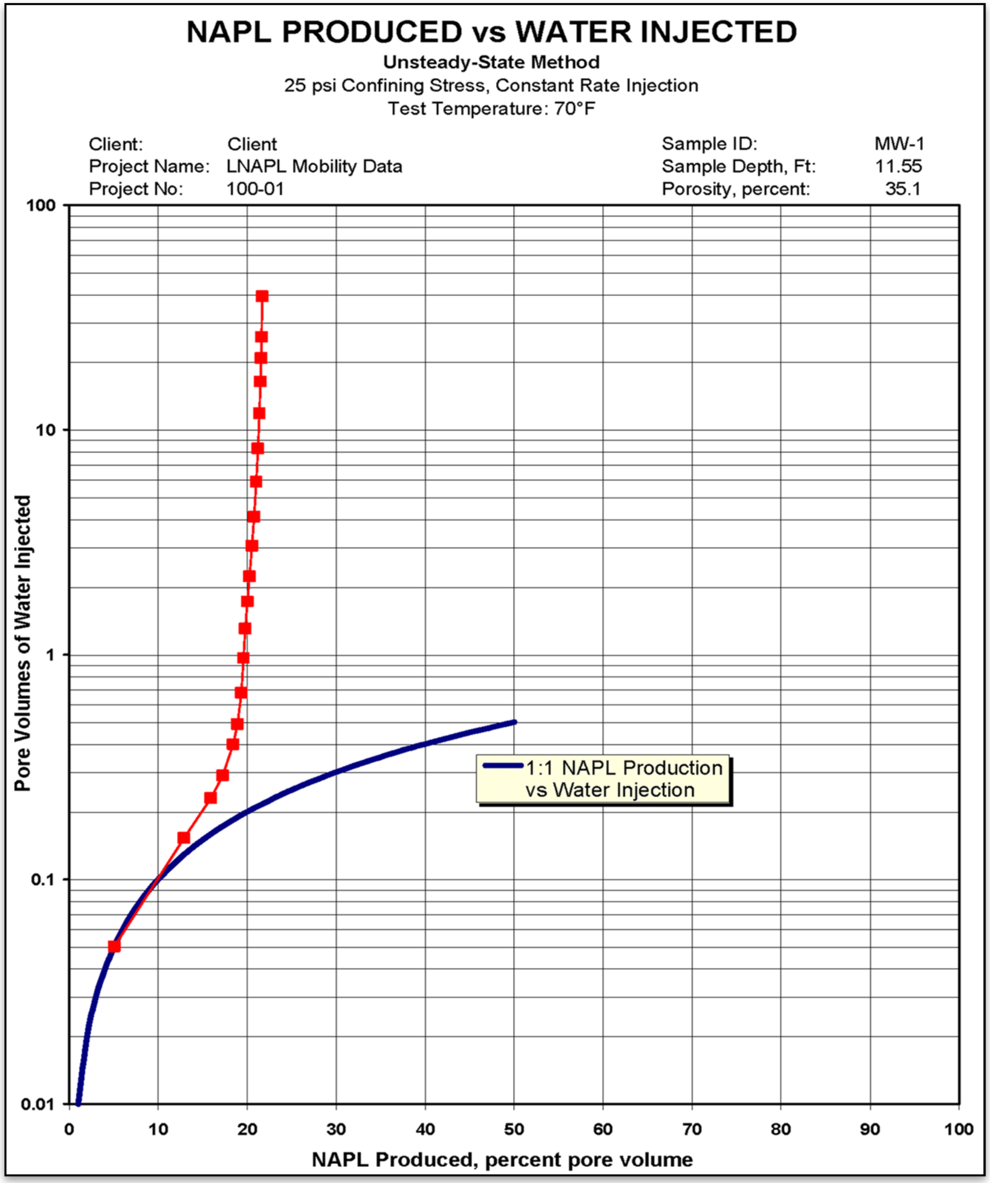
Relative Permeability Analysis



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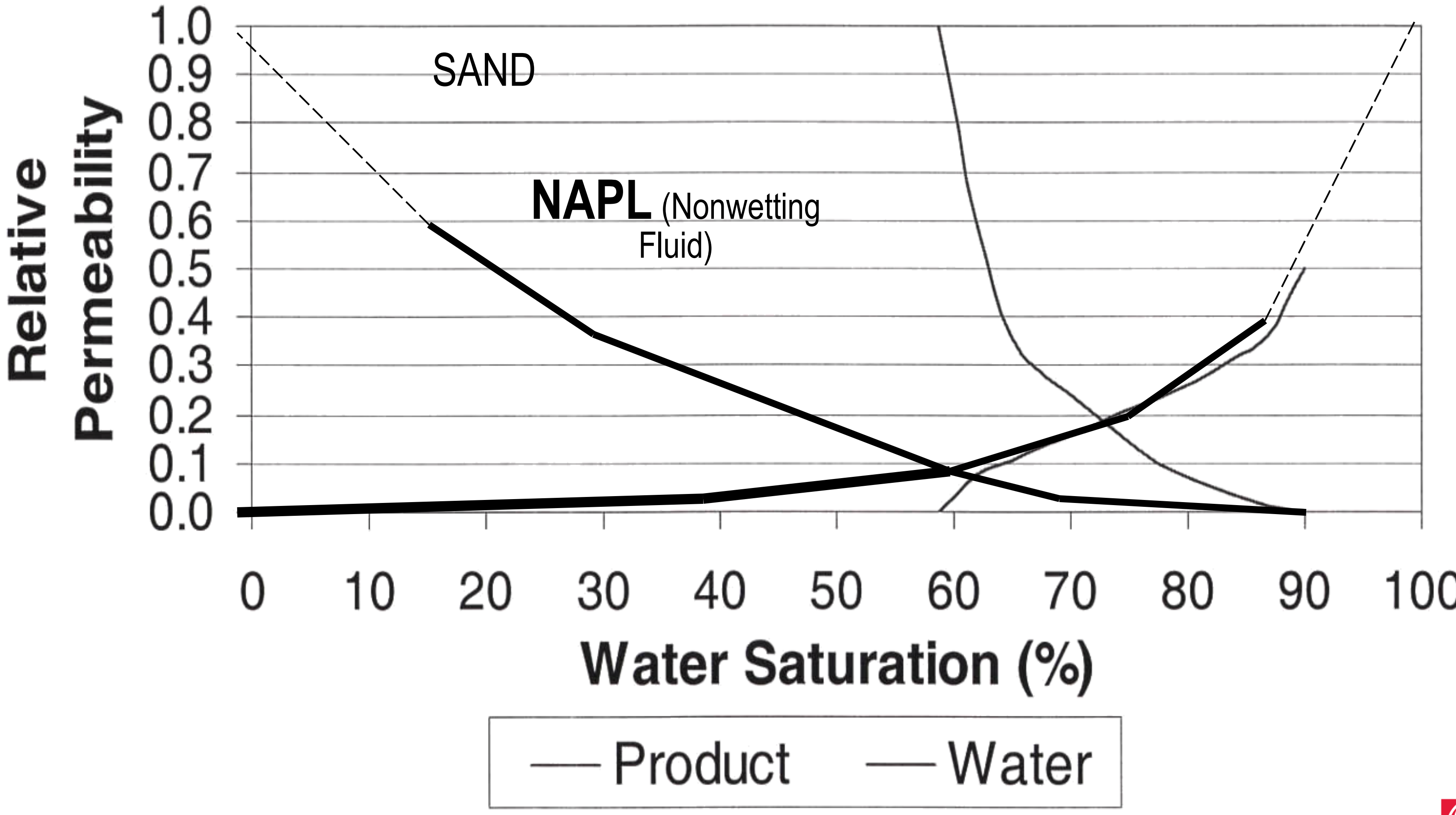
Average Water-LNAPL Relative Permeability Curves



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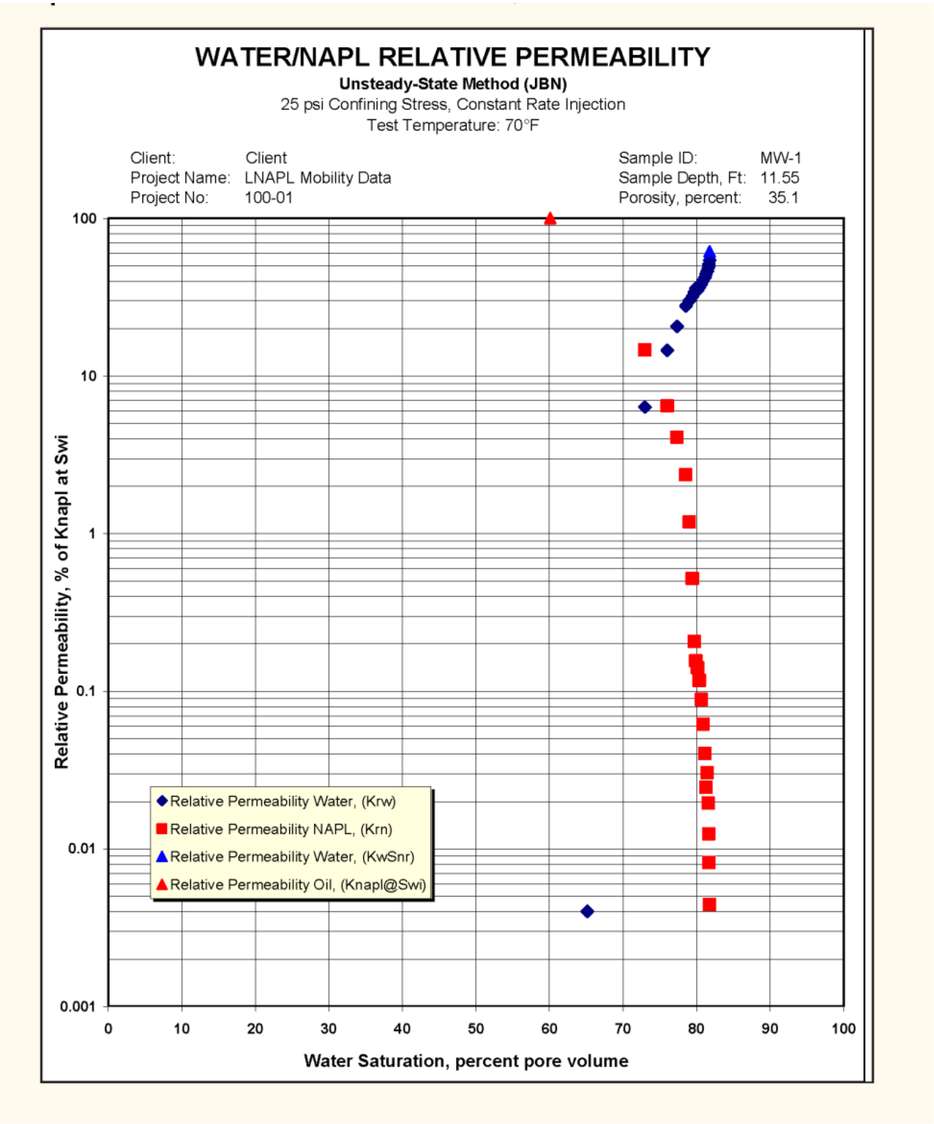
Pore Water Volume Drainage Analysis



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Modeling Results vs Laboratory Results

Model Calibration with Laboratory Results

Well ID	Maximum Apparent LNAPL Thickness bo_{max}	Average Apparent LNAPL Thickness bo_{avg}	Maximum LNAPL Relative Permeability K_{ro}	Maximum Effective LNAPL Saturation S_o
B-501	0.71	0.32	0.000	0.105
B-502	1.44	0.77	0.005	0.164
B-503	0.82	0.57	0.000	0.112
B-305	0.03	0.03	0.000	0.082
MW-13	1.04	0.29	0.001	0.129
BF-15	2.07	0.69	0.022	0.215
BF-16	1.40	0.65	0.004	0.161

Laboratory Results (So)

A So = 12.7-15.5%

B So = 1.3-7.1%

Residual Saturation Sors Relationship to So

	A	B
S_{ors}	10.9%	20.5%
	So > Sors	So < Sors

GEI Consultants

Questions?

CAN ANYONE TELL WHY THE SATURATION ANALYSIS OF THE MODEL DID NOT REFLECT THE **So** LABORATORY ANALYTICAL RESULT FOR SAMPLE B ……?

The answer was in the White Light Photograph**.**

GEI Consultants

In Situ Geochemical Stabilization (ISGS) for NAPL Management

LSP Association

LNAPL- Assessment and Extraction Technologies

Westborough, MA

Dec 12, 2013

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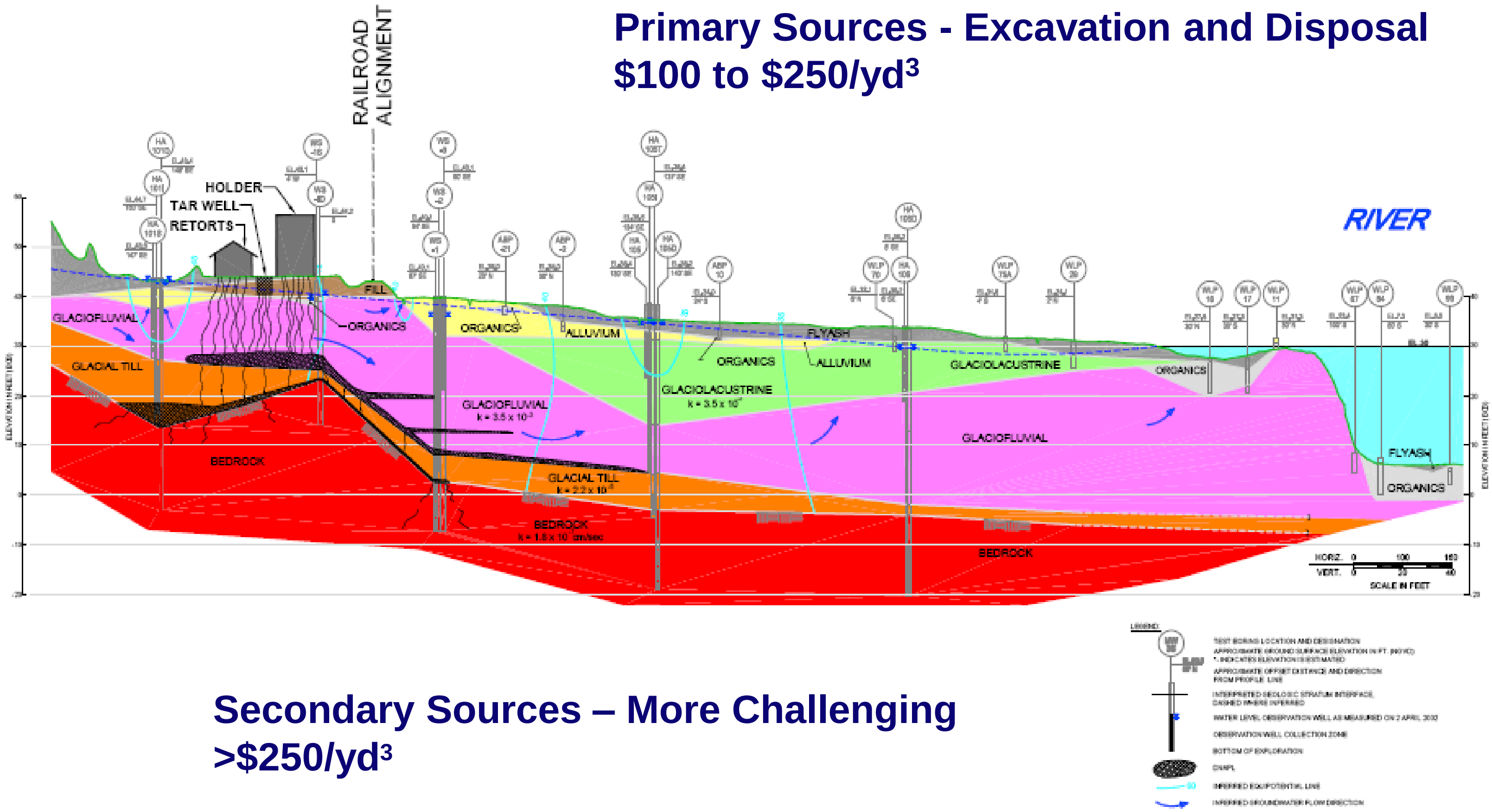
Presentation Overview

- What is ISGS Technology?
- History of ISGS Technology
- Bench Test / Proof of Concept
- Field Applications
  - Denver, CO
  - Gainesville, FL
  - Boston, MA
- Geochemical Modeling and Longevity
- Costs

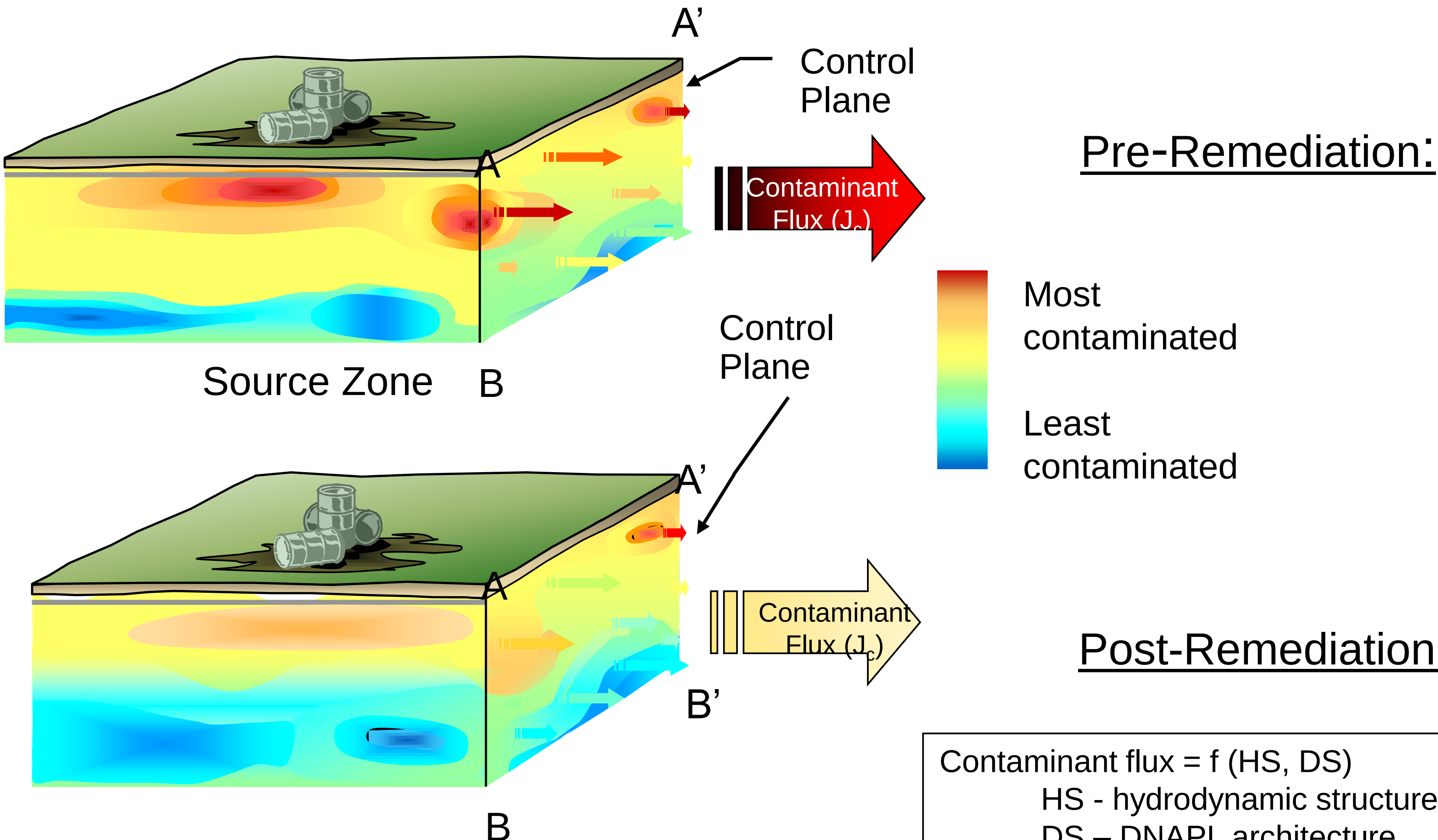
The NAPL Challenge – "Secondary Sources"

Primary Sources - Excavation and Disposal $100 to $250/yd³



Secondary Sources – More Challenging >$250/yd³

Contaminant Flux Definition (Enfield, 2001)



Contaminant flux = f (HS, DS)
HS - hydrodynamic structure
DS – DNAPL architecture

ISGS™ Chemistry

ISGS solution is a proprietary blend of permanganate and mineral salts that form a stable mineral precipitate

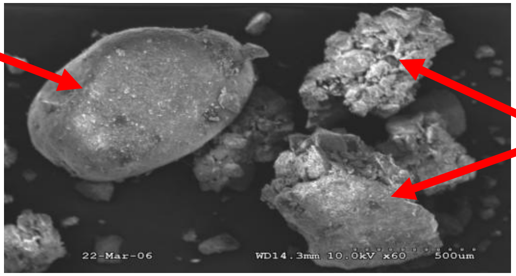
In the presence of an organic compound (R), MnO_4 reactions yield an oxidized intermediate (Rox) or CO_2 ,… plus MnO_2

$R + MnO_4^- \rightarrow MnO_2 + CO_2$ or Rox

A New NAPL Management Tool

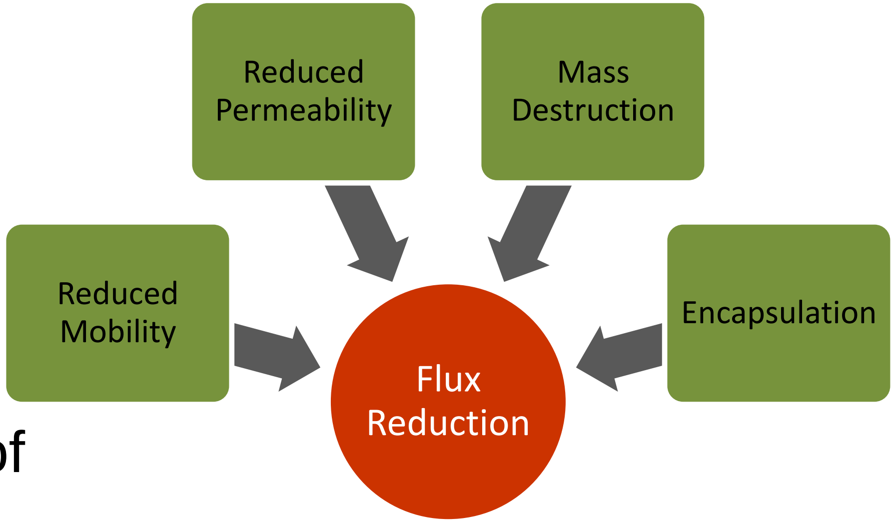
- **ISGS Effects**
  - Creates a stable “crust”
  - Reduces permeability
  - Immobilizes NAPL

NAPL-coated soil grain not exposed to ISGS



NAPL-coated soil grain exposed to ISGS

- **ISGS Addresses NAPL Challenges**
  - Reduces measurable NAPL
  - Reduces dissolution of NAPL constituents
  - Reduces flux of NAPL into groundwater
  - Enhances natural attenuation of NAPL constituents



ISGS for NAPL Challenges - Advantages

1. Liquid amendment – easy to inject and target source areas.
2. Rapid reactions (days) yield reduced aquifer permeability and COI flux
3. Applicable to wide range of organic and inorganic COIs
4. Only treat a fraction of TOD
5. Long term (crust analyses & geochemical modeling suggest > 100 yr, supported by over 10 yr field data)
6. Relatively low cost for localized source areas
7. Logical alternative to mass removal and mass destruction

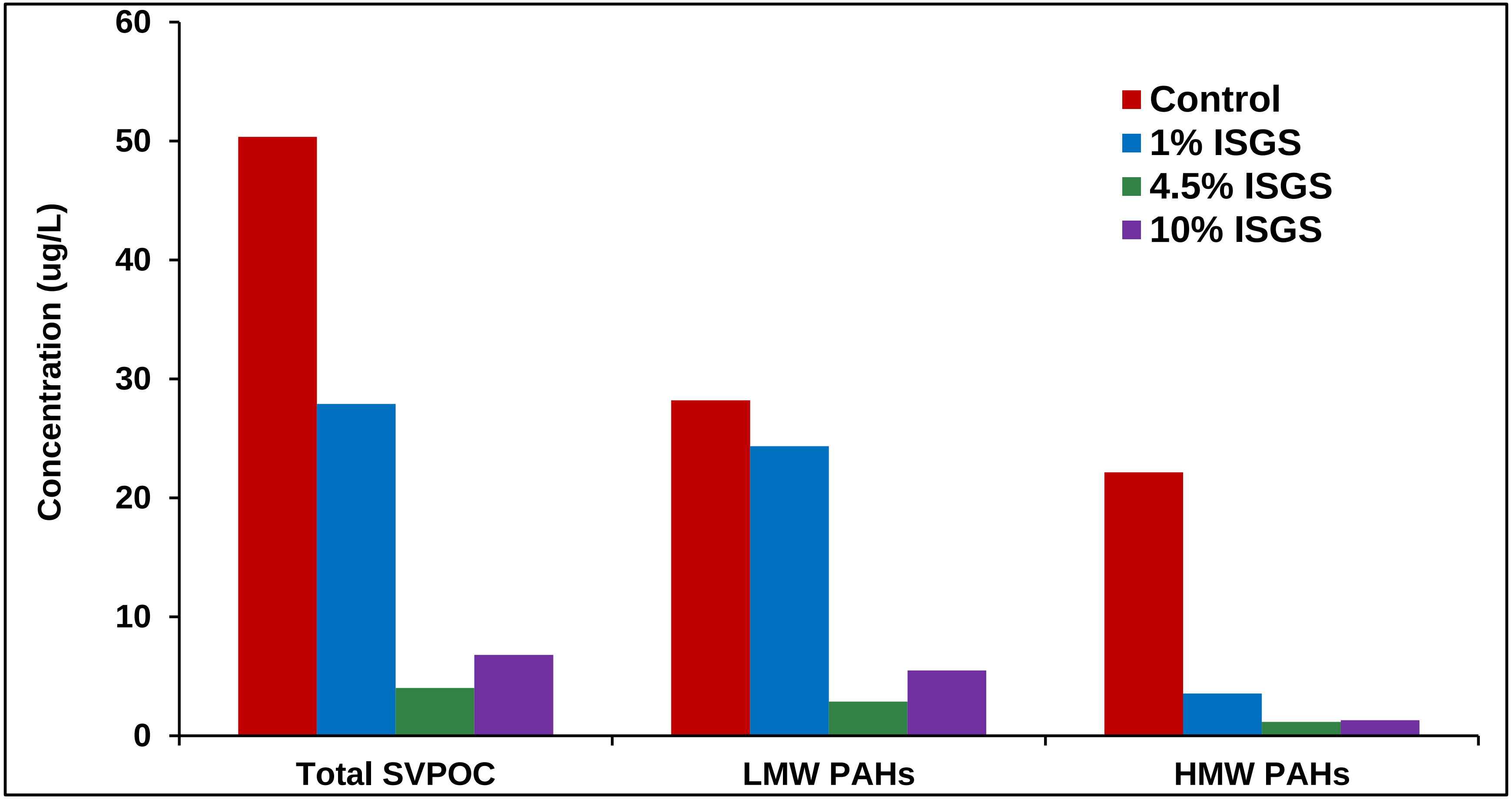
Technology Development

- ✓ 1997 Conceptualization / Proof of Concept
- ✓ 1998 - 1999 TCE - R&D at UW and Adventus
- ✓ 1999 - 2001 Camp Borden (pilot)
- ✓ 2002 - 2003 PAHs, PCP – Denver, CO (pilot)
- ✓ 2004 – PAHs – Denver, CO (full scale)
- ✓ 2004 – PAHs, PCP – Gainesville, FL (bench).
- ✓ 2005 - PAHs, PCP - Gainesville, FL (pilot)
- ✓ 2007 – PAHs - MGP NE Utilities (bench)
- ✓ 2008 – PAHs, PCP - Gainesville, FL (pilot)
- ✓ 2008 – PAHs - Creosote works, LA (bench)
- ✓ 2009 – solvents, benzene - plastics manufacturer (bench)
- ✓ 2010 – PAHs - Montgomery, AL (full scale)
- ✓ 2010 – LNAPL – South Boston, MA (bench test)
- ✓ 2013 - LNAPL – Fanwood, NJ (full-scale)
- ✓ 2013 – LNAPL and DNAPL, Frankford, PA (pilot test)
- ✓ 2013 – Creosote and PAHs – Gainesville (full scale)

Proof of Concept – Bench Testing

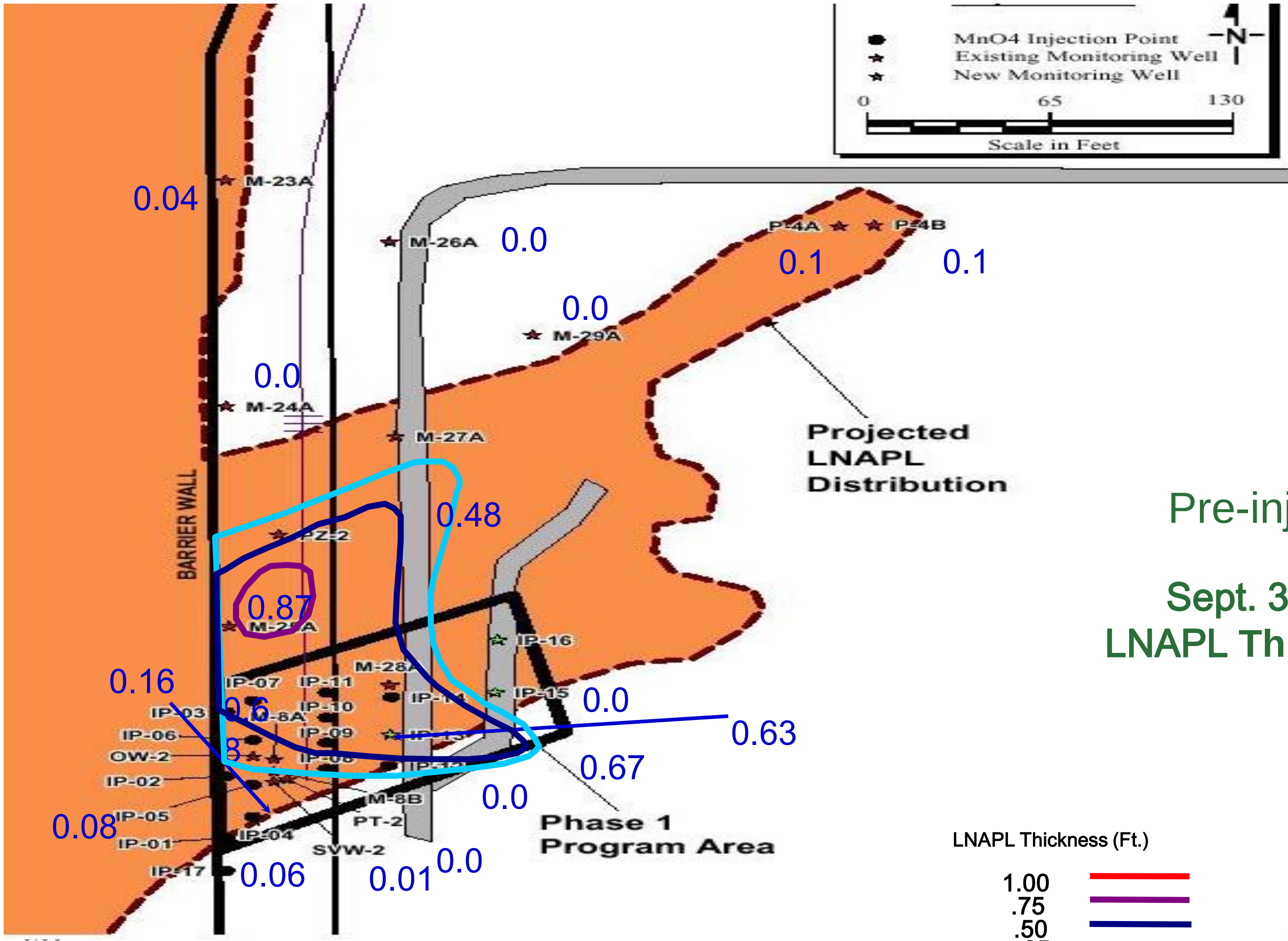
- Saturate w/ISGS reagents
- 20 days reaction time
- Drain
- Run Up-flow Column (DI)
- Compare with Control

Typical Bench Test Results – COIs in Leachate (ca. 7 days treatment time)



First Full-Scale Application - Denver, CO

Pre Injection – NAPL Thickness (ft)



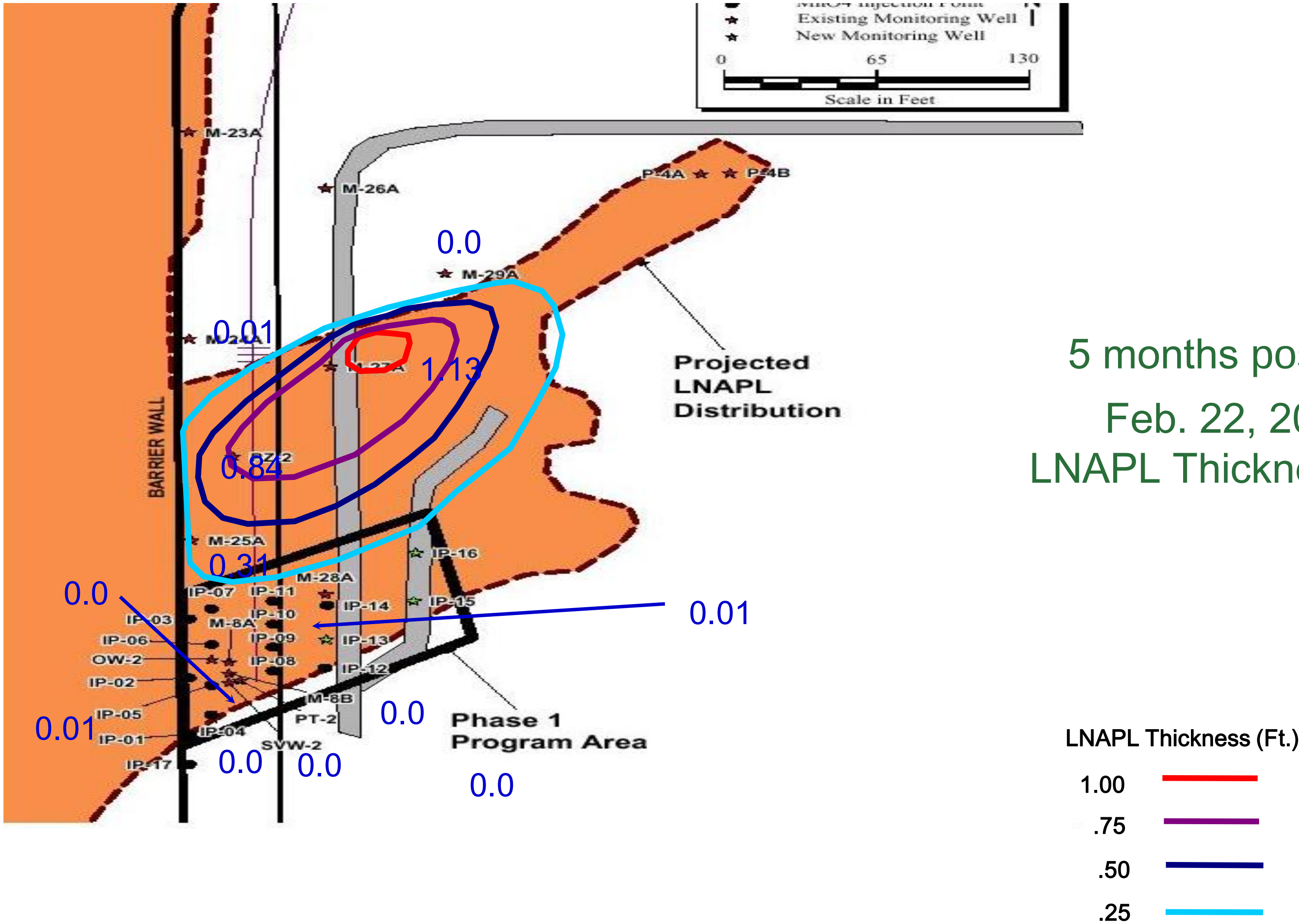
Pre-injection

Sept. 3 2001 –
LNAPL Thickness (Ft)

LNAPL Thickness (Ft.)

1.00
.75
.50
.25

Post Injection – NAPL Thickness (ft)



5 months post-injection

Feb. 22, 2002

LNAPL Thickness (Ft)

Non-Treated Soil 14 ft bgs

ISGS Treated Soil 14 ft bgs

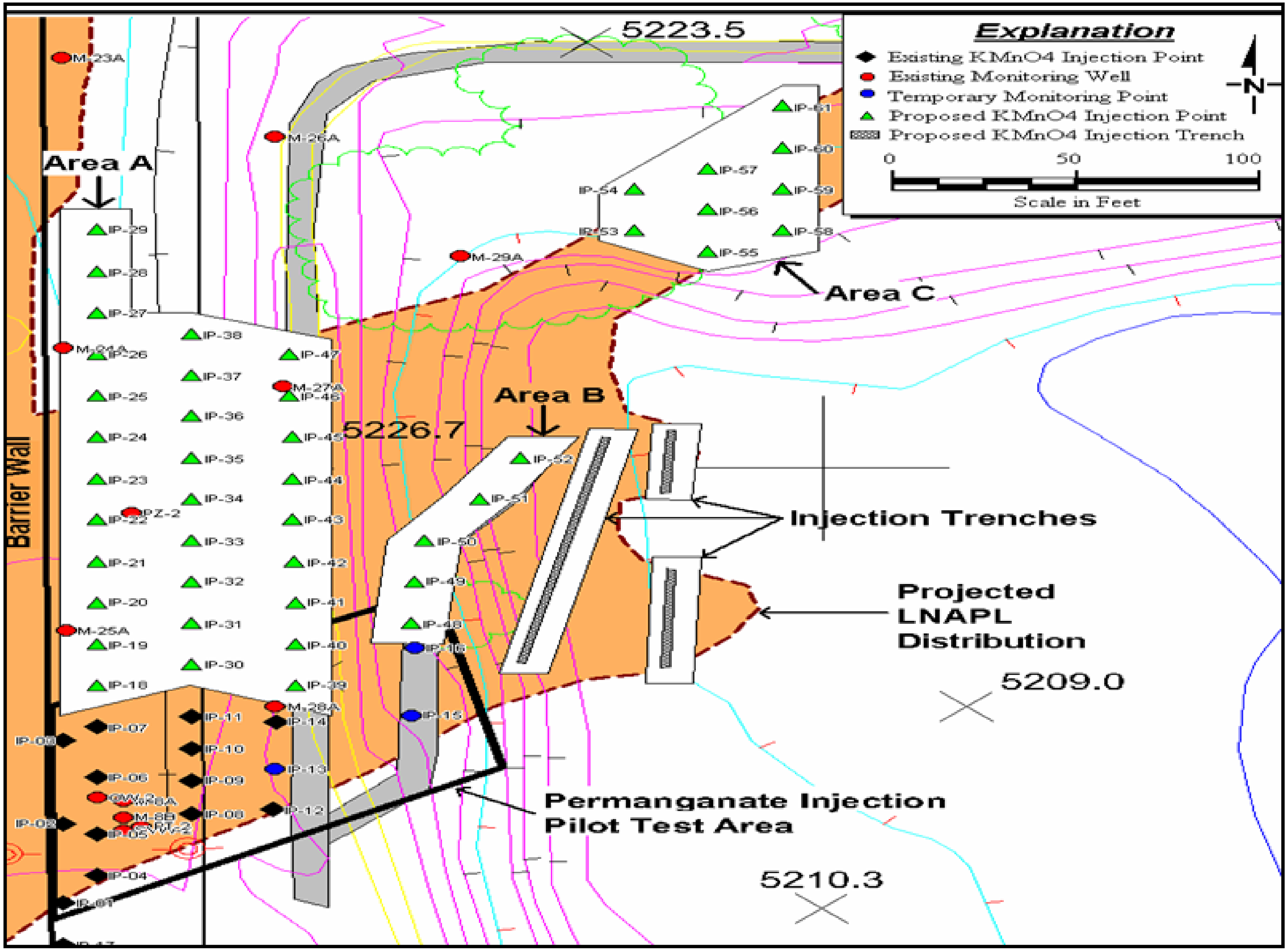
Flux Reduction

The HMW COI were removed at a proportionally higher rate than the LMW compounds.

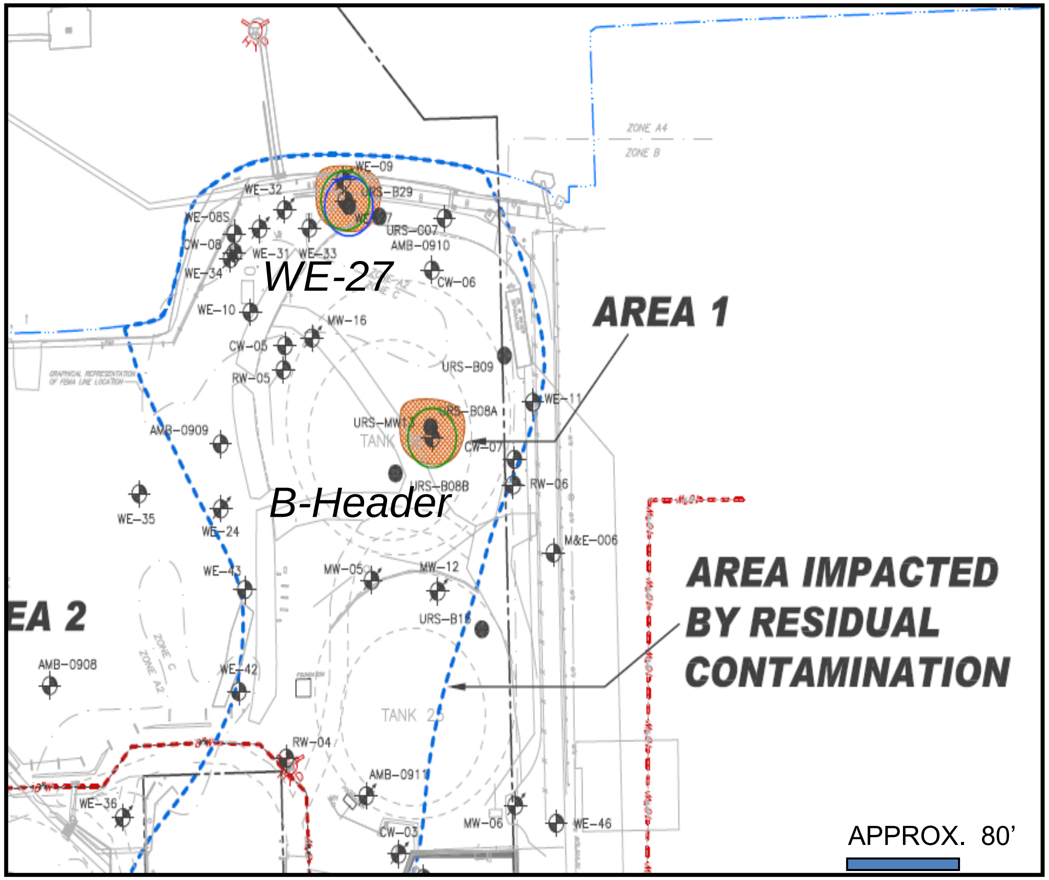
COI (mg/L)	Average Background	Average Treated	% Reduction
LMW PAHS	34.41	12.75	73
HMW PAHs	6.05	0.11	99
TOTAL PAHs	**40.46**	**12.86**	**79**
* PENTA	18.91	9.66	49
*** TOTAL CPs**	**23.38**	**10.41**	**56**

*** Excludes sample IB05A-14 to 14.5 ft bgs (80 v. 8 ppm dissolved phase penta + 296 ppm total penta)**

Phase II ISGS Application (2004)



South Boston Site – Bench Test



<u>2009 LNAPL THICKNESS DATA</u>

WE-27 – 0.07’ AVG (MAX 0.19’)

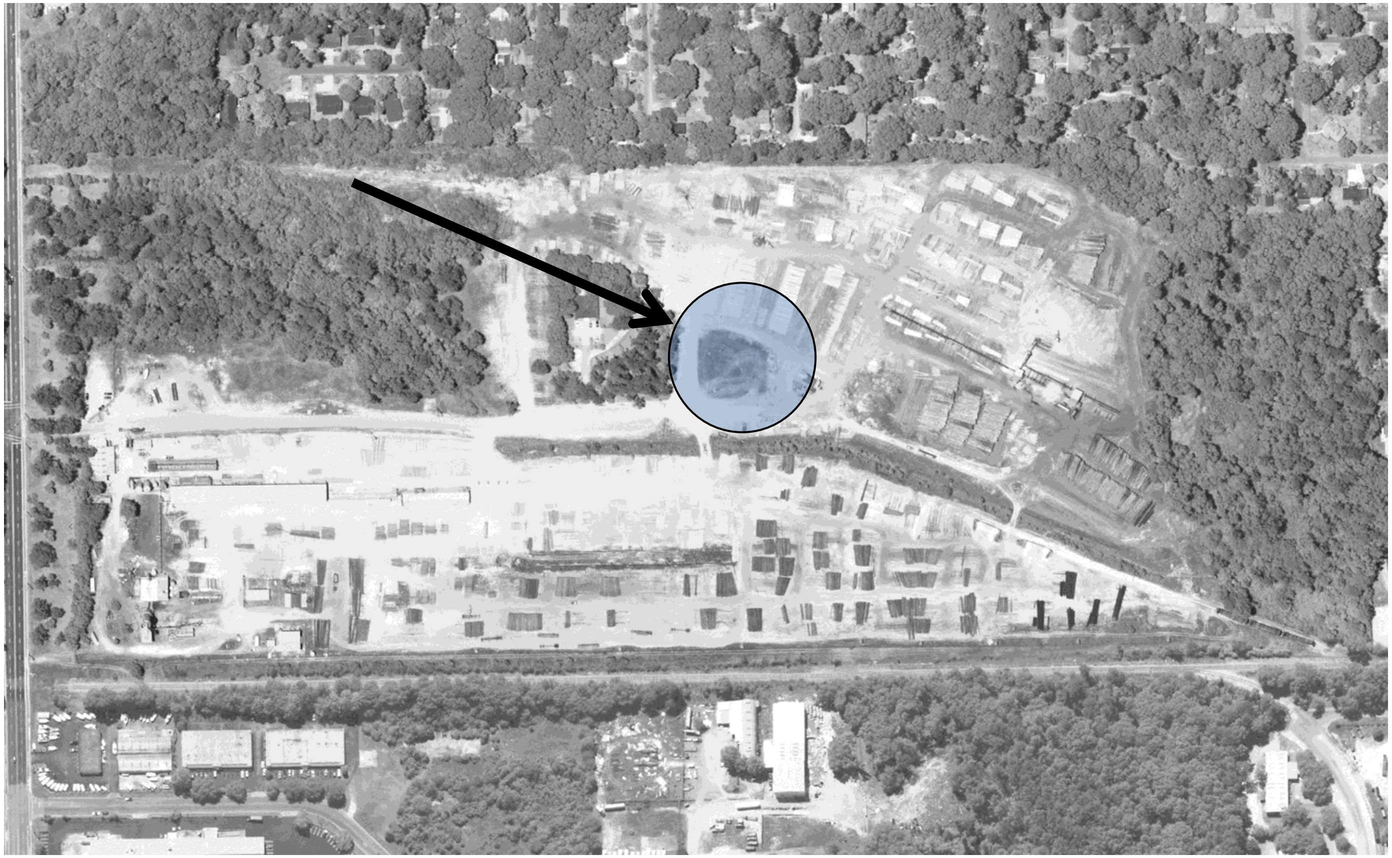
MW13 – 0.04’ AVG (MAX 0.07’)

WE-33 – 0.02’ AVG (MAX 0.07’)

South Boston Bench Test Results

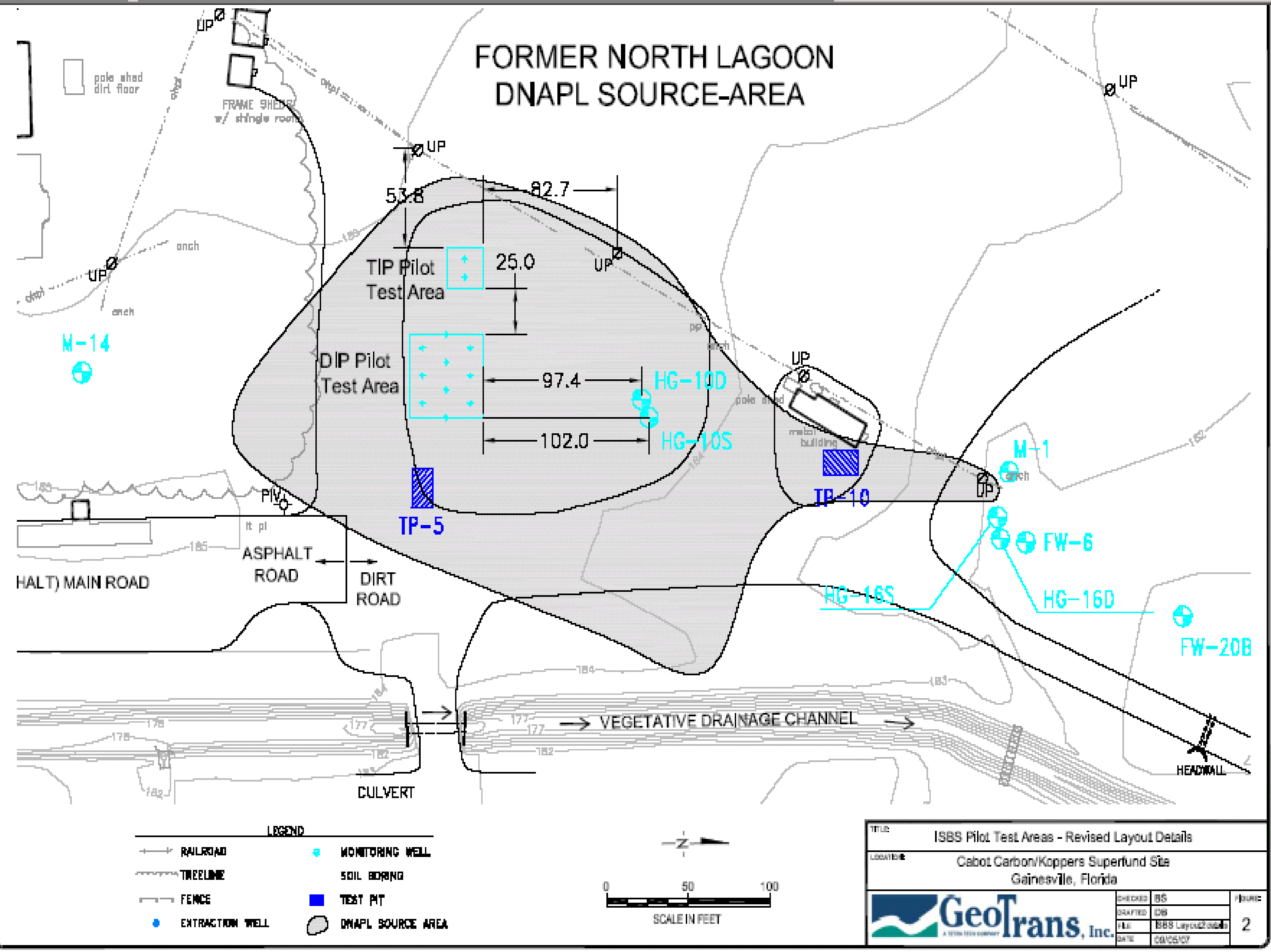
- **Objectives:**
  - Validate ISGS treatment applicability to TPH
  - Identify most cost-effective treatment regime (based on site soil)
- **Method:**
  - batch & column studies
- **Results:**
  - TOD 5 to 8 g/kg (B-Header), 30 to 42 g/kg (WE-27)
  - 60 to 80% reduction in EPH leachate concentrations in 14 days
  - 13 to 30% reduction in EPH soil concentrations in 14 days
  - **44 to 67% reduction in permeability to NAPL** and **17% reduction in NAPL fluid saturation**
  - ISGS was effective for NAPL stabilization for soils and constituents at this site
  - 4.5% ISGS solution was recommended for full-scale

Cabot Carbon / Koppers Superfund Site, Gainesville, FL

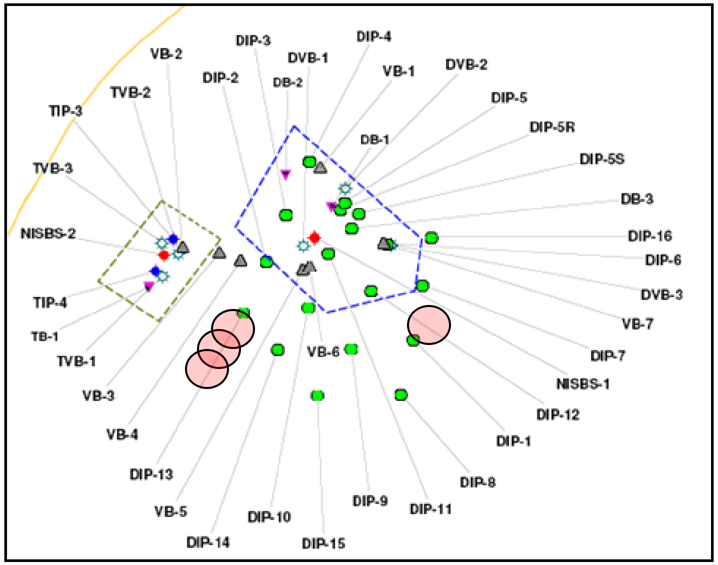


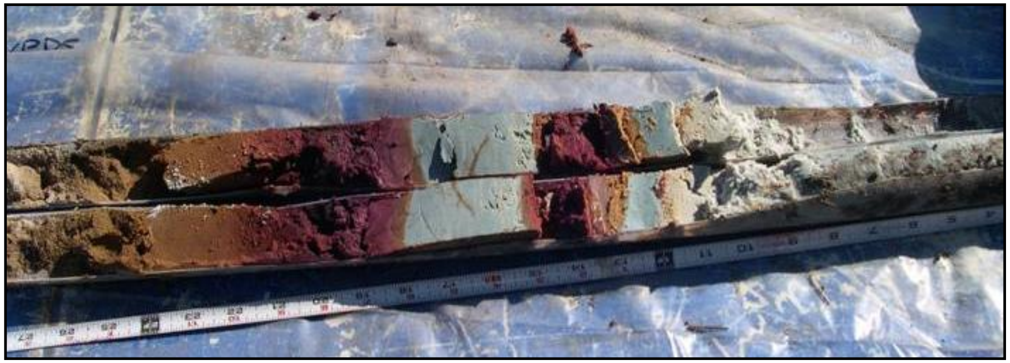
- 90 acre site
- Pump & treat in place
- Secondary NAPL issues

Soil & Groundwater remediation


FORMER NORTH LAGOON
DNAPL SOURCE-AREA
TIP Pilot
Test Area
DIP Pilot
Test Area
53.8
82.7
25.0
97.4
102.0
HG-10D
HG-10S
TP-5
TP-10
M-14
M-1
FW-6
HG-16S
HG-16D
FW-20B
UP
pole shed
dirt floor
FRAME SHED
w/ shingle roof
match building
PIV
HALT) MAIN ROAD
ASPHALT
ROAD
DIRT
ROAD
VEGETATIVE DRAINAGE CHANNEL
CULVERT
HEADWALL
LEGEND
RAILROAD
TREELINE
FENCE
EXTRACTION WELL
MONITORING WELL
SOIL BORING
TEST PIT
DNAPL SOURCE AREA
0
50
100
SCALE IN FEET
TITLE
ISBS Pilot Test Areas - Revised Layout Details
LOCATION
Cabot Carbon/Koppers Superfund Site
Gainesville, Florida
GeoTrans, Inc.
CHECKED BS
DRAFTED DB
FILE
DATE 09/05/07
FIGURE
2

Results - NAPL Monitoring Wells

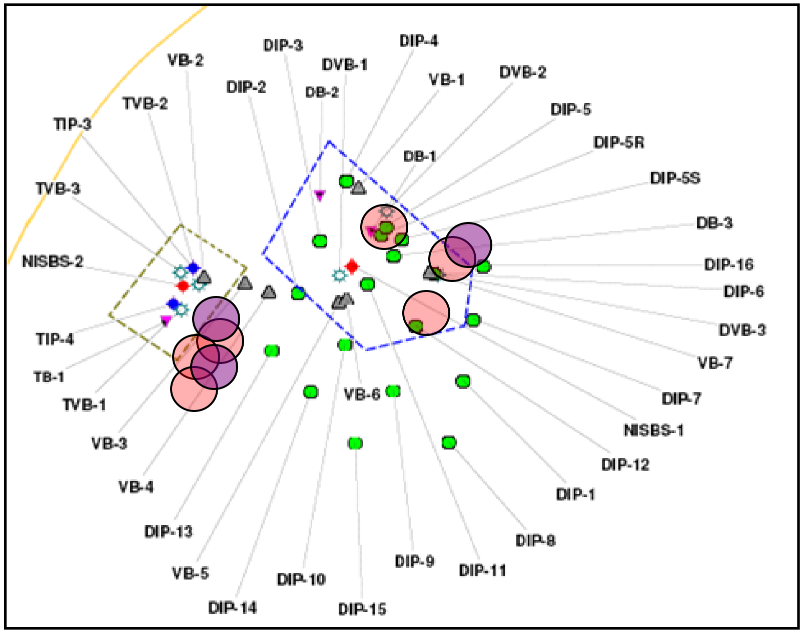




Monitoring Well	Pre-Injection	Post-Injection
NISBS- 1	NAPL	stain
NISBS-2	NAPL	stain
TIP-3	ND	ND
TIP-4	ND	ND
UGH Recovery	NAPL	No NAPL

1 week Post ISGS treatment = no measurable free-phase NAPL in any of the monitoring wells.

Results -Total PAH Concentrations in Soil and in Leachate



6 cores (3 sections) before treatment

6 cores (2 depths) after treatment

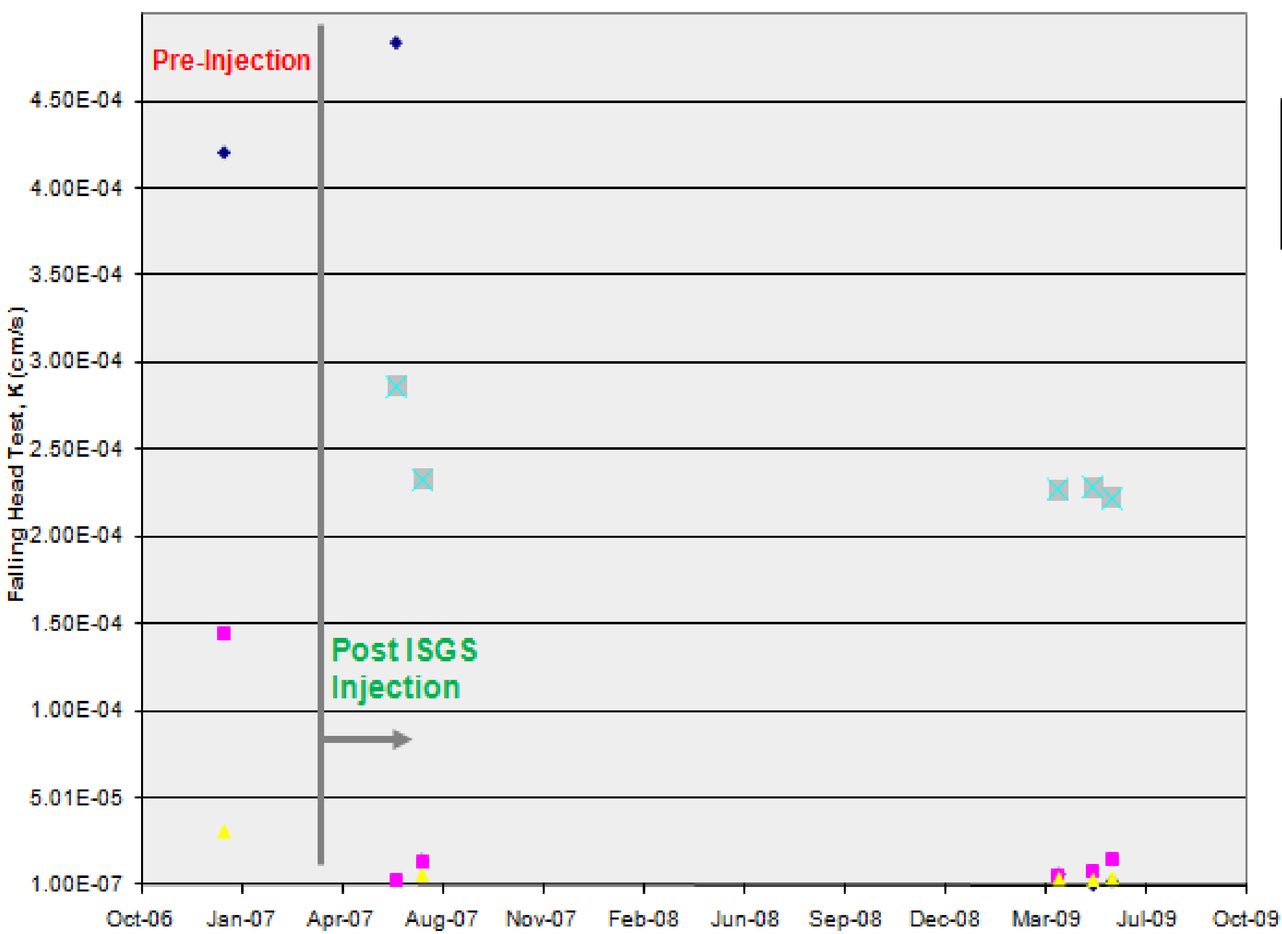
Best matched cores (SOIL):
dropped from 7,250 mg/kg to 3,600 mg/kg

Best matched cores (LEACHATE):
dropped from 11,700 mg/L to 560 mg/L

PAH concentrations in soil reduced by up to 50% within 3 months.

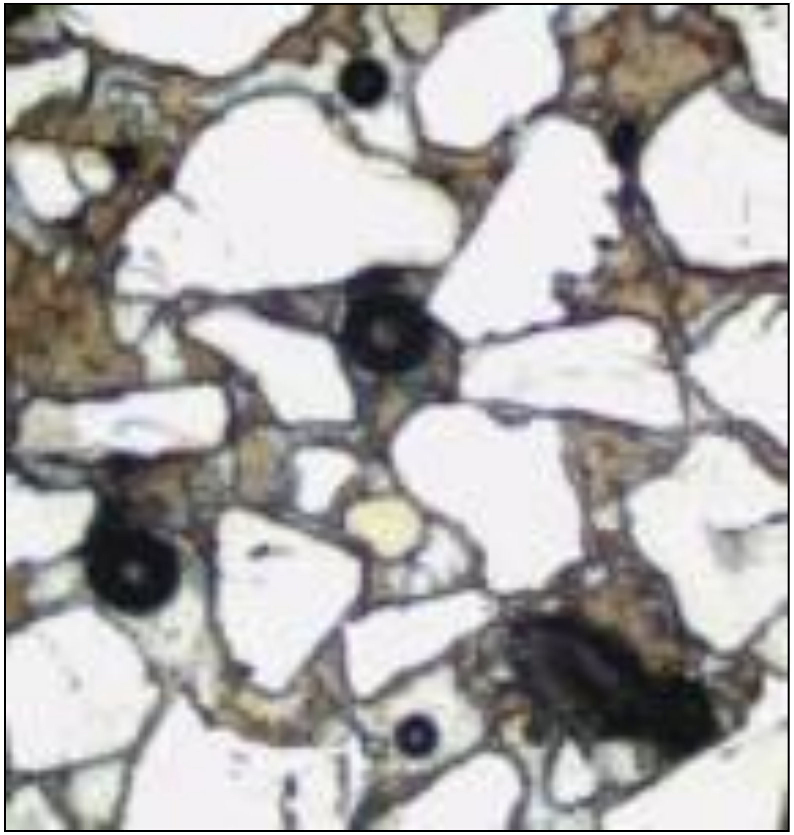
PAH leachate concentrations reduced by up to 98% within 3 months.

ISGS Field Data – Decrease in K_h Values Woodward Coke Site – Dolomite, AL

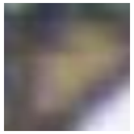


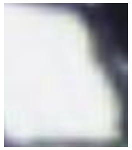
- 2 years post ISGS injection
- 1-2 log decrease in values
- No NAPL in MW

Treated Soil Core Close-up Showing ISGS "Crust" or Coating and NAPL Ganglia




Likely NAPL


ISGS coating


Soil Grain


Epoxy (open pore space)

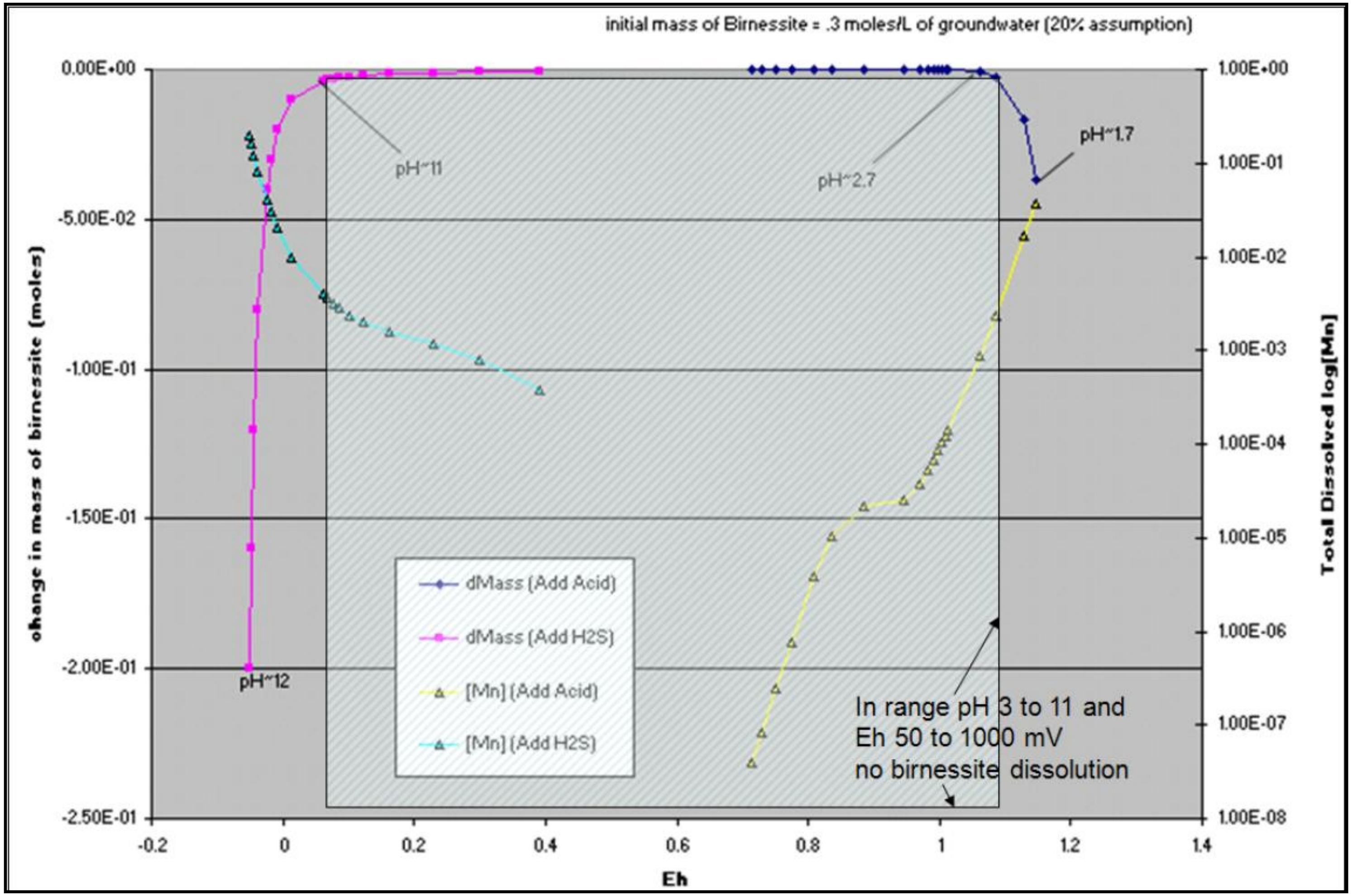
Conclusion: Soil grains and NAPL blobs coated with ISGS crust

Birnessite is an oxide of Mn and Mg along with Na, Ca and K with the composition: (Na,Ca,K)(Mg,Mn)$Mn_6O_{14}.5H_2O$

Regulatory Issues for Full-Scale Applications

- Crust Longevity
  - Crust weathering is dependent on changes in Eh and pH
  - Conduct mineralogy assay
  - Validate using geochemical modeling
- Performance Monitoring
  - Eh, pH for crust stability
  - Permeability tests for flux reduction
  - NAPL fluid saturation

Geochemical Modeling of the Crust



Crust Longevity

- Back of the envelope calculations suggest crust life ~ 400 years.
- This may be over-estimated because it assumes Eh (-400 mV) and pH (6) at which birnessite is sparingly soluble

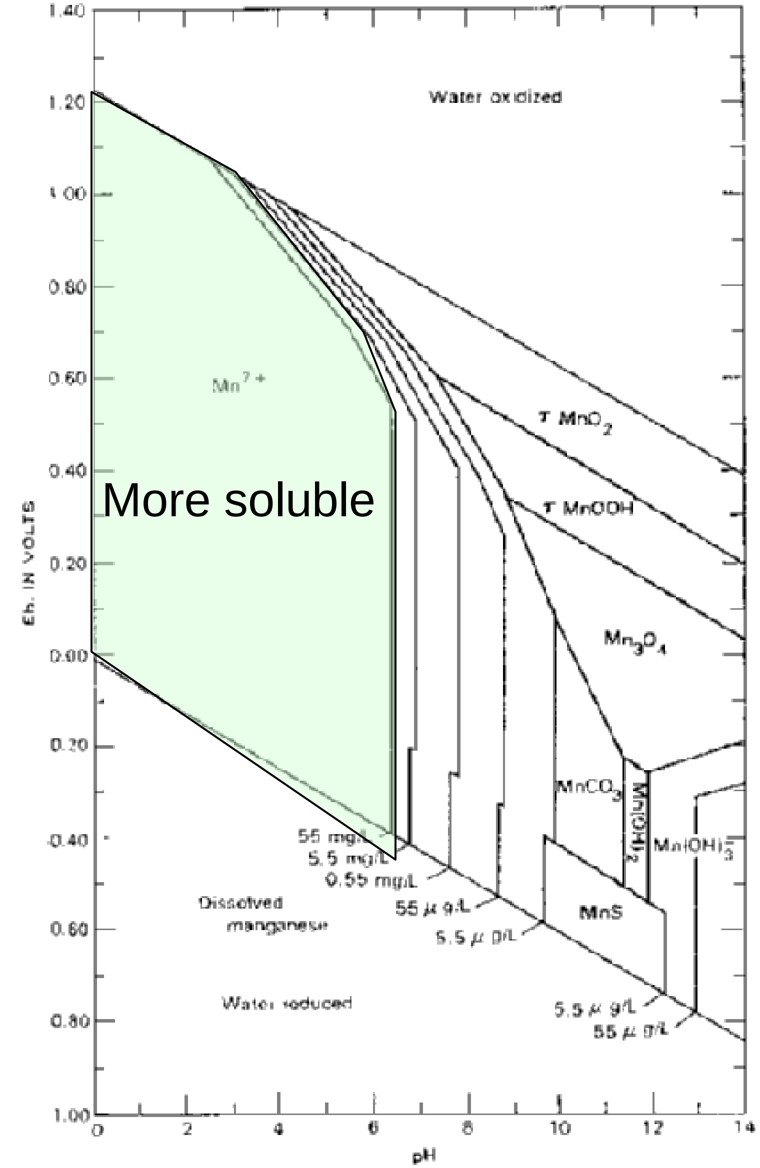


Figure 16. Fields of stability of manganese solids and equilibrium dissolved manganese activity as a function of Eh and pH at 25°C and 1 atmosphere pressure. Activity of sulfur species 96 mg/L as SO_4^{2-}, and carbon dioxide species 61 mg/L as HCO_3^-.

Eh-pH diagram from Hem (1985)

Representative Experience
ISGS – Creosote and Related Sites

Site	COI / Environmental Setting	ISGS Approach / Status
Active Wood Treating Site Superfund Site Denver, CO	Phase separated creosote (PAHs) and pentachlorophenol (penta). Consolidated shallow alluvium.	$KMnO_4$ (no catalysts; no buffer) successful bench and pilot studies completed; full-scale application completed 2004.
(Active) Wood Treating Site Superfund Site Gainesville, FL	Phase separated creosote (PAHs). Sand silt environment, 5 to 22 ft bgs.	$NaMnO_4$ (catalyzed, buffered) completed bench-scale engineering optimization tests; Pilot-scale technology validation performed in January 2008. 2012 Full-scale application recommended as part of the ROD – installation 2013 to 2015.
Former Wood Treating Site Montgomery, AL	Phase separated creosote (PAHs)	Field Scale application completed 2009. One to two orders of magnitude reduction in permeability.
Former Wood Treating Site Cape Fear, NC	Phase separated creosote (PAHs)	Conceptual design completed.
Former American Creosote Works Winnfield, LA	Phase separated creosote (PAHs)	Engineering optimization bench work completed.
Former Wood Treating Site Sand Point, ID	Phase separated creosote (PAHs)	Engineering optimization bench work completed; Field Pilot Completed Q3 2010.
Former Wood Treating Site Netherlands	Phase separated creosote (PAHs)	Engineering optimization bench work completed. Field Pilot pending

ISGS Material Cost – Field Applications

Denver, CO	Dolomite, AL	Gainesville, FL
TOD = 18 g/kg	**TOD = 1 g/kg**	**TOD = 122 g/kg**
Dense Alluvium $KMnO_4$ @ 4.5 g/kg Injection Wells	**Fractured Karst RemOx EC Push-Pull**	**Sand/Silt RemOx EC Direct Push and Injection wells**
1,273 m^3 soil 3% solutions 1,850 USG/IP 2-5 gpm (20 psi)	**1,500 m^3 soil 1% solutions 20,000 USG 13 gpm (20-50 psi)**	**1,415 m^3 soil 4.5 % solutions 620 USG/DIP 2-5 gpm (<50 psi)**
Cost = \$40 - 50/m^3 \$31 - 38/yd^3	**Cost = \$45 - 50/m^3 \$34 -38/yd^3**	**Cost = \$60 - 75/m^3 \$50 -60/yd^3**

The amount of ISGS reagent required for a given site has a significant influence on project cost. Typical **material costs** range from \$13/yd^3 to \$53/yd^3.

Questions?