Kentucky AIPG Spring 2013 Short Course

Cleaning Up the World…

One Site at a Time.

Remedial Design:

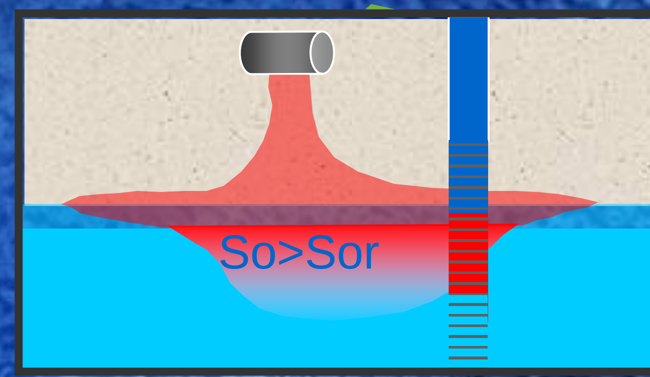
Selection of Solution(s) based on Refined CSM

Agenda

1. Residual LNAPL – What is it?
2. Conceptual Site Model
3. High Resolution Sampling - RDC
4. Remedial Design – Mass Calculations
5. Technology Selection
6. Case Studies

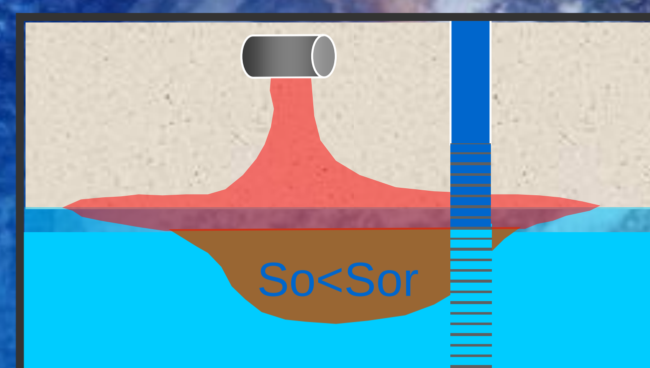
LNAPL Saturation & Residual LNAPL Saturation

LNAPL Saturation (So) > Residual LNAPL Saturation (Sor)

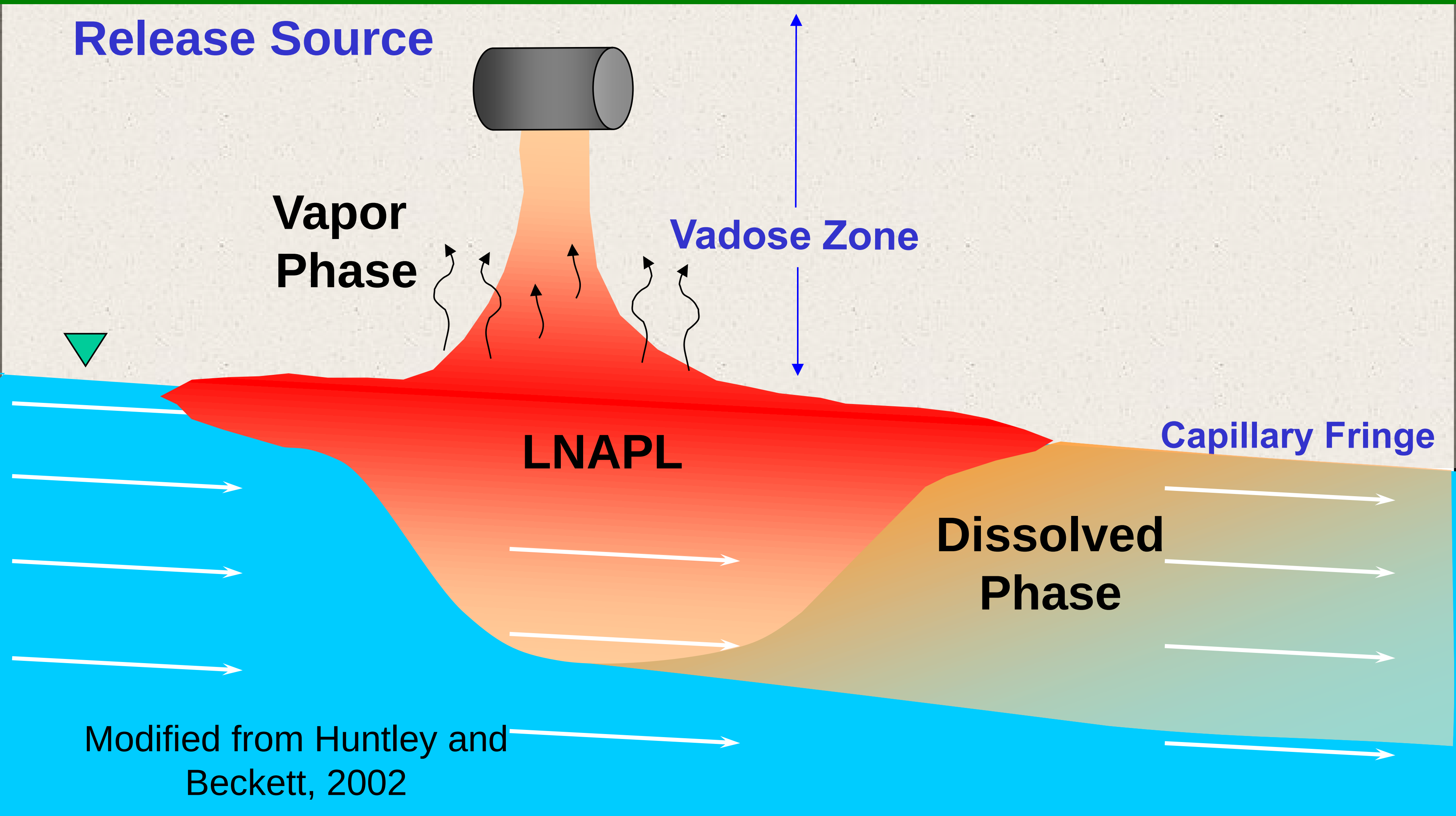


LNAPL Saturation (So) < Residual LNAPL Saturation (Sor)

Sor = LNAPL that will not freely drain from the soil into a monitoring well



Simplified LNAPL Conceptual Site Model for a Gasoline Release to the Subsurface

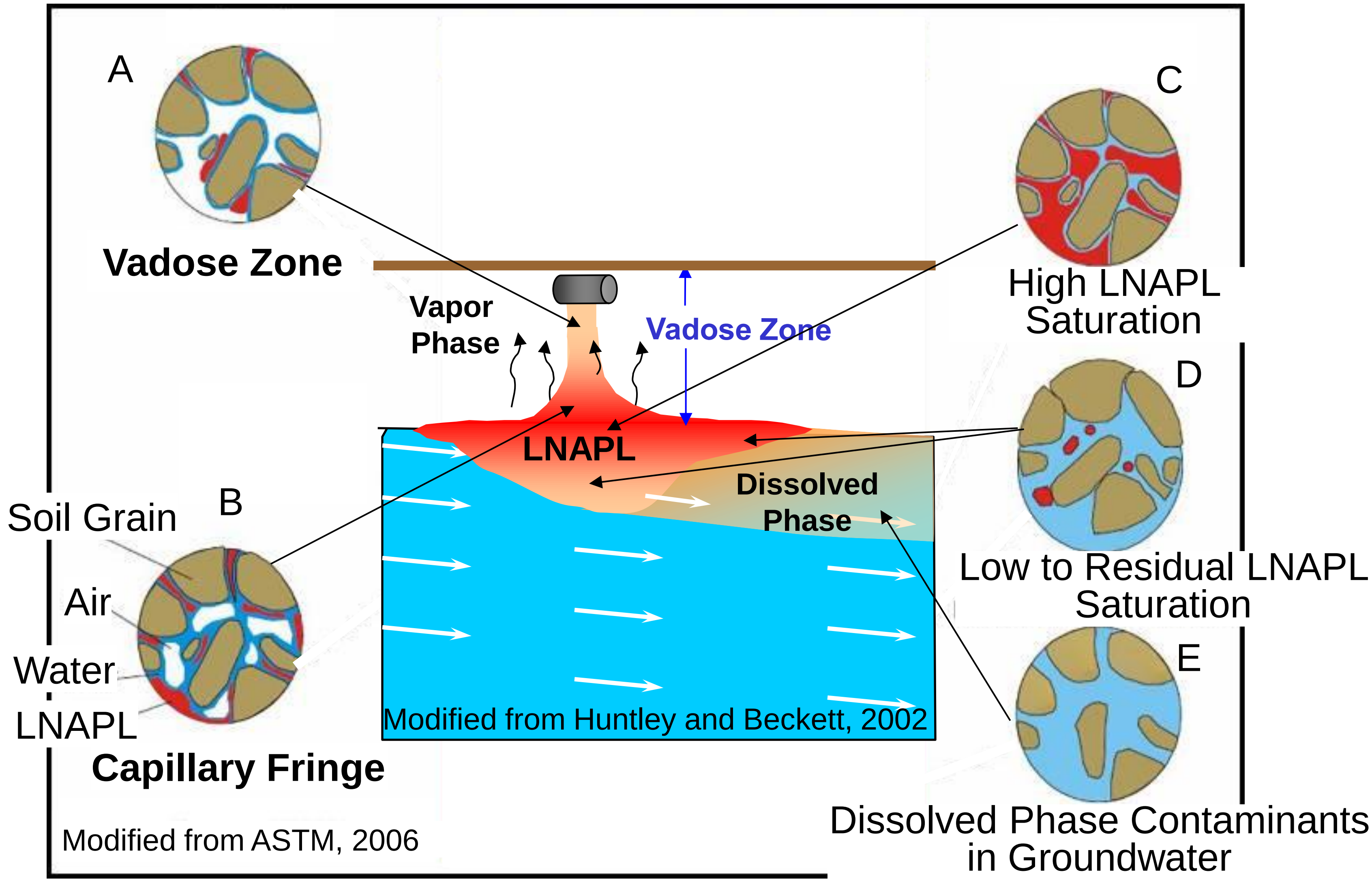


Modified from Huntley and Beckett, 2002

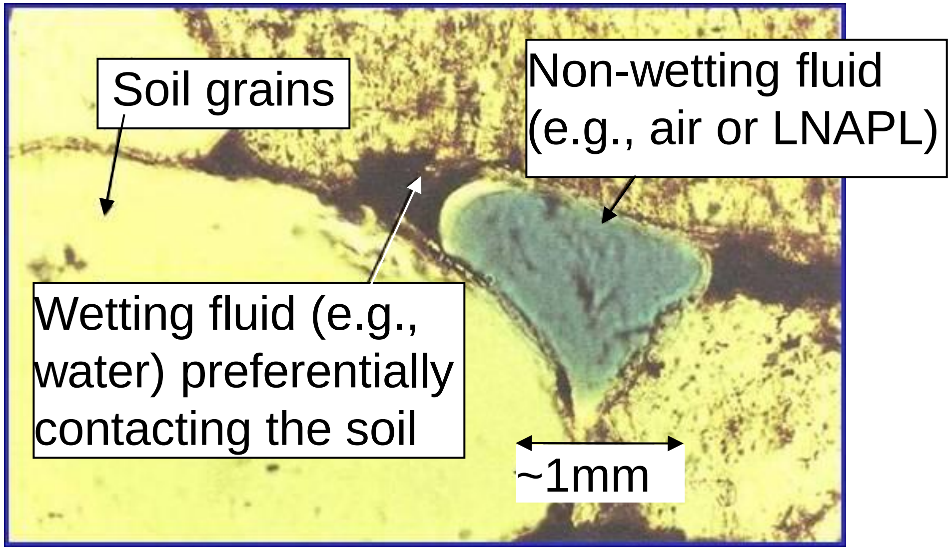
Common (mis) Perceptions about LNAPL

- LNAPL enters the pores just as easily as groundwater
- You can recover all LNAPL
- All the pores in an LNAPL plume are filled with LNAPL
- LNAPL floats on the water table or capillary fringe like a pancake and doesn't penetrate below the water table
- Thickness in the well is exaggerated by a factor or 4, 10, 12, etc.
- LNAPL thickness in a well is always equal to the formation thickness
- If you see LNAPL in a well it is mobile and migrating
- LNAPL plumes spread due to groundwater flow
- LNAPL plumes continue to move over very long time scales

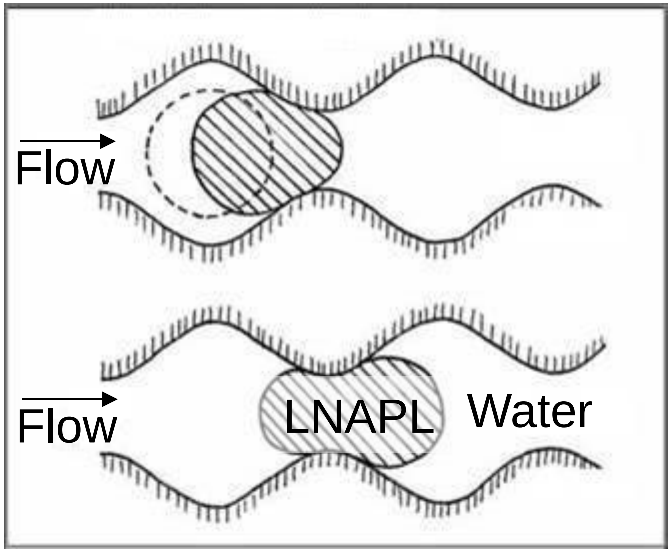
Soil Pore-Scale LNAPL Distribution



"Resistance" to Movement of LNAPL into and Out of Water-saturated Soil Pores



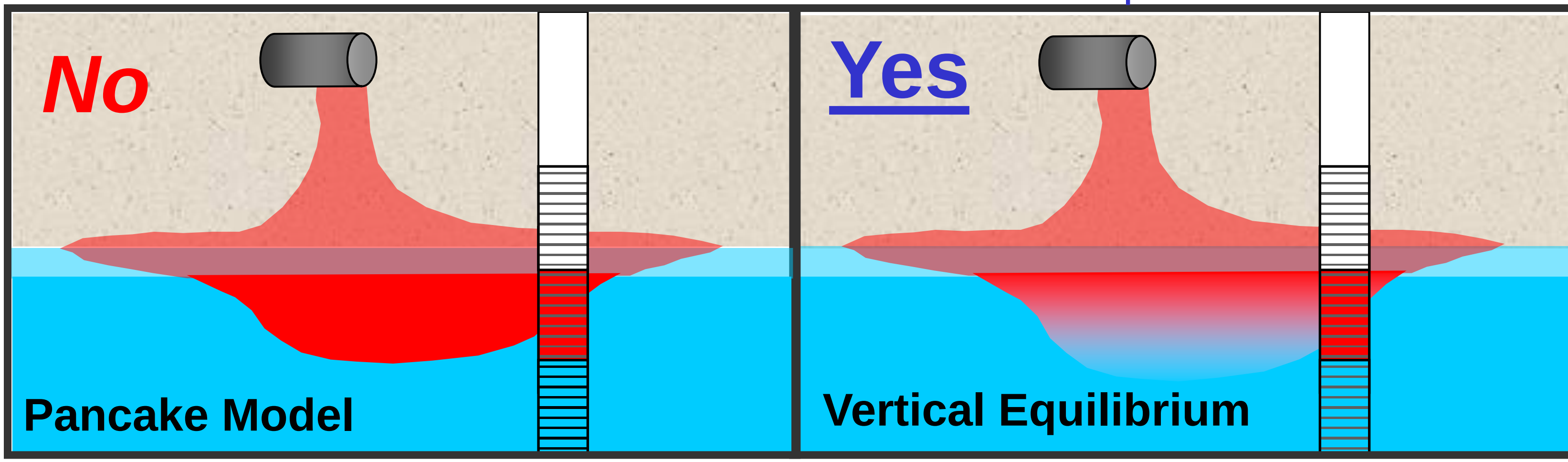
For water wet media



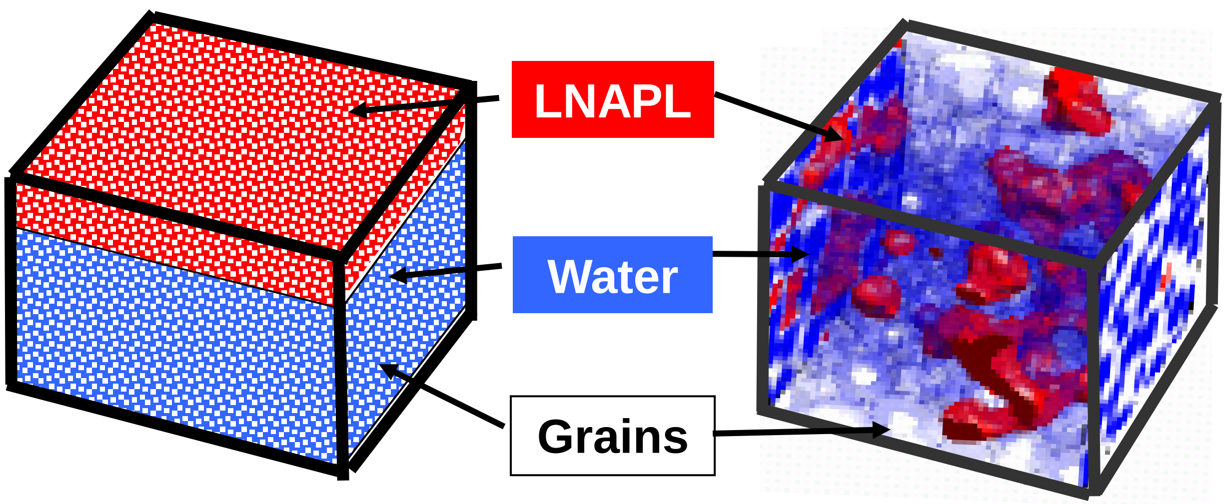
- LNAPL will only move into water-wet pores when entry pressure (resistance) is overcome
  - To distribute vertically and to migrate laterally

Vertical LNAPL Distribution

Pancake Model vs. Vertical Equilibrium Model



- Assumes LNAPL floats on water table
- Uniform LNAPL saturation



- LNAPL penetrates below water table
- LNAPL and water coexist in pores

Macro Pores/Secondary Porosity

- Macropores (fractures, root holes, etc) - low displacement head (hd)
- Very low LNAPL volume in the macropore, but LNAPL potentially would still show up in a well

Conceptual Site Model

Goal/Objective of the CSM**:** ***Develop a three dimensional picture of the contaminant distribution (vertical and horizontal) and how it varies over time at a given site.***

Use of the CSM: ***The anchor for the decision making regarding: 1) additional data needs, 2) risk based closure considerations and/or the remedial approach to achieve site cleanup goals.***

Conceptual Site Model

Status of Mass Released:

- ***Estimate the contaminant mass (i.e. free phase, sorbed phase and dissolved phase).***
- ***Spatial distribution (vertical and horizontal) of the contaminant mass.***
- ***If present, estimate the free phase mass present.***

Remedial Design Characterization (RDC)

1. ***Remedial Design Characterization (RDC):***
   - ***Field Sampling Effort to Fill Data Gaps that are Identified During Conceptual Site Model***
     - ***High Resolution Screening Tools - UVOST***
     - ***Continuous Soil Sampling and Analyses of both Unsaturated and Saturated Soil***
     - ***Collect Discrete Groundwater Samples using Micro Wells (aka Implants)***

UVOST

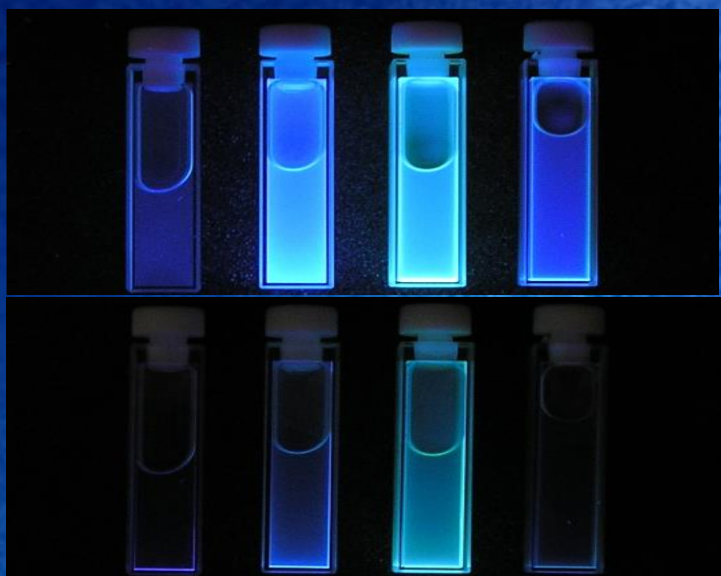
- **Ultra Violet Optical Screening Tool (UVOST)**
  - **Detects PAH fluorescence**
  - **Fuel NAPL where MIP is not preferred (e.g. SVOC, NAPL)**
  - **Best for use where presence of NAPL is driver for investigation**
  - **Cannot see dissolved phase PAHs**

Summary of Detectable Compounds

Reliable	Not as Reliable	Not Recommend
Gasoline	Coal Tar (MGP waste)	Polychlorinated bi-phenyls (PCB)s – due to internal heavy atom effect
Diesel	Creosote, Pentachlorophenol (wood treating)	Chlorinated solvent DNAPL
Jet (Kerosene)	Bunker	Dissolved phase PAHs
Motor Oil		
Cutting Fluids		
Hydraulic Fluid		
Crude oil		
Fuel oils		

UVOST

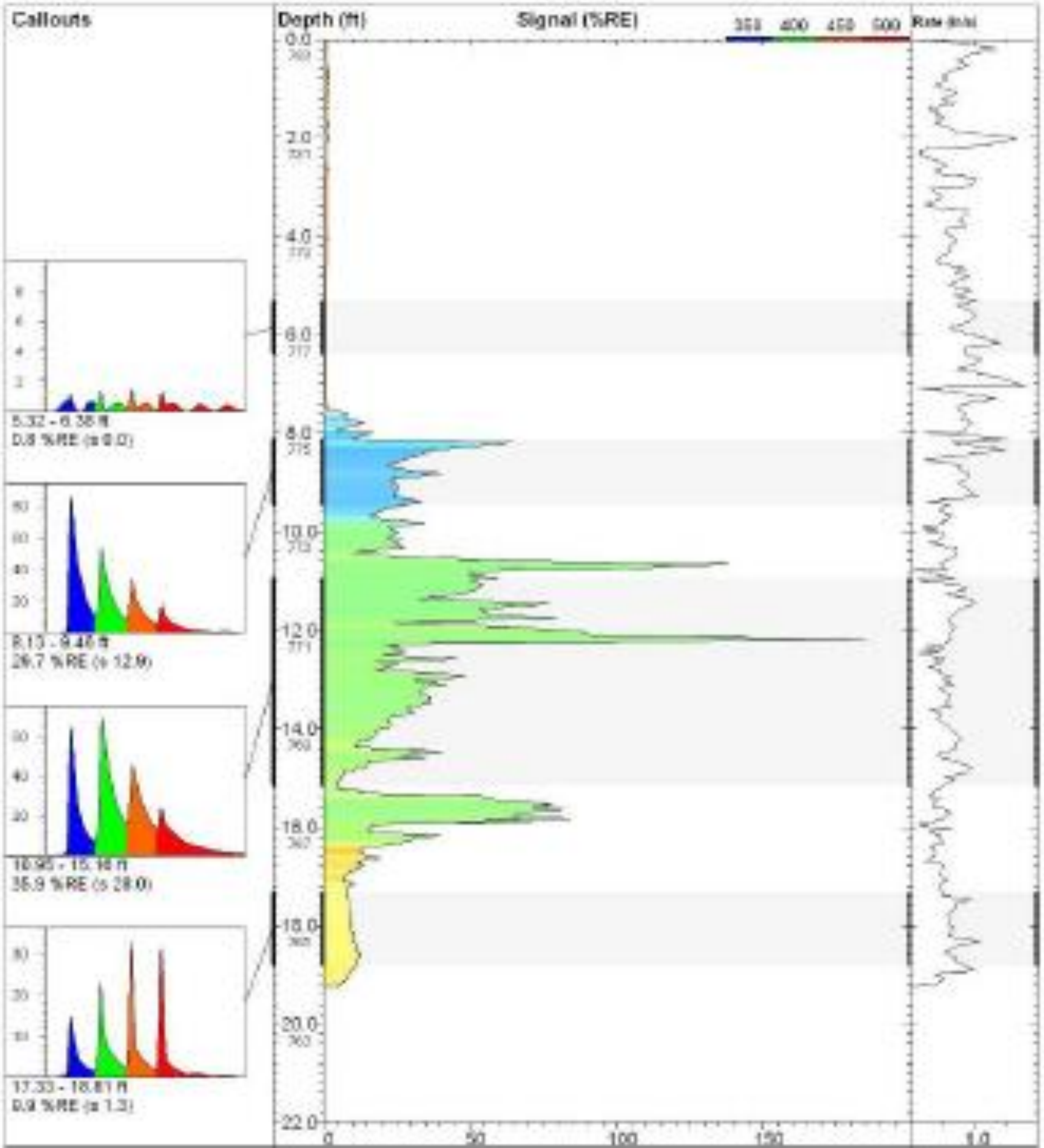
kerosene gasoline diesel oil



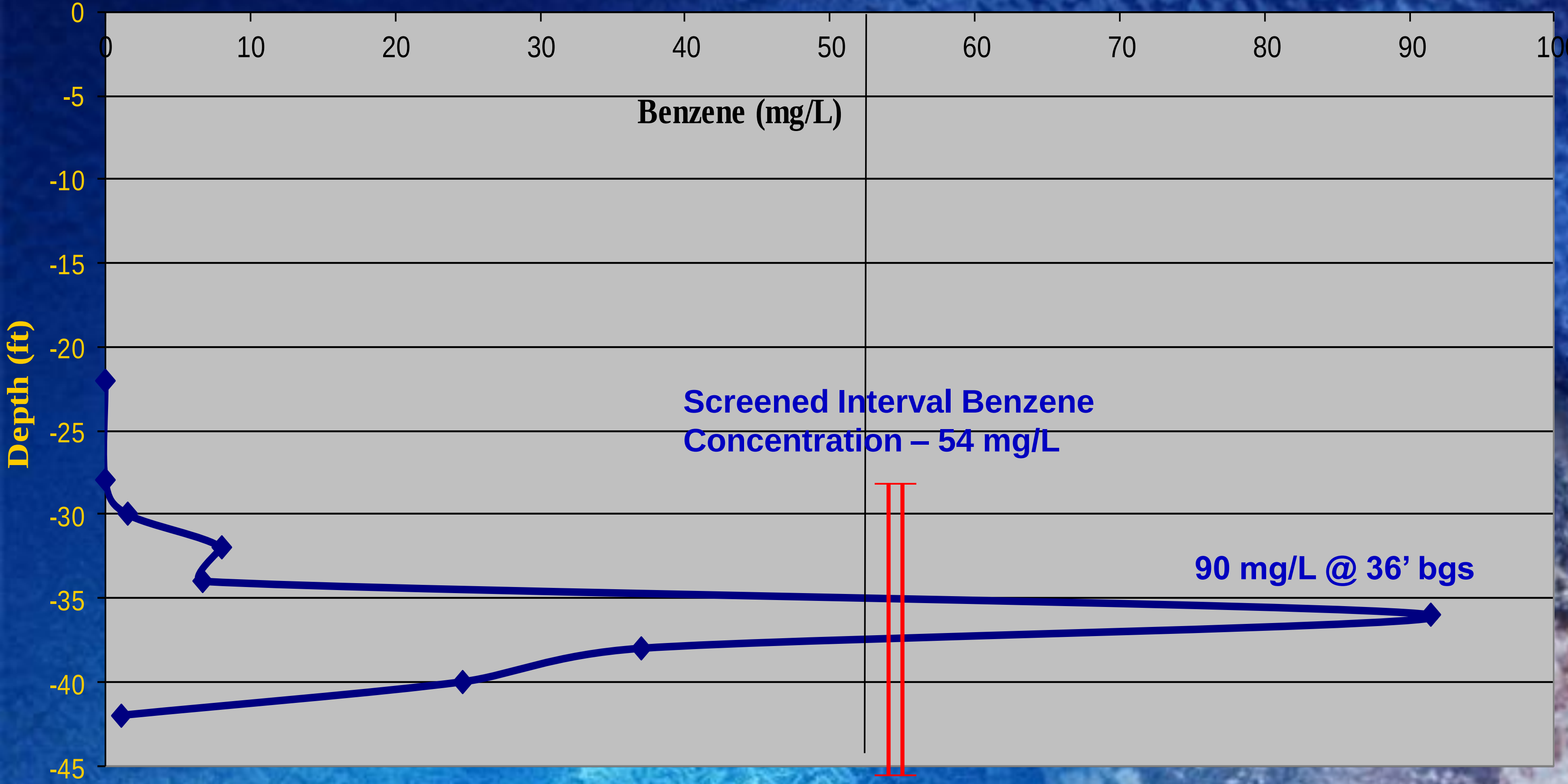
long UV

short UV

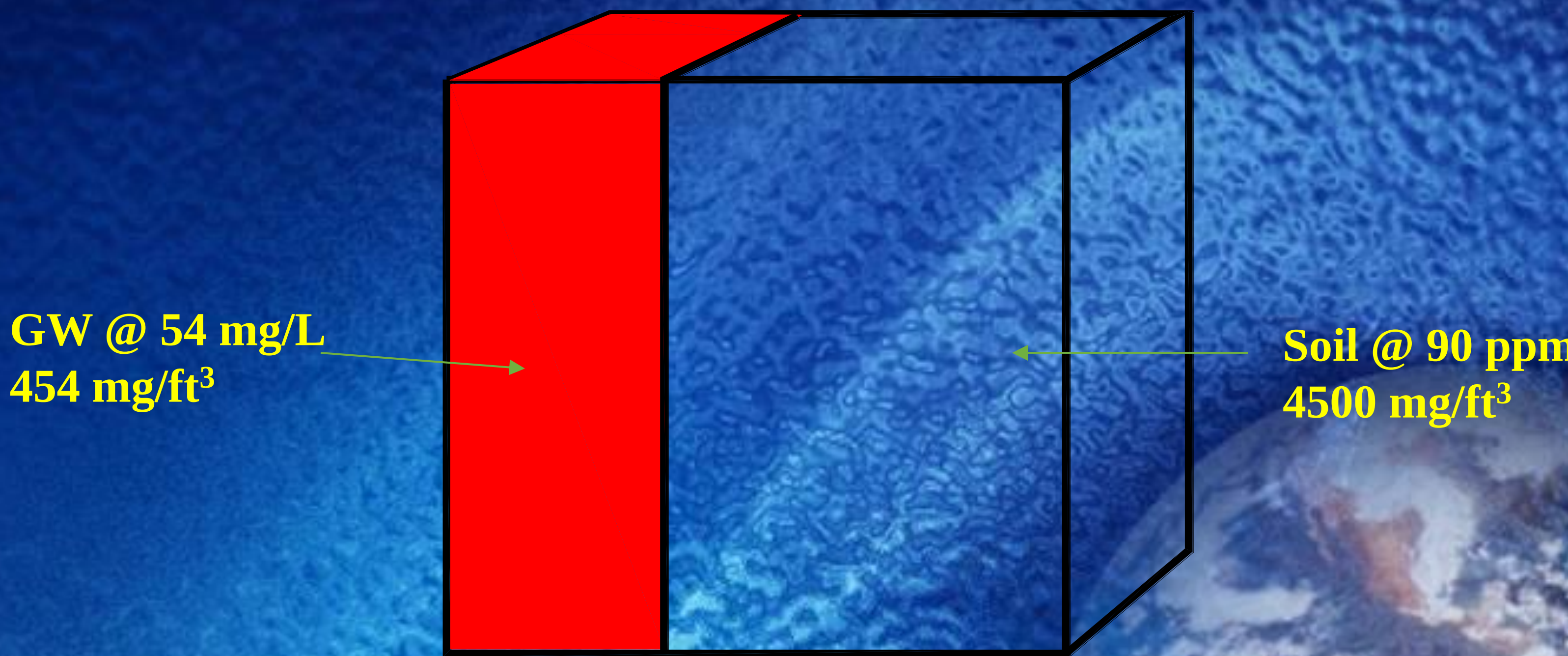
- **All PAH NAPLs Fluoresce**
- **PAH fluorescence is a way to detect them by their “glow”**


Callouts
Depth (ft)
Signal (%RE)
8.13 - 9.48 ft
26.7 %RE (± 12.8)
10.95 - 15.16 ft
35.9 %RE (± 28.0)
17.33 - 18.81 ft
8.9 %RE (± 1.3)

Benzene (mg/L) in Groundwater as a Function of Depth



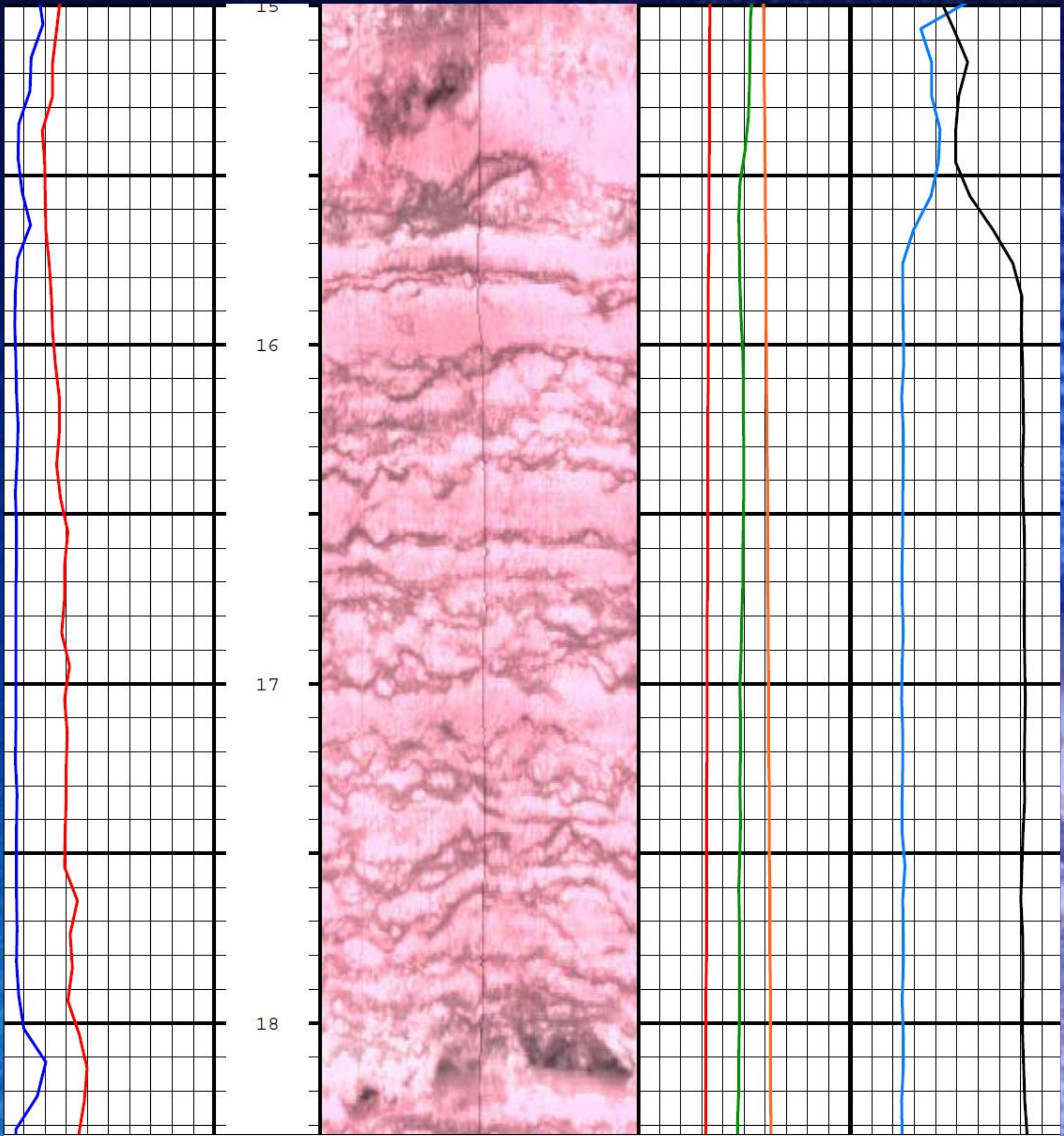
Why Saturated Soil Contamination Is Important



In Saturated Conditions: The Soil Contains as much as 10 times the Contaminant Mass As Does The Groundwater

RPI Group

Moisture Content	PID (ppm)	TCE Result (ug/kg)	Sample Interval (m)	Depth (m)	Recovery (m)	Soil/Rock Type
	1		10.89 - 10.95			CL
	ND	97		11.08		
WET	1		11.2 - 11.26			ML
	333	428		11.4		
	9	53,760	11.54 - 11.6		1.5	CL
	9,999+	25,477,000	11.66 - 11.72	11.7		ML
	390	915,300	11.78 - 11.85			
MOIST	124			12		CL
	4	193	12.12 - 12.19			
	9			12.3		ML


15
16
17
18

So what do you do with all the Data…

Calculate the Loadings (lb/ft^3)

- ***Use Refined Site Model to Determine Contaminant Loadings (lb/ft^3) throughout the Site.***
- ***Remedial Technology Evaluation***
- ***Design the Remedial Insitu System based on the Contaminant Loadings***

Remedial Technology Evaluations

Technology Description	Development Status	Treatment Train	O&M	Capital	System Reliability/ Maintainability	Relative Cost	Time
Groundwater Extraction & Exsitu Treatment	●	⊞	○	○	⊞	○	○
Air Sparging	●	⊞	⊞	⊞	⊞	⊞	⊞
In well air stripping	⊞	⊞	○	○	⊞	⊞	○
Insitu - Chemical Oxidation	●	●	⊞	⊞	⊞	⊞	●
Insitu – Enhanced Bioremediation	●	●	⊞	●	⊞	⊞	○
Insitu - Rapid Remediation Compounds (BOS 200®	●	●	●	●	●	⊞	●
Dual phase extraction	●	○	○	○	⊞	⊞	⊞

● Above average
⊞ Average
○ Below Average

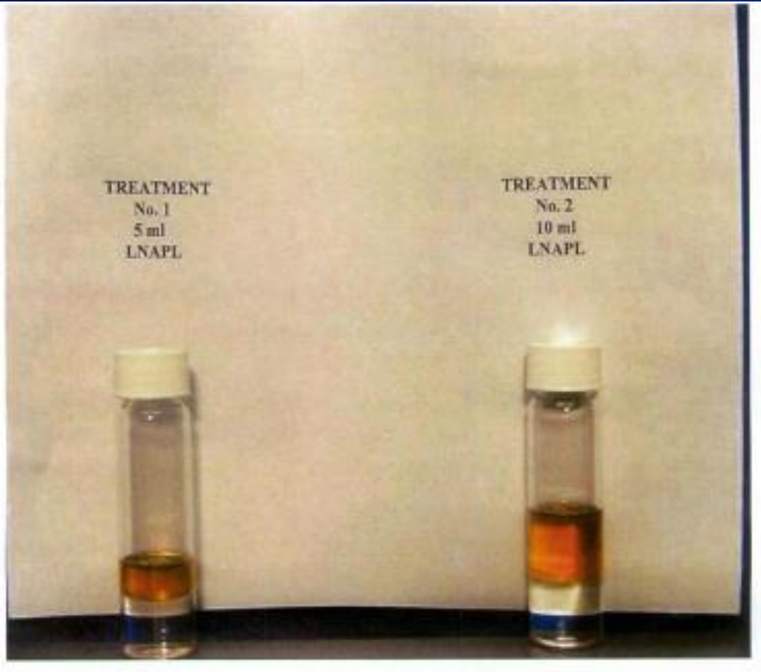
Project Summary - Iowa City Terminal
Coralville, Iowa USA

BOS 200® for Treatment of Petroleum LNAPL

Iowa City Terminal Background

- Coralville, Iowa
- 66-acre refined products terminal
- Iowa Department of Natural Resources (IDNR)
- Investigations and Remediation – 1991
- LNAPL and dissolved phase petroleum hydrocarbons in five monitoring
- Silt and Clay with discontinuous sand stringers
- 1997 RPI Contacted to Complete Remedial Efforts on-site

Bench Adsorption Test



- ***Vial No. 1 – 5 ml LNAPL, 10 ml. reagent, 5 grams carbon***
- ***Vial No. 2 – 10 ml LNAPL, 10 ml. reagent, 5 grams carbon***

- ***Vial No. 1 – No visible LNAPL, Capacity - Greater than 80% wt***
- ***Vial No. 2 – 9 mm LNAPL remaining (59% LNAPL adsorbed), Capacity -~94% wt.***

Full Scale Design

- *Impacted Wells: MW-23, EP-01B, EP-26, EP-27, MW-47D (0.1 to 1 foot of free product)*
- *Silt and Clay with discontinuous sand stringers*
- *Remedial Goals: Remove LNAPL and Achieve Dissolved Phase Standards*
- *BOS 200® Loadings in Impacted Saturated Zone averaged 0.81 lbs/ft^3 – loadings varied with depth*
- *Targeted Injection Area – ~500 s.f. around each well, injection zone varied for each area from 13 to 33 feet bgs*
- *65 injection points, 585 injections, 24,750 lbs BOS 200® ~50 gallons of concentrated bacteria*

Installation

- December 10, 2007
- Top Down Injection through Direct Push Rods
- Positive Displacement Diaphragm Pump (1,200 psi at 35 gpm)
- Injection Pressure varied from 200 to 400 psi
- Pressure Injection (fracturing and soil lifting in silts)
- Radial mixing in sands

Installation

EP-1B Close up of 22'bgs.

PHOTO #1

EP-1B Cross-section from 26-30' bgs. Deeper to top.

PHOTO #2

Pre- and Post-Injection Results Summary

September 2008, IDNR issued a "No Further Action" for LNAPL and Dissolved Phase

Well ID	Post-Injection Total TEX (ug/L)	LNAPL (ft) Pre-Injection	LNAPL (ft) Pre-Injection	Notes
EP-01B	36	>0.2	Non-Detect	MW-2A and MW-46D in the same area as EP-01B had >0.2 ft of LNAPL prior to the injection
EP-26	ND	>0.02	Non-Detect	
EP-27	ND	>0.2	Non-Detect	MW-20 and EP-23 in the same area as EP-27 had >0.2 ft of LNAPL prior to the injection effort
MW-23	2500 ug/l within 4-months, 6-months <100 ug/L	>0.2	0.03 within 4-months, Non-Detect 6-months later	EP-29 in the same area as MW-23 had >0.2 ft of LNAPL prior to the injection effort
MW-47D	No Data Provided by the Consultant	>0.2	Non-Detect	LNAPL varied from 0.1 to 0.5 ft (within the previous 6 months prior to the injection)

Project Summary – Active Petroleum Facility, <u>Copenhagen, Denmark</u>

BOS 200® for Treatment of Petroleum LNAPL

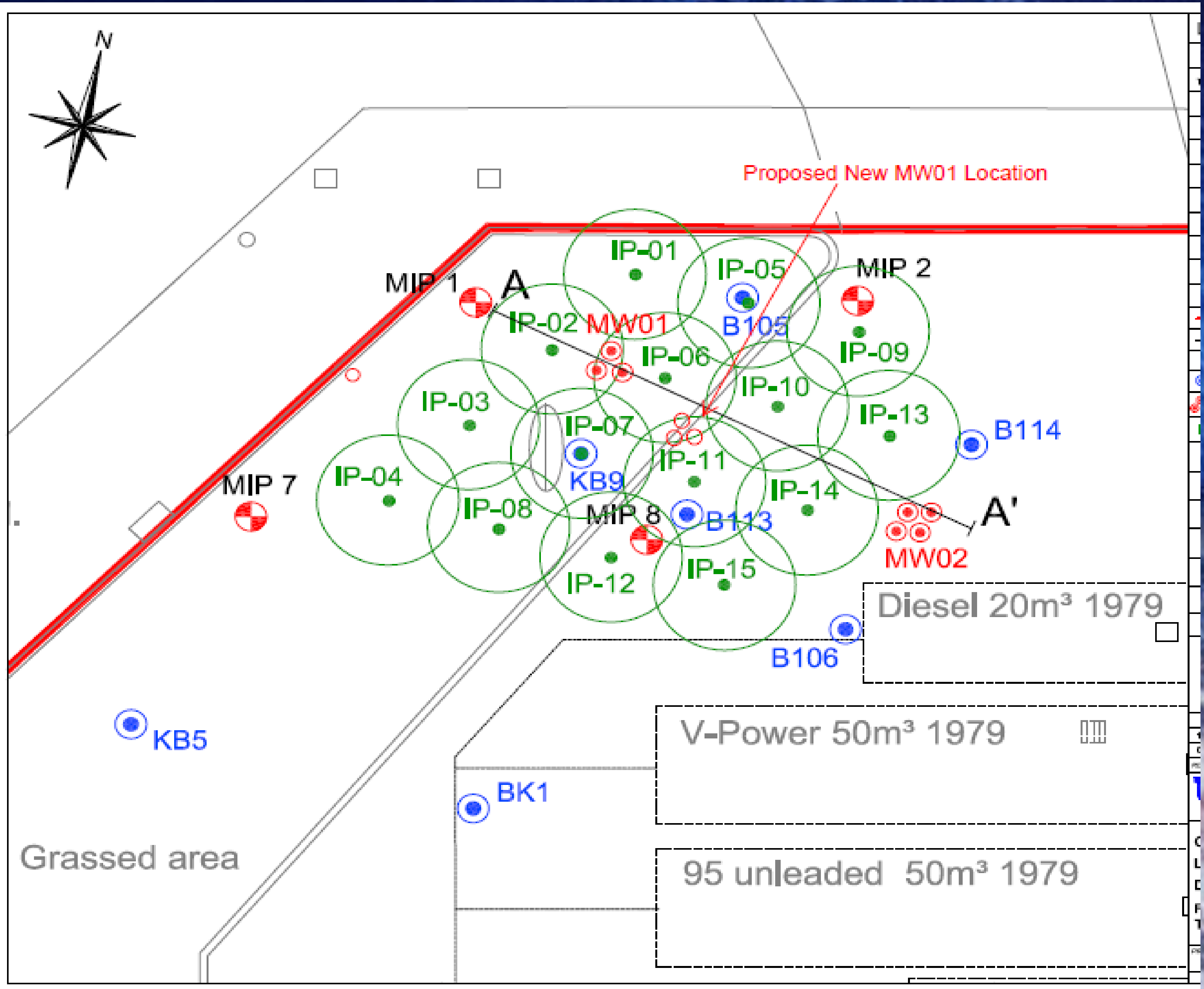
Shell Copenhagen – Active Retail Facility

- *Brondby, Denmark*
- *Most Active Retail Facility in all of Denmark*
- *Investigations and Remediation – 1996*
- *Active Pump and Treatment and SVE System*
- *LNAPL in 5 five monitoring and dissolved phase Benzene concentrations as high as 70,000 ug/l*
- *Boulder Clay*
- *2011 RPI Contacted to Remediate LNAPL*

Remedial Design Characterization

- Install monitoring well cluster consisting of three wells screened at varying depths and one bedrock well
- 4 MIP direct push profiles carried out in and near the LNAPL area to approx. 42 ftbgl (refusal).
- 4 soil borings with samples collected every 2 feet in depth.
- Samples analyzed by RPI in Golden, Colorado .
- Soil concentrations as high as 8,500 mg/kg TVPH

Injection Point Layout



Full Scale Design

- LNAPL Wells: B113, B105, B106, MW-03, MW-01C (0.1 to 1.5 feet of free product)
- Remedial Goals: Remove LNAPL and Achieve 80 % in Benzene Dissolved Phase Concentrations in Groundwater
- Targeted Injection Area – ~850 s.f.
- Vertical Injection zone from 19 to 42 feet bgs
- Pre-clearance of all injection points to 5 feet using air-knife
- 15 injection points, 173 injections, ~9,000 lbs BOS 200® ~20 gallons of concentrated bacteria

Post-Injection Results Summary

- ***LNAPL removed from all wells, except 0.5 inches observed in MW-01C during last event (as much as ~5 feet in MW-01C during injection)***

- ***Achieve from 50% to 90 % reduction Dissolved Phase Benzene Concentrations in Groundwater***

- ***Biological Treatment demonstrated through anion monitoring (nitrate and sulfate consumption)***

- ***BOS 200® planned for site wide dissolved phase groundwater remediation Summer 2013***