Surfactant Enhanced Extraction (SEE) at LNAPL and DNAPL Impacted Sites. Pilot To Full Scale Applications.

REMTECH
Remediation Technology Symposium
Virtual Conference
October 14-15, 2020

IVEY-SOL®
Surfactant Technology
"TODAY'S ENVIRONMENTAL SOLUTIONS FOR A BETTER TOMORROW"

remediation technologies symposium

Ivey
www.iveyinternational.com

Our Products Are Free of Unwanted Impurities

PFOA & PFOS Free

1,4 Dioxane Free

Dioxins, Furans, and PCB Free

Tested and Free For USEPA Regulated Compounds

NAPL LNAPL DNAPL PSH Free Product

Non-aqueous phase liquids (NAPL) are liquid solution contaminants that do not dissolve in or easily mix with water (hydrophobic), like oil, gasoline and petroleum products, chlorinated solvents. NAPL contaminates soil, groundwater, and can generate vapor intrusion.

Light NAPL [LNAPL] have a lower density than water so they will tend to float on the groundwater table.

Dense NAPL [DNAPL] are denser than water so will tend to sink below groundwater table.

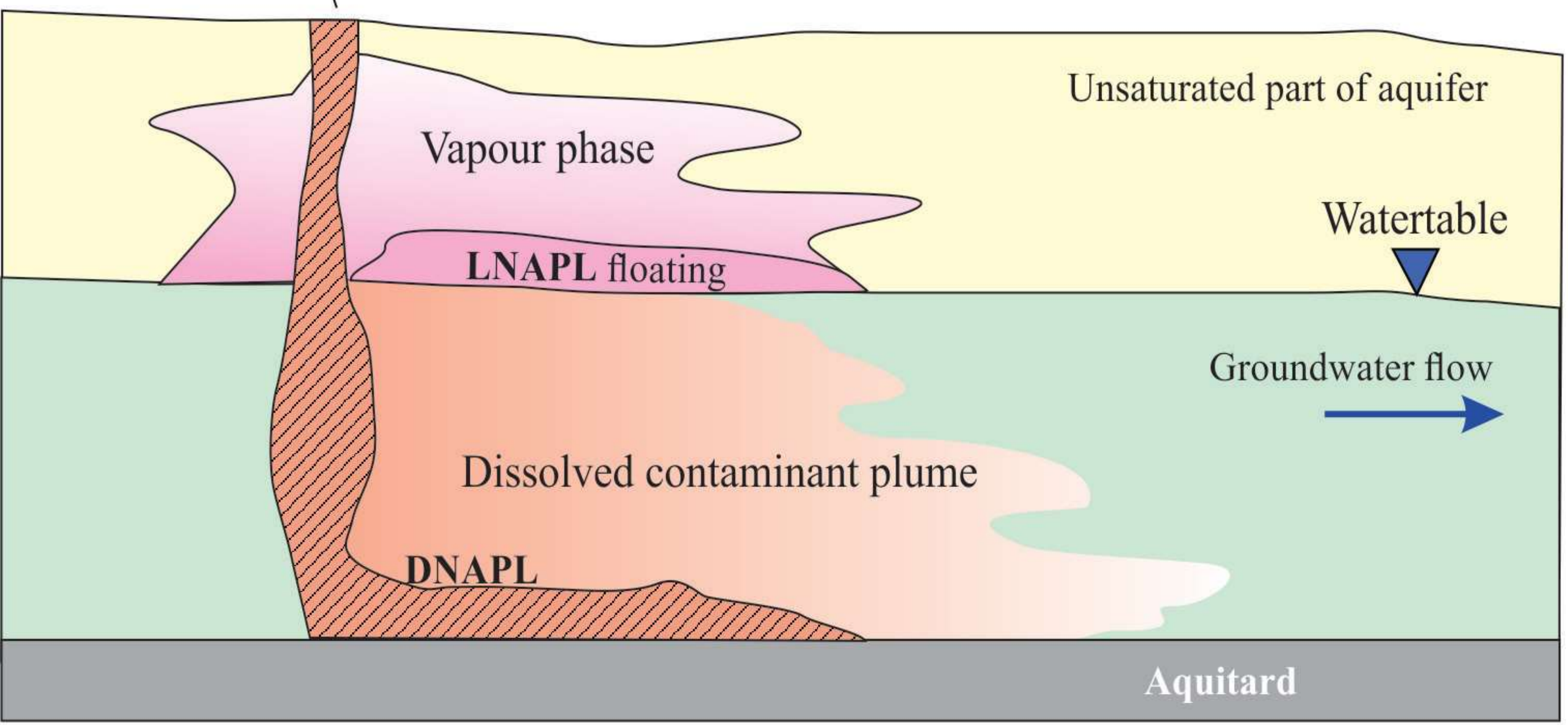
NAPLs are immiscible in, or do not dissolve in groundwater. They can become trapped in pore spaces (*interfacial tension → pathway interference*) and sorb to soil surfaces - limiting availability for physical, biological and chemical remediation.

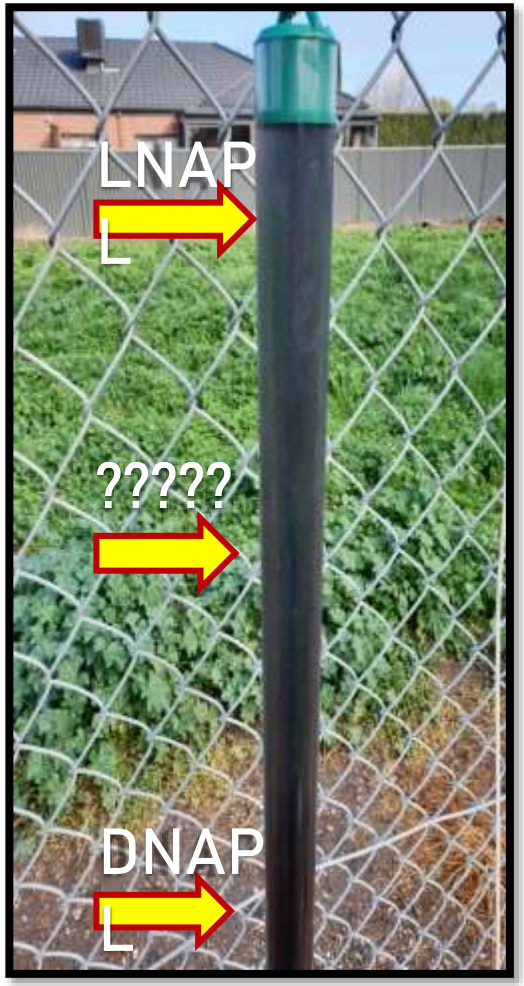
LNAPL = Light non-aqueous phase liquid (e.g. petroleum, benzene)
pronounced 'ell napple'

DNAPL = Dense non-aqueous phase liquid (e.g. coal tar, creosote Trichlorethylene (solvent))
pronounced 'dee napple'

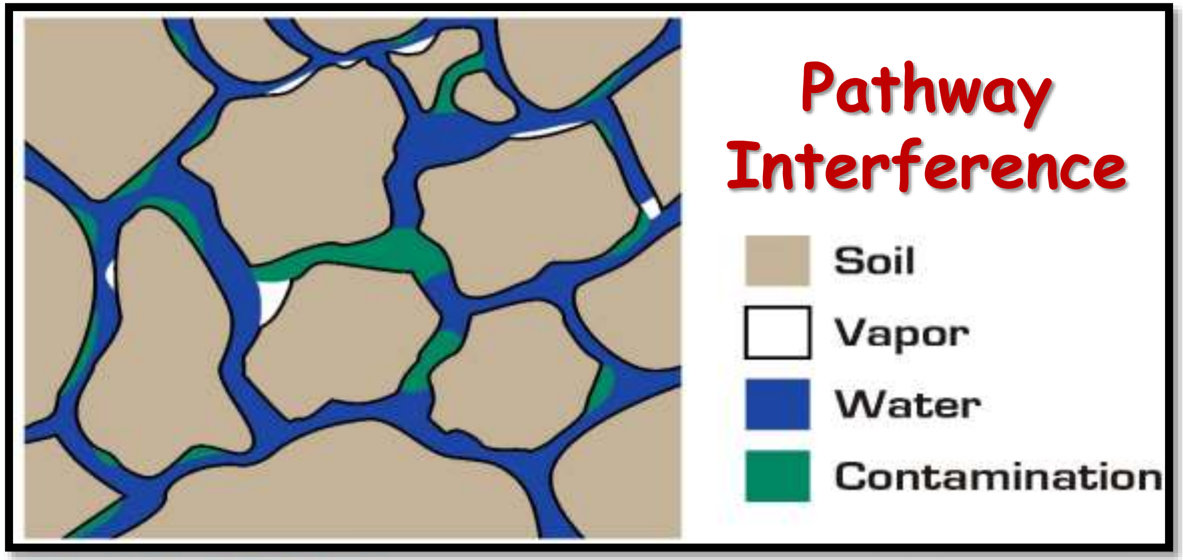
Sources: UST, AST, Pipelines, Surface Spills, Truck Rollovers, Sabotage, Off-shore Spills, etc.

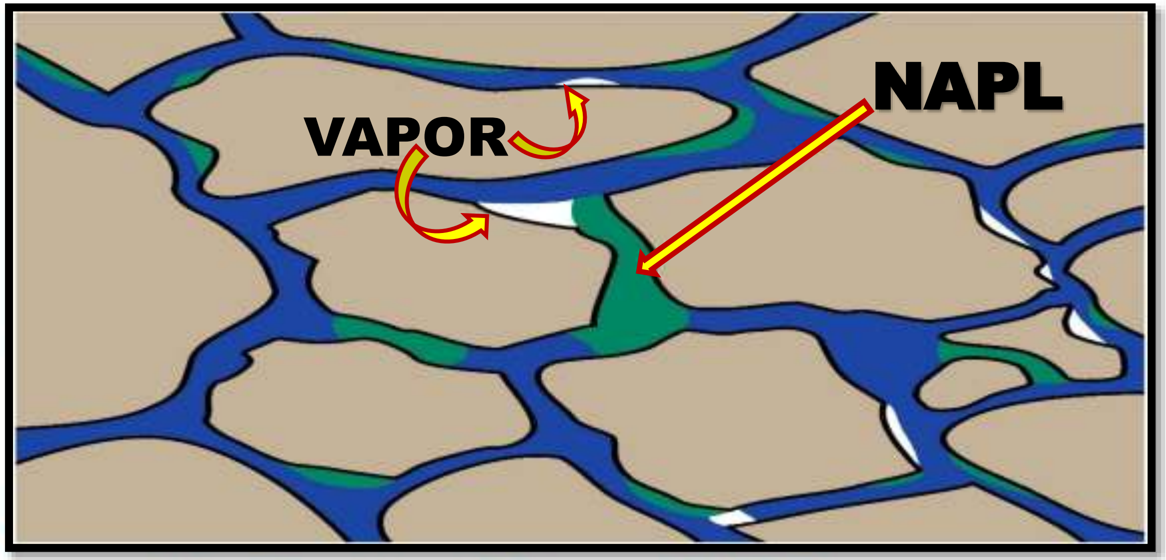
Disposal site spill, leakage





Organic contaminants, like petroleum fuels and solvents may be present as a free liquid, dissolved liquid (in water) and as vapour





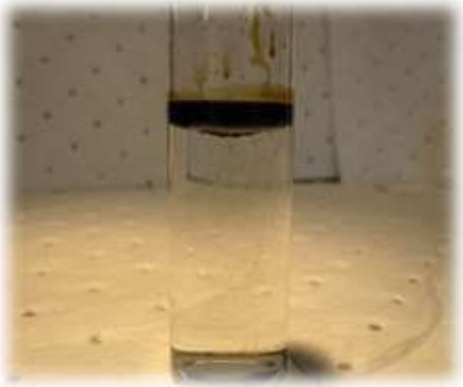
Mobile NAPL
NAPL body is continuous and its capillary pressure is high enough to exceed groundwater pore entry pressure, displace groundwater, and migrate through the subsurface.

Potentially Mobile NAPL
NAPL body is continuous, but its capillary pressure is not high enough to exceed groundwater pore entry pressure; under current conditions, it will not displace groundwater and migrate. If conditions change (for example, drilling through a potentially mobile DNAPL body, soil fracturing), potentially mobile DNAPL may mobilize and begin migrating.

Immobile Residual Phase NAPL
"Droplets" of NAPL called ganglia are present in the pore spaces but are not connected to other NAPL ganglia. They are immobile because they cannot exceed the capillary pressure and displace groundwater in the formation.

Interfacial Tension (dynes/cm) is the force that holds the surface of a particular phase together, and exists when two phases: gas/oil, oil/water, or gas/water come in contact. Interfacial tension can immobilize (trap) LNAPL and DNAPL within pore spaces → source of mass-flux = Rebound!

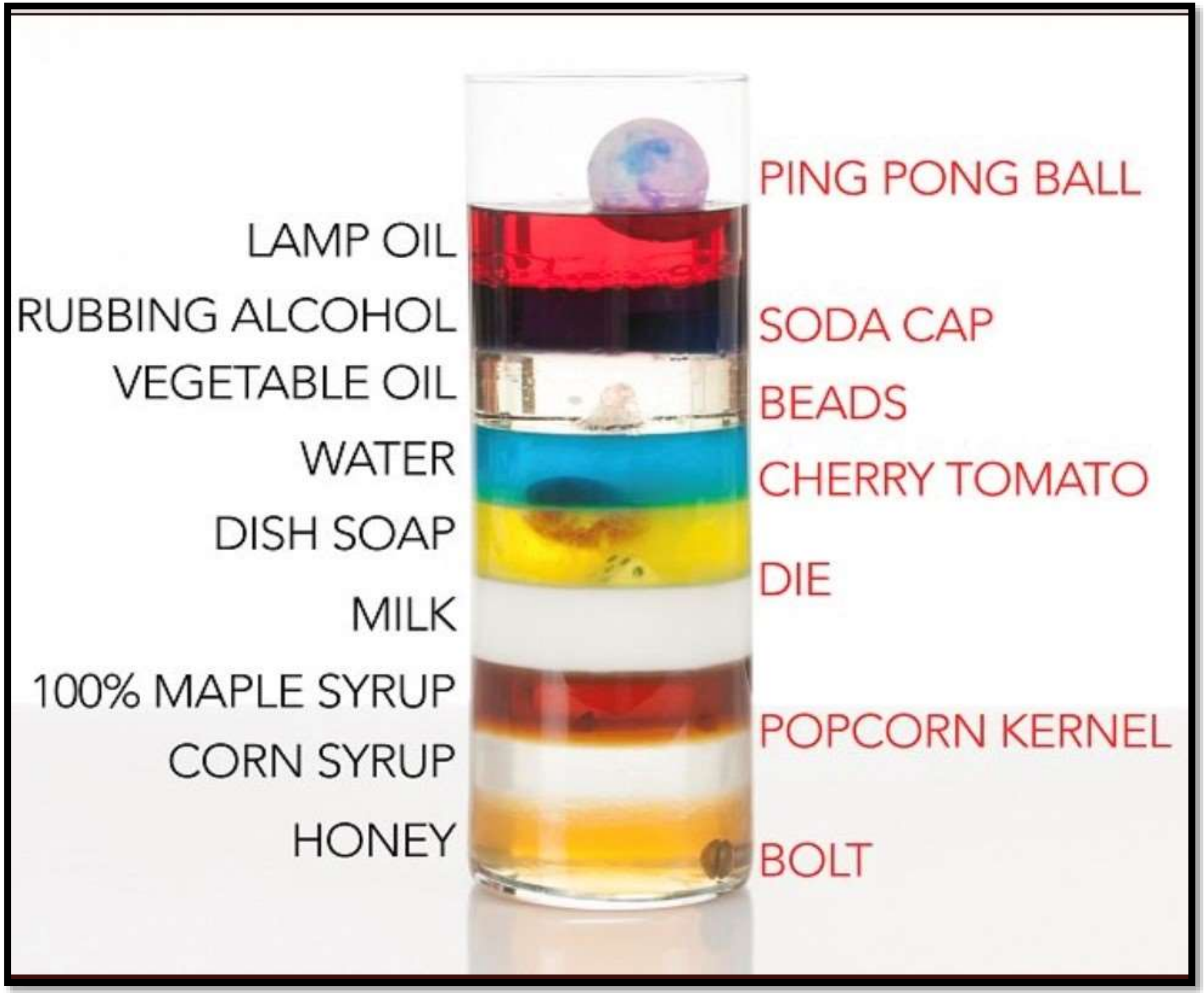
Interfacial Tension



Water Has
Interfacial Tension of 73 Dynes

LNAPL and DNAPL Have (On Average)
Interfacial Tension of 21-23 Dynes

NAPL Density Affects Its Behavior In Soil, Groundwater, and Vapor Phase Intrusion



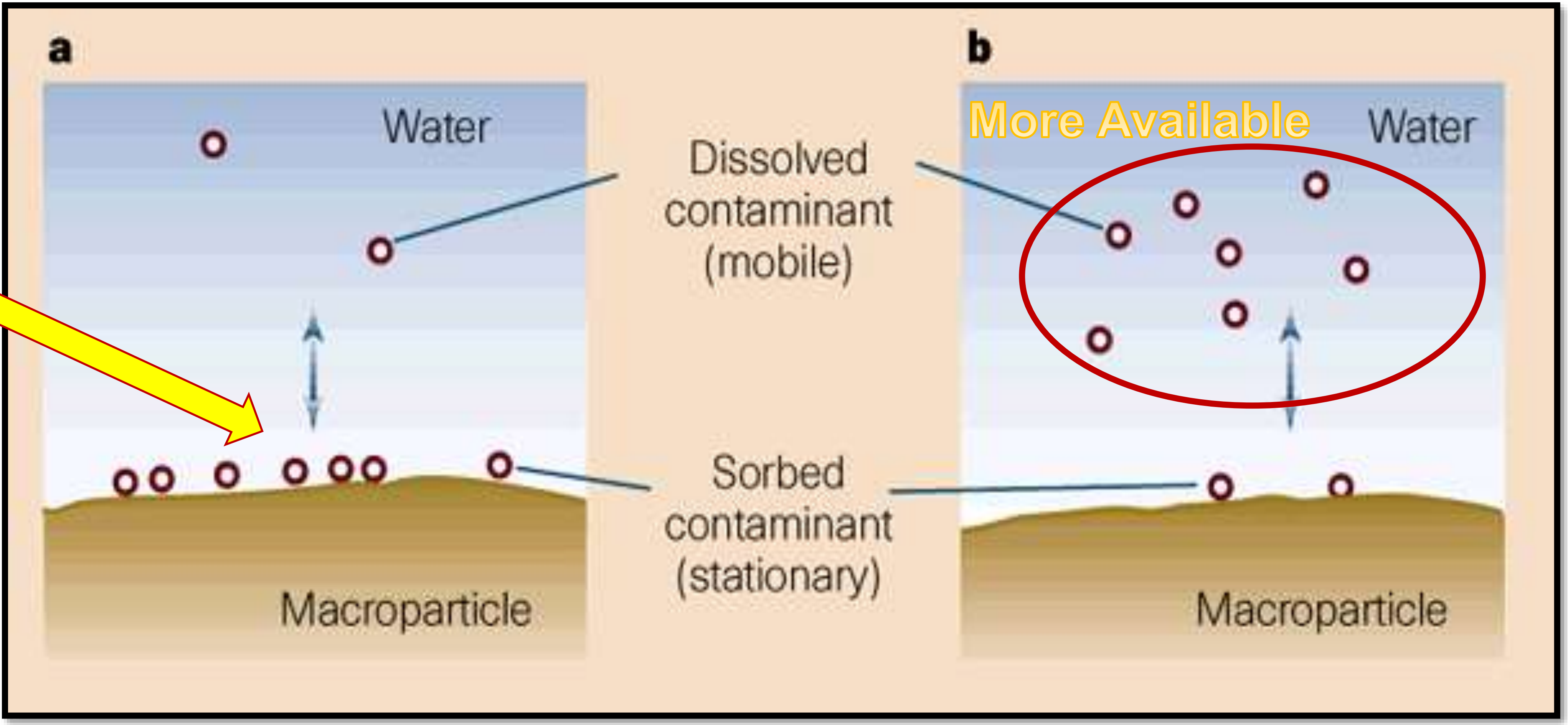
Knowing how contaminants, like NAPL, tend to behave allows us an opportunity to improve how we investigate and remediate impacted sites.

Allowing us to take a more forensic approach…

SORPTION

Hydrophobic organic chemicals exhibit limited solubility in groundwater. As a result the contaminants (Vapors, Dissolved, Sorbed, or NAPL) *Phase Partition* and sorb (i.e., absorb and adsorb) onto the soil surfaces or form NAPL (Globules or Layers). Contaminant Sorption & NAPL negatively effects Availability for Remediation.

Sorbed or NAPL Phase Globules With Limited Availability For Remediation



Sorption Literature Reference

The growing concern regarding contaminant sorption, and its reduced availability for remediation, has been well cited in literature as demonstrated by the following quotation:

"During the past decade, much discussion has centered on the unavailability of absorbed compounds to soil microorganisms; it is generally now assumed that desorption and diffusion of bound contaminants to the aqueous phase is required for microbial degradation."

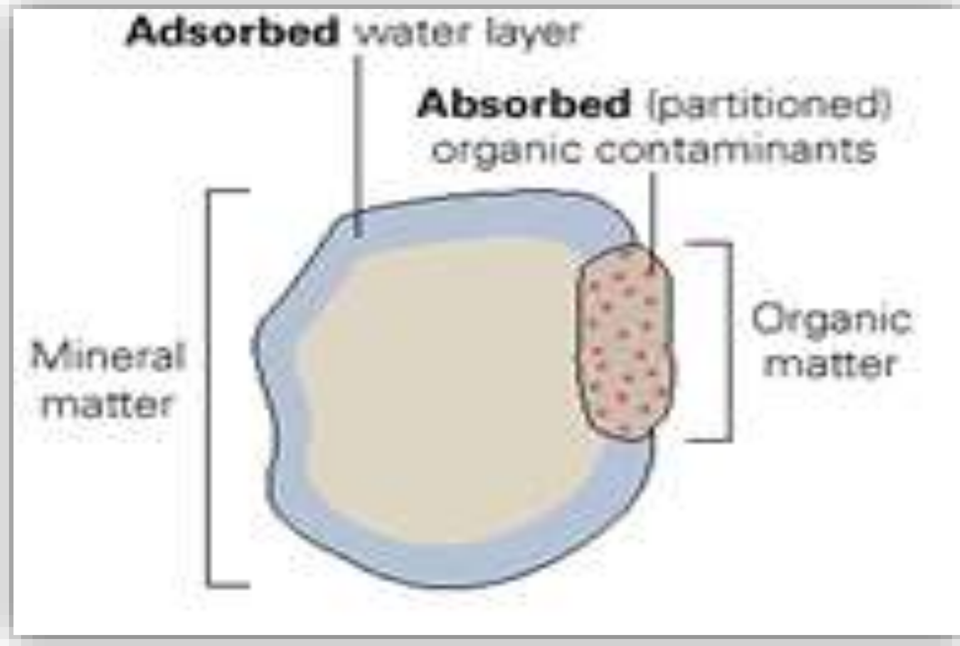
(W.P. Inskeep, J.M. Wraith, C.G. Johnston, Hazardous Substance Research Center, 2005).

FACT

Sorption Limits Contaminant Availability For Remediation

Sorption or NAPL Formation Limits Contamination Availability For All Forms of Remediation

Ivey-sol Overcomes This Limitation To Improve Their Remediation!



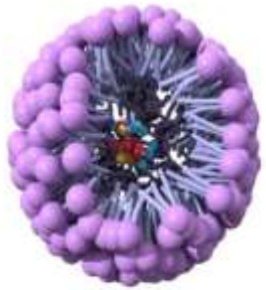
Sorption / NAPL limits the *'Availability'* of Contaminants for in-situ and ex-situ remediation by ***limiting their mobility***. As a result, they are:

- Less *'Physically Available'* for Multi-Phase Extraction (MPE), Pump & Treatment, and Soil Washing;
- Less *'Biologically Available'* for Bioremediation (Aerobic or Anaerobic), and
- Less *'Chemically Available'* for Chemical Oxidation or Reduction

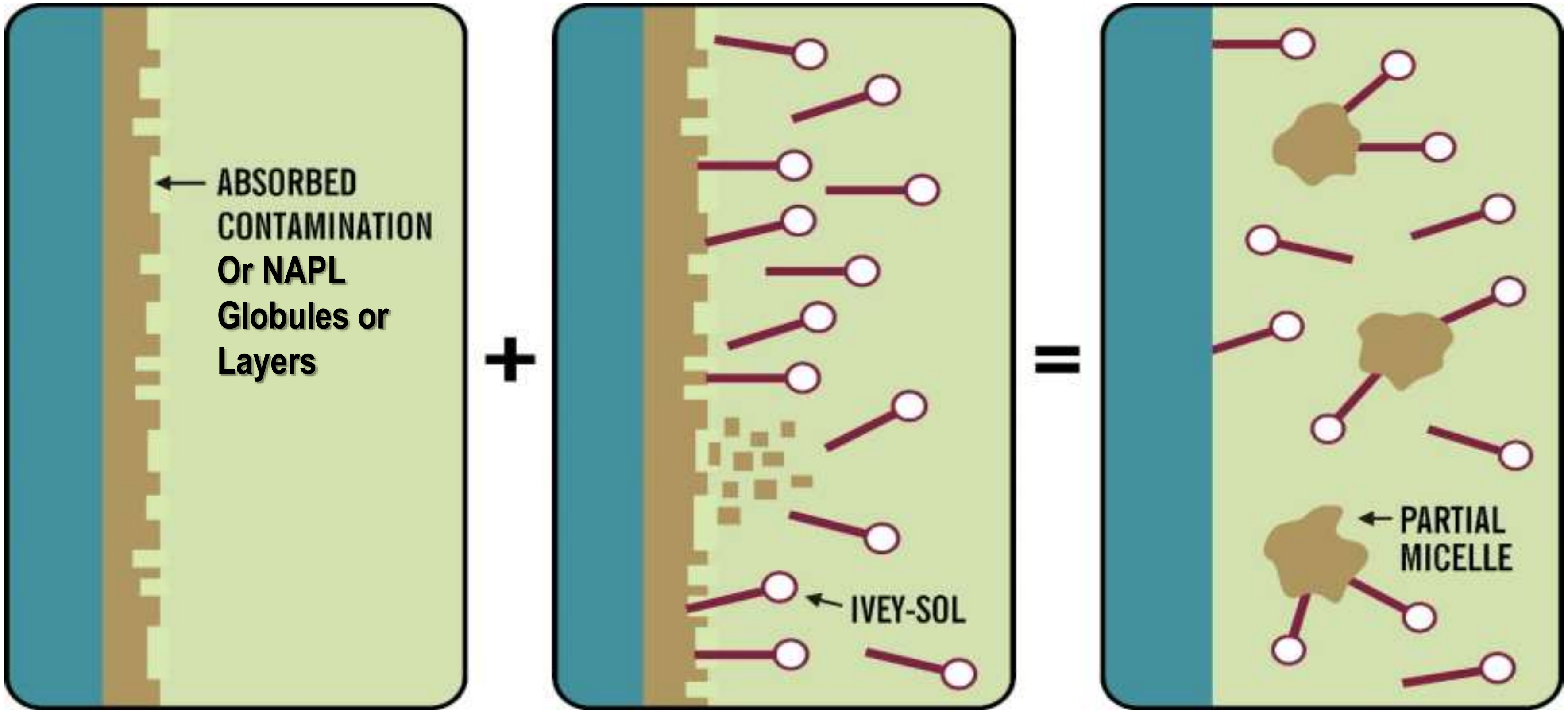
IVEY-SOL®

Surfactant Technology

"TODAY'S ENVIRONMENTAL SOLUTIONS FOR A BETTER TOMORROW"



How >99% of all other surfactants work by encapsulating the contaminants hindering their 'Availability' for remediation.



Ivey-sol® mechanism is selective and works below the CMC

Increasing Physical, Biological and Chemical Availability For Enhanced Remediation

Biodegradable, pH Neutral, Non-toxic, Effective For Treating Broad Ranges of Contamination

(Peer Reviewed Journal Paper Available On Request Available)

Selective Below CMC on Sorbed, NAPL, Dissolved and Vapor Phases

- Ivey-sol® 103 — BTEX, Jet Fuel, Gasoline
- Ivey-sol® 106 — Diesel (Light-Medium-Heavy), PAH's, Heating Oils
- Ivey-sol® 106 (Cl) — Chlorinated Solvents
- Ivey-sol® 108 — Motor Oil, Lubricants, Bunker-C
- DECON-IT ® — Equipment Decontamination Product

Dilute 1:50+ With Water -> So A Little Will Goes A Long Way -> Increasing Availability

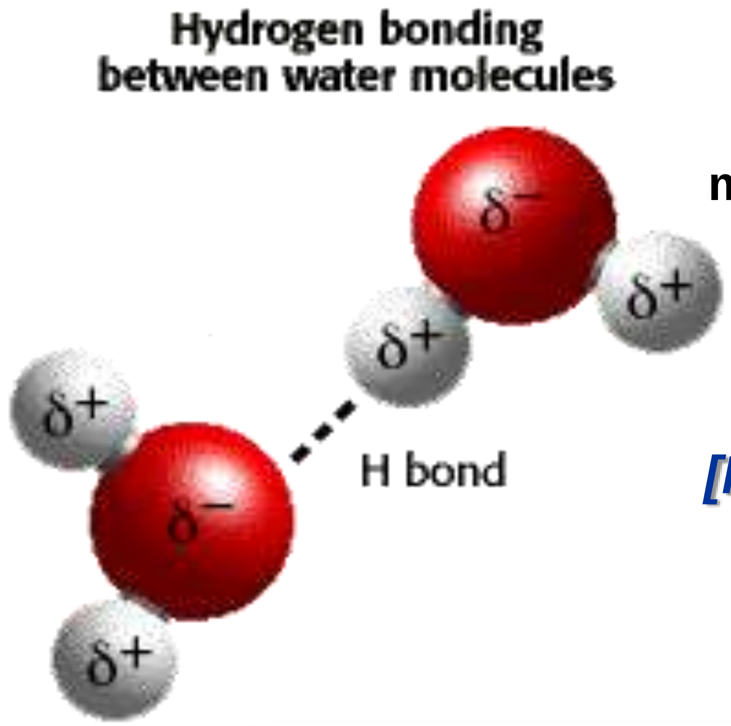
Water Beading On Fine Sand

Ivey-sol® Also Overcomes Surface Tension of Water

Why Is This Droplet Not Entering The Sand Soil?

What you see at the Macroscopic level is indicative of what is occurring at the Microscopic, and also what is occurring at the Molecular level… simply put Water is not H_2O.

Hydrogen Bonding

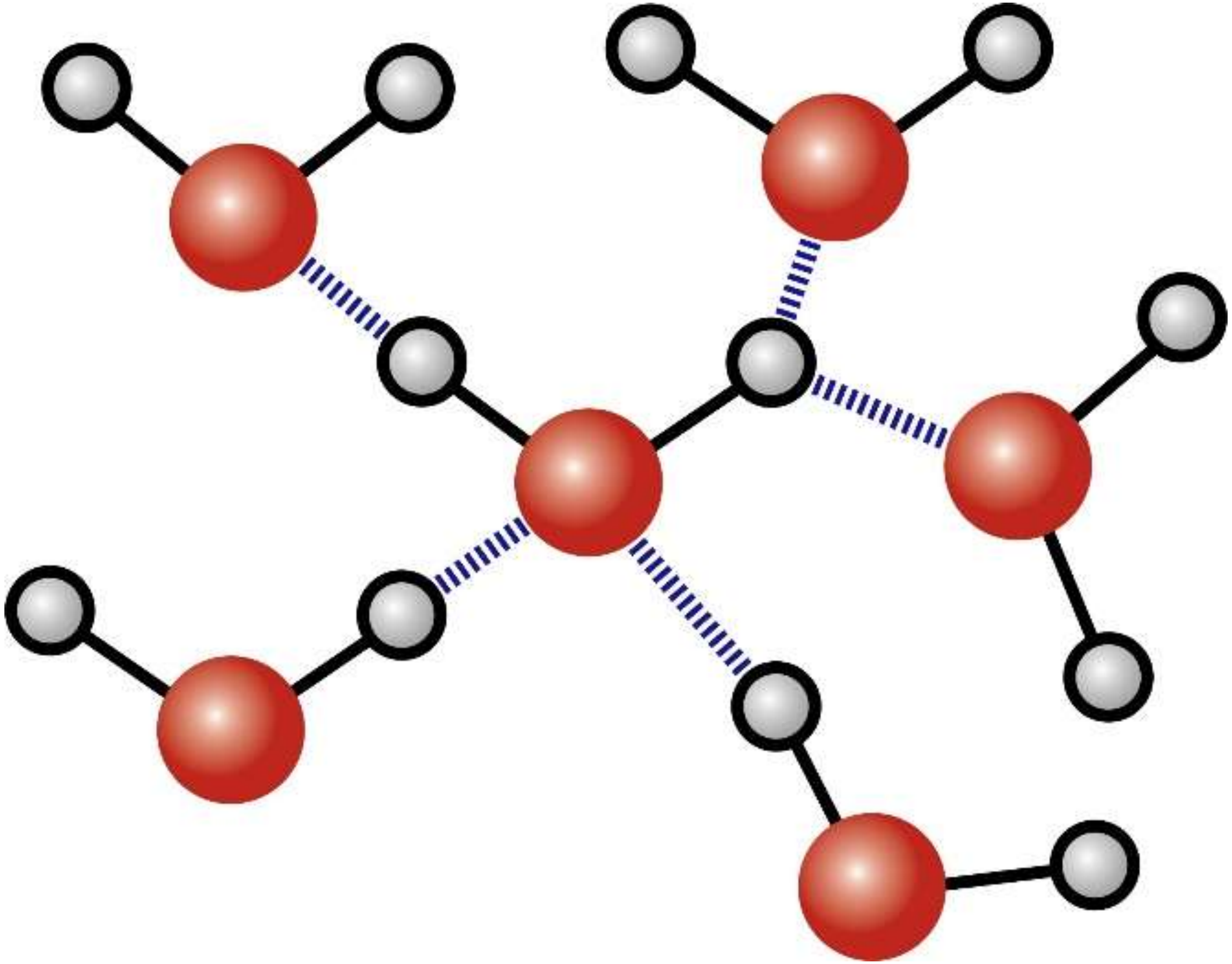


Oxygen (O) on one water molecule is attracted to Hydrogen (H) on neighboring water molecule - giving rise to *Hydrogen-Bonding.*

[Now we know why a belly-flop on water hurts! Has surface tension of 73 dynes]

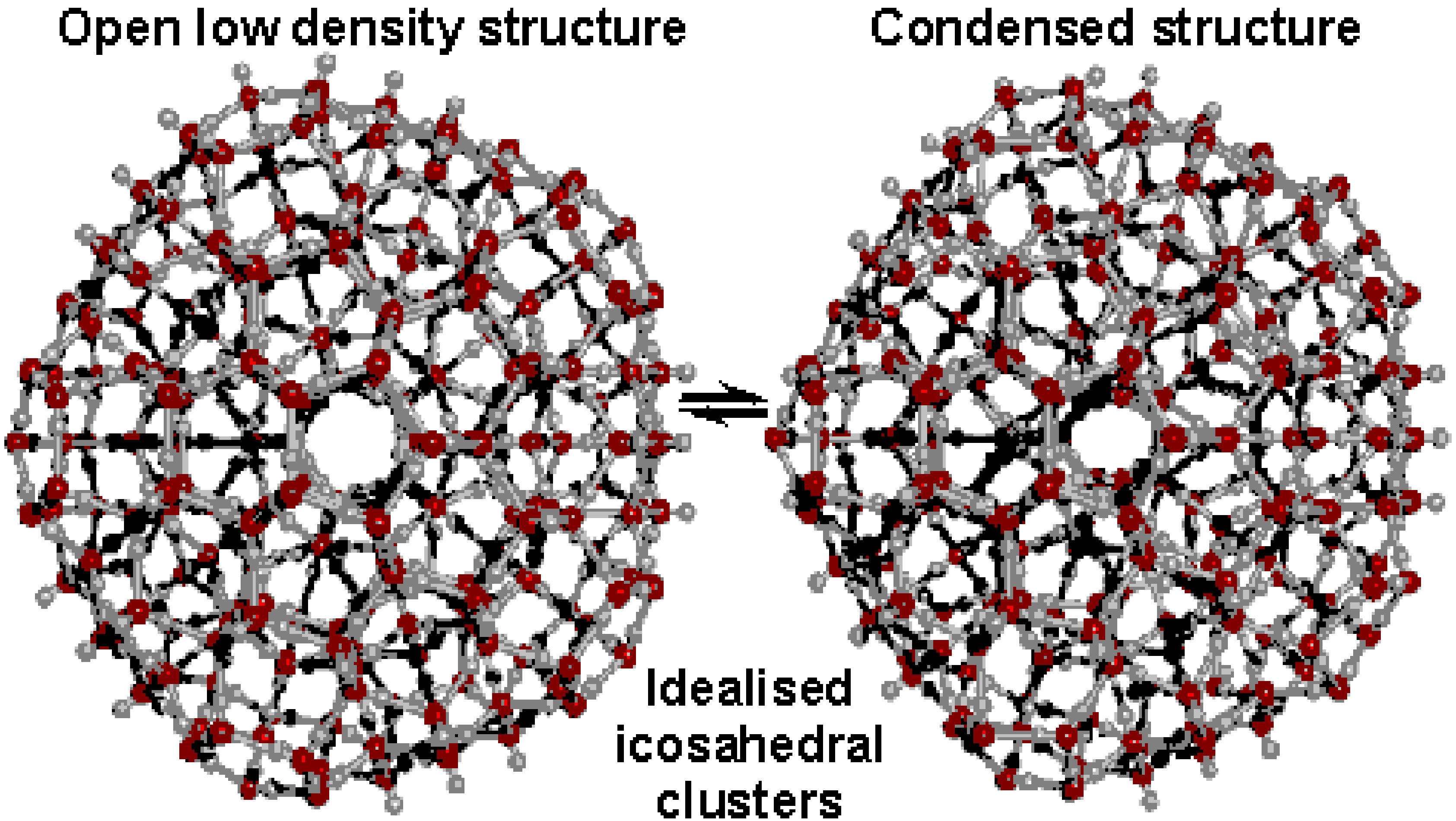
FACT: **Oxygen (O) is more electronegative than Hydrogen (H) Yielding its Polarity Analogous to behaving like magnets.**

Hydrogen Bonding Expanded

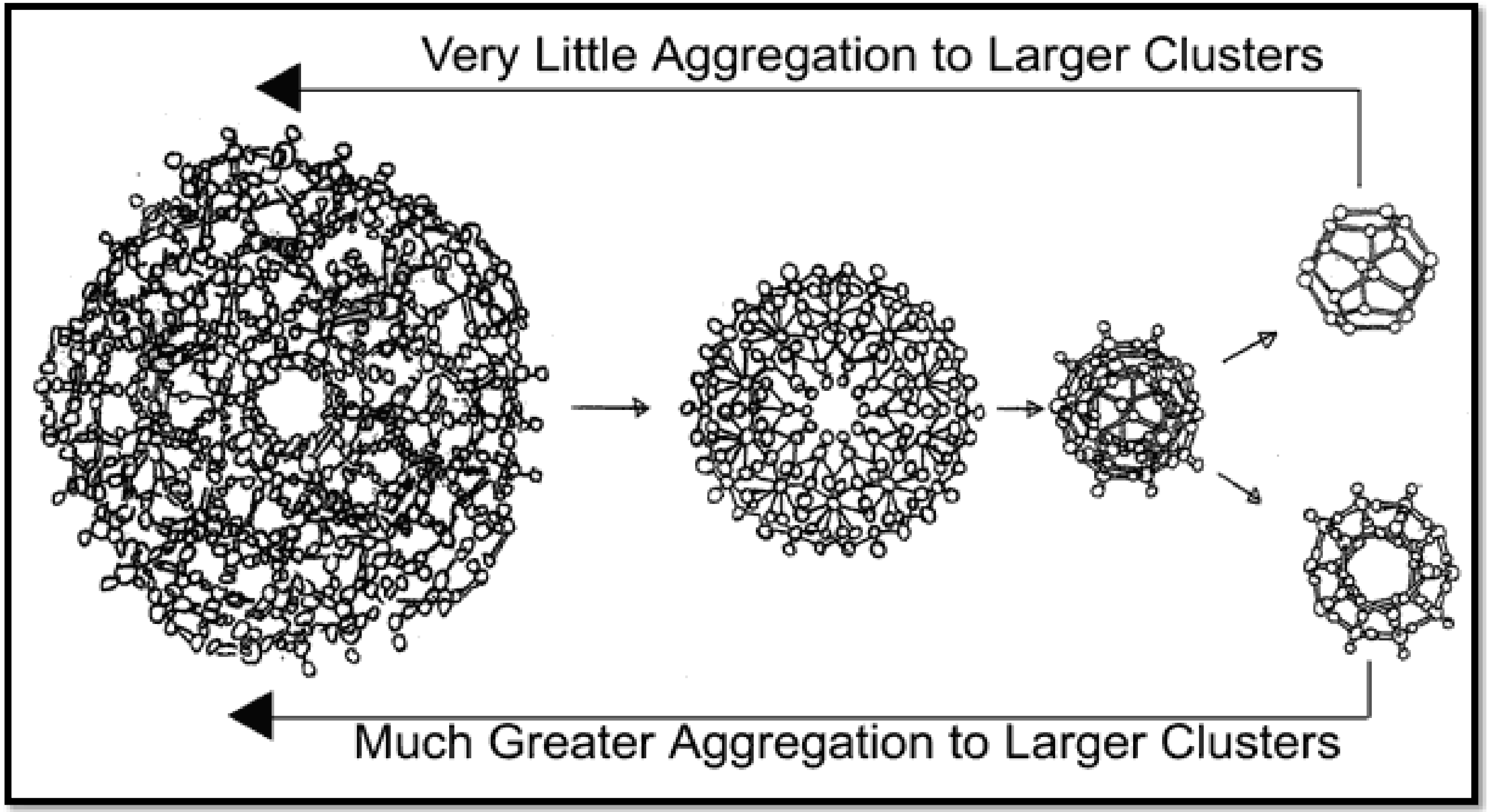


Water Is A 3-Dimensional '*Cluster*' - With Surface Tension of 73 Dynes
Water Cluster Size Limits (K) It's Ability To Move In Finer Texture Geology

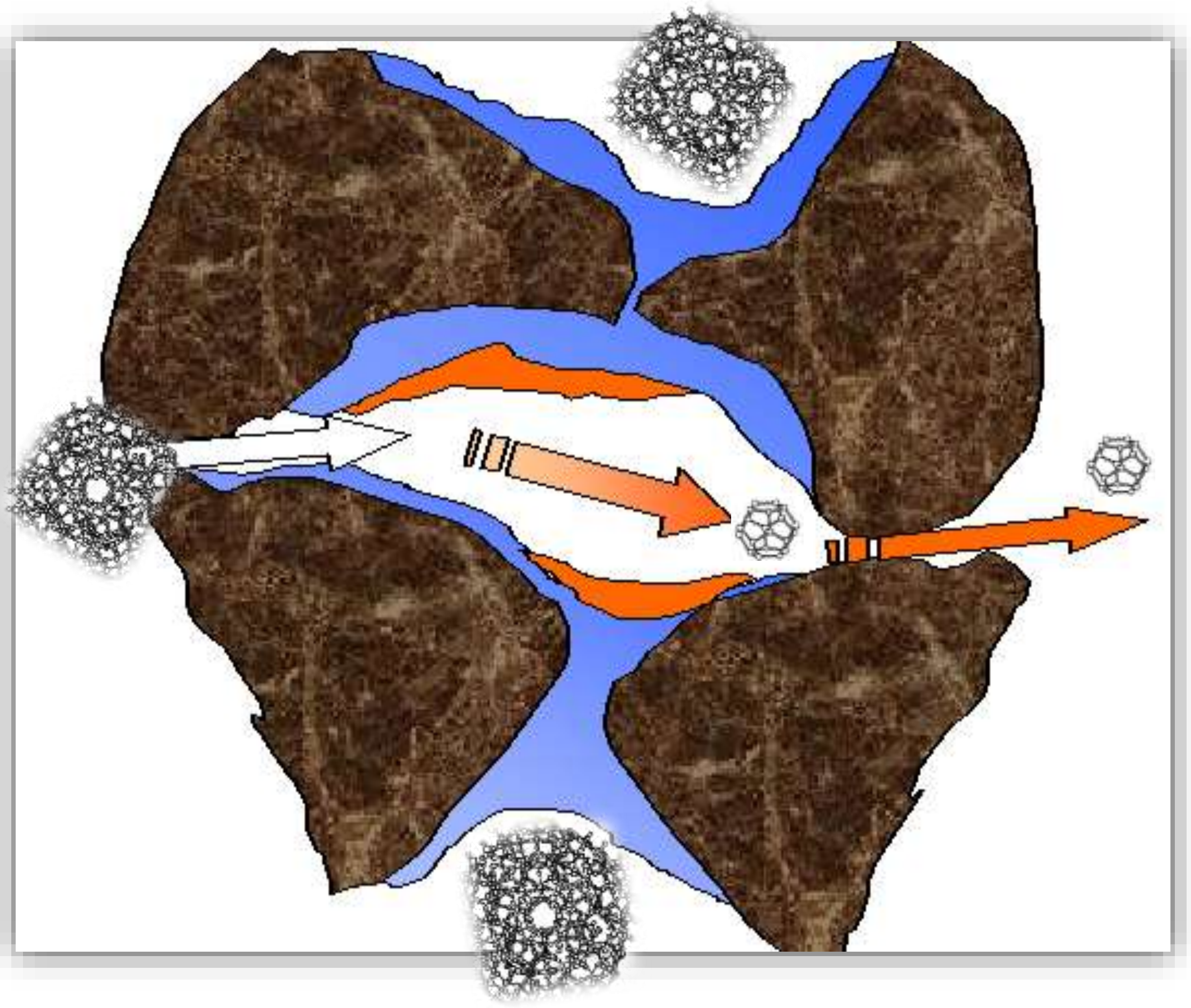
Ivey-sol® Makes Water Clusters Smaller So Enter And Move More Easily Through Finer Grain Soils *(Lower Surface Tension < 30 Dynes)*



Ivey-sol Reduces The Size of Water Clusters
(Lower Surface Tension from 73 Dynes to < 30 dynes)
Allowing Access & Regress within Finer Grain Soil Textures Temporarily Improving K



Over Coming Low K and Retardation Within Finer Grain Geology Containing NAPL



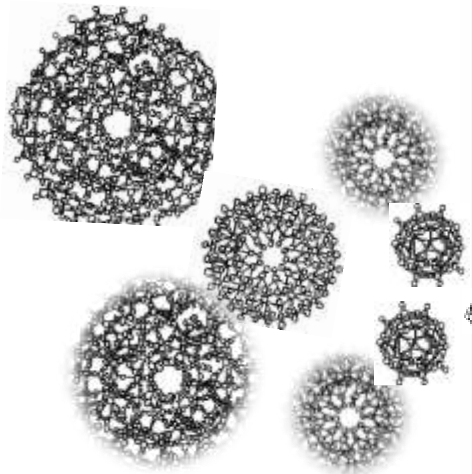
It's a well accepted understanding that water and contaminants flow much slower in finer grain soils than coarse grain soil.

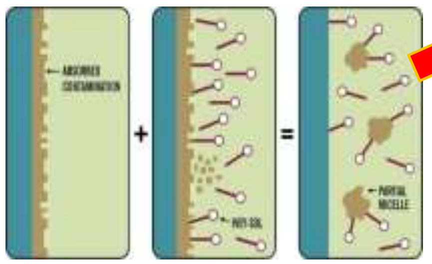
This limitation makes contaminant remediation in fine grain soil more difficult.

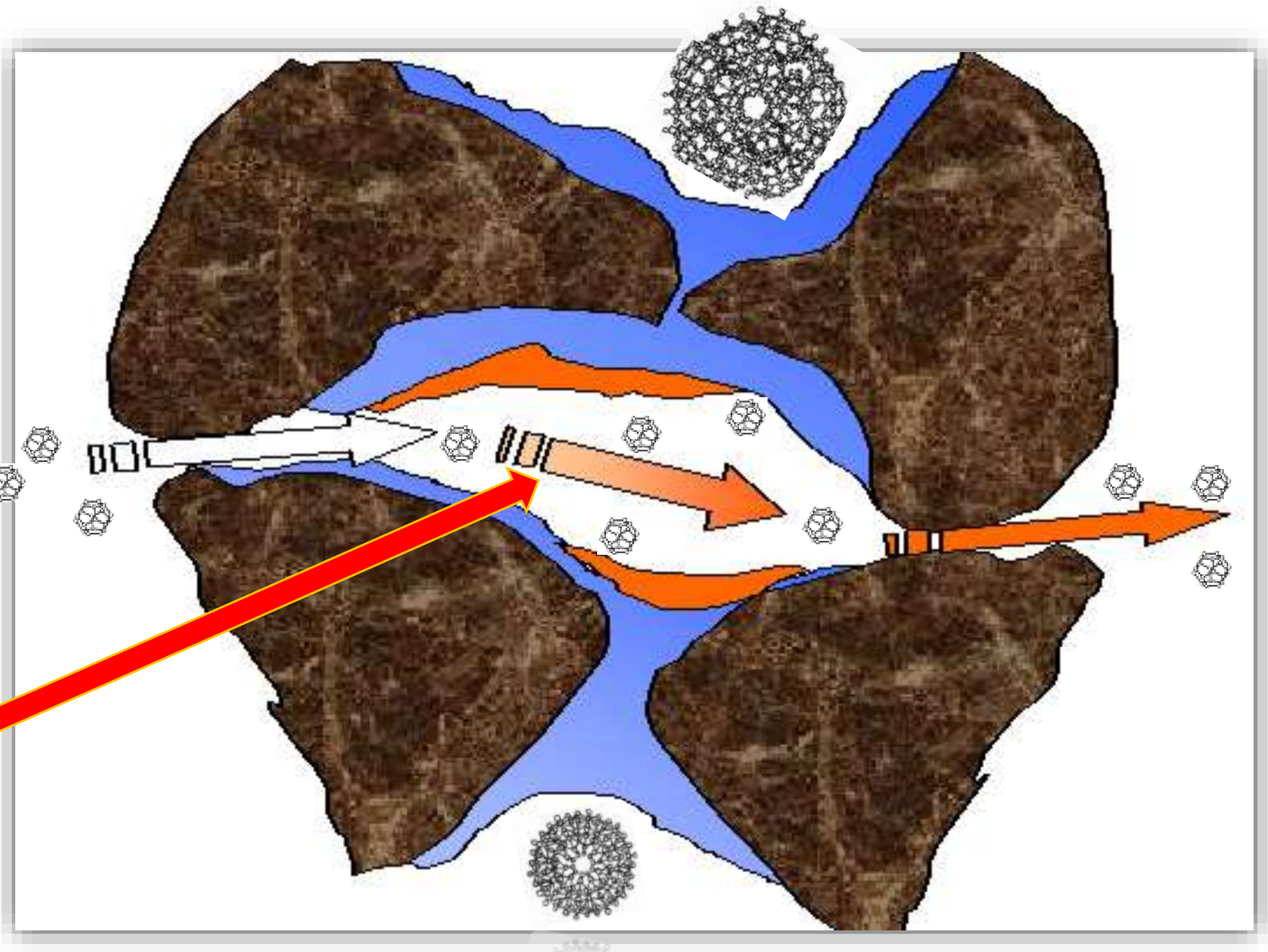
If we could overcome this limitation in fine texture soil, improve the 'apparent K' and improve the controlled movement (transmissivity) of contaminants across pore spaces (lower retardation), we could improve all forms of Remediation!

Ivey-sol Overcomes Low K and Retardation In Finer Grain Soil
Improving Access, Regress, and Remediation

ACCESS







Interfacial Tension Will Effect NAPL Behaviors

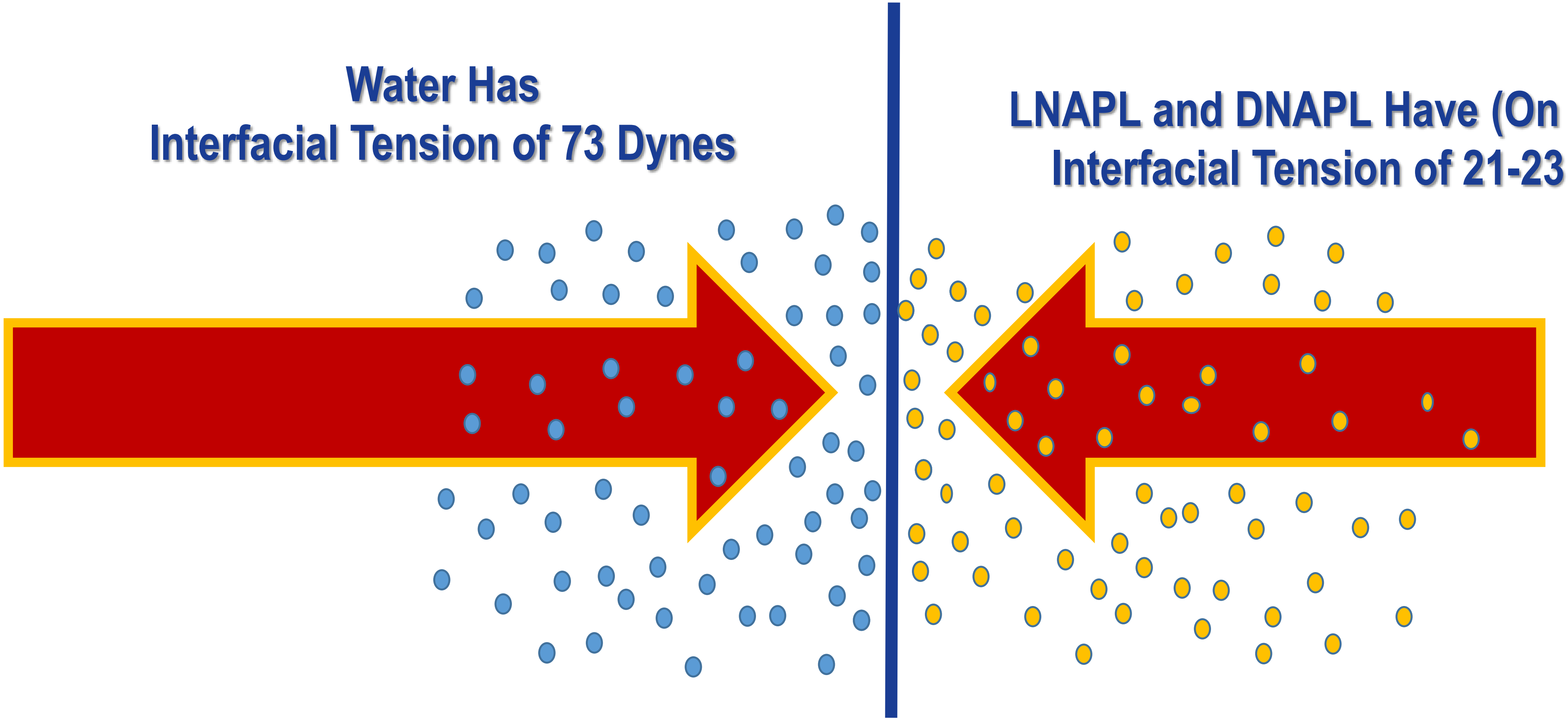
More Available
(Physio-Bio-Chem)

REGRESS

Interfacial Tension

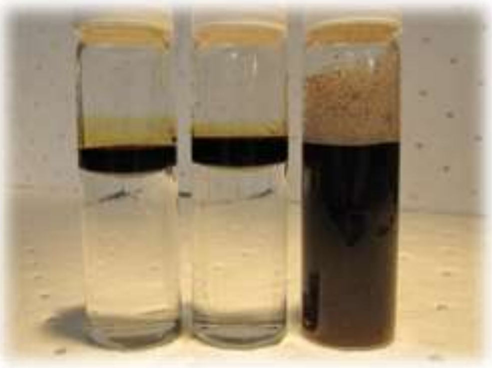
Water Has
Interfacial Tension of 73 Dynes

LNAPL and DNAPL Have (On Average)
Interfacial Tension of 21-23 Dynes



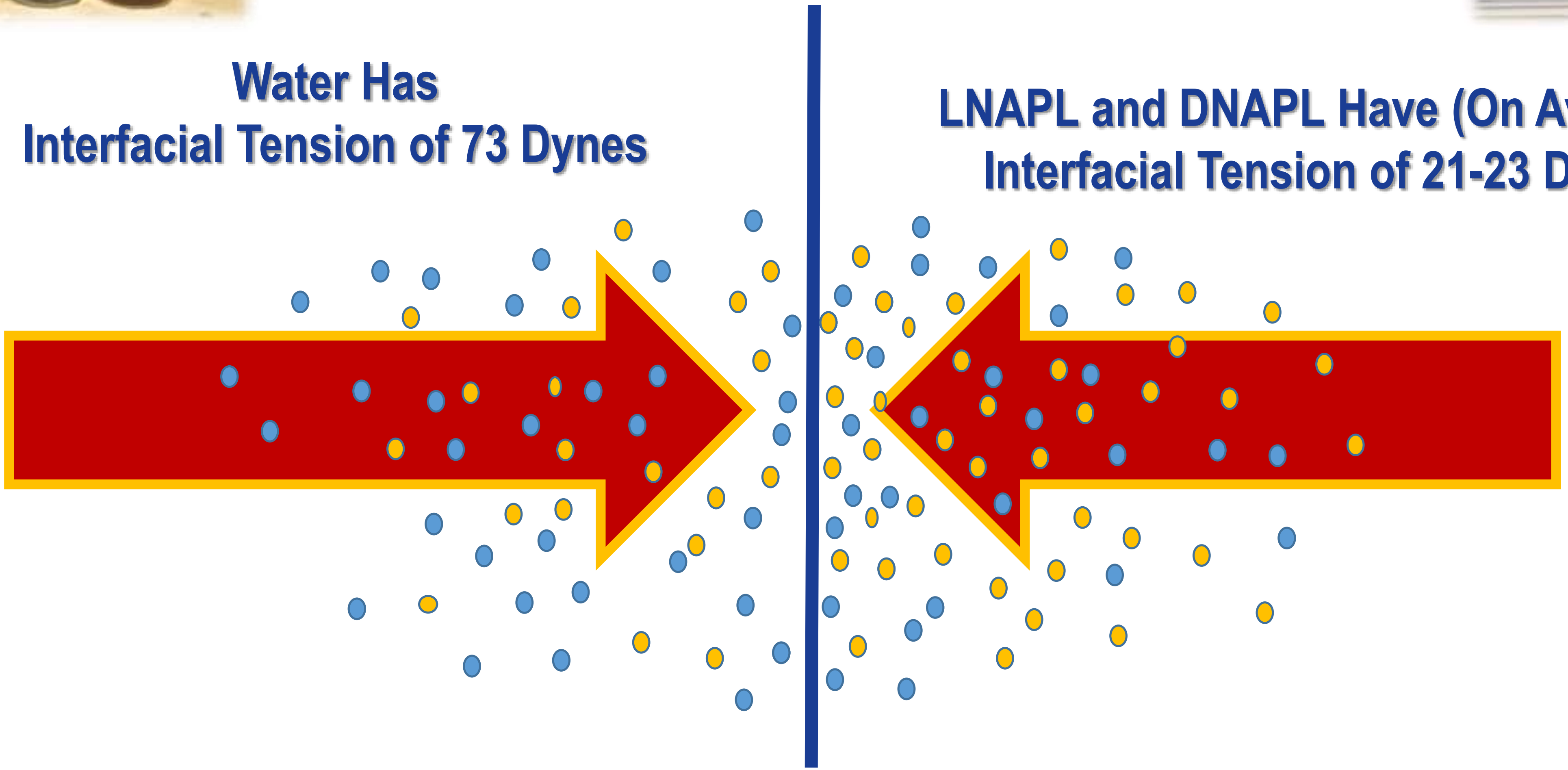
Interfacial Tension Limits Access, Delivery, & Availability of NAPL / Contaminants For Physical-Biological-Chemical Remediation

Interfacial Tension



Water Has
Interfacial Tension of 73 Dynes

LNAPL and DNAPL Have (On Average)
Interfacial Tension of 21-23 Dynes



Overcoming Interfacial Tension & Increasing NAPL / Contaminant 'Availability' With Ivey-sol For Remediation

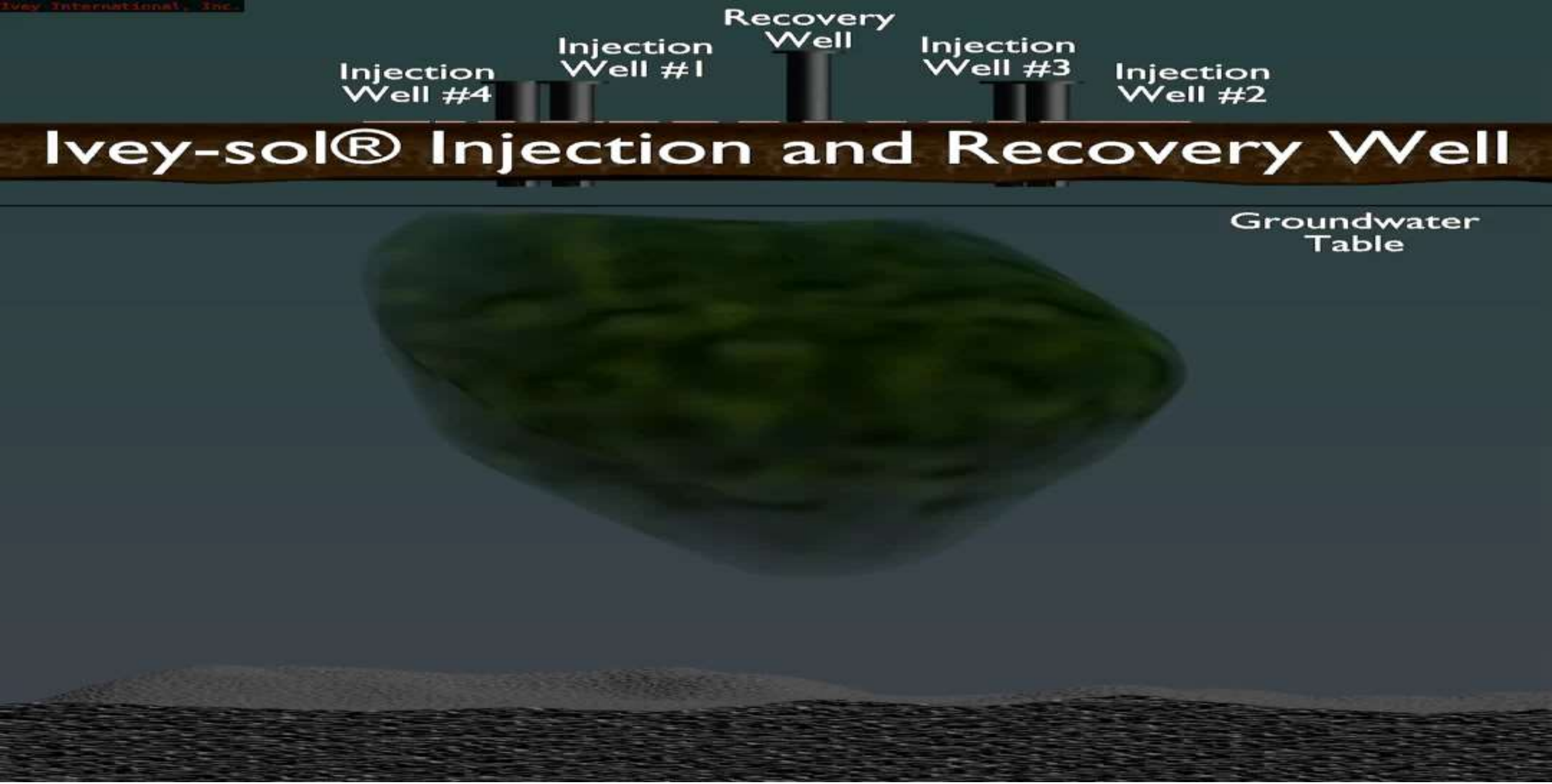
3 Dimensional Animations

In-situ '*Push-Pull*' Ivey-sol® Application Options

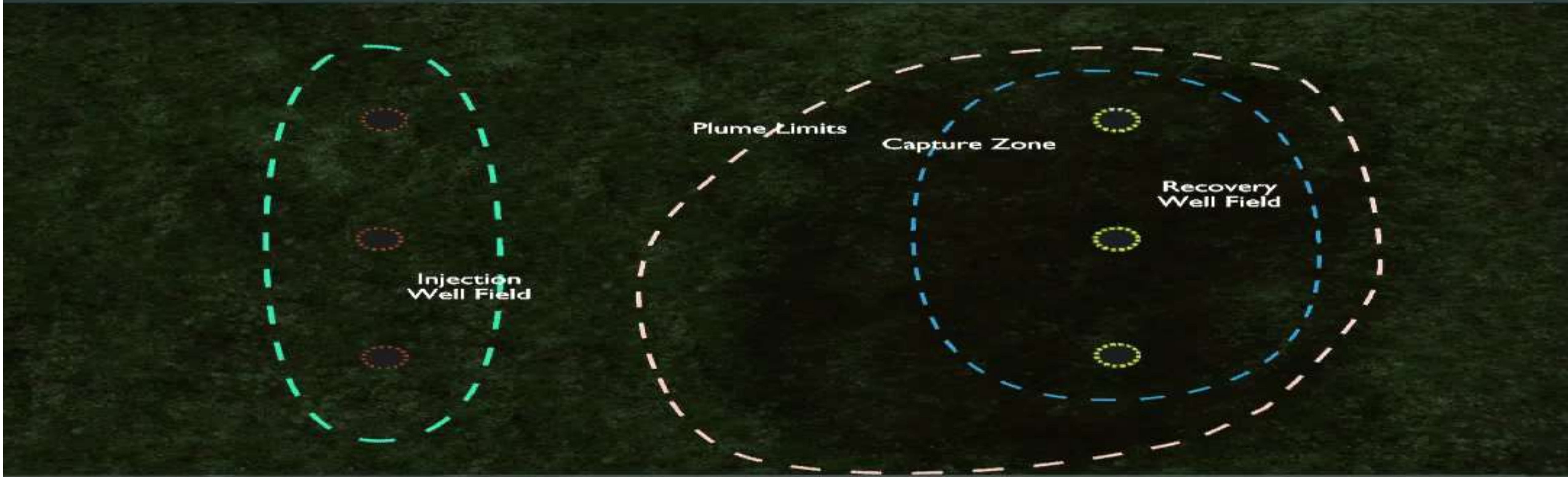
Link For PDF Version To See Ivey-sol Animations:

http://www.iveyinternational.com/videopresentation

Ivey-sol® Injection and Diffusion Radius


Ivey International, Inc.
Recovery Well
Injection Well #1
Injection Well #4
Injection Well #3
Injection Well #2
Ivey-sol® Injection and Recovery Well
Groundwater Table

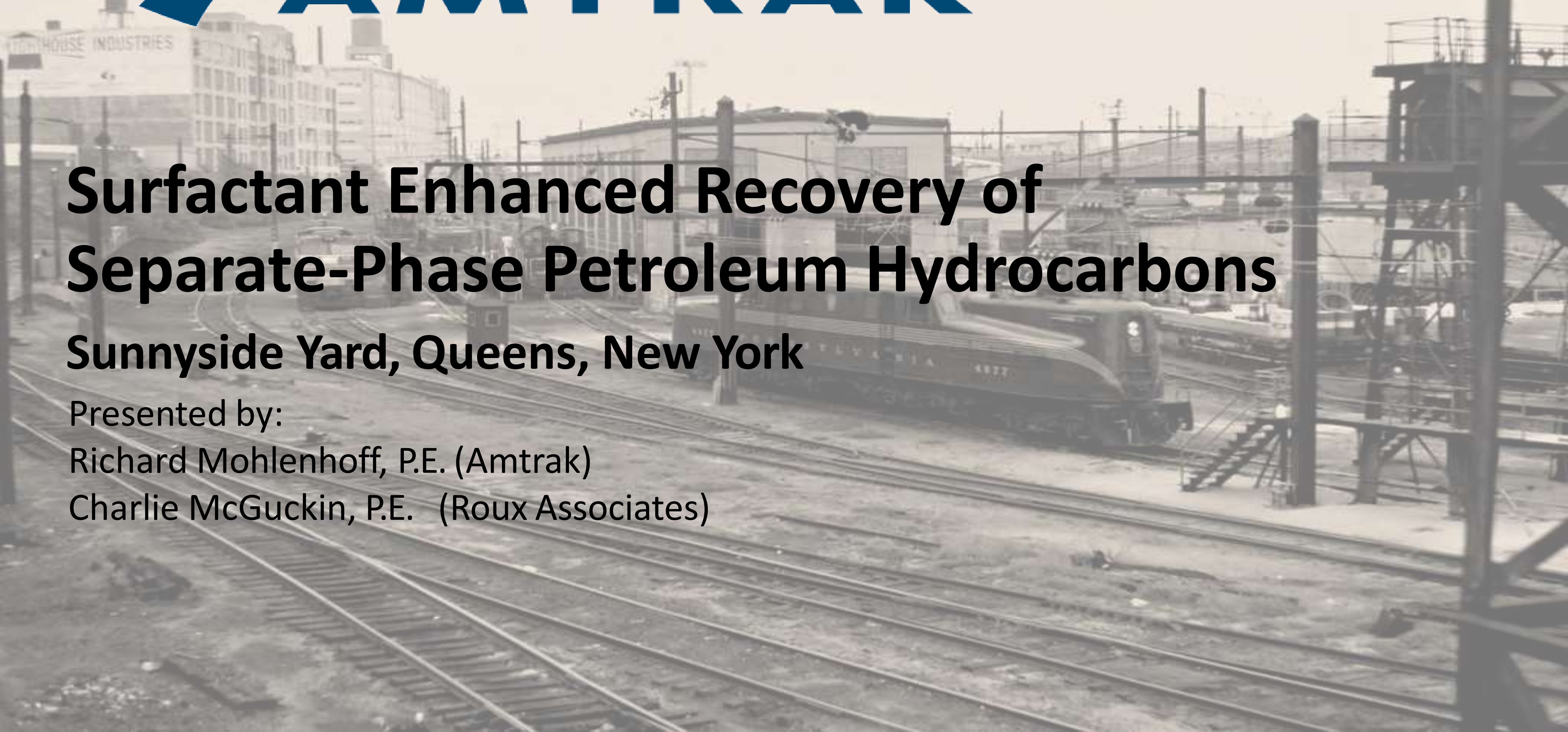
Ivey-sol® Injection and Recovery Well Fields



CASE STUDY #1

AMTRAK

Abbreviated Presentation Version. Contact IVEY for full version if interested.



Surfactant Enhanced Recovery of Separate-Phase Petroleum Hydrocarbons

Sunnyside Yard, Queens, New York

Presented by:
Richard Mohlenhoff, P.E. (Amtrak)
Charlie McGuckin, P.E. (Roux Associates)

Site History

- Located in Sunnyside Yard, Queens, New York
- Over 100 years of service
- State Superfund Site
- Six Operable Units (OUs)
- 130 acre Site
- OU-3 LNAPL and PCB Plume

ROUX

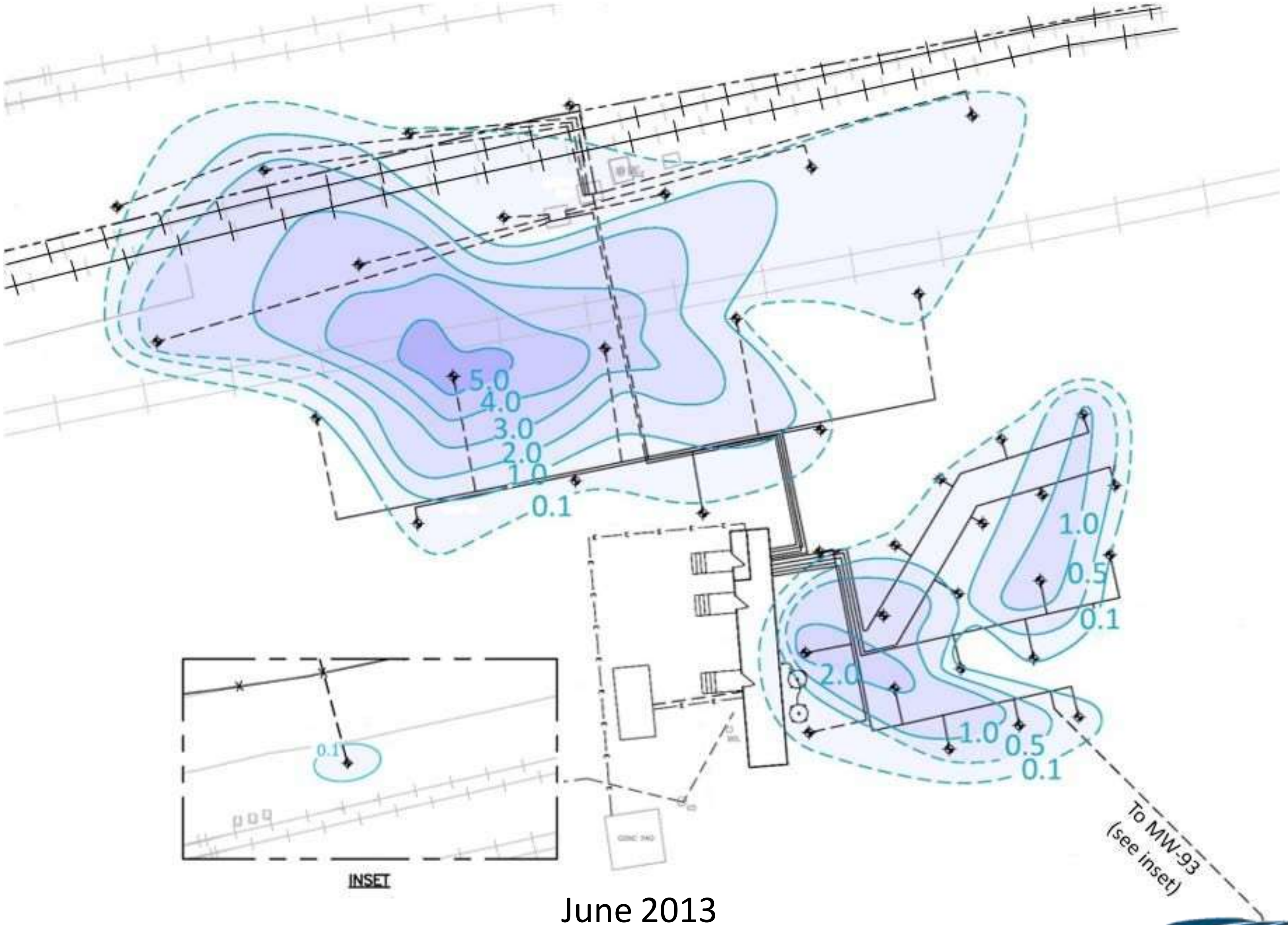
AMTRAK

OU-3 Record of Decision

Cleanup Standards

- **PCBs < 25ppm** ***(Selectivity of Ivey-sol® would not mobilize soil PCB's)***
- **Lead < 3,900 ppm**
- **cPAHs < 25 ppm** **(total of 7 compounds)**
- **SVOCs < 500 ppm**
- **LNAPL thickness < 0.1 foot**

Dual Phase Vacuum Extraction (DPVE) System



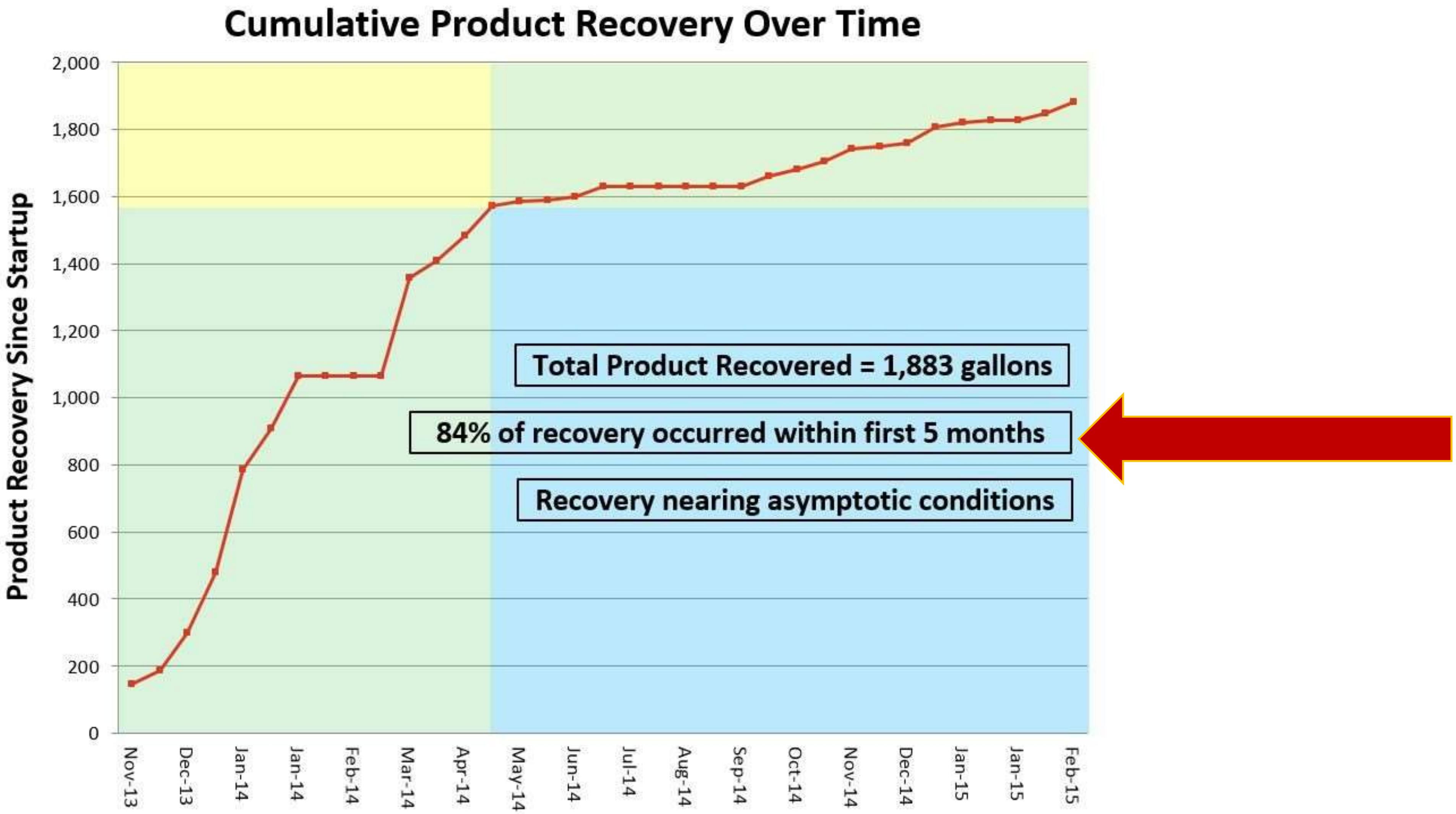
June 2013

ROUX

AMTRAK

Dual Phase Vacuum Extraction (DPVE) System

DPVE System Performance



ROUX

AMTRAK

Ivey-sol® Surfactant Technology

- Composition
  - Several patented non-ionic surfactant formulations
- Applications
  - Desorb and liberate free-phase LNAPL and/or sorbed petroleum hydrocarbons
- Mechanism
  - Makes the contaminants more miscible in the aqueous phase, increasing the “physical availability”
- Additional Uses
  - Enhances bioremediation

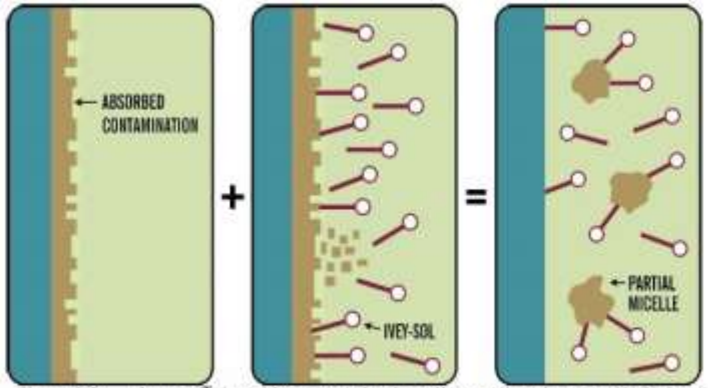
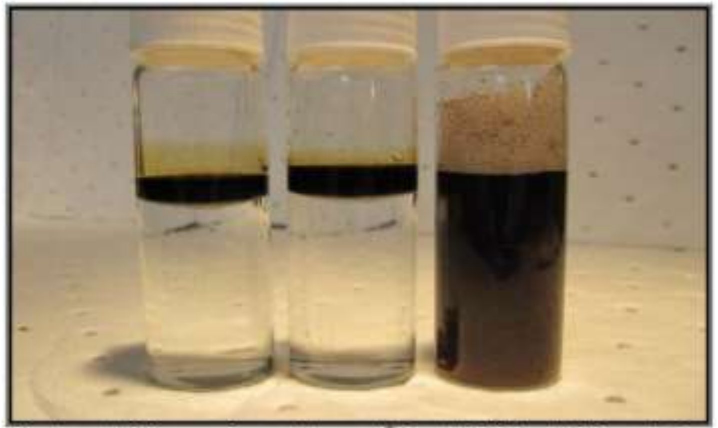


Figure 2-2: Ivey-sol® desorbing contamination off the soil surfaces, or NAPL layer making it more 'Available' for in-situ or ex-situ remediation.



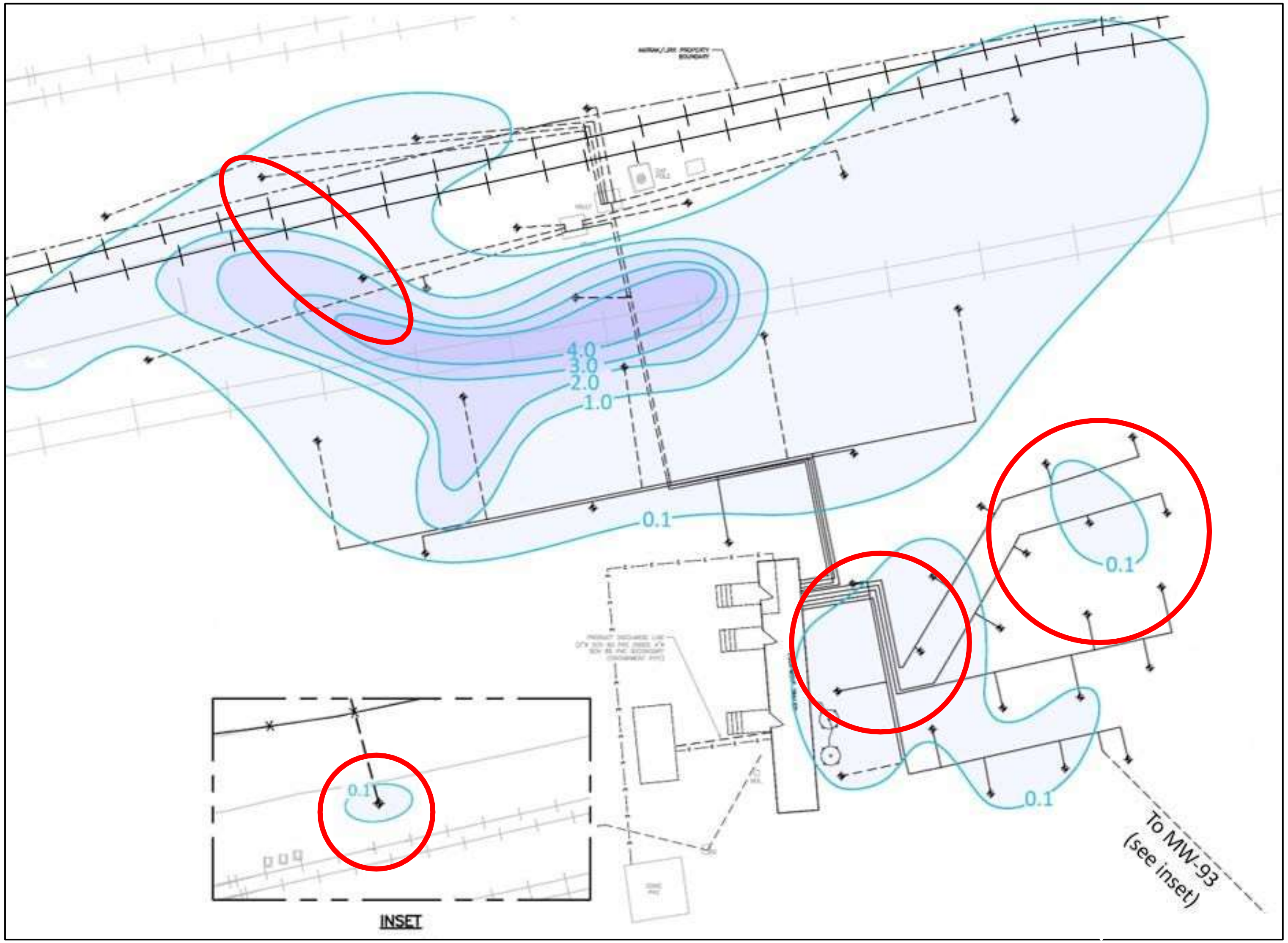
Photograph 2-2: Pre-post Ivey-sol® Free NAPL Product Remediation

Ivey International Inc.
“Today's Environmental Solutions For A Better Tomorrow”™

ROUX

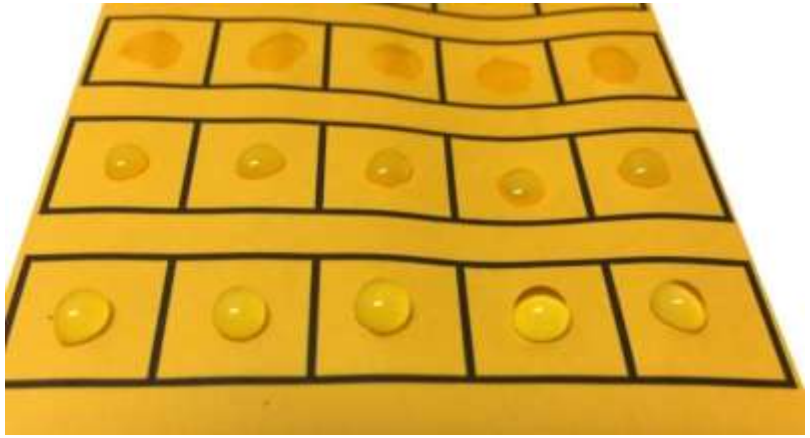
AMTRAK

Injection Areas (8 LNAPL Wells)



Pilot Study Methods

1. Injection (gravity fed/geoprobe)
   - Experimented with surfactant to water ratios
   - Experimented with volumes of total mixture
2. Extraction (DPVE system)
   - Removed at least 3x the injection volume
   - Continued extraction until no surfactant was present
3. Extract from injection point or nearby extraction well

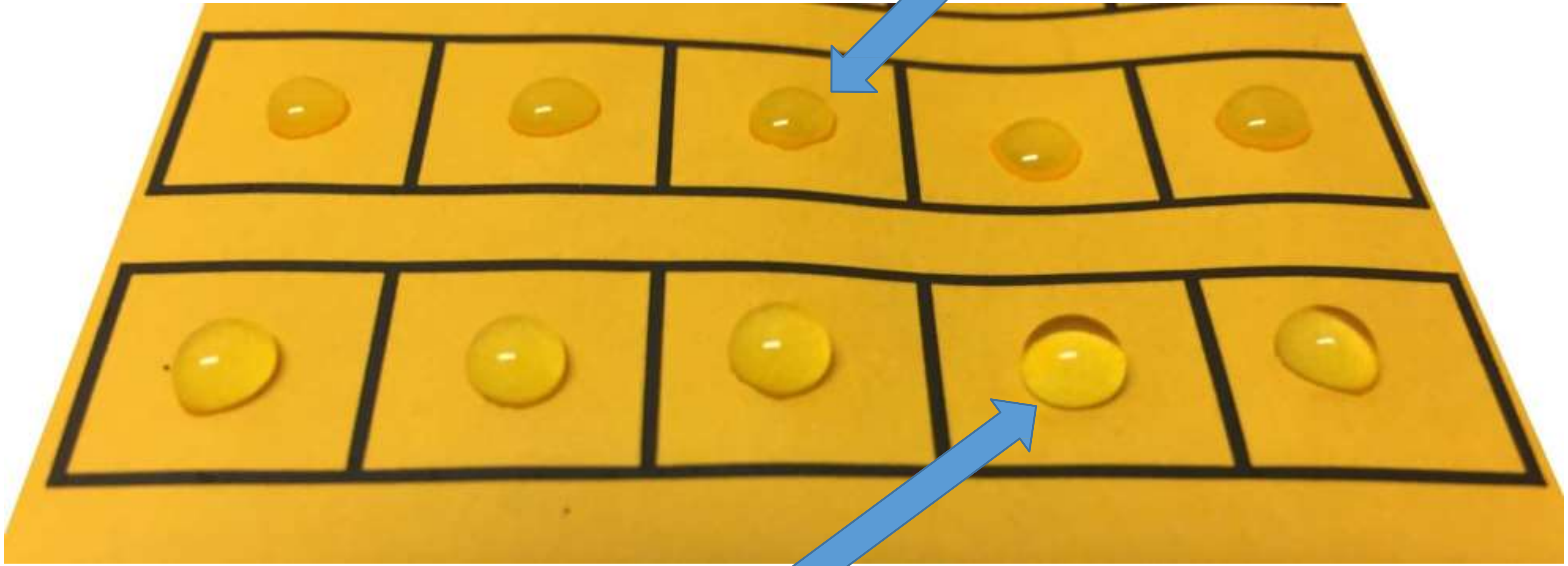


ROUX

AMTRAK

Water mixed with Surfactant

Irregular edges Loses its beading and Absorbed by the paper



Water free of Surfactant

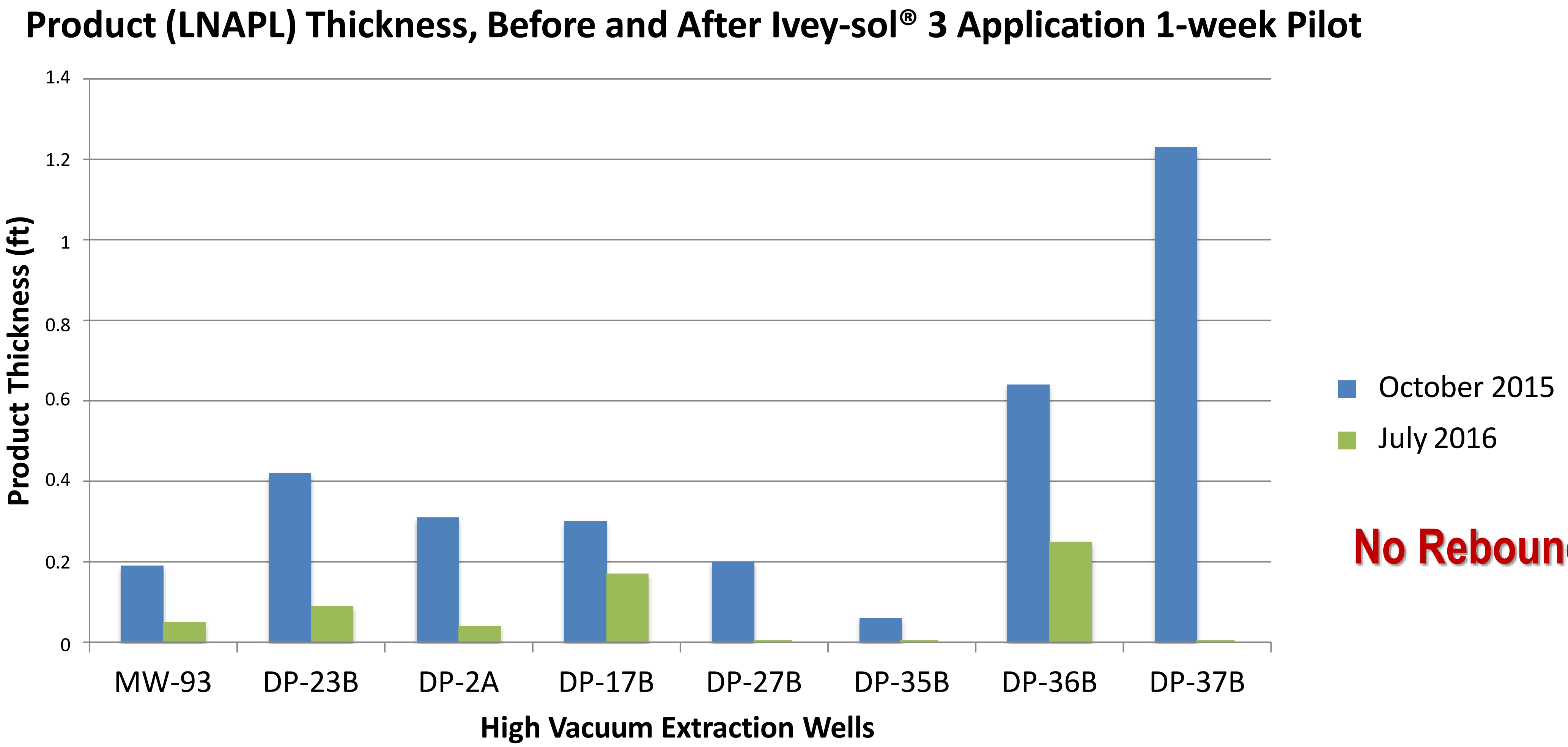
Forms near-perfect circles Retains its beading Does Not absorb into the paper

ROUX

AMTRAK

Pilot Study Results

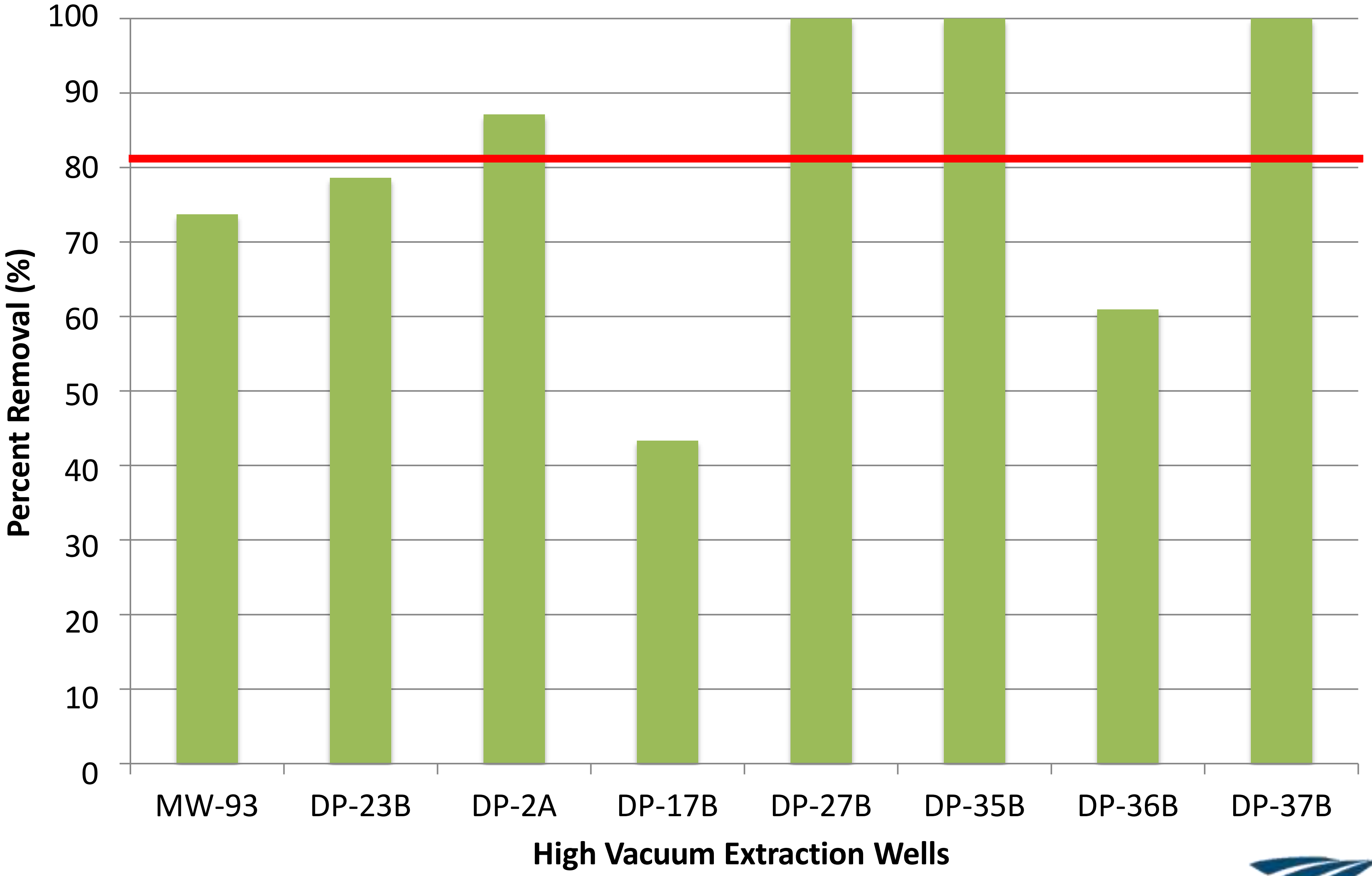
(IVEY On-site For 1 Week Application)



No Rebound

Free Product (NAPL) Percent Removal
3 Applications in 1 week

81% Average LNAPL Mass Removal



ROUX

AMTRAK

Conclusions

- NAPL recovery was enhanced by the increase of NAPL miscibility
- Free product was not observed in the extracted groundwater
- Reduction of NAPL thickness was usually observed within 24 hours of Ivey-sol surfactant injection and persisted for several weeks or longer.
- Low concentration ratios of surfactant (1:50) are effective and higher concentrations (1:20) do not increase observed effectiveness
- Low injection volumes or injection rates were generally needed in OU-3 due to the low permeability soil conditions and high groundwater table.
- *Pilot lead to full scale application with clean-up achieved in < 6 months.*

ROUX AMTRAK

TIME CHECK

CASE STUDY #3

Abbreviated Presentation Version. Contact IVEY for full version if interested.

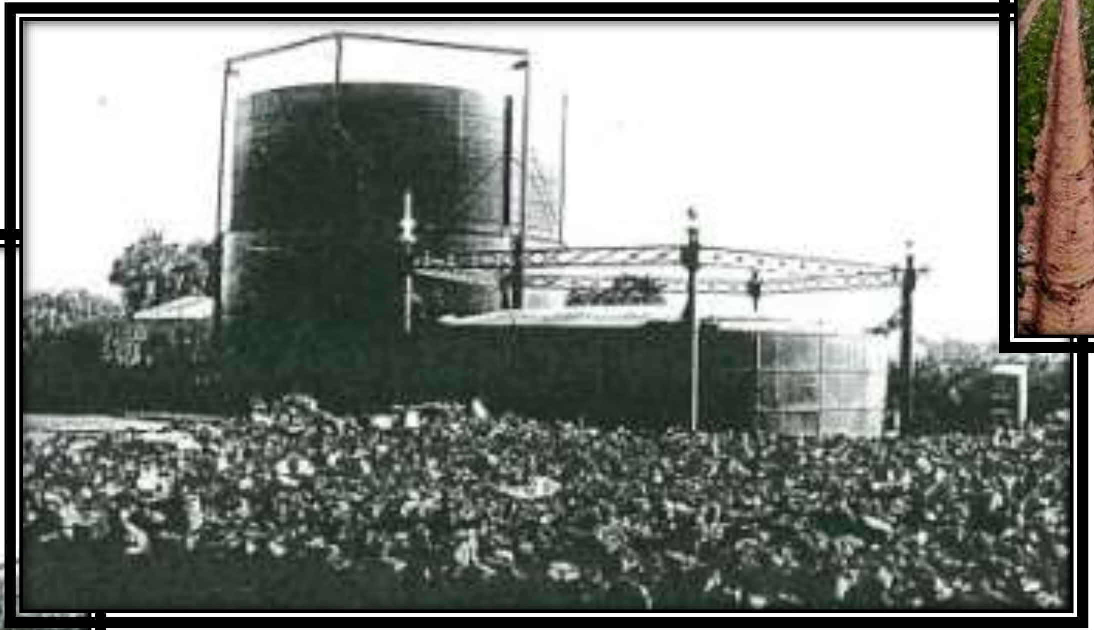
Sustainable outcomes with Ivey-sol® surfactant enhanced aquifer remediation (SEAR) of coal tar NAPL

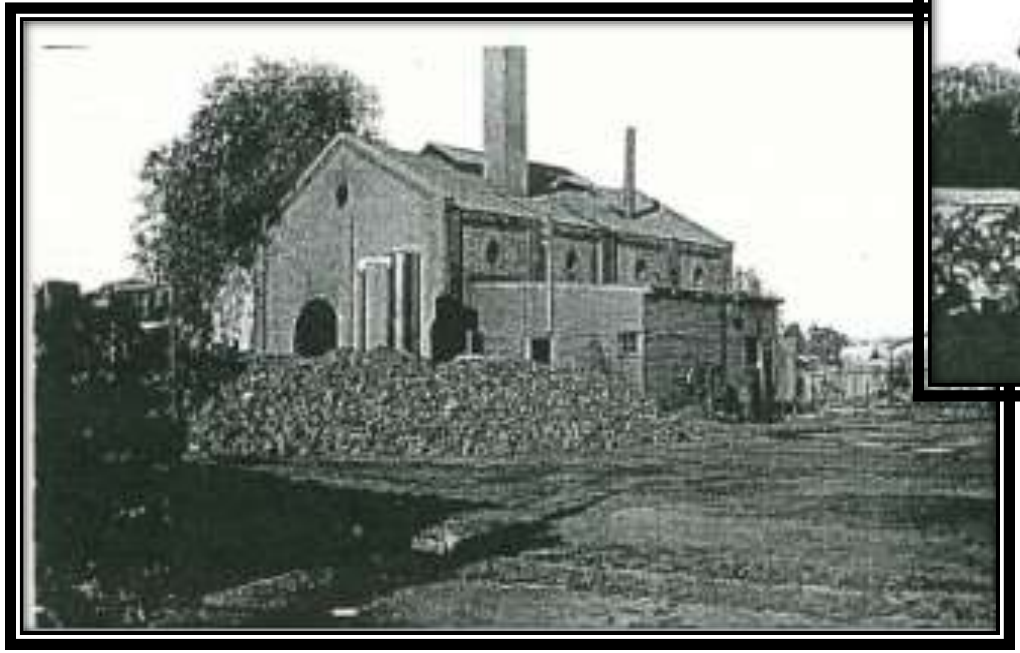
Australasian Groundwater Conference 2019,
Updated 15 January 2020

Daniel Hirth, CEnvP
BlueSphere Environmental Pty Ltd
113 Ferrars Street
Southbank, VIC 3006
Australia

Background

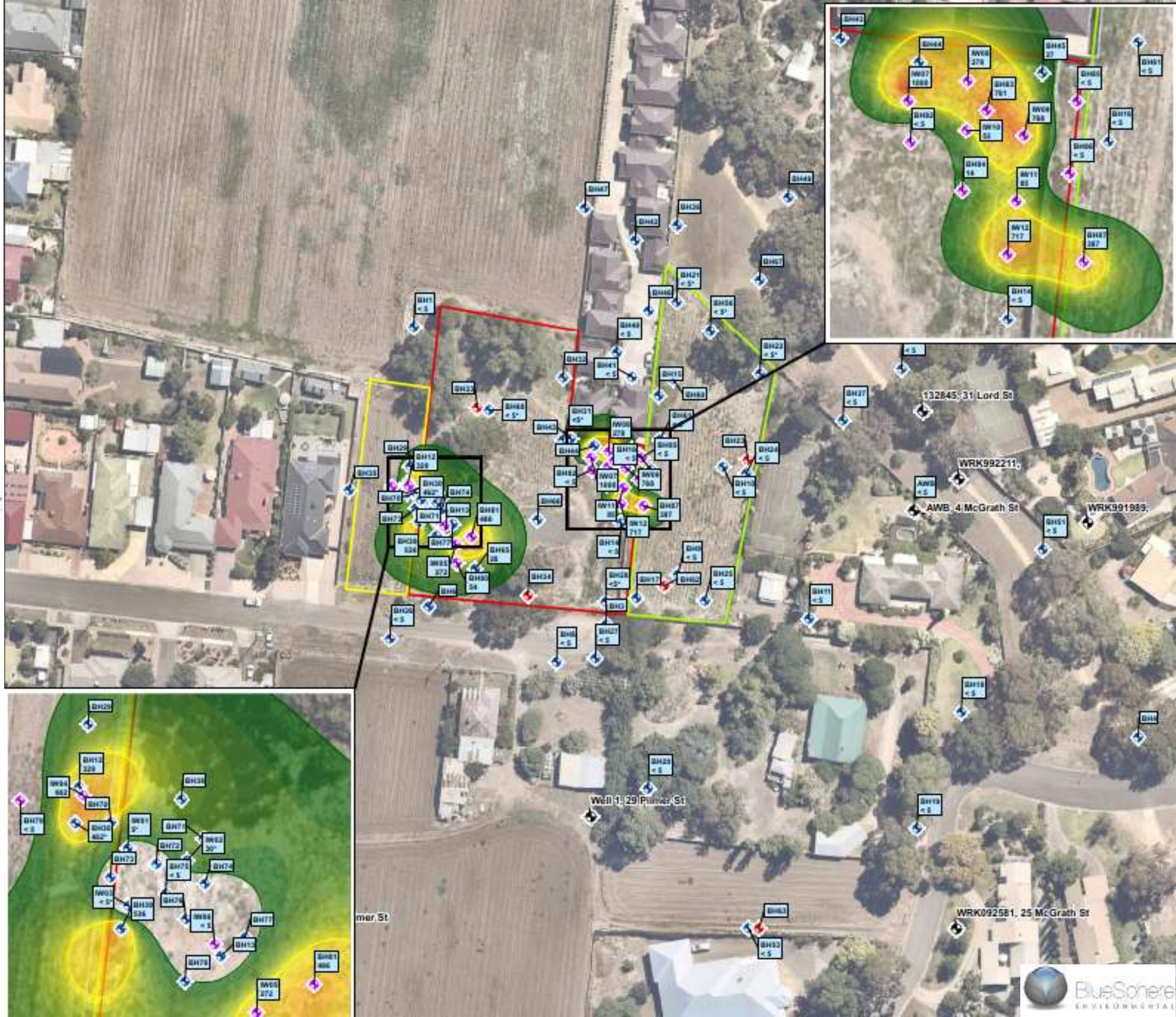
Rural gasworks from 1889-1973
Coke, tar and ammonia by-products generated
Soil and groundwater impacted.





Background

Two source zones: former tar/liquor disposal wells. Plan shows dissolved naphthalene as an indicator of NAPL.



Legend

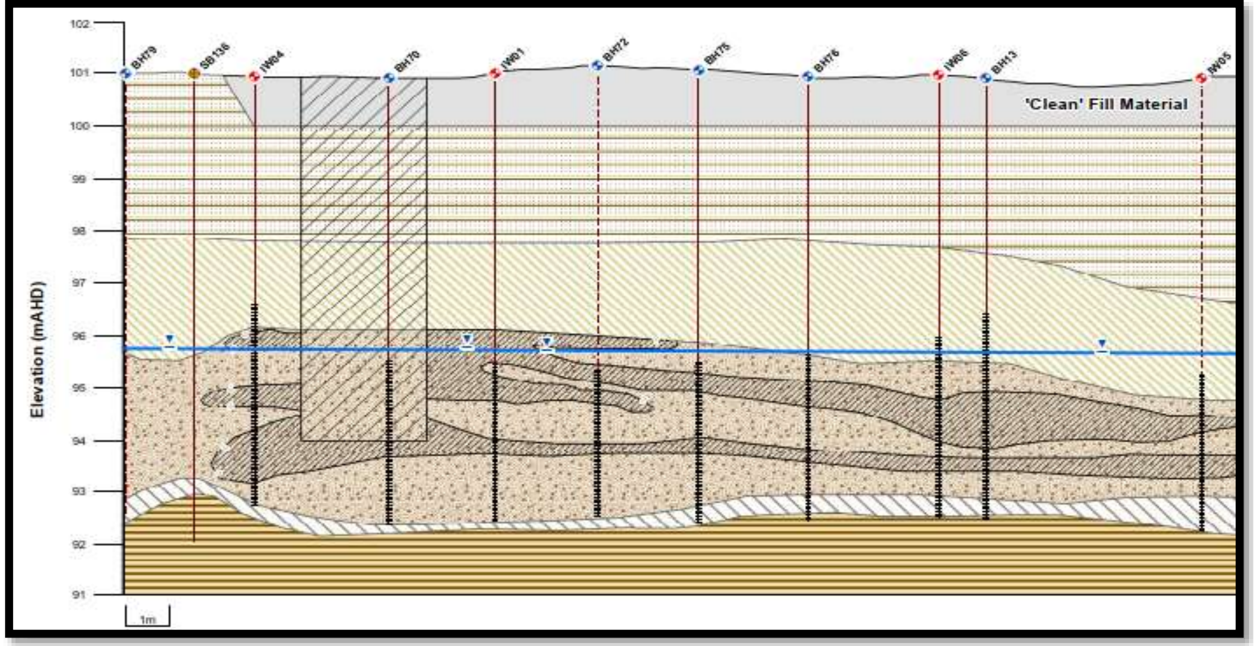
DTF Parcel Boundaries

- Site - 28 Pilmer Street (Former Bacchus Marsh Gasworks)
- 26 Pilmer Street (Former Provenzano Property (DTF))
- DTF McGrath Street
- Newly Installed Well
- Shallow Aquifer Well
- Deep Aquifer Well
- Private Well

Naphthalene Concentration (µg/L)

- 10
- 100
- 1000

Objective



Issues:

- Non-aqueous phase liquid (NAPL) presence
- Dissolved chemicals of concern: naphthalene, benzene, ammonia, cyanide (free), sulfate

Site objective:

- Remove/reduce contamination liability
- Limit impacts to adjoining sensitive receptors including residences
- Divestment of surplus land

Remediation Objective:

- Reduce source zone contaminant mass, so far as reasonably practicable.

NAPL Conceptual Model:

- Over 100 wells installed, half in the source zones.
- Alluvial aquifer 16 – 28 feet BGL (5 - 8.5 mBGL);
- Clayey lignite lower confining unit (Werribee Fm);
- Distributed NAPL beneath tar wells, minor LNAPL

Methodology

Process:

ROA → Trials → RAP → Approvals

Surfactant Enhanced Aquifer Remediation (SEAR)

We used a non-ionic, selective surfactant (Ivey-sol) engineered for use with long-chain hydrocarbons to lower the surface tension (not to emulsify).

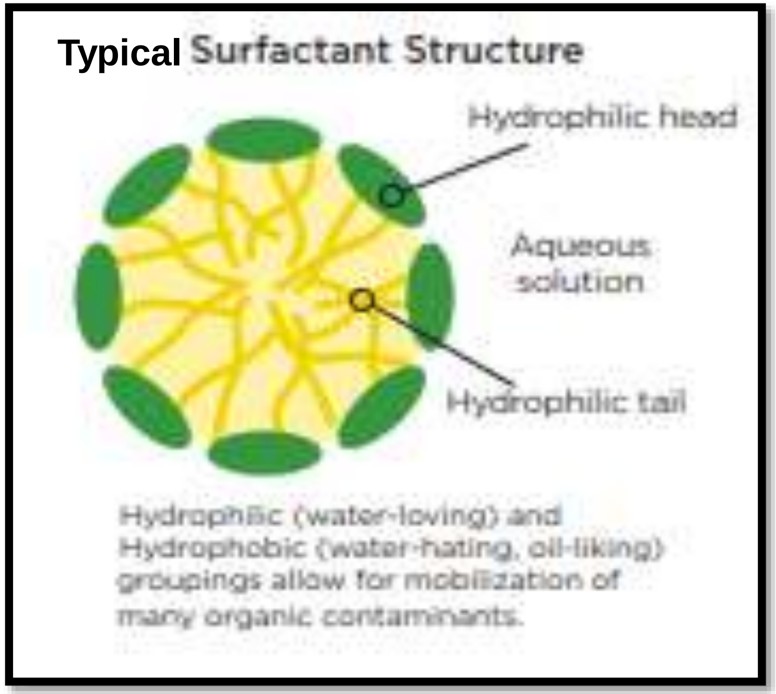
Sub-critical micelle application

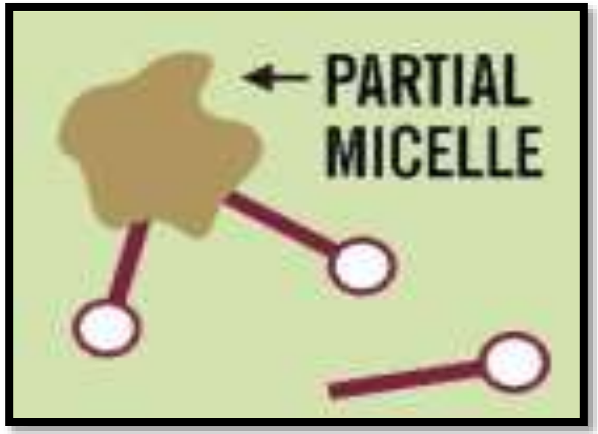
Applied through injection and recirculation

NAPL continuously removed from recirculated water

Last stage is to extract surfactant and treat

1) re-injection (limited by cyanide concentrations)
2) trade waste (primary method of disposal)
3) Off-site transport





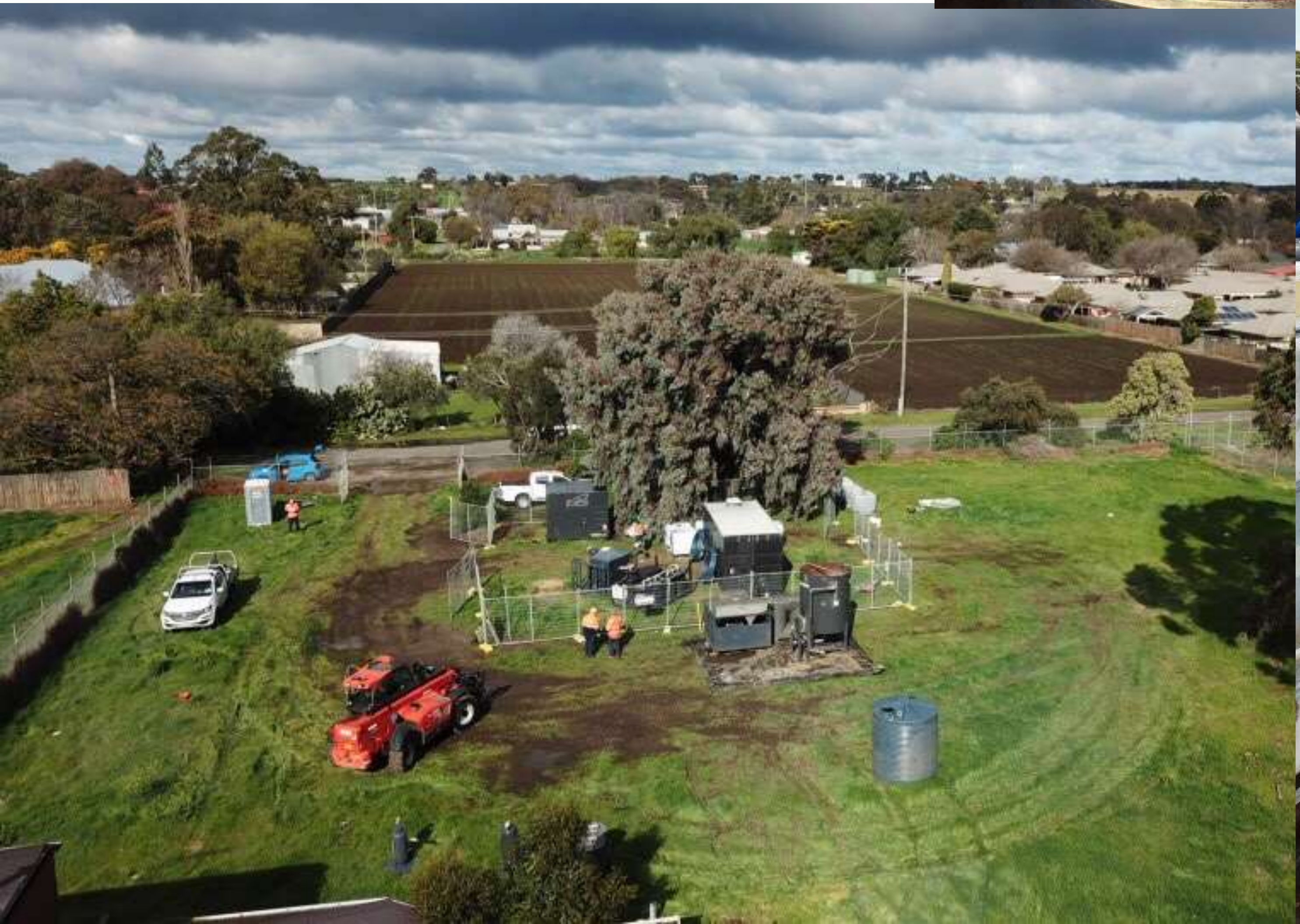
Ivey-sol only needs to form a partial micelle.

So lower dosage and greater SEAR economics.

Ivey-sol does not need to emulsify contaminants. As selective below the CMC = greater precision and accuracy for in-situ SEAR applications.

Methodology

SEAR (Ivey-sol) - MPE system



Results

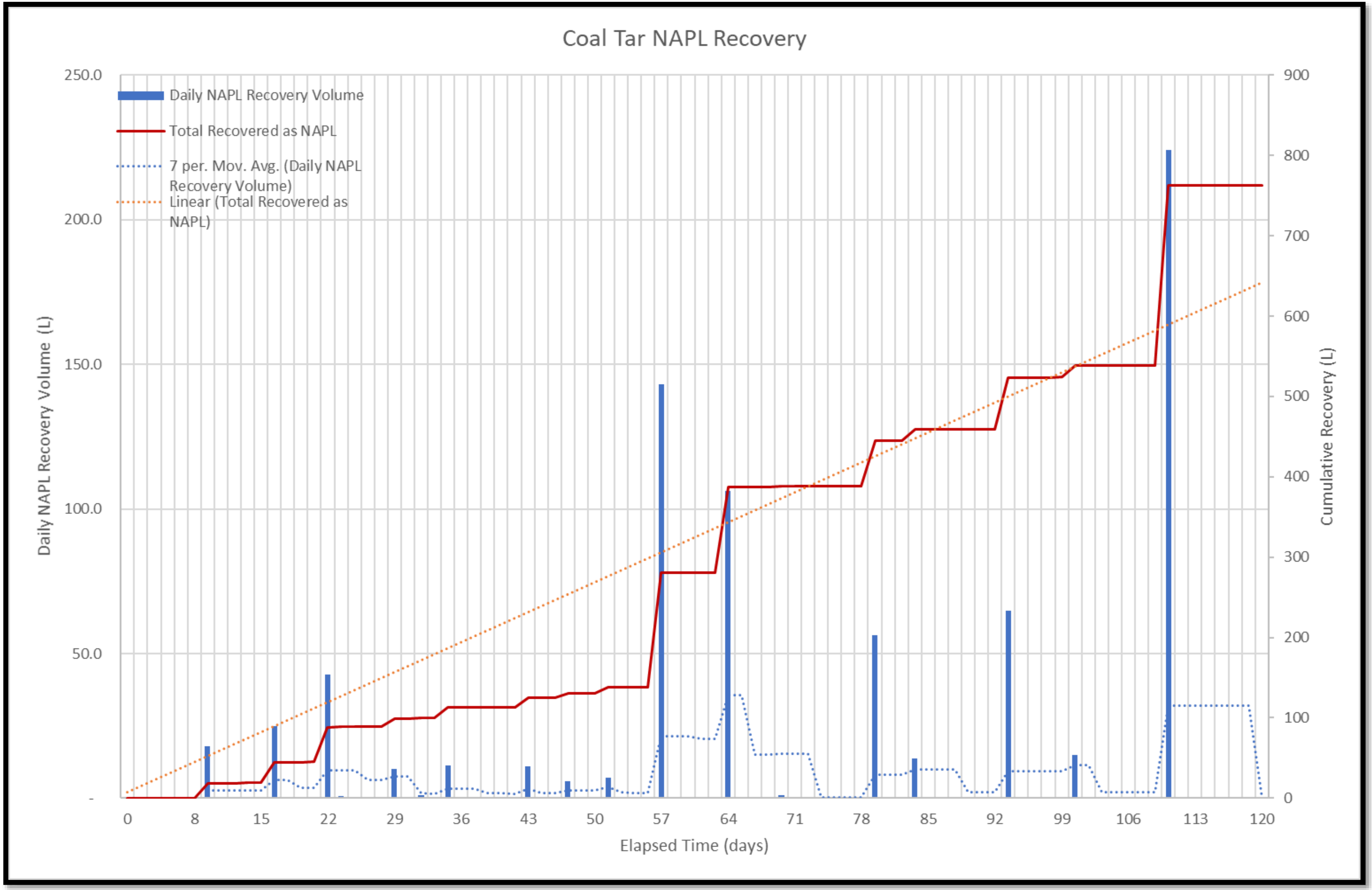
What we observed:

Very rapid NAPL coalescence (~15min); and

NAPL mobilisation for enhanced recovery **(both LNAPL & DNAPL)**

Both visual and quantitative NAPL recovery over Ivey-sol SEAR four (4) month application. Realizing Effective NAPL mass removal.

Results



Coal Tar NAPL Recovery
Daily NAPL Recovery Volume
Total Recovered as NAPL
7 per. Mov. Avg. (Daily NAPL Recovery Volume)
Linear (Total Recovered as NAPL)
Daily NAPL Recovery Volume (L)
Cumulative Recovery (L)
Elapsed Time (days)
250.0
200.0
150.0
100.0
50.0
-
900
800
700
600
500
400
300
200
100
0
0
8
15
22
29
36
43
50
57
64
71
78
85
92
99
106
113
120

Conclusions

- **SEAR (Ivey-sol)** with groundwater extraction can be a viable remediation method for tar NAPL in aquifers that have:
  - Limited human and environmental receptors
  - Unconsolidated sediments
  - Sufficient effective permeability for NAPL entry,
  - And sufficient, interconnected permeability for NAPL extraction.
- **Sustainability**
  - Economic: <cost than other possible methods (e.g. co-solvent, thermal, stabilisation)
  - Social: low noise, no odour, reduced street traffic
  - Environmental: Biodegradable Ivey-sol surfactant, reduced wastewater generation, reduced filter media requirements
- **Audit CUTEP completion by late 2020**.
  - With land returned to normal use.
- ***Remediation system was turned off in late January 2020.***

BlueSphere ENVIRONMENTAL

Steps To Using Ivey-sol At Petroleum, Chlorinated, and PFAS Remediation Sites

Step #1 (Evaluation)

Ivey-sol® Surfactant Technology

Ivey International Inc.
Suite 61-2955-156 St,
Surrey, BC, Canada V3S 2W8
Tel: 1-800-246-2744
Fax: 1-888-640-3622
Email: budivey@iveyinternational.

General Site Information Form

Client Information

Date: ________ Ivey Contact: ________

Company name: ________ Contact Person: ________

Email: ________ Phone: ________

Fax: ________ Cellular: ________

Street address: ________

Shipping address: ________

Project Information:

Project Name: ________

Project Location: ________

Project Number: ________

Regulatory Agency: ________

Land Use and Zoning (Circle): ○ Parkland ○ Agricultural ○ Residential ○ Commercial ○ Industrial

Site Information:

Remediation Objectives: ________

Contaminant(s) of concern (TPH, BTEX, TCE, PCB, etc.) ________

Soil Impacted: Yes / No Groundwater Impacted: Yes / No Vapor Impacts: Yes / No

Is NAPL Present: ________ Time Since Release: ________

Soil Type(s): ________ Soil Porosity: ________

Depth to Groundwater: ________ Hydraulic Conductivity (K): ________

Hydraulic Gradient: ________ Groundwater Flow Direction: ________

Area of Contamination: ________ Maximum Depth of Contamination: ________

Current Remediation Activities: ________

Monitoring Well Network Information:

Number of Existing or Proposed Monitoring Wells: ________

Number of Proposed Injection Wells: ________

Number of Proposed Extraction Wells: ________

Please Provide the Following:

- Site location map or drawing
- Site map showing source/treatment area and isoconcentration contours (if available)
- Site map showing monitoring and injection well locations and ROI estimates
- Table summarizing well construction details and GW level history
- Pilot test results (if available)
- Geologic cross section
- Copy of laboratory analytical results or summary table of contaminants of concern
- Site photographs
- Site investigation report

Please complete this site information form and return to: budivey@iveyinternational.com

©Ivey International Inc.

Step #2 (In-situ/Ex-situ Application Model Development)

Step #3 (Ivey-sol Selection)

Contaminant of Concern (COC)	Ivey-sol® Formulation Required
BTEX, Gasoline, Jet Fuel	103
Diesel (Light-Medium Heavy), PAH	106
Chlorinated Solvents (DNAPL, API <10)	106 (CL)
Motor Oil, Lubricants, Bunker-C	108

Note: For contaminants of concern (COC) not listed above contact IVEY directly.

Step #4 (Dosage Determination)

If Contamination is sorbed or dissolved Phase Apply ≤ 2% Ivey-sol
If LNAPL or DNAPL Phase Apply ≤ 4% Ivey-sol.

Step 5 (Proposal)

IVEY-SOL®
Surfactant Technology
www.iveyinternational.com

In consideration of COVID-19 Impact on Environmental Industry We Are Giving Attendees Preferred Client Discount of 5% on IVEY Products For Balance of 2020

Ivey International Inc.

The annual listing of 10 companies that are at the forefront of providing Environmental Technology solutions and transforming businesses

CONTACT INFORMATION

George (Bud) Ivey
President & Senior Remediation Specialist
Ivey International Inc.
Mobile: + 1 250 203 0867
Toll Free: 1 800 246 2744
Email: budivey@iveyinternational.com
info@iveyinternational.com
Web: www.iveyinternational.com