Management of Chlorinated Solvent DNAPL Pools and Ganglia: Nightmare or Opportunity to Speed Up Remediation

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deltanova

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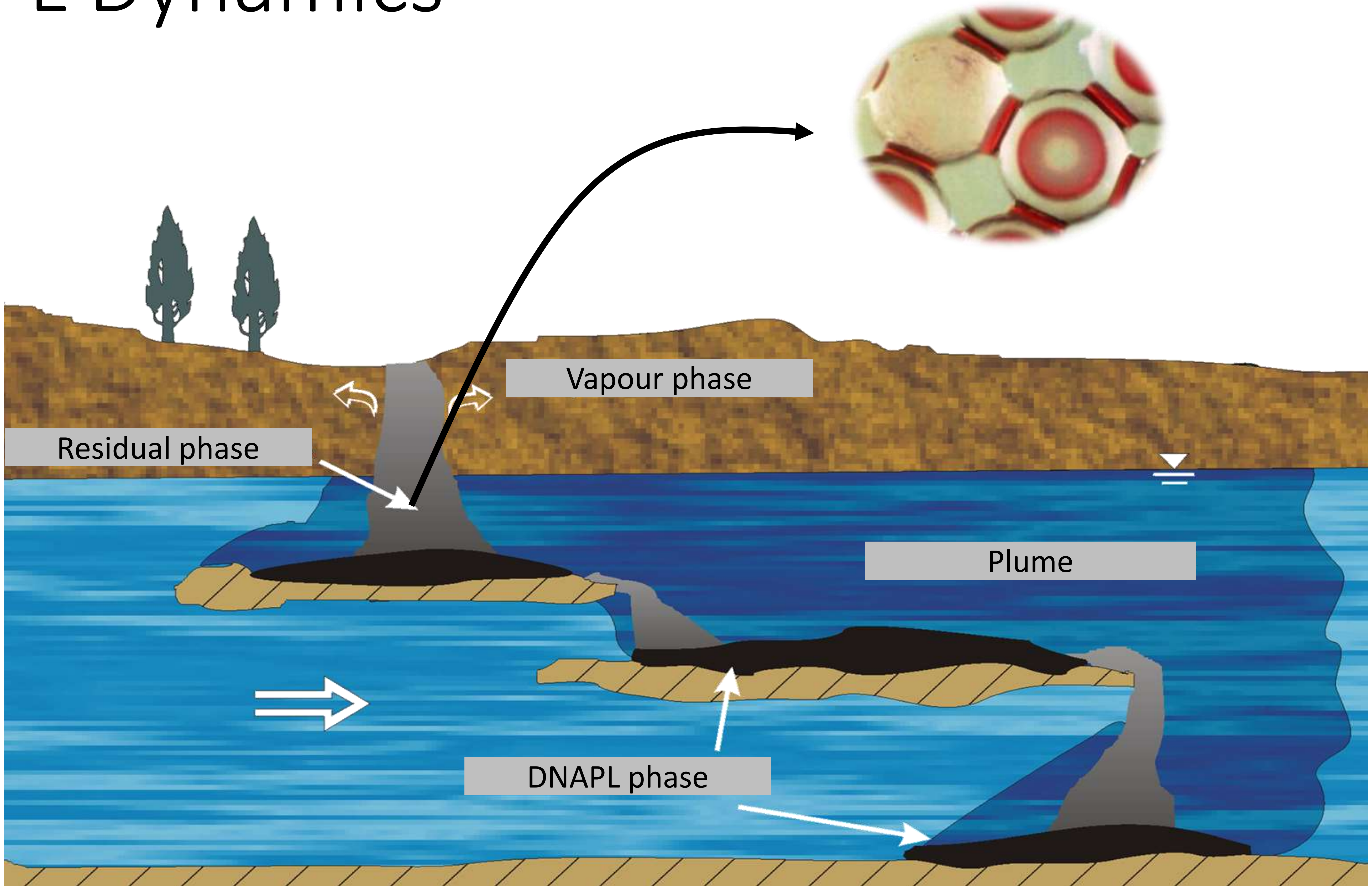
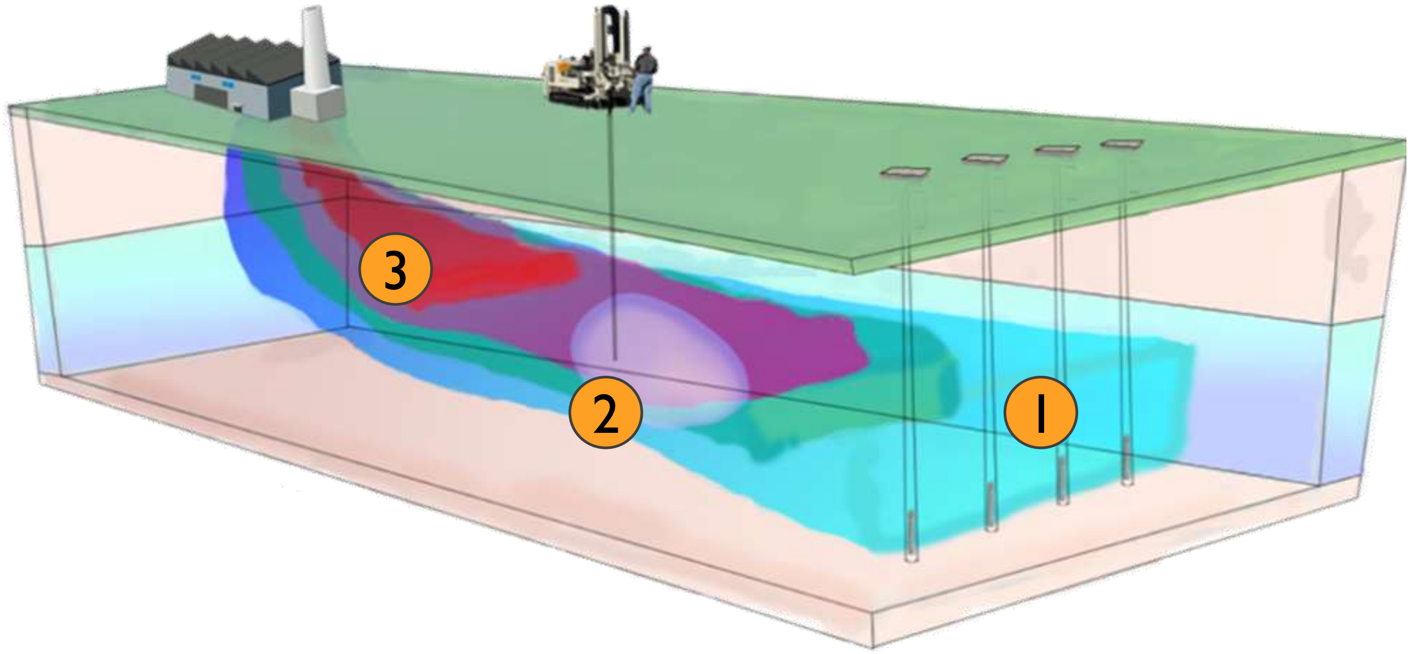
DNAPL – a nightmare for remediation

- Dense Non-Aqueous Phase Liquids
  - **Immiscible** in water
  - **High density**
- **Persistent** contaminants
- **Low solubility** in water
- **High toxicity** – low MCLs

DNAPL Dynamics



Treatment options



1 Plume containment

- Hydraulic barrier or PRB
- Slow NAPL dissolution, long treatment time

2 Plume treatment/Source treatment

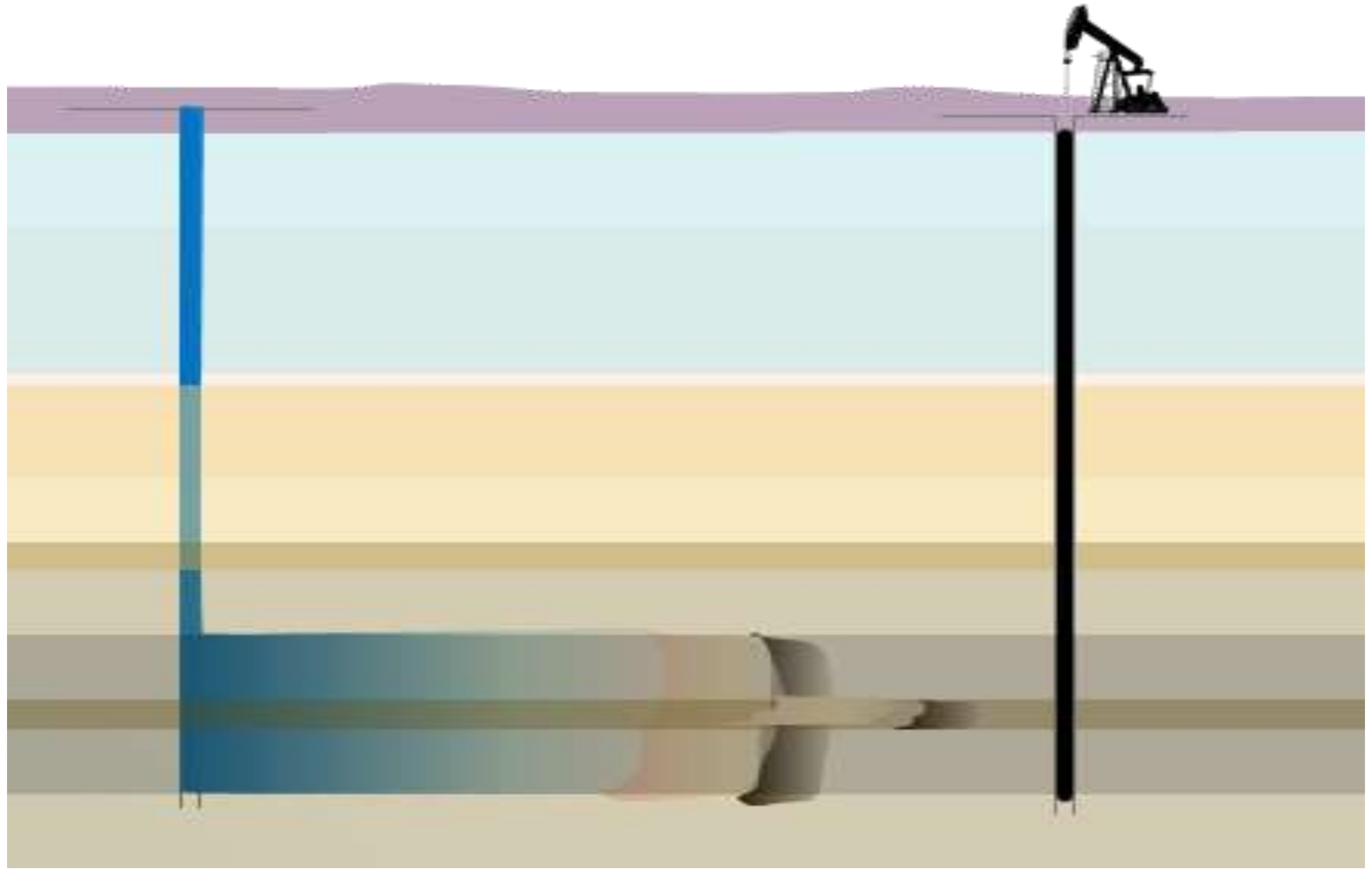
- ISCO, ISCR, Bioremediation
- Liquid phase reaction, increase NAPL dissolution, long remediation time
- Multiple applications may be required, e.g. high background flow

3 Source treatment

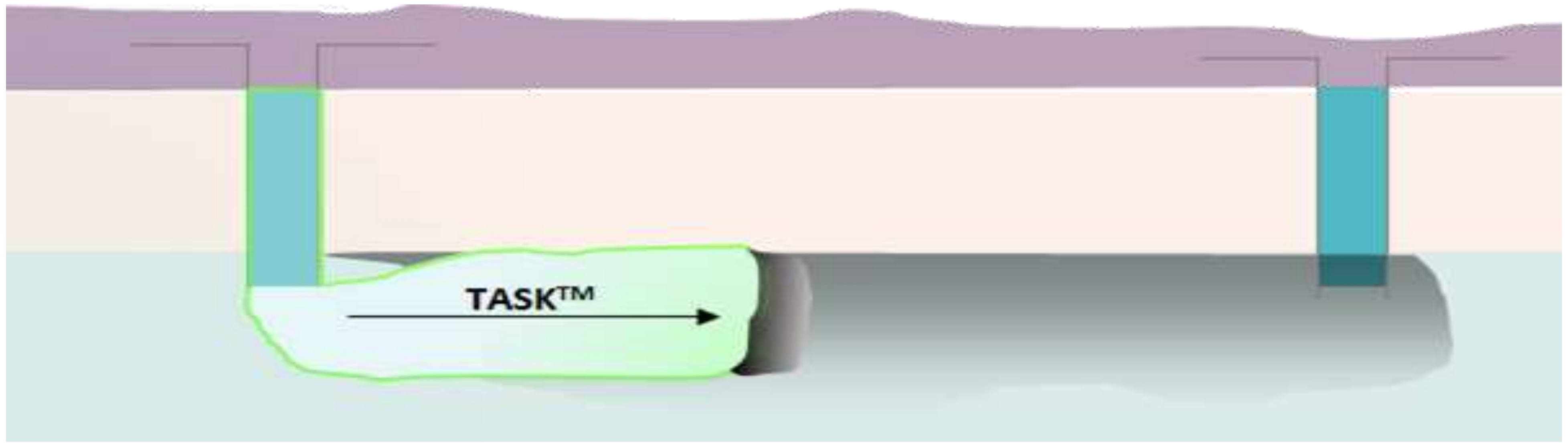
- Hydraulic pumping
- Ineffective vs residual phase due to interfacial forces

Surfactant-Enhanced Aquifer Remediation

Enhanced Oil Recovery (EOR)



SEAR



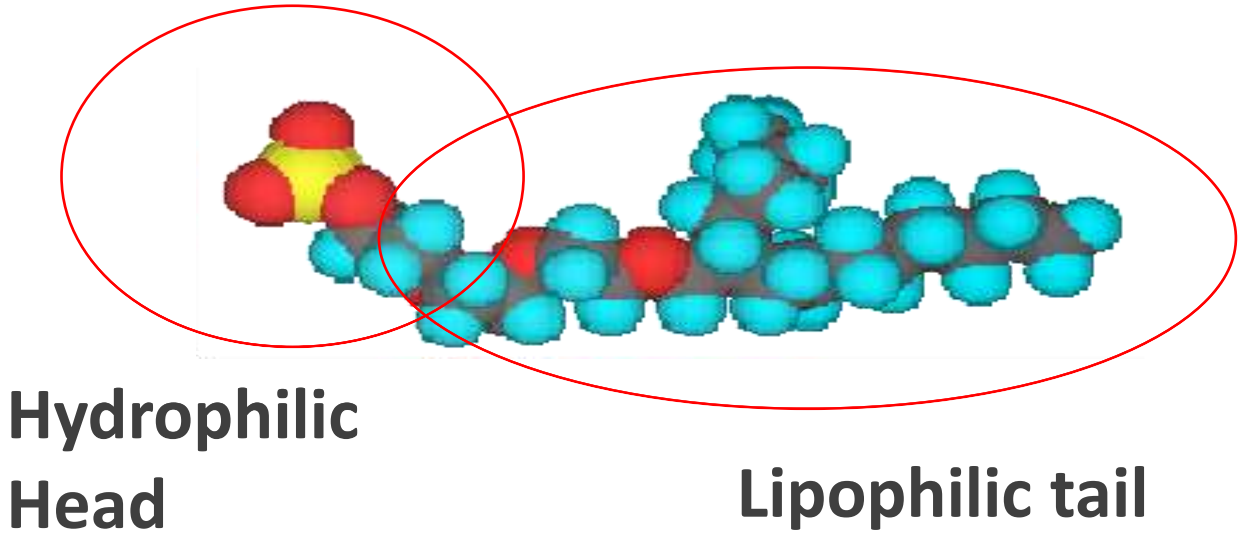
- Releases NAPL from aquifer pores → **Quick NAPL removal**
- It is a **mass removal technology**, not a polishing technique

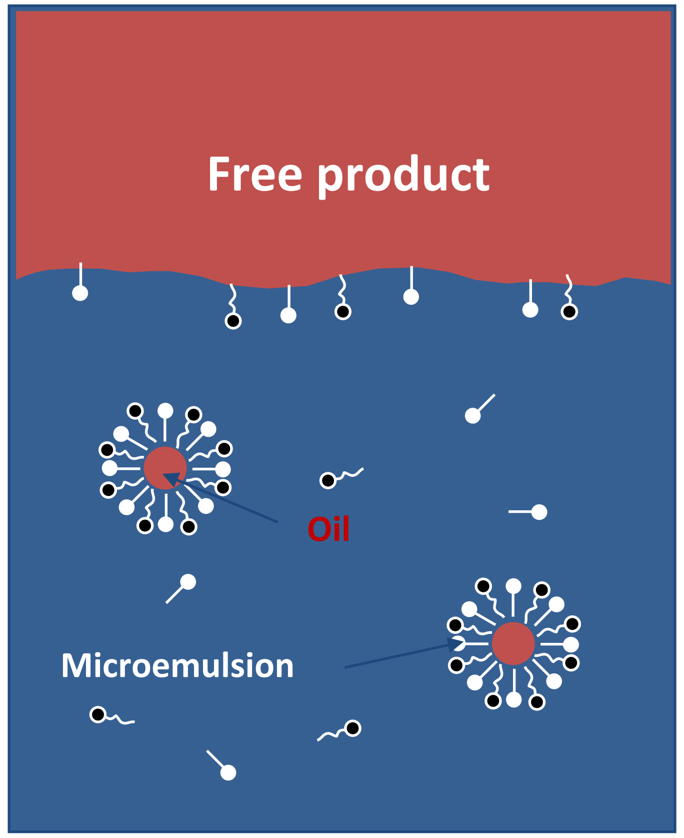
Surfactant-Enhanced Aquifer Remediation

- **TASK™ Surfactant** (Tersus Advanced Surface Kinetics)
- Anionic Surfactants for NAPL Mobilization
- Non-toxic and easily biodegradable
- Commercial surfactants passing EPA biodegradation requirements
- Tersus assigned Patents
  - U.S. Patent No. 6,913,419 B2
  - U.S. Patent No. 7,021,863 B2
  - U.S. Patent No. 7,364,386 B2
  - U.S. Patent No. 7,677,836 B2
  - U.S. Patent No. 7,708,496 B2

Surfactants

- <u>Surface Active Agent</u>
  - Found in everyday products
  - A substance which reduces the surface tension of a liquid in which it is dissolved



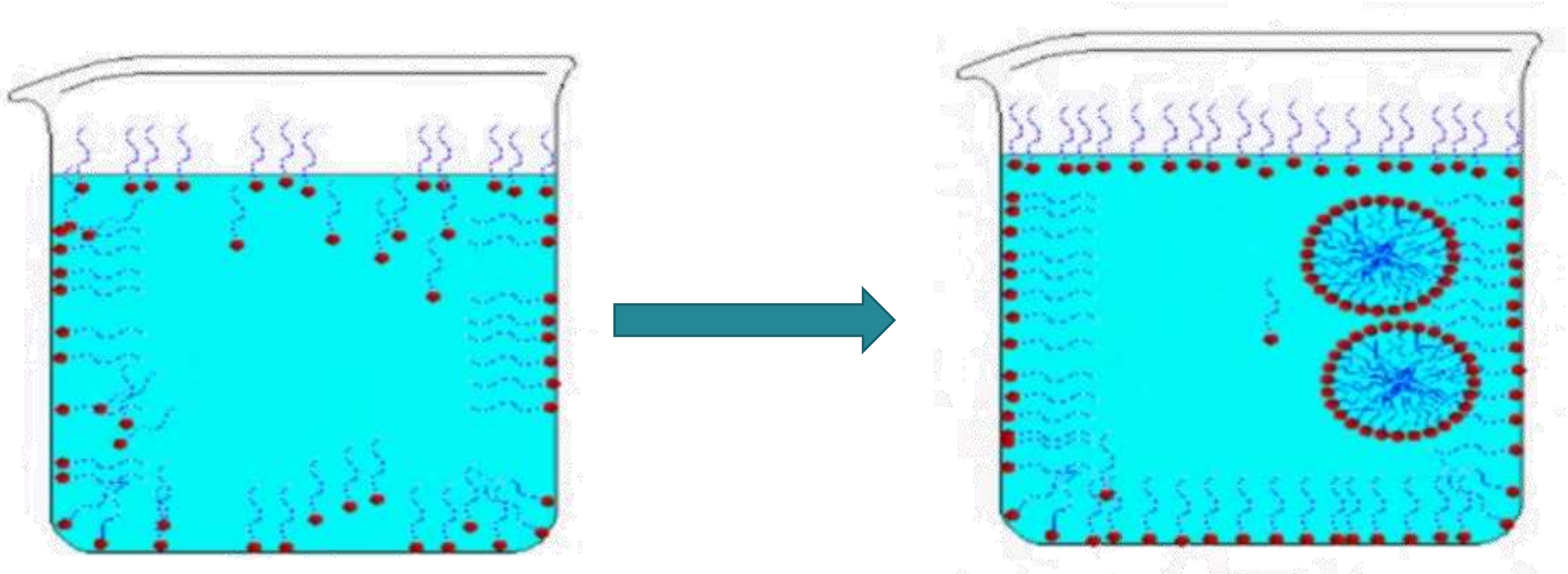


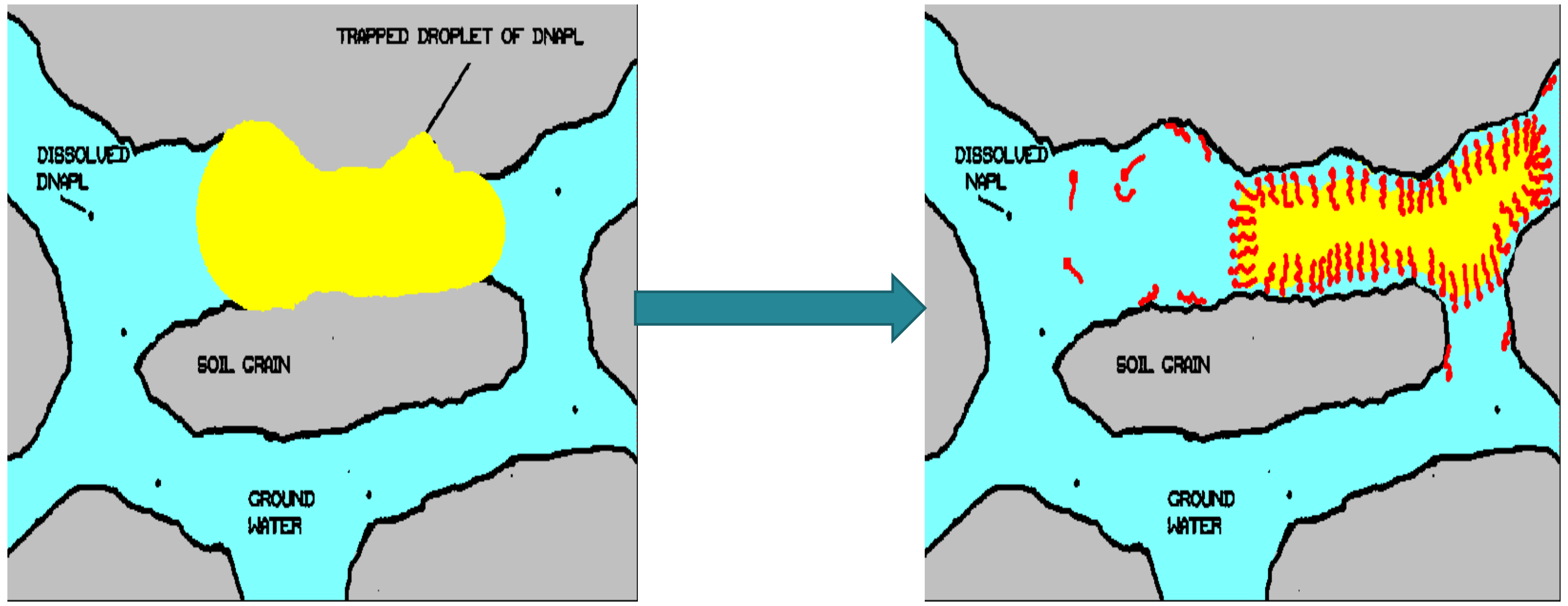
How surfactants work?

Faster

Solubilization vs. **Mobilization**

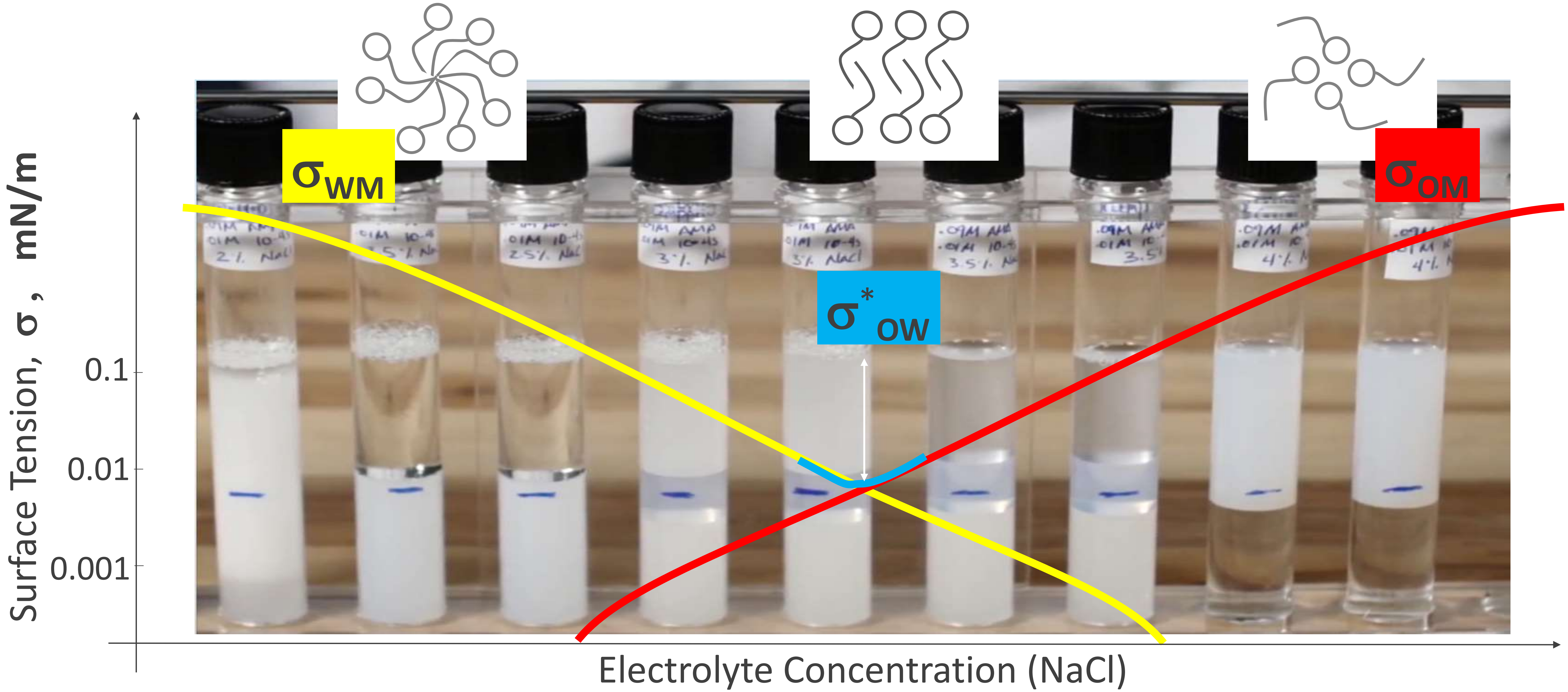
(micelles formation) (capillary displacement)





Optimizing surfactant formulations

SOW Phase Behavior

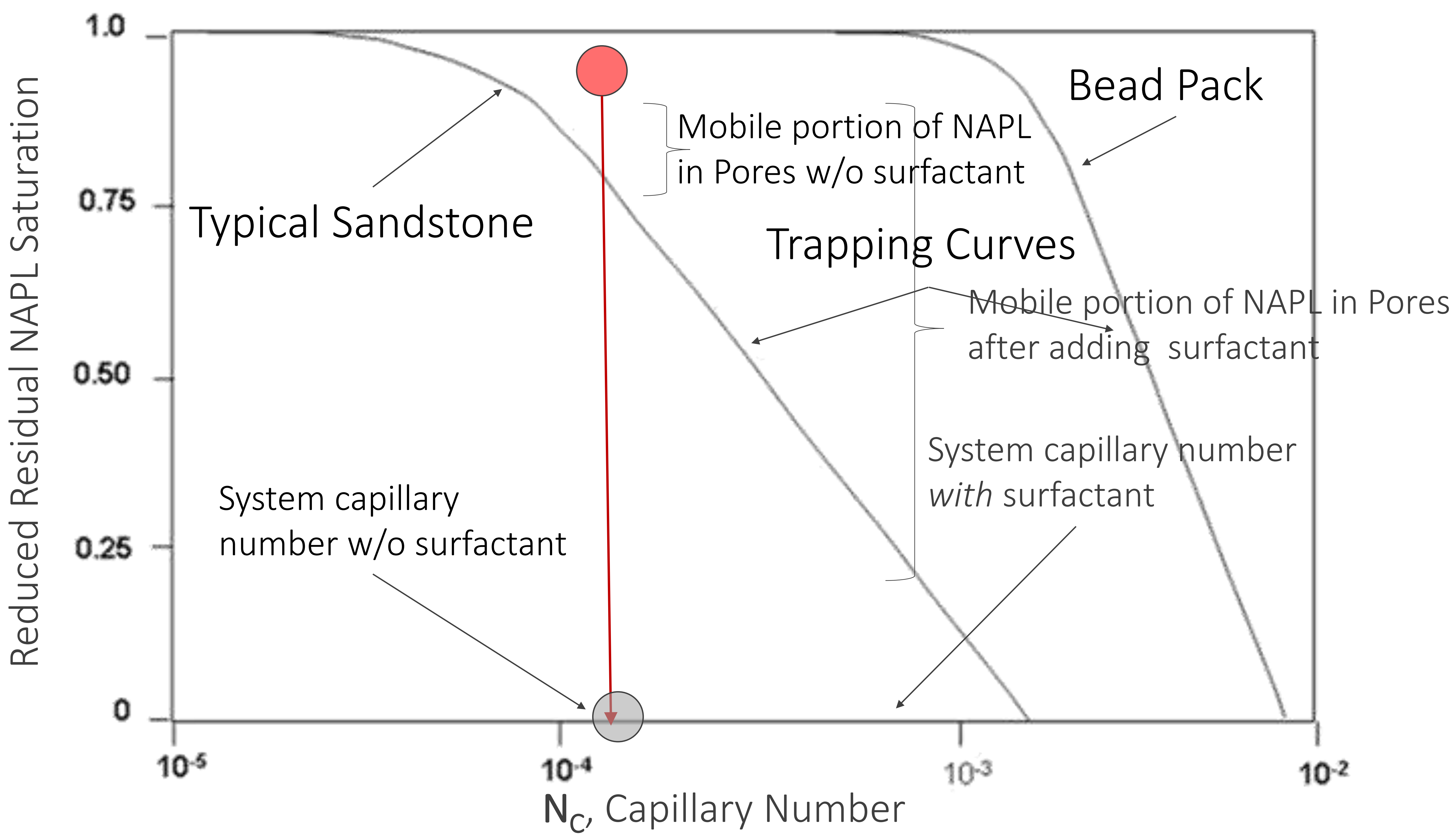


$$N_C = \frac{\mu v}{\sigma}$$

μ = fluid viscosity

v = fluid velocity

σ = surface tension



σ = 30 mN/m oil/water interface with no surfactant

σ = 2 mN/m oil/water interface with laundry detergent formulation

σ = 10^{-3} mN/m oil/water interface with phase behavior optimization

Optimizing surfactant formulations

Hydrophilic Lipophilic Difference

$$HLD = ln(S) - EACN \cdot k + C_c - a_T \cdot (T - 25) + f(A)$$

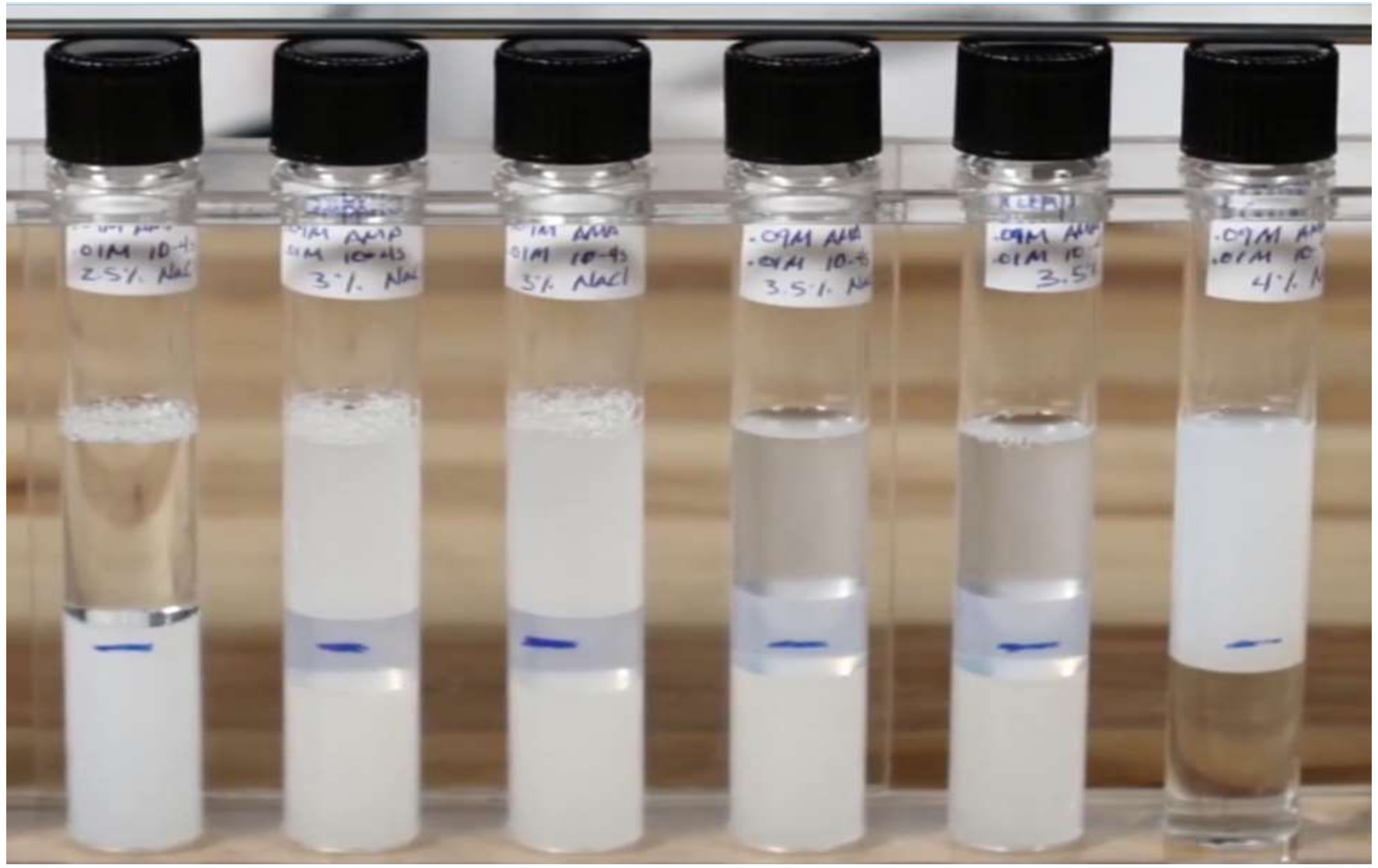
Electrolyte Type/conc.

Oil type

Surfactant parameters

Temperature coefficient

Cosolvent function



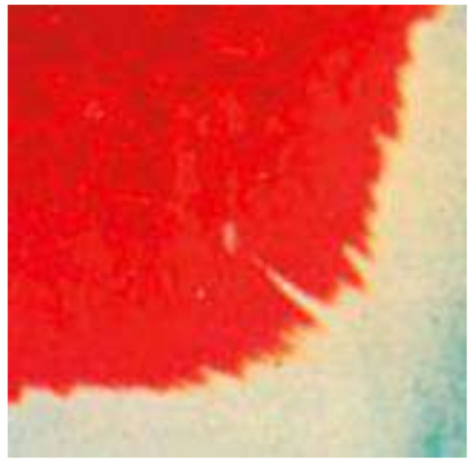
HLD=0, ultralow interfacial tension

Optimizing surfactant formulations

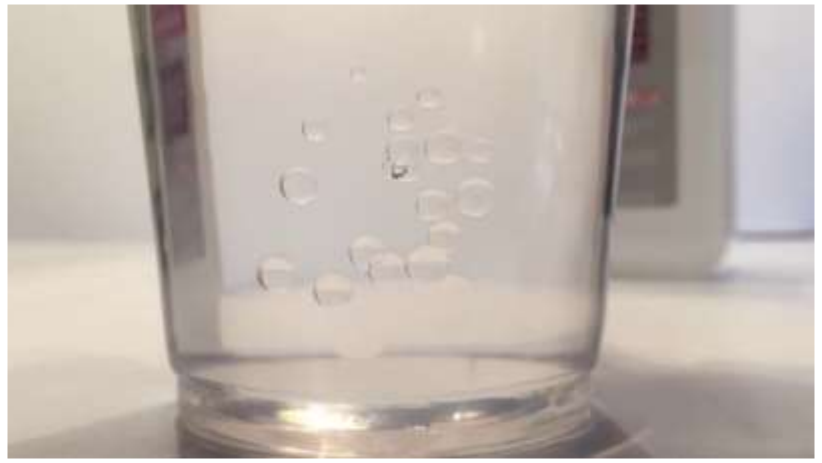
- **Sweep Efficiency Agents** for optimal removal of viscous NAPL

w/o SEA

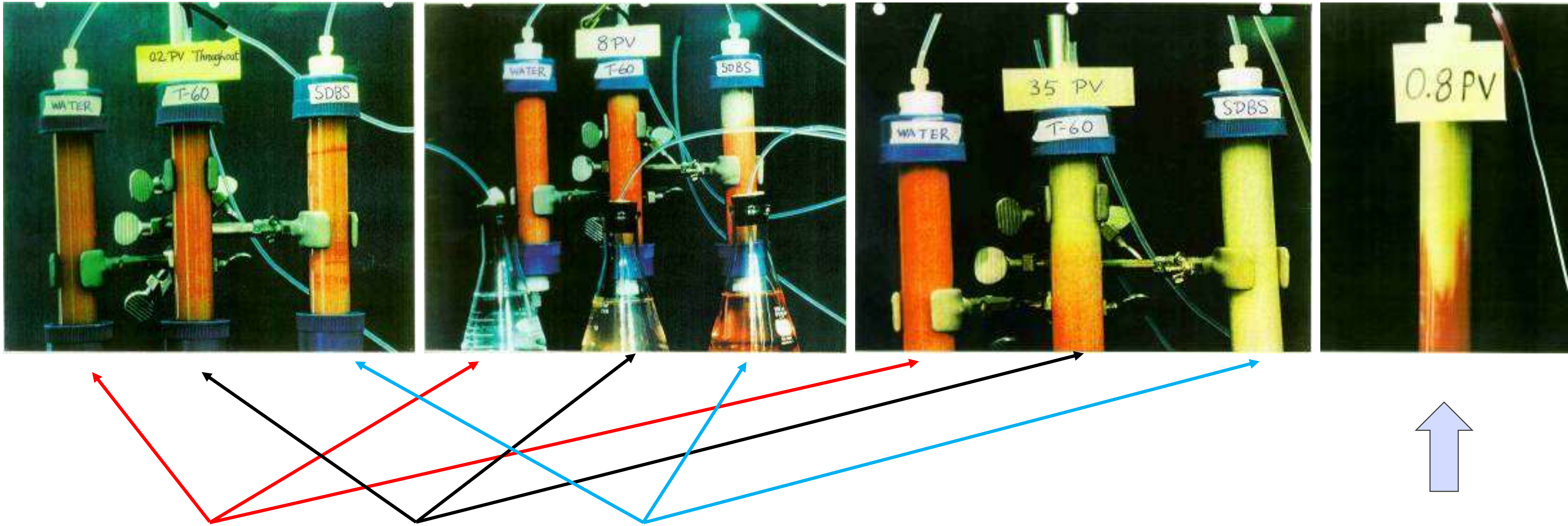
w/ SEA



- **Engineered co-solvents** to achieve neutral buoyancy for mobilizing DNAPL

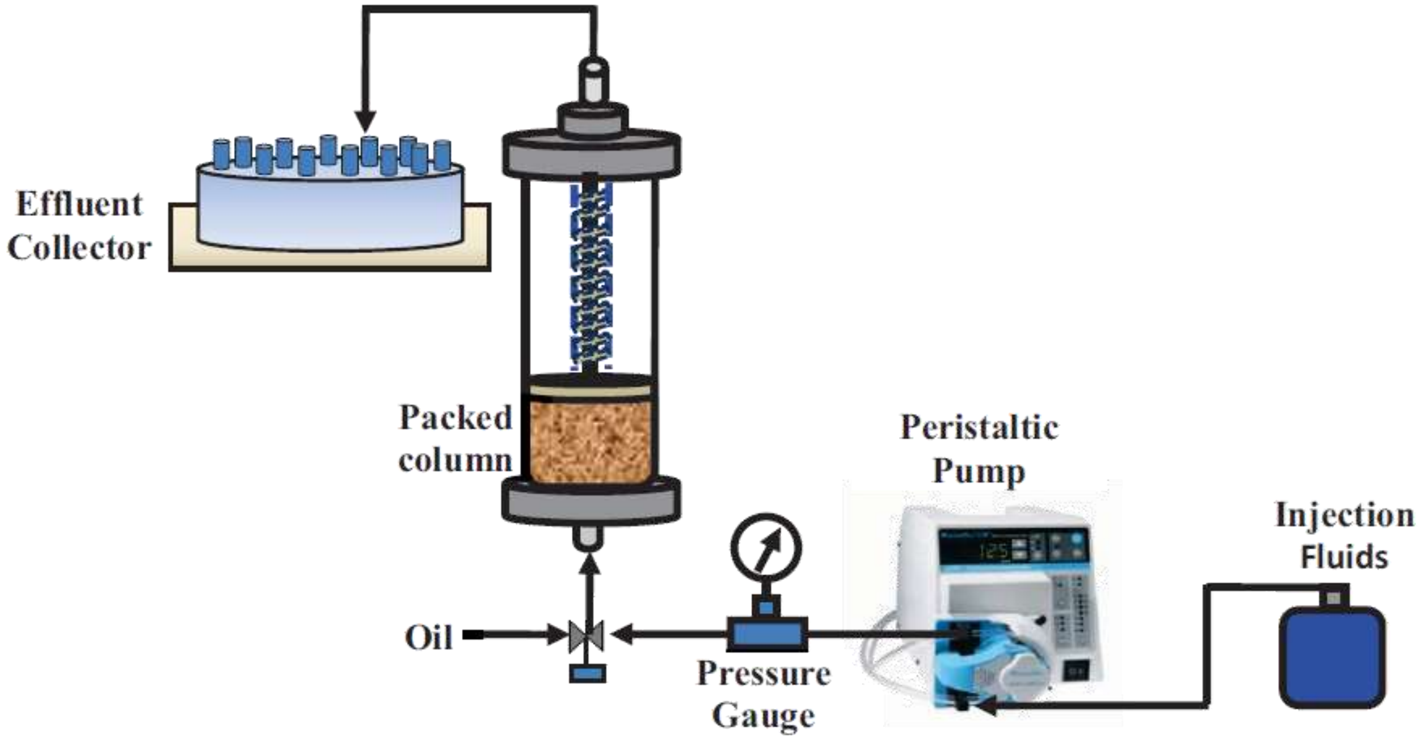


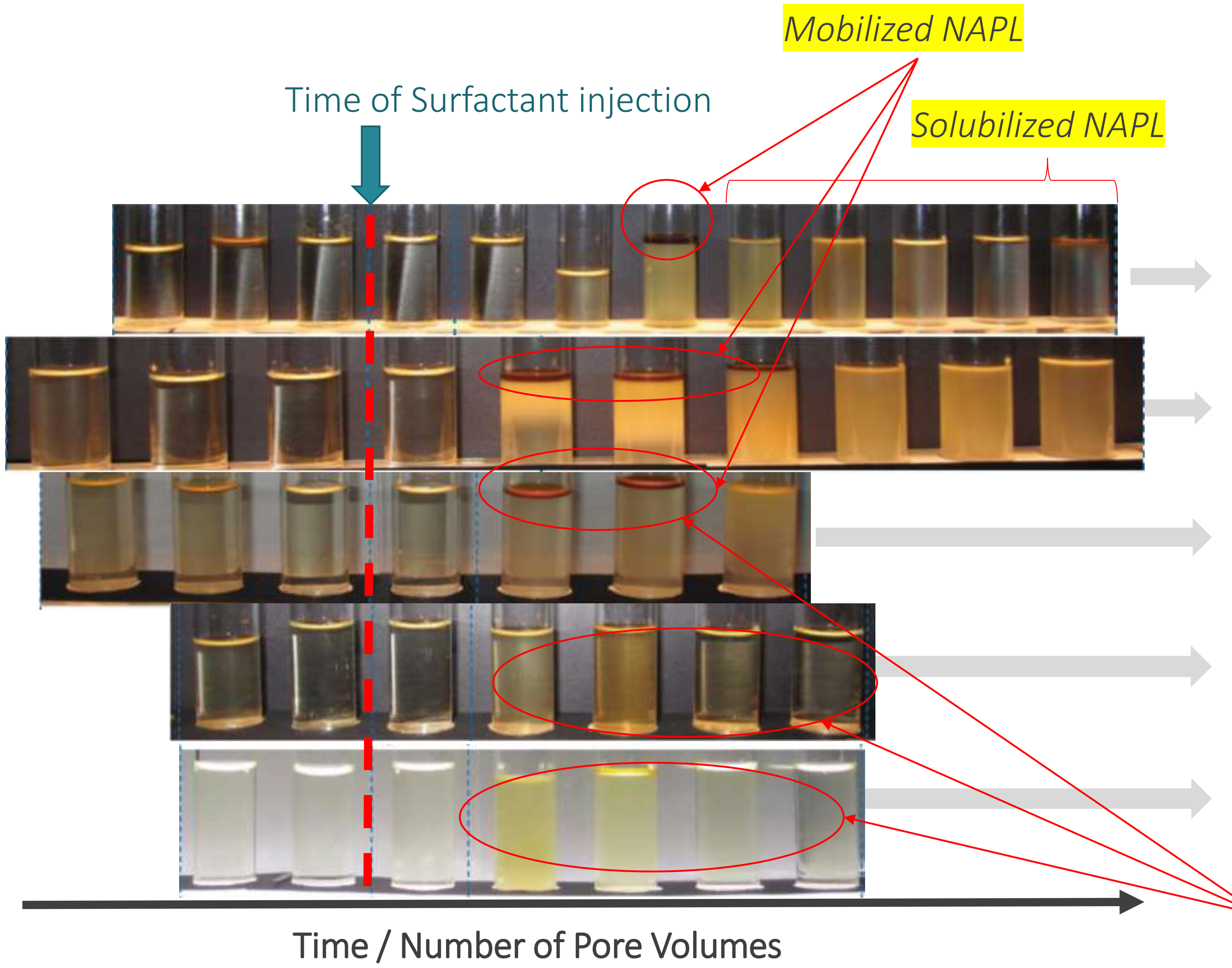
Lab Studies



Groundwater **Food** **Laundry** **OU Designed Blend**

Lab Studies

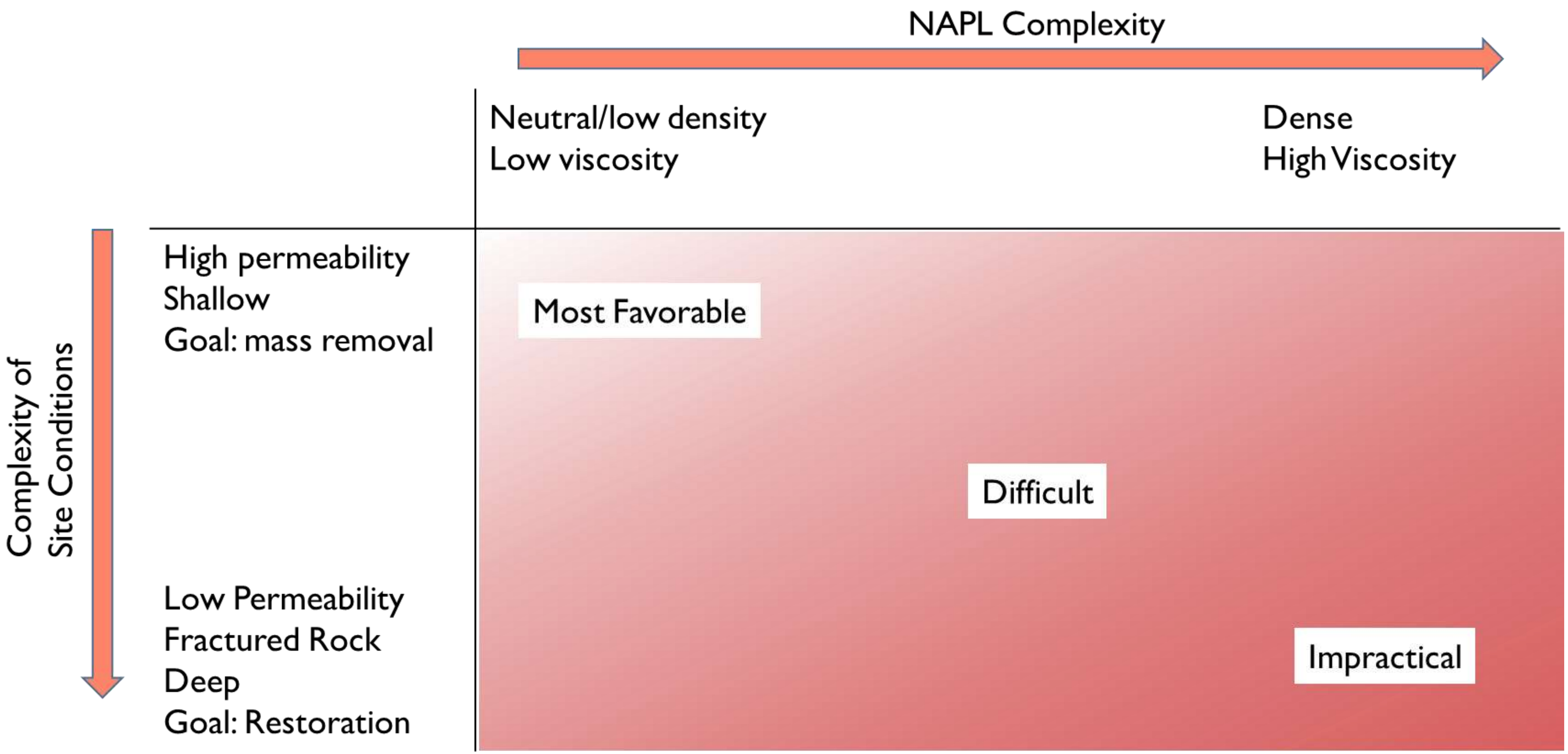




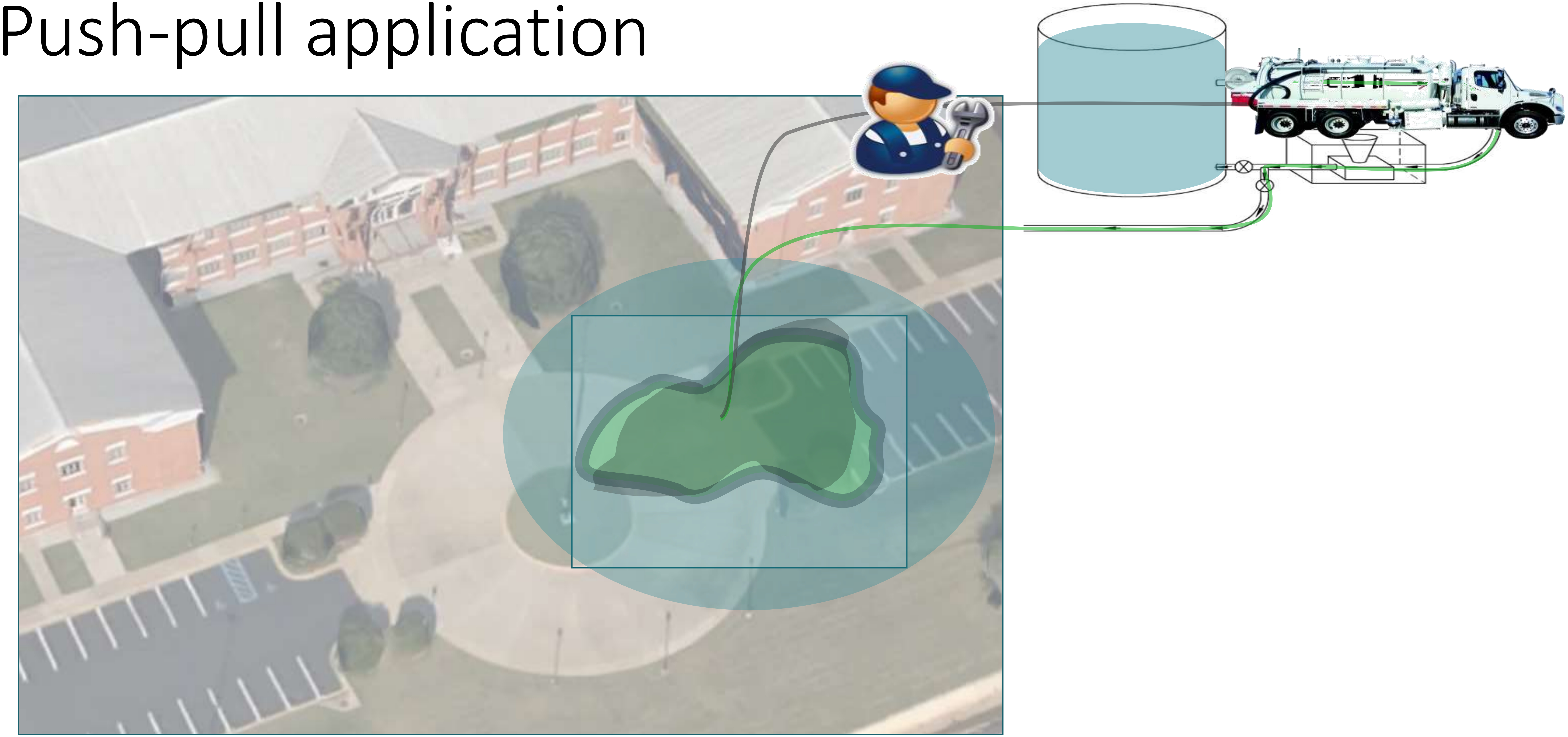
Surfactant	# PV	Recovered NAPL
Tersus (1.6%)	1.0	93%
Tersus (1.6%)	1.5	92%
Brand X (4%)	1.0	59%
Brand Y (4%)	1.0	48%
Brand Z (4%)	1.0	18%

Off-the shelf surfactants mostly “solubilize”, and don’t significantly mobilize

When SEAR is more favorable?

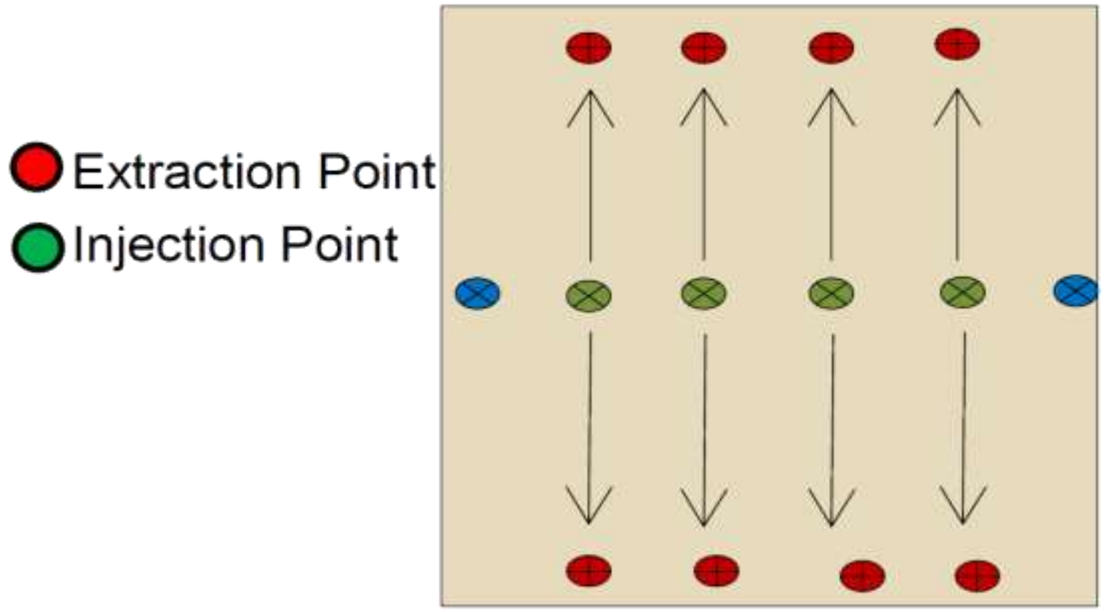


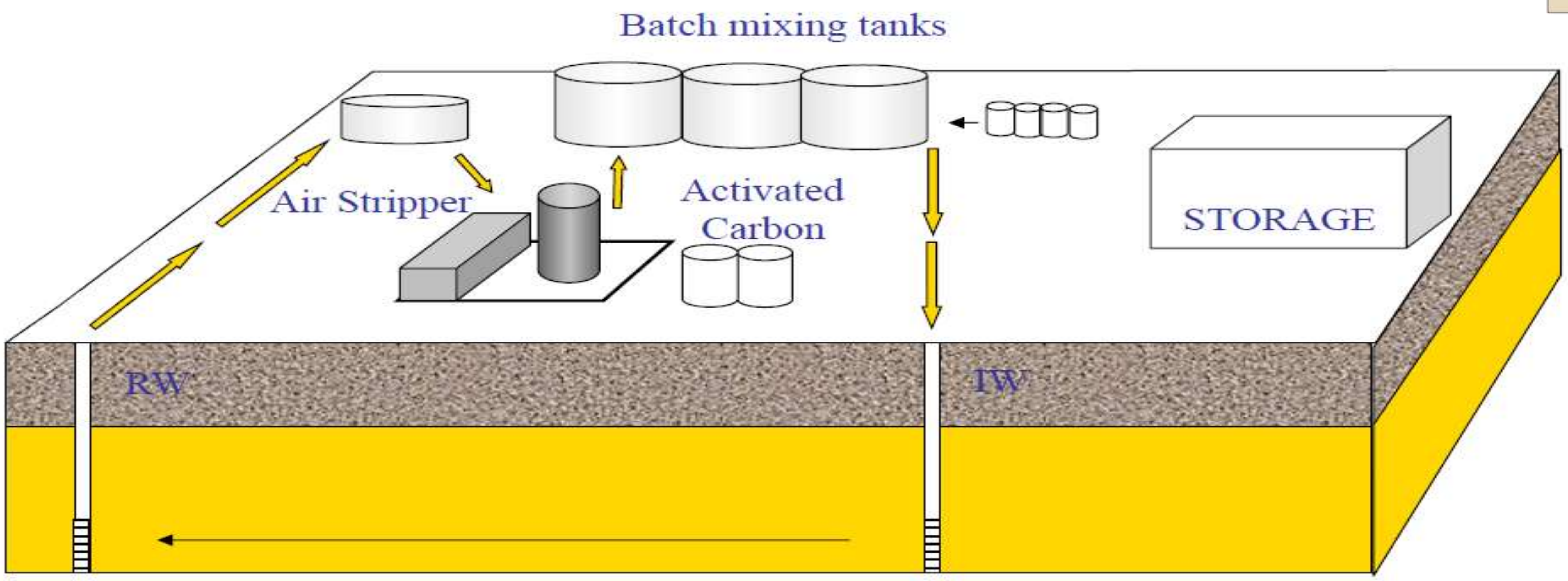
Push-pull application



Love’s Stores, Oklahoma City, OK

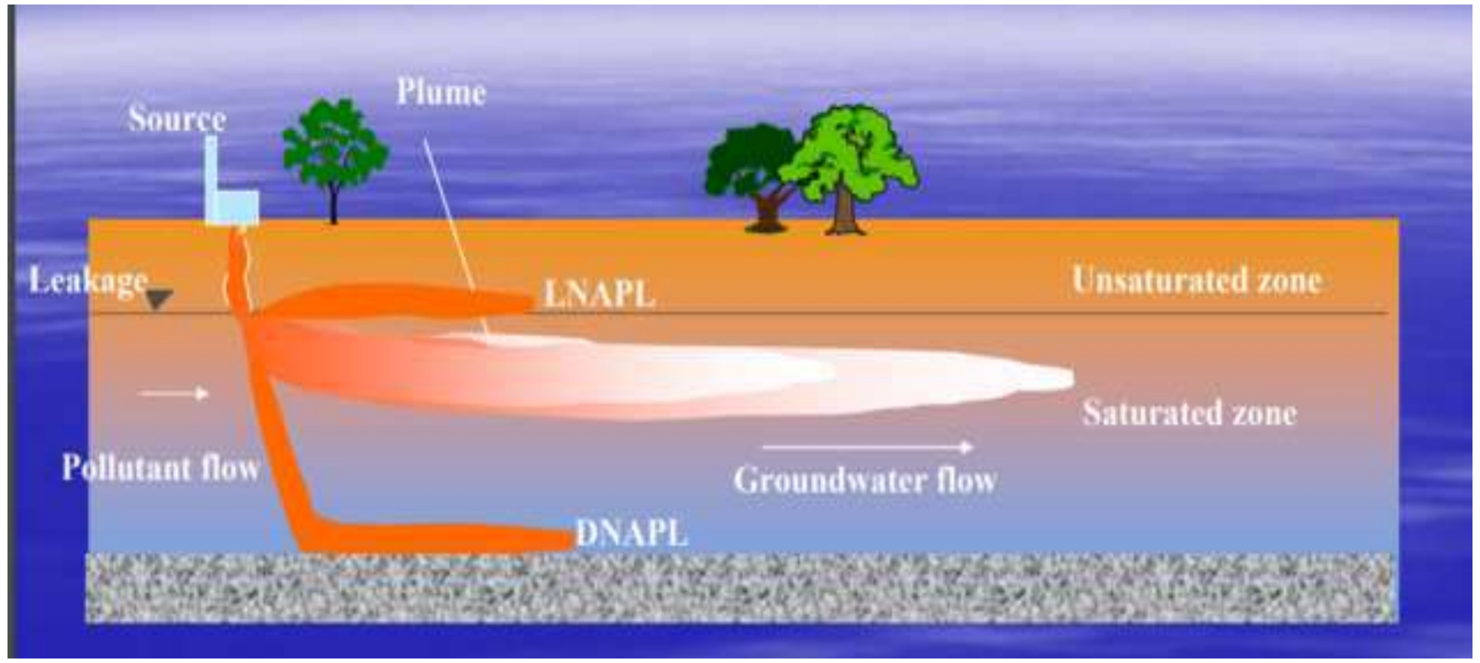
Full-Scale Implementation





Case study – SEAR Pilot application

- Site:
  - Manufacturing facility in USA
  - Commingled DNAPL/LNAPL
  - P&T for hydraulic control to protect receptor
  - TCE DNAPL primary contaminant



- **TASK™ Surfactant**
  - Injected at < 1% concentration → cost reduction
  - 1.4 to 2 pore volumes for up to 95% mass removal

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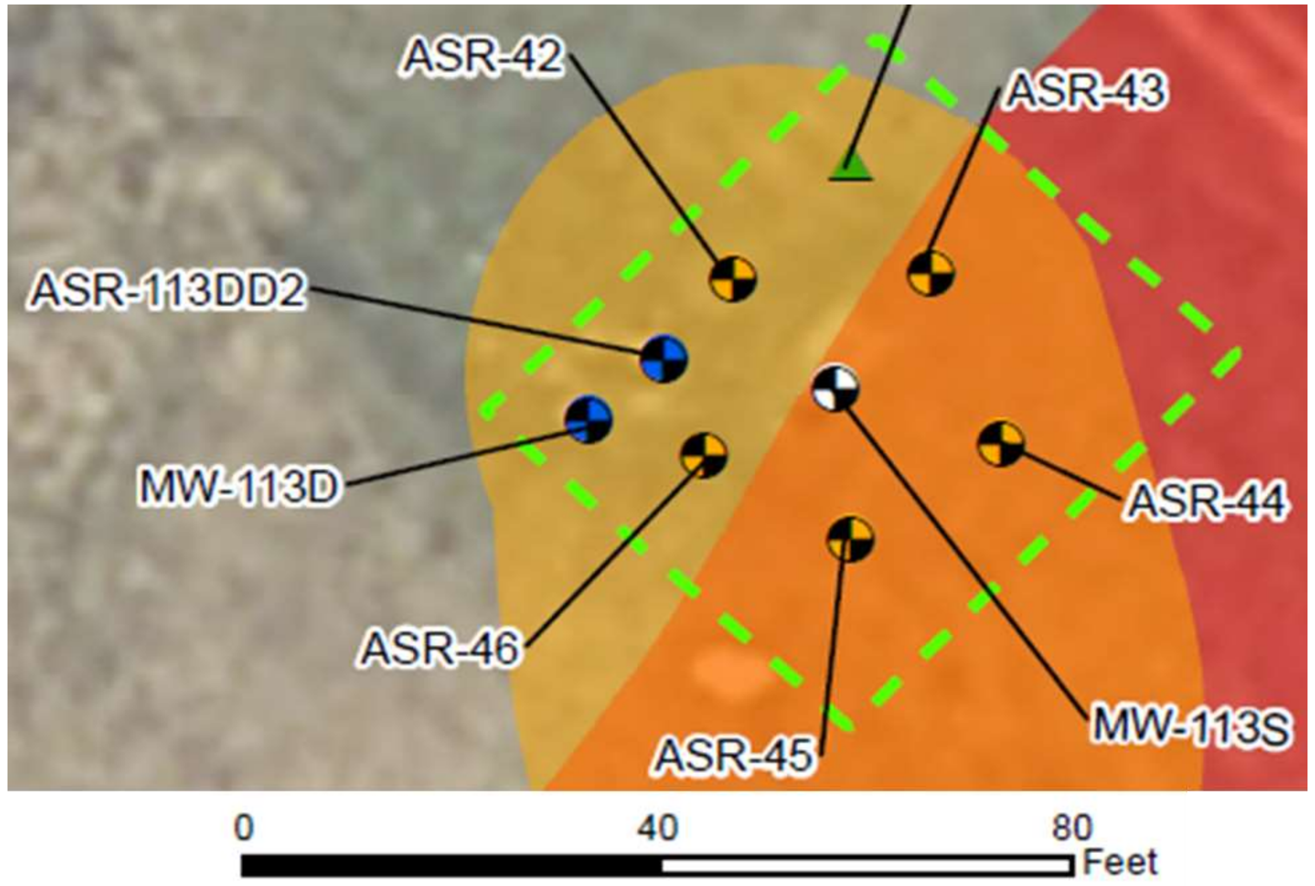
Case study – SEAR pilot application

- **Outside-In Approach**: Recovery well in center of injection well array

1. Pre-surfactant electrolyte flood
2. Surfactant Injection
   - TASK™ Soy
   - TASK™ Surfactant
3. Post-surfactant electrolyte flood

- Injection rate: 30 l/min – 5 injection wells
- Extraction rate: 38 l/min – 1 recovery well



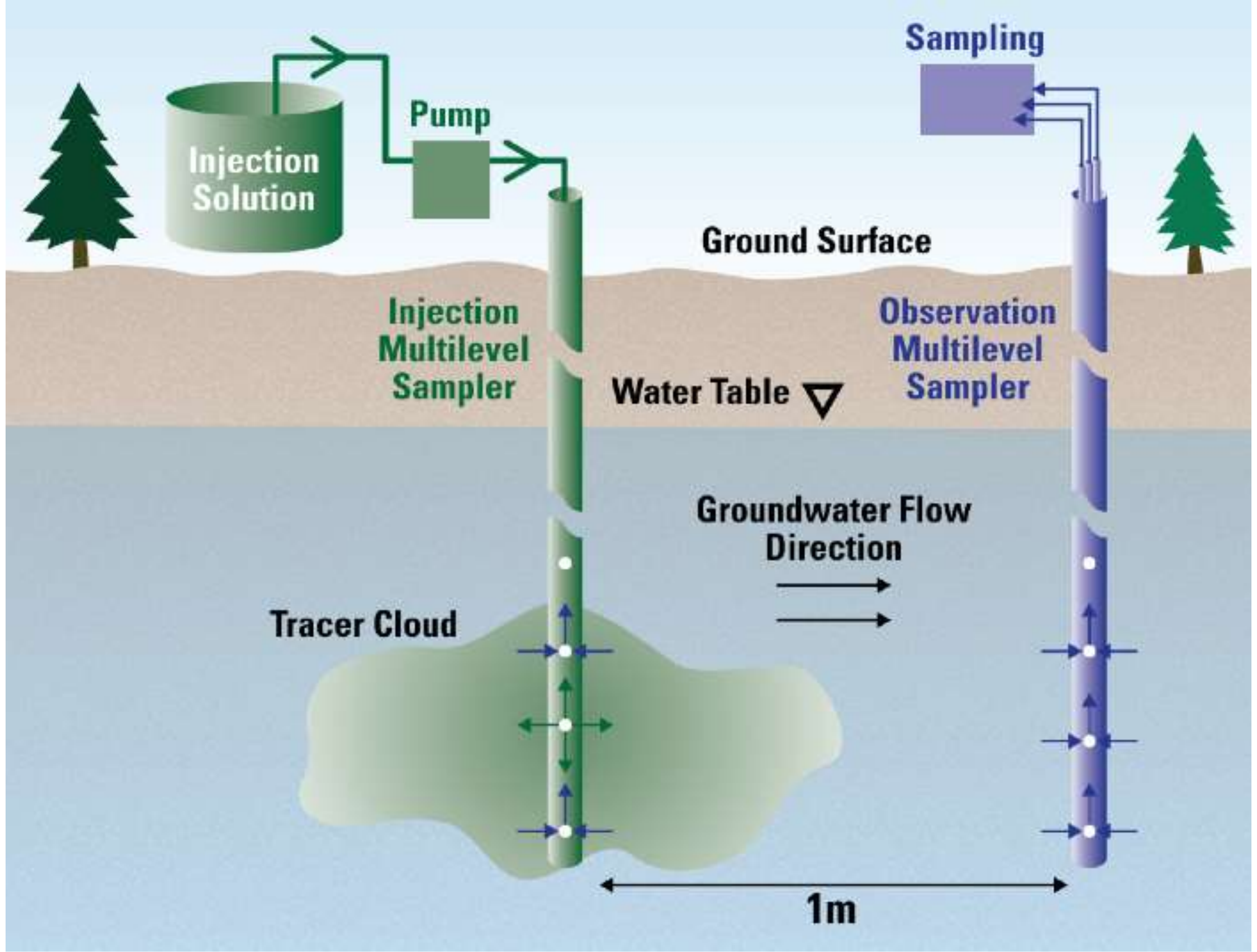
You apply surfactants to **mobilize NAPL**.

Hydraulic control is imperative during injection and extraction process.

Inter-well Tracer Test

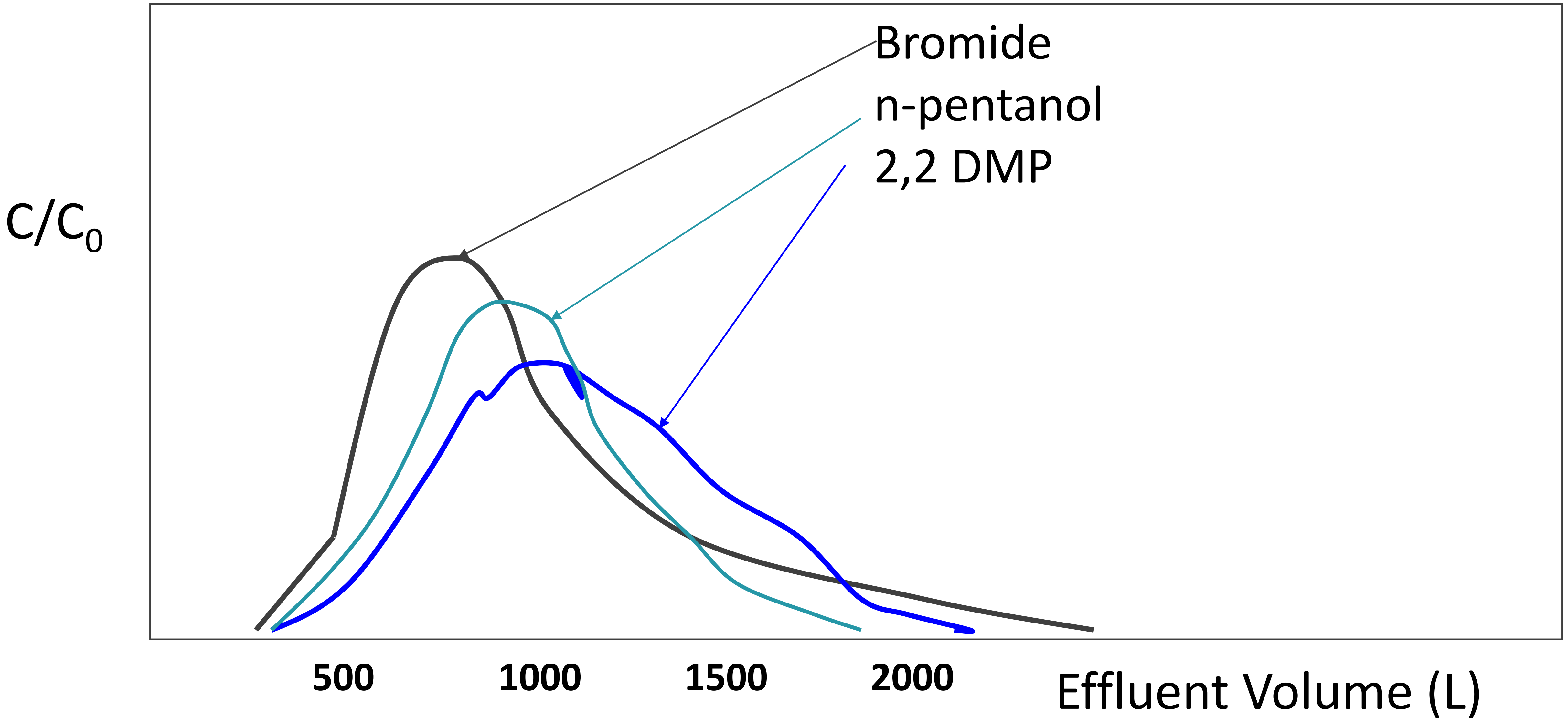
- Tracer test with conservative tracer to evaluate **recovery** and estimate **pore volume** (~ 8 m^3)

- **Partitioning tracer test** before and after SEAR application to estimate the amount of DNAPL
  - initial saturation ~ 3.23%



Inter-well Tracer Test

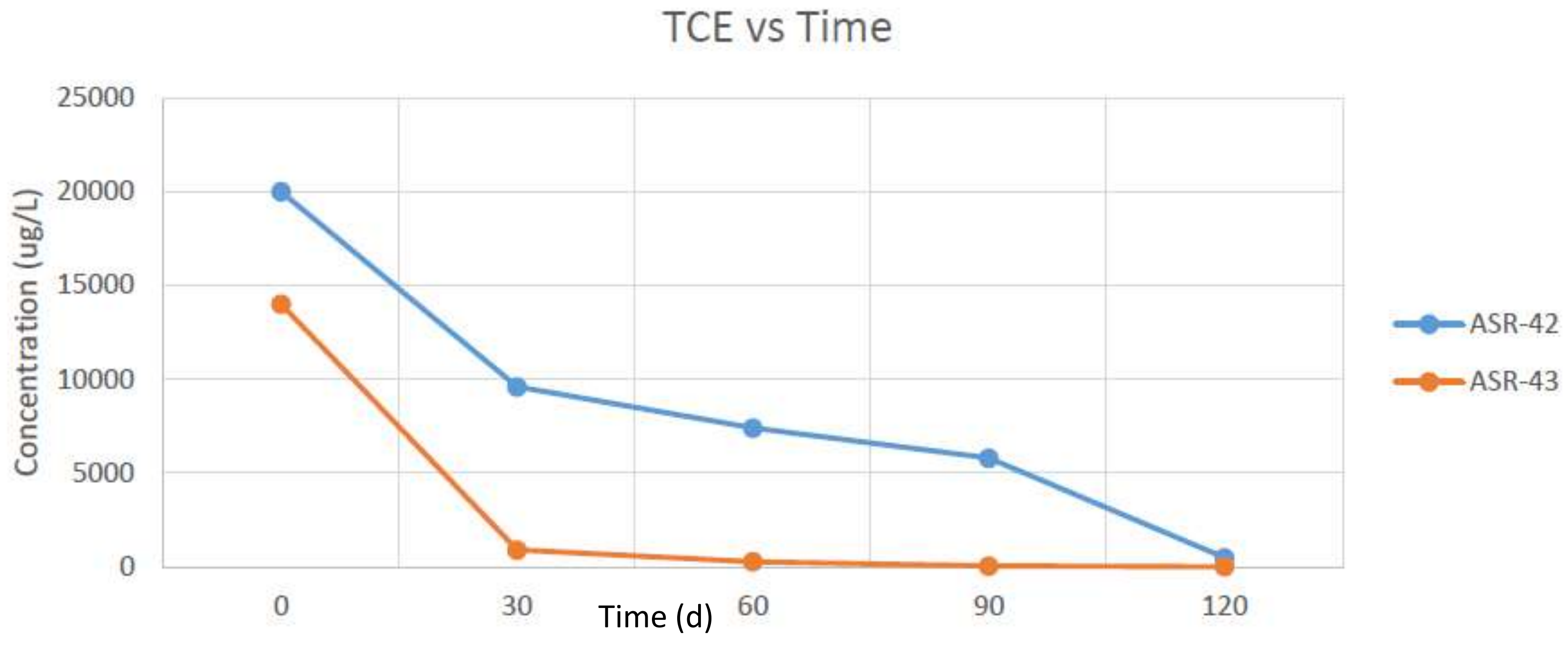
- Time difference between different chemicals allows calculation of DNAPL saturation



Breakthrough Curve
(EPA, US air force report 1994)

Results

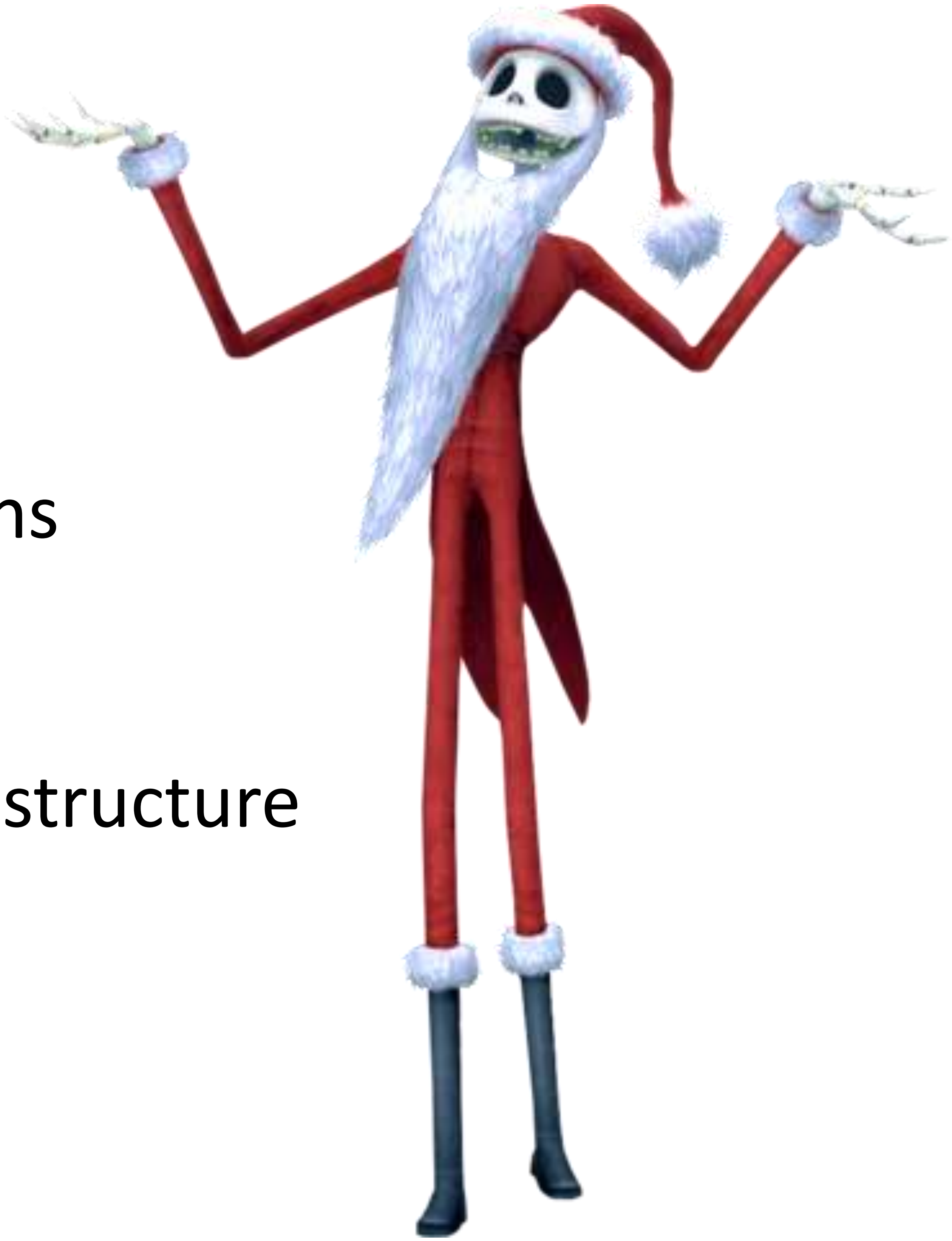
- More DNAPL extracted than originally estimated to be present
- **450 L of DNAPL recovered** (270 L estimated)
- TCE concentration reduced by > **90%** in well network



Remarks

- SEAR is a **source zone approach**
  - Goal is **Mass Removal**
  - Support polishing techniques
- **Surfactant optimization** for site-specific conditions
  - Low Pore Volume, Low surfactant Concentration
  - Neutral buoyancy and Sweep Efficiency
- SEAR can use existing P&T or NAPL recovery infrastructure
- **Reduce remediation costs and time**

Turn your nightmare into an opportunity to speed up remediation!!



Injectable products for the effective and sustainable in-situ remediation of contaminated aquifers

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