In-Situ Flushing Technologies

By

Michael D. Annable

Department of Environmental Engineering Sciences

UNIVERSITY OF FLORIDA

Talk Outline

- Brief Intro on In-Situ Flushing
- Hill AFB Surfactant/Cosolvent Comparison
- Dover AFB Surfactant/Cosolvent Comparison
- Sages Dry Cleaner Site Cosolvent Flood
- Long-Term Post-Flushing Monitoring
- Summary

Potential in-situ flushing injection fluids:

- water (~ pump and treat or heated)
- cosolvents (alcohols)
- surfactants/microemulsions/foams

Truckload of consumable ethanol

PCE-contaminated dry cleaner site
Jacksonville, FL

Barrels of surfactant and alcohol

Multi-component NAPL site
Hill AFB, UT

Cosolvents

- Exponential Solubility Enhancement
- High percentage of alcohol (70+%)
- Agent less dense than water
- Rapid dissolution kinetics

Surfactants

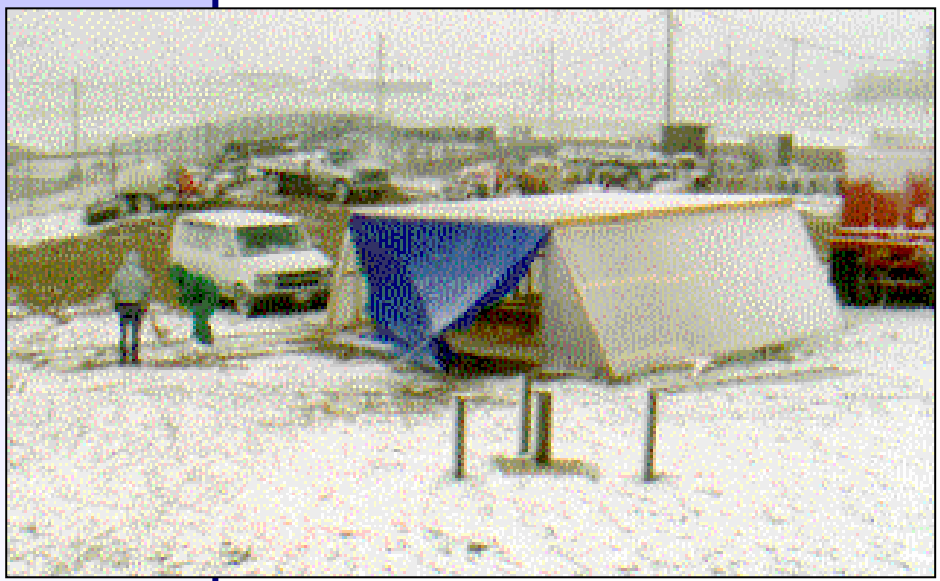
- Linear solubility increase
- Low percentage of surfactant (<5%)
- Sometime uses a cosolvent
- Some kinetic limitations
- Neutral buoyancy possible
- Foam stability can be used

Brief Cosolvent Flushing History

- Before 1980 Cosolvents theory - Pharmaceuticals
- Mid 1980s Cosolvents used to study transport of hydrophobic compounds in soils
- Early 1990s Cosolvents investigated for remediation
- 1995 First Cosolvent Flood at Hill AFB (Florida)
- 1996 Second Cosolvent Flood at Hill AFB (Clemson)
- 1998 Cosolvent Flood at a Dry Cleaner Site (LFR, Sages)
- 1999 Cosolvent Flood at Dover AFB
- 2001 2nd Cosolvent Flood at Dover AFB (Clemson)
- 2002-3 Full-Scale Flood at Sages (Others?)

Two Field Studies at Hill Air Force Base, Utah

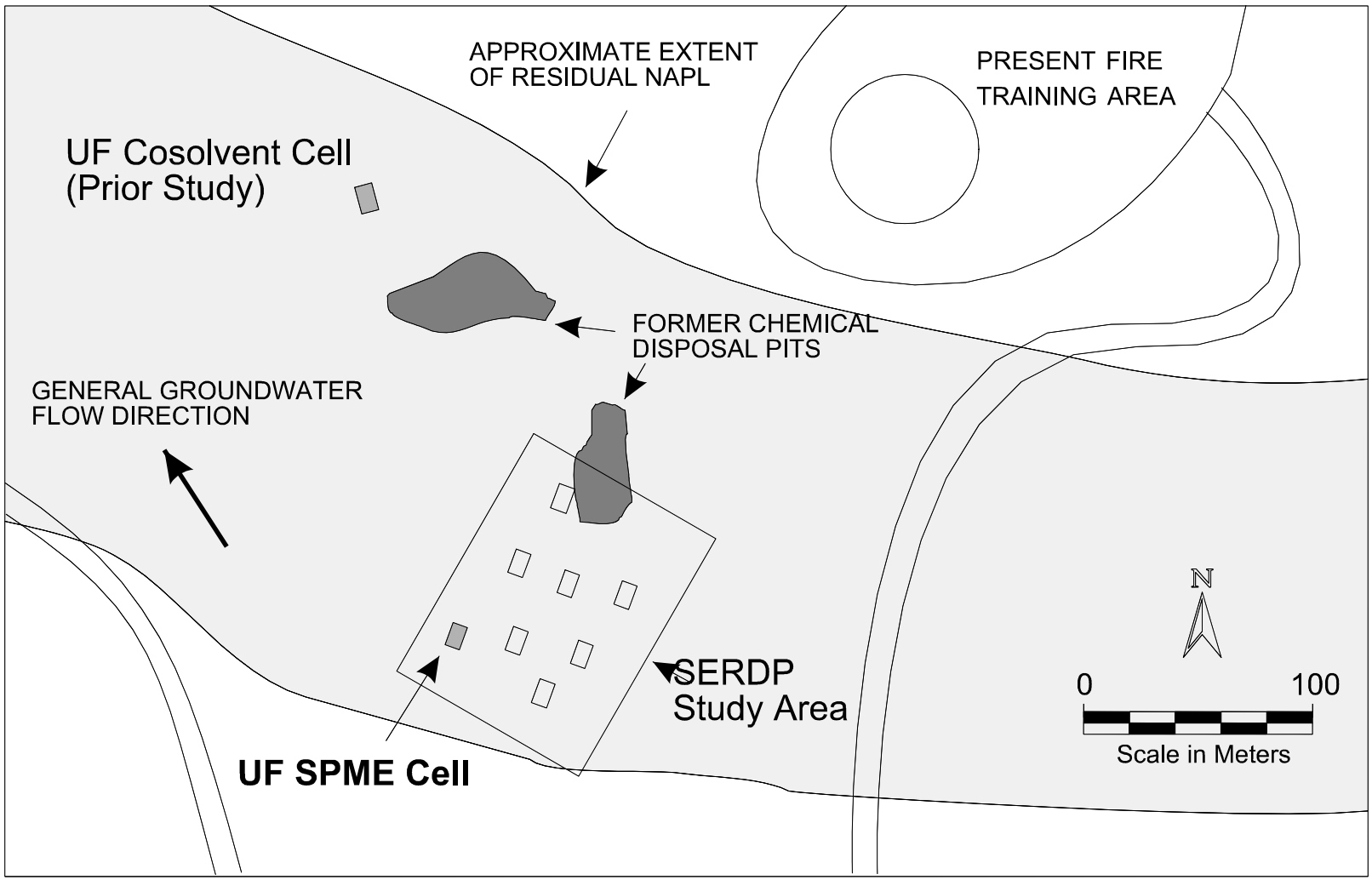
- Surficial sand-gravel-cobble aquifer with a thick, clay confining unit 6.1 m bgs.
- Multi-component (>200) LNAPL:
  - aviation fuel hydrocarbons
  - chlorinated solvents



Cosolvent flushing study (1994-1995)

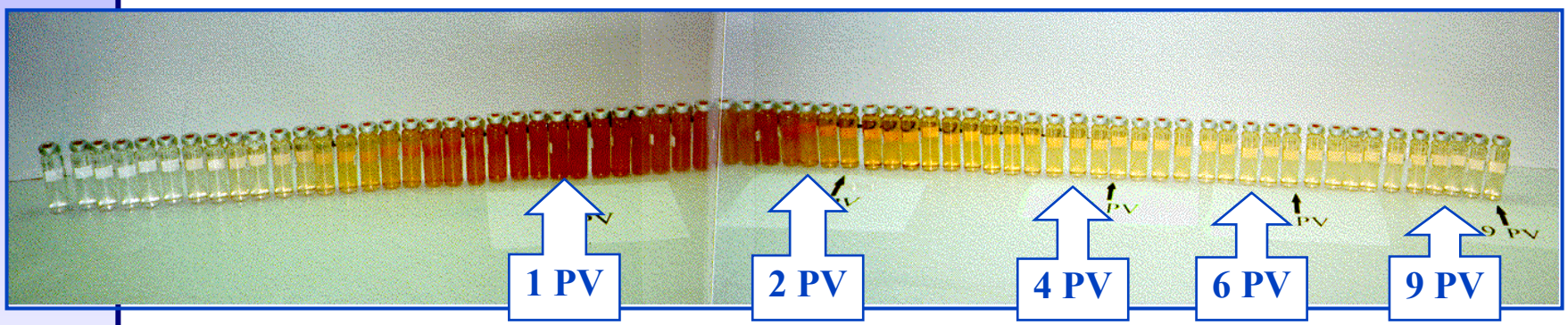
Microemulsion (surfactant/cosolvent) study (1996)

Hill AFB, Operable Unit 1



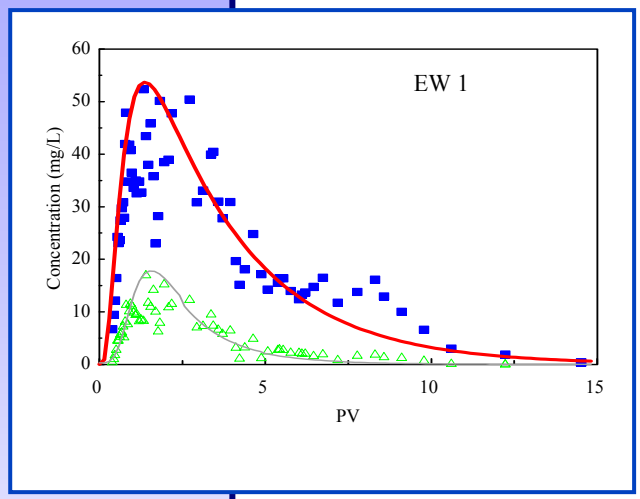

Microemulsion cell

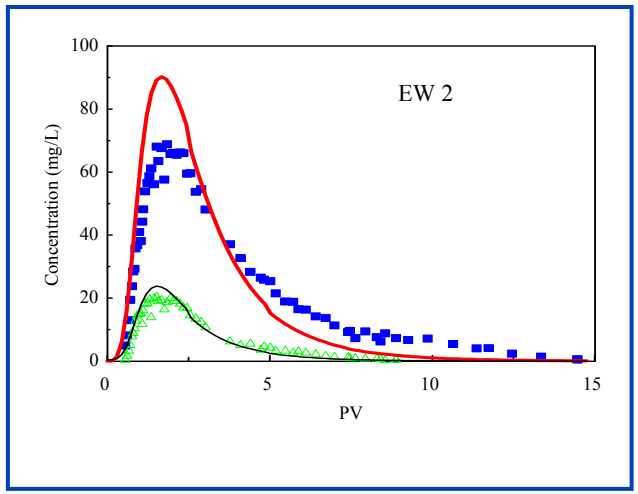
Surfactant Flood Results - Extraction Well Effluent

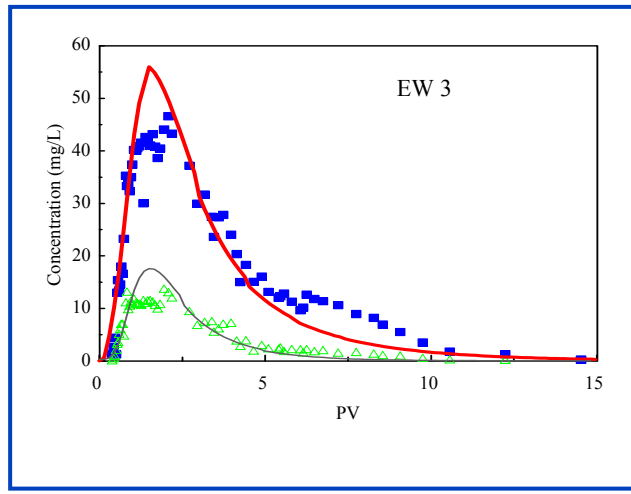


Hill AFB: Surfactant/Cosolvent Comparison

Surfactant:

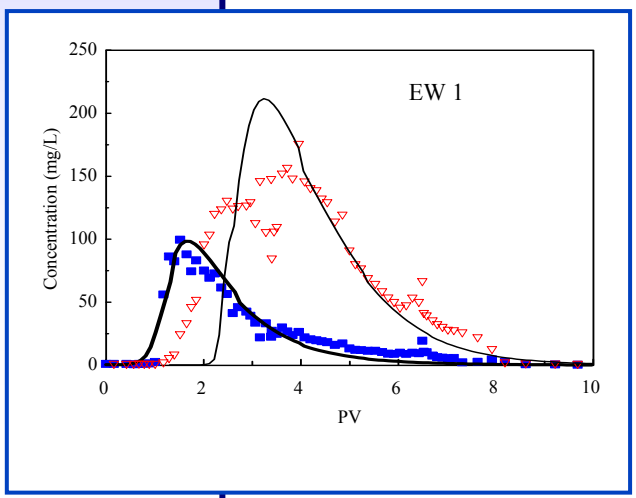


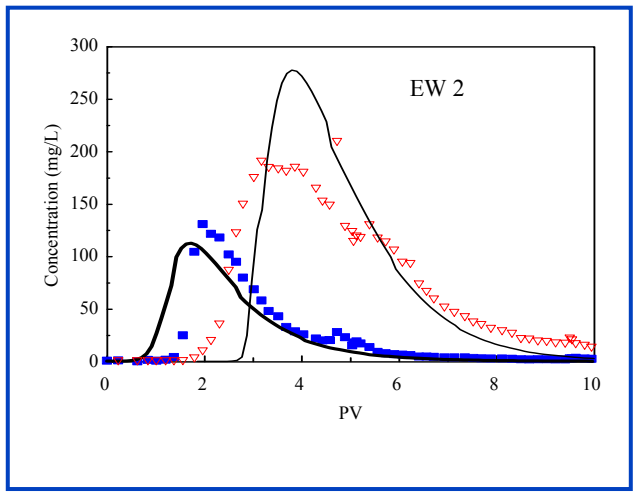


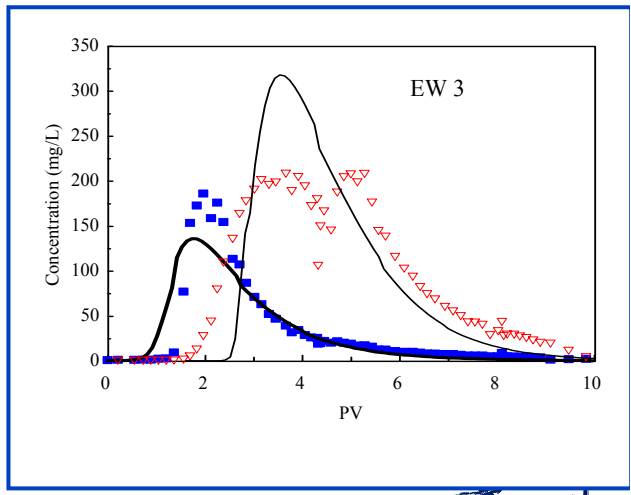


dodecane (squares) and p-xylene (triangles)

Cosolvent:



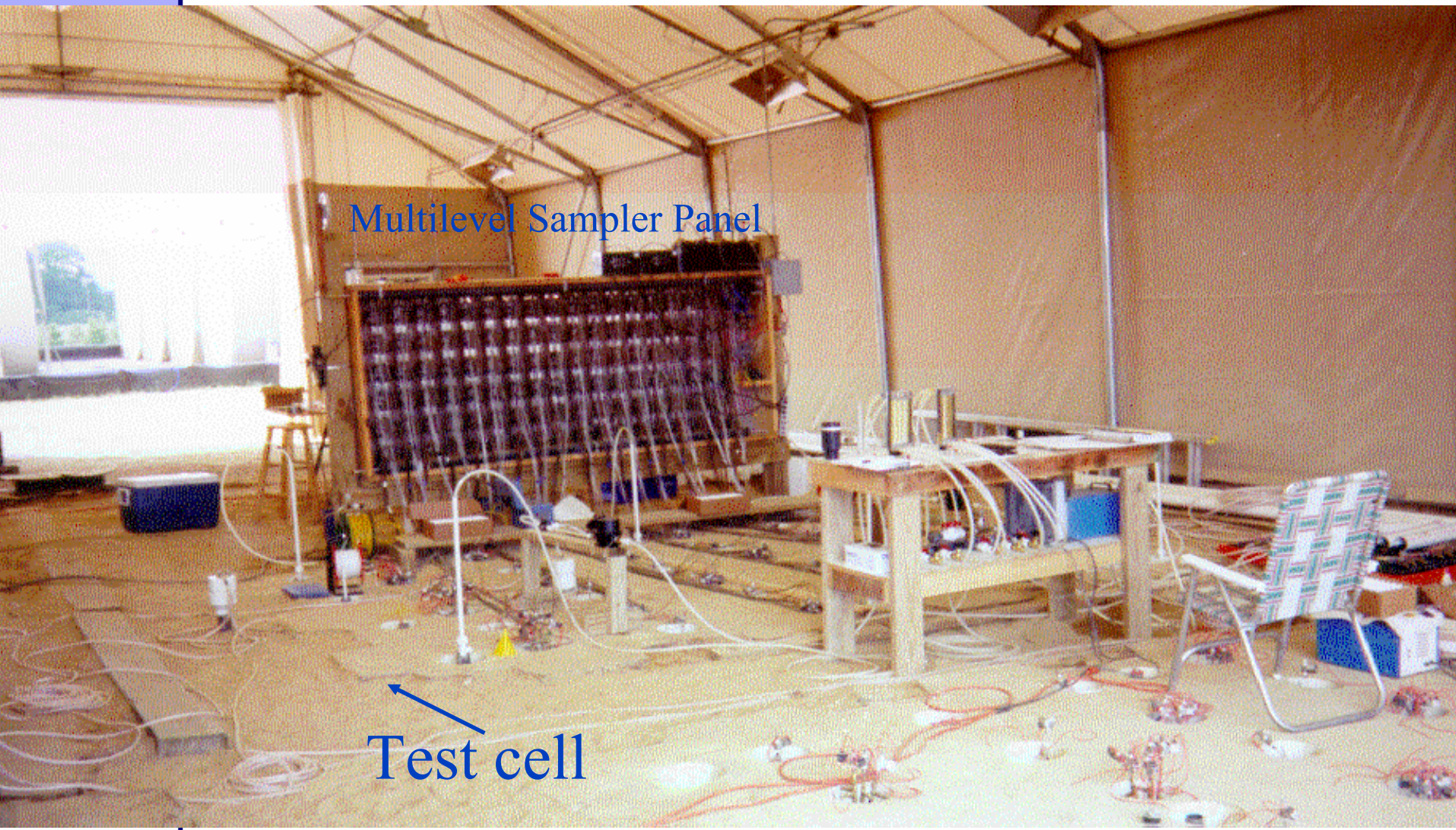




1,2-dichlorobenzene (squares) and *n*-undecane (triangles)

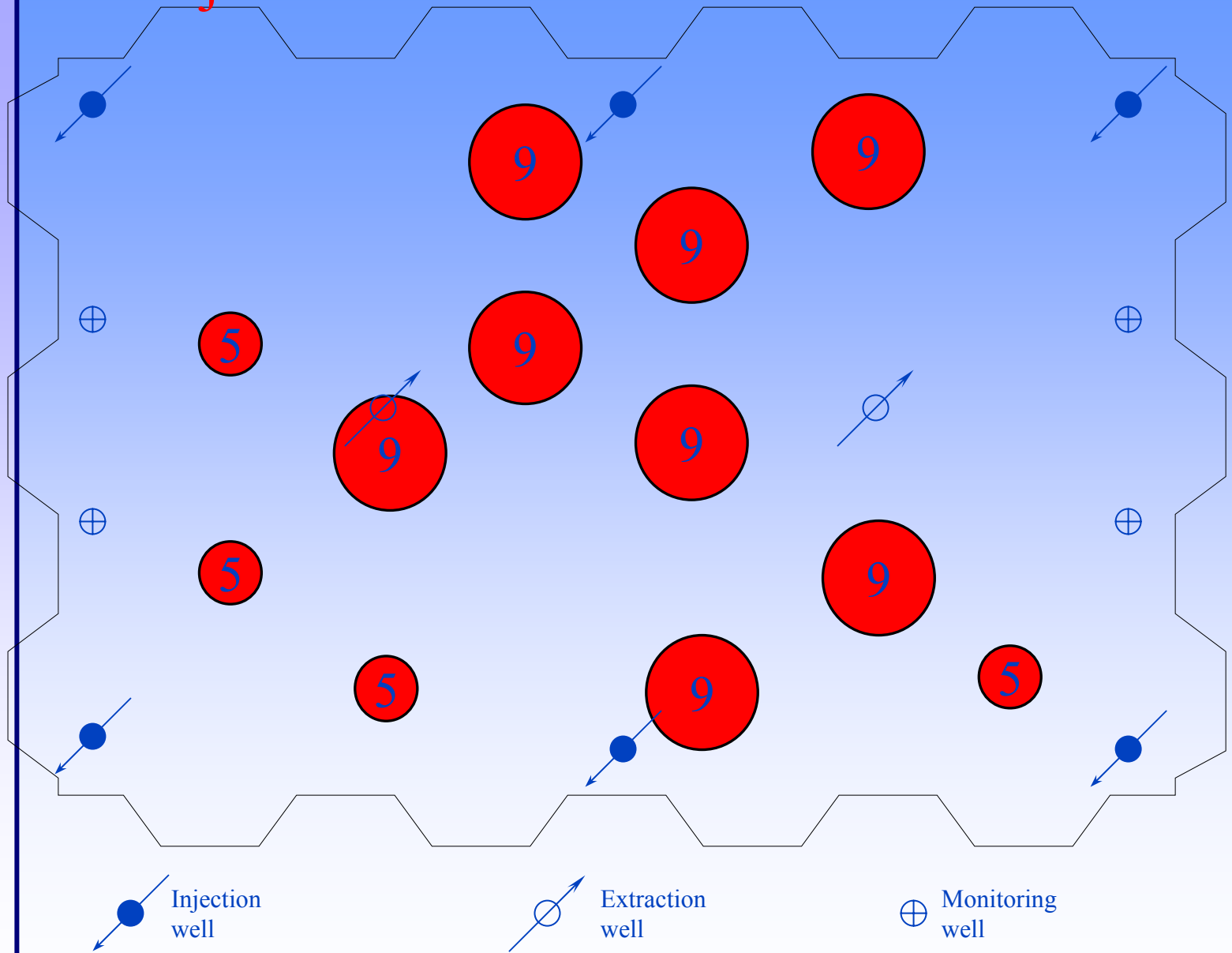
Dover AFB

Cosolvent Flushing

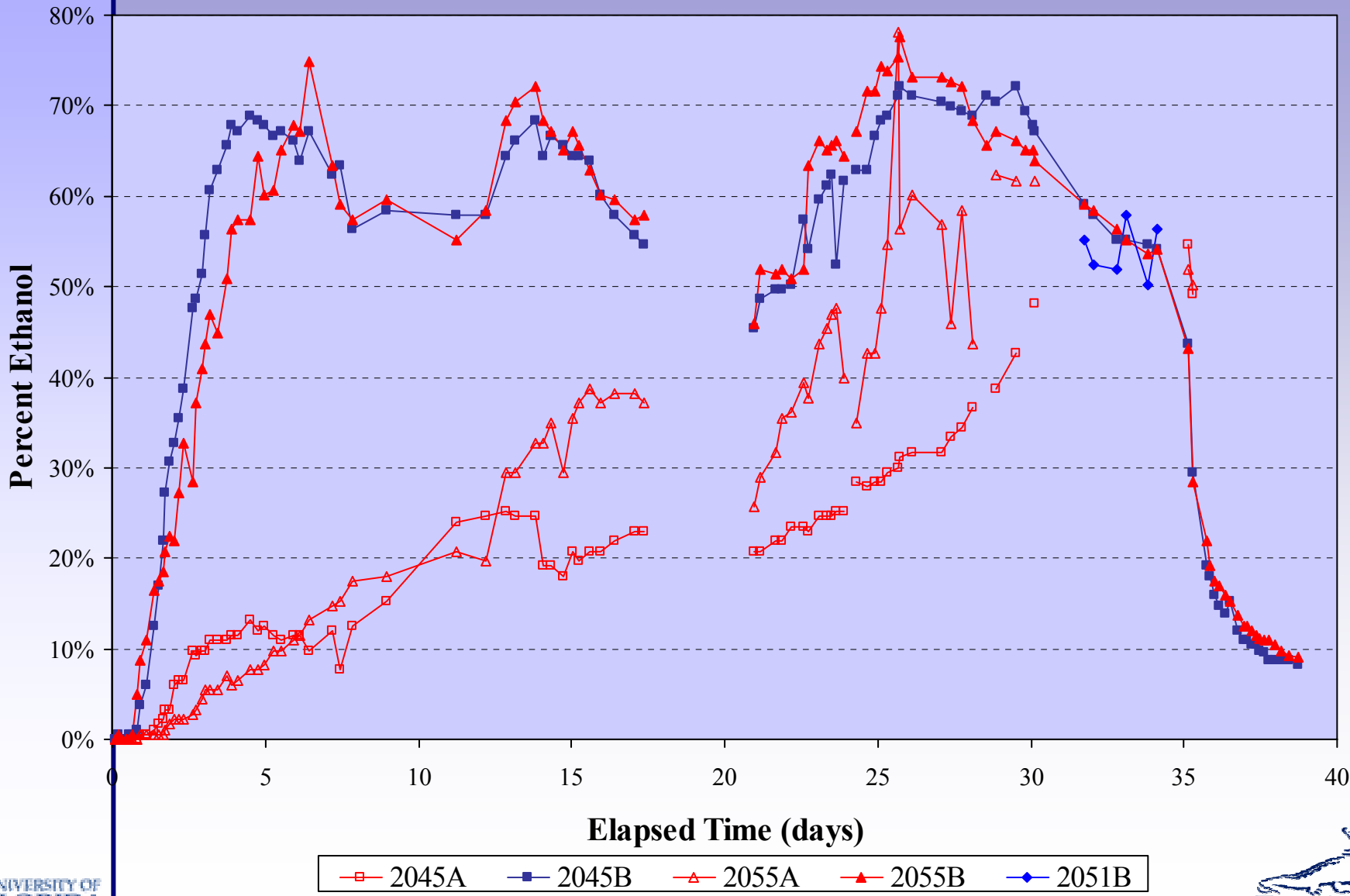


Where's the DNAPL?

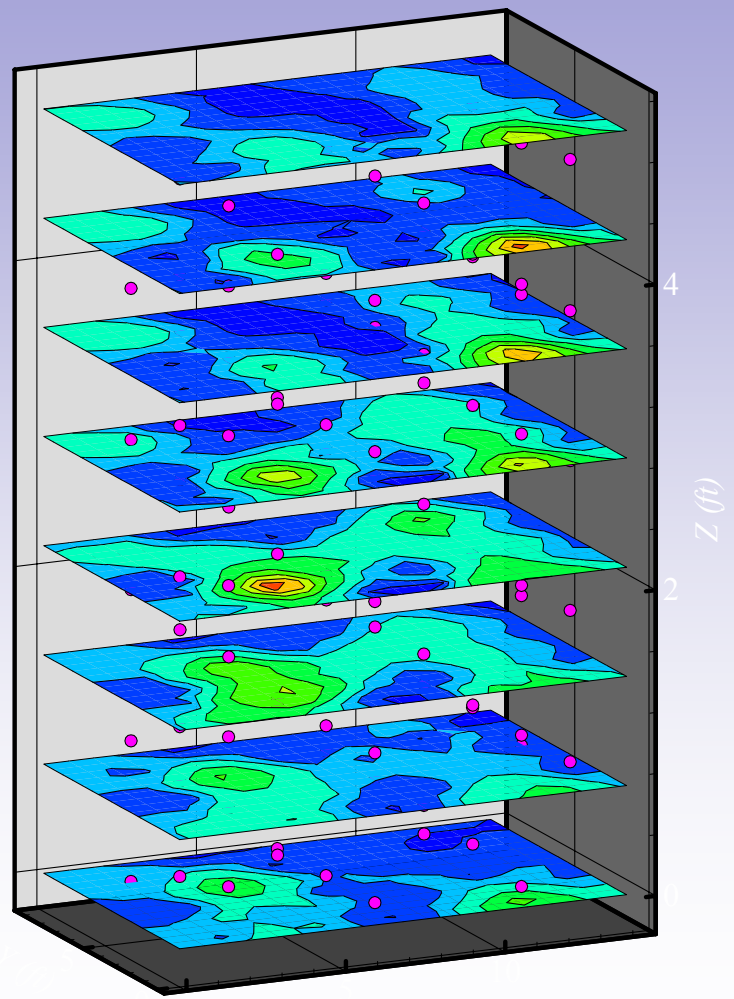
PCE Injection Pattern



Effluent Percent Ethanol based on Density Measurements



Aqueous PCE Concentrations toward the end of the Flood



Ethanol and Waste Minimization

Ethanol Conservation

Ethanol Solution Injected into LZ: 80,600 liters

Ethanol Used: 40,700 liters

Ethanol saved by recycling: 39,900 liters

Waste reduction by recycling:

Lower Zone: 39,900 liters

Upper Zone: 7,400 liters

Summary

Test	Test Results	Mass Balance	Difference
Pre-Flushing PITT	60	85	25
Ethanol Flood	53	83	30
Post-Flushing PITT	5	30	25

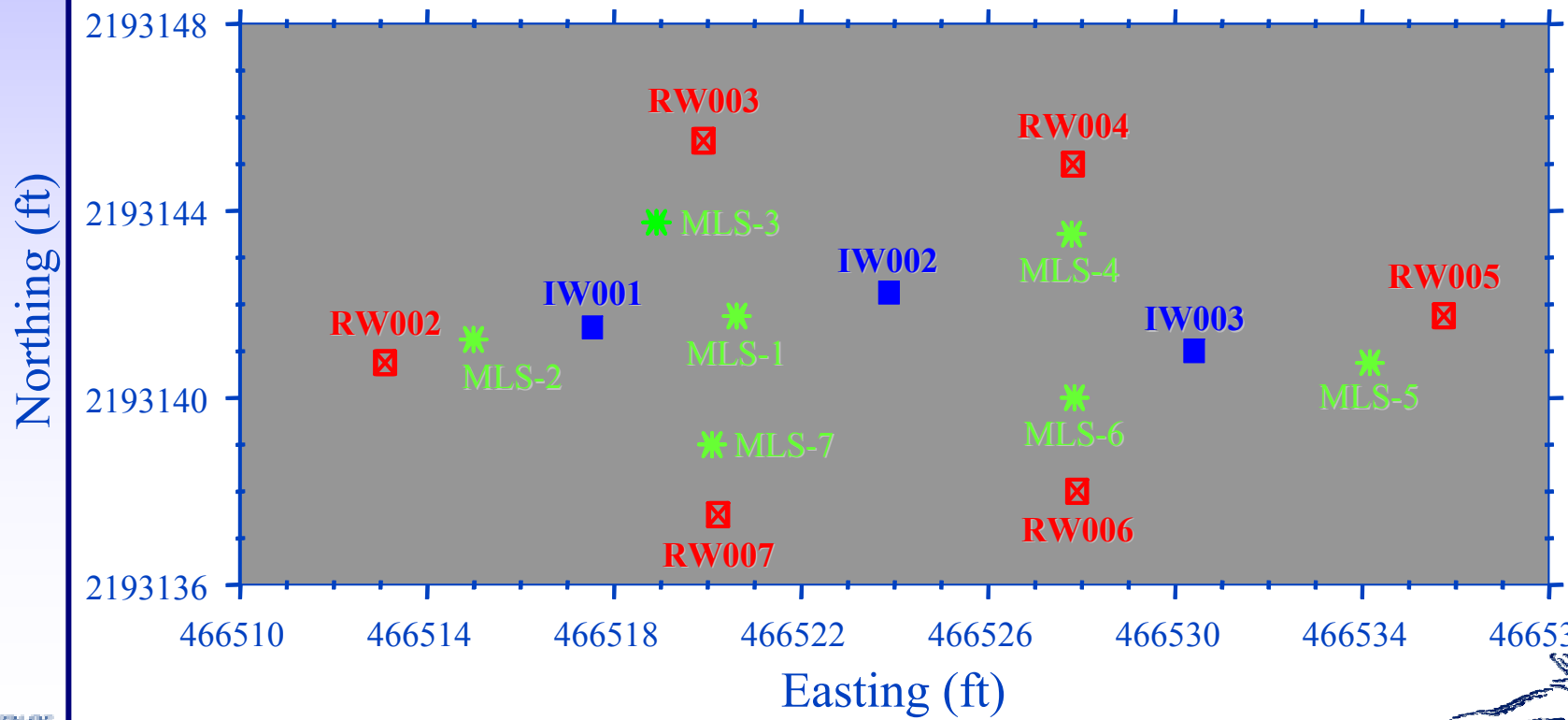
Sages Dry Cleaner Site Jacksonville, Florida

Pilot test at Jacksonville, FL (Sages):

- Dry Cleaner PCE source zone
- 8 to 9.5 m below ground surface
- 7 m long by 3 m wide
- Performanced based cores and tracers

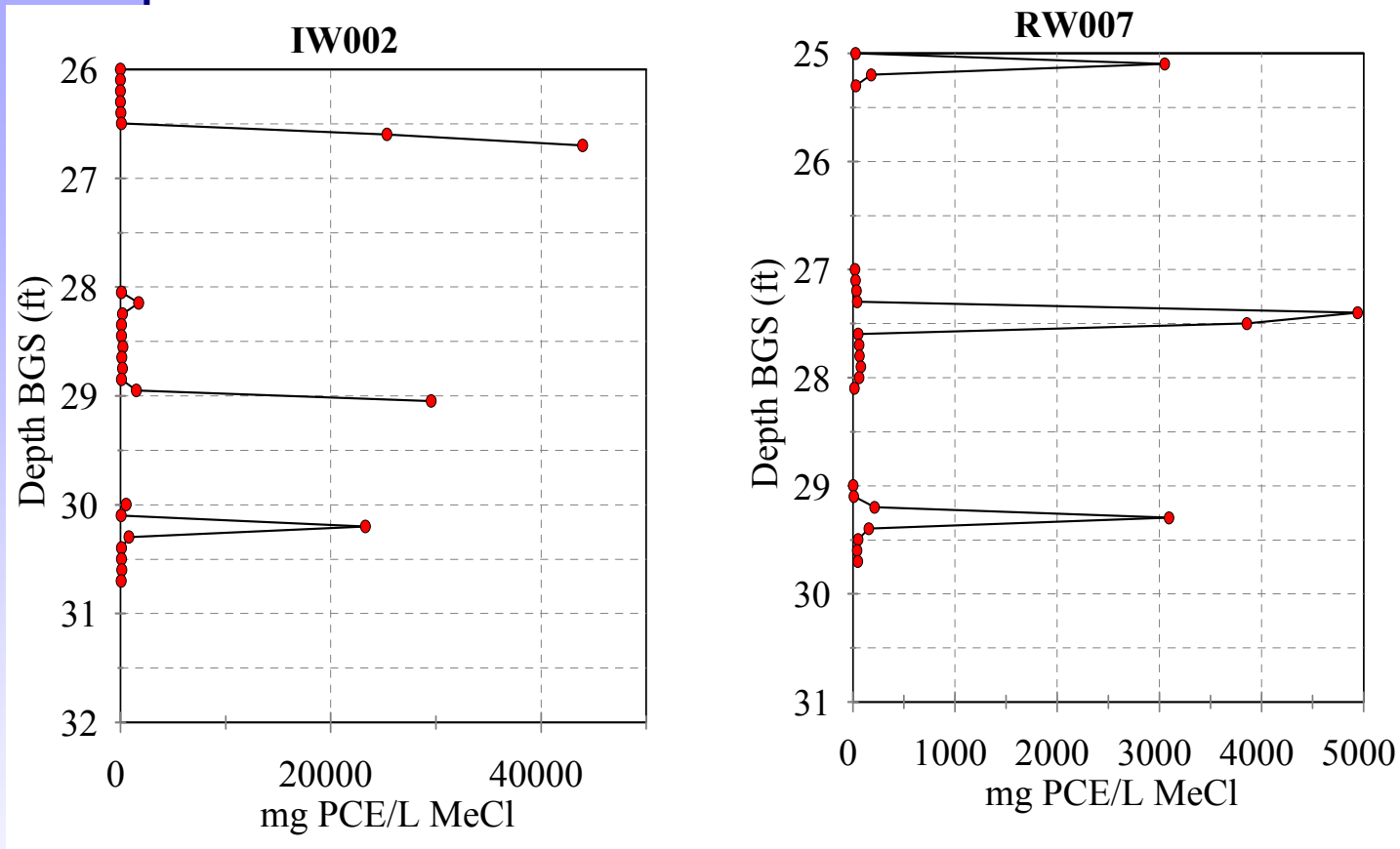
Sages Site

- 3 Injection Wells (IWs)
- 6 Recovery Wells (RWs)
- 7 Multi-Level Samplers (MLSs)



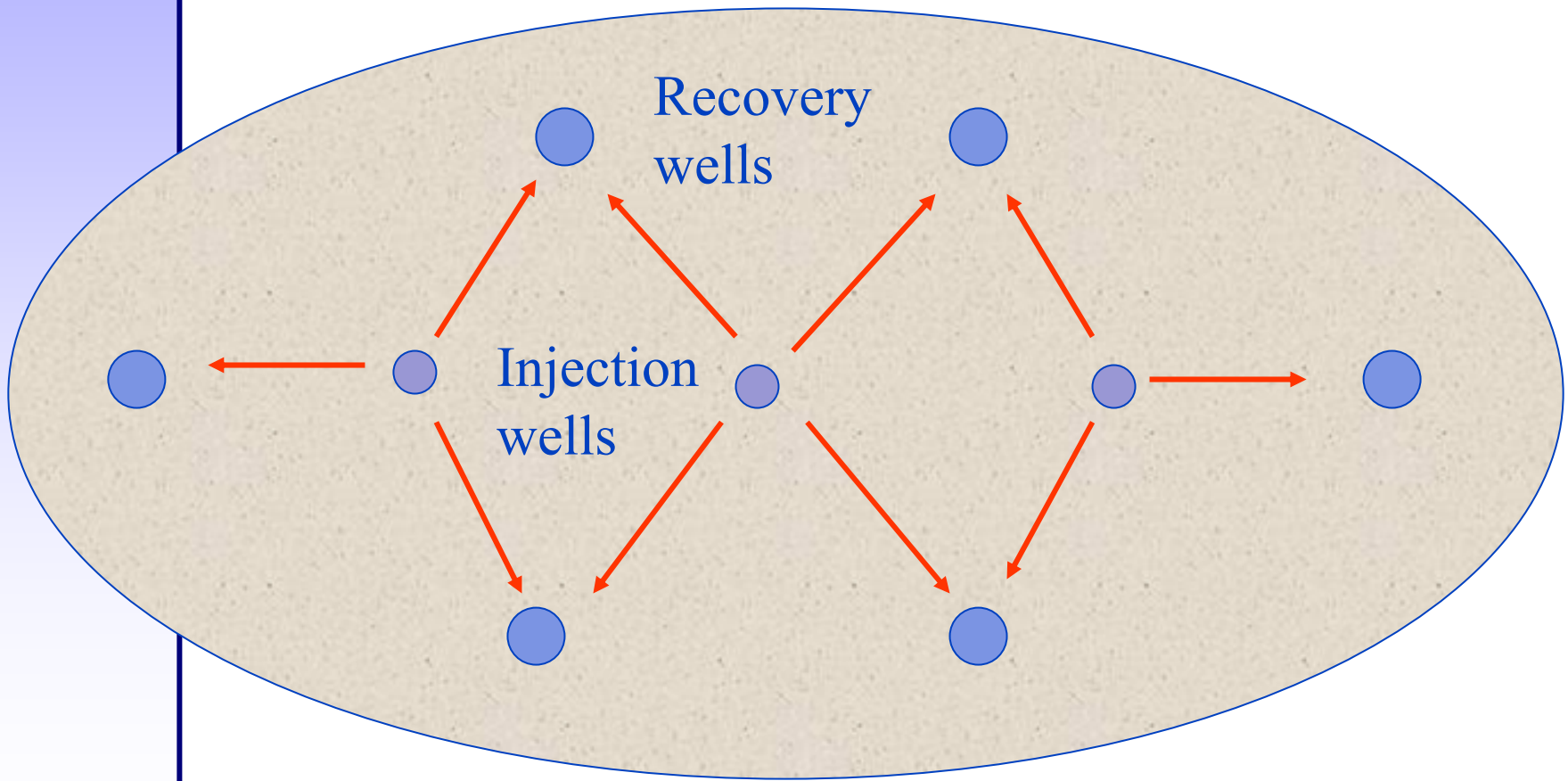
Soil Cores collected by cone penetrometer (20 ton truck)

High Frequency Soil Sampling at Sages



Thin lenses of DNAPL on minor permeability contrasts

Sages Well Layout

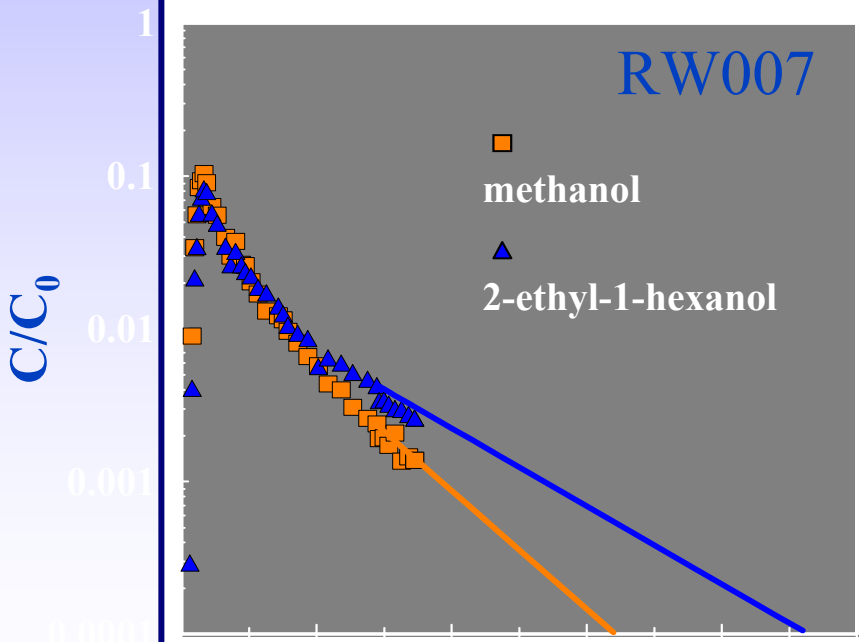


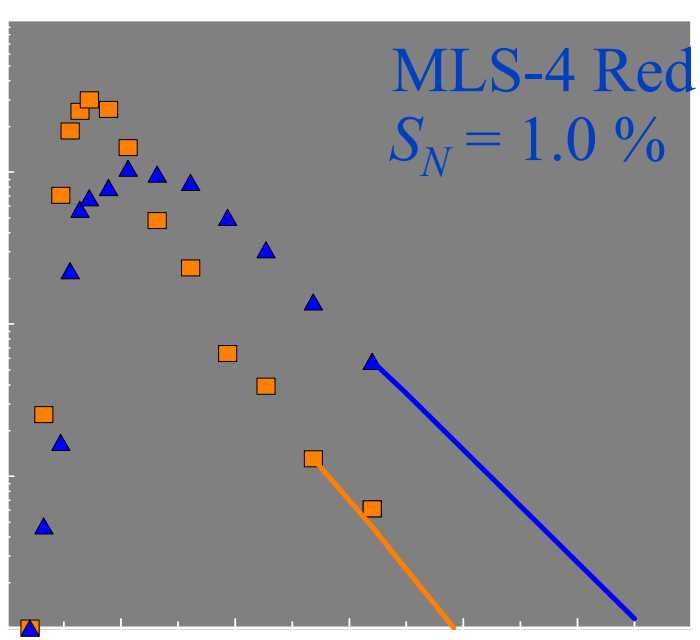
Sages Site

Partitioning Tracer Test:

$S_N = 0.26\ \%$

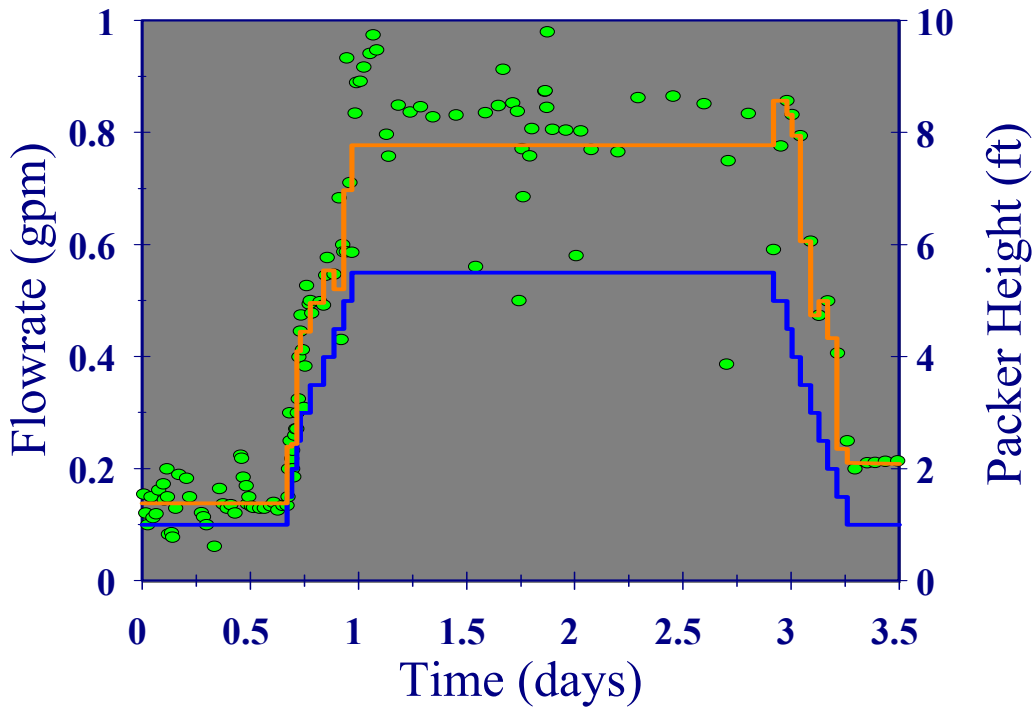
$V_{PCE} \approx 50\ \text{L}$





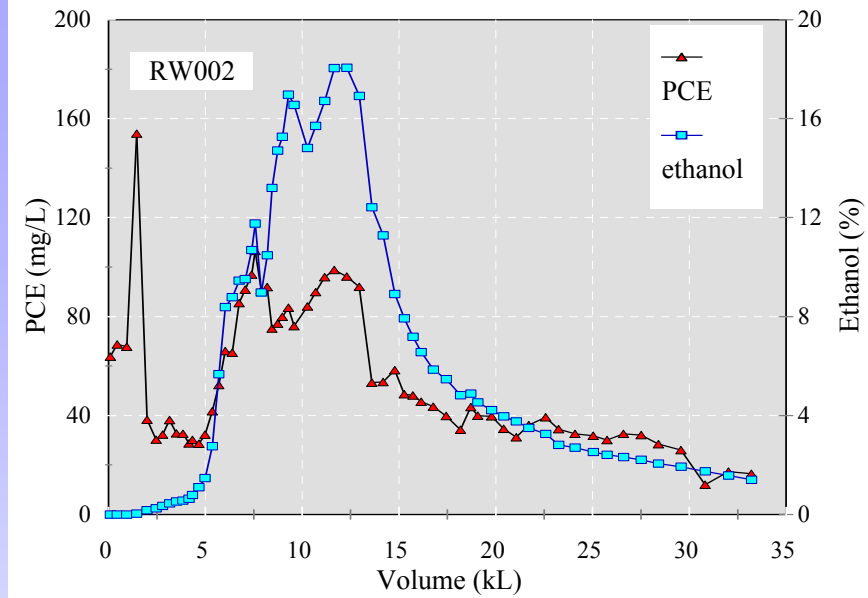
Sages Site

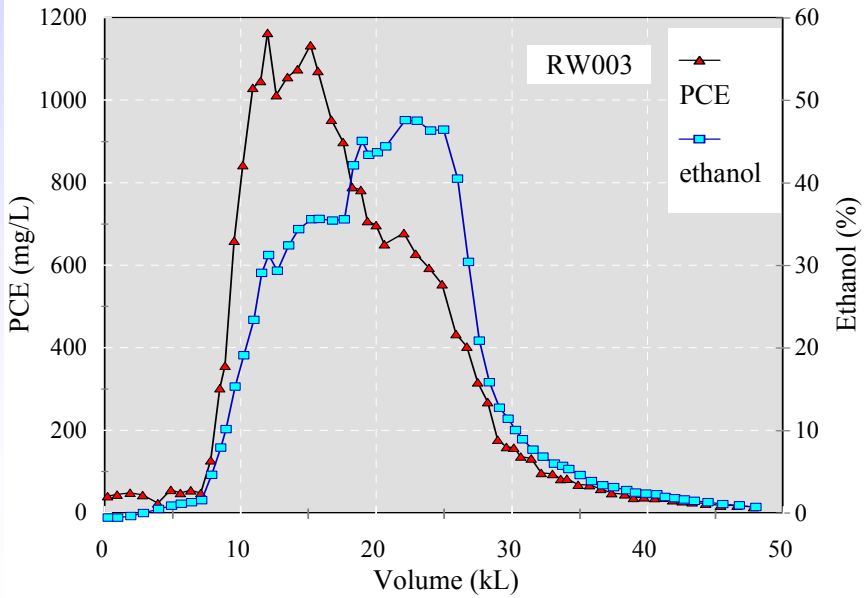
Cosolvent Flushing



95 % consumable grade ethanol

Cosolvent Flushing



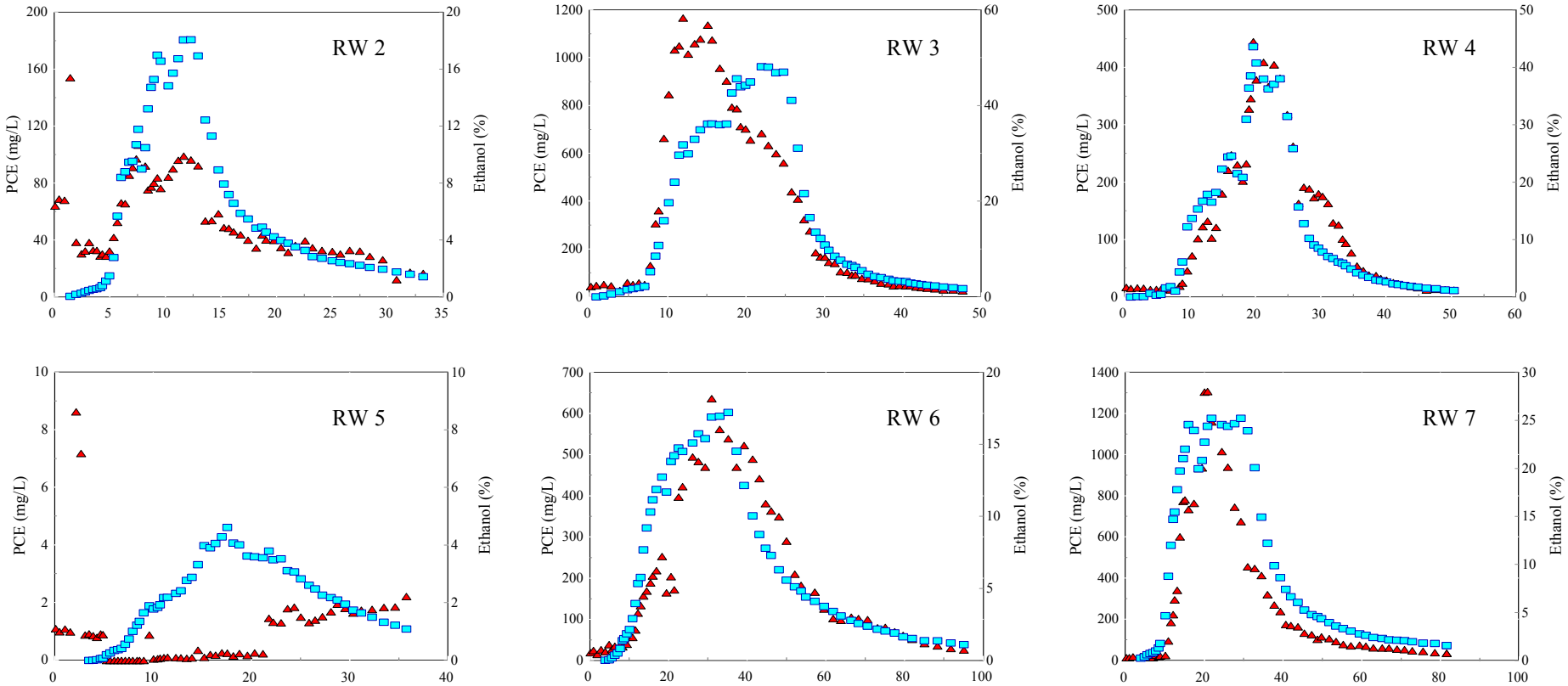


Total PCE Removed

67.4 kg

41.5 L

Jacksonville Results



Sages Site

Waste Treatment:

- Air Stripping
- Macro Porous Polymer (MPP)

Trailer-mounted MPP system

PCE recovered from effluent

Summary Results

Cosolvent Extraction:

43 L PCE Removed (Mass Recovery)

~63 % PCE Removed (Partitioning Tracer)

65% Removal based on Soil Core Data

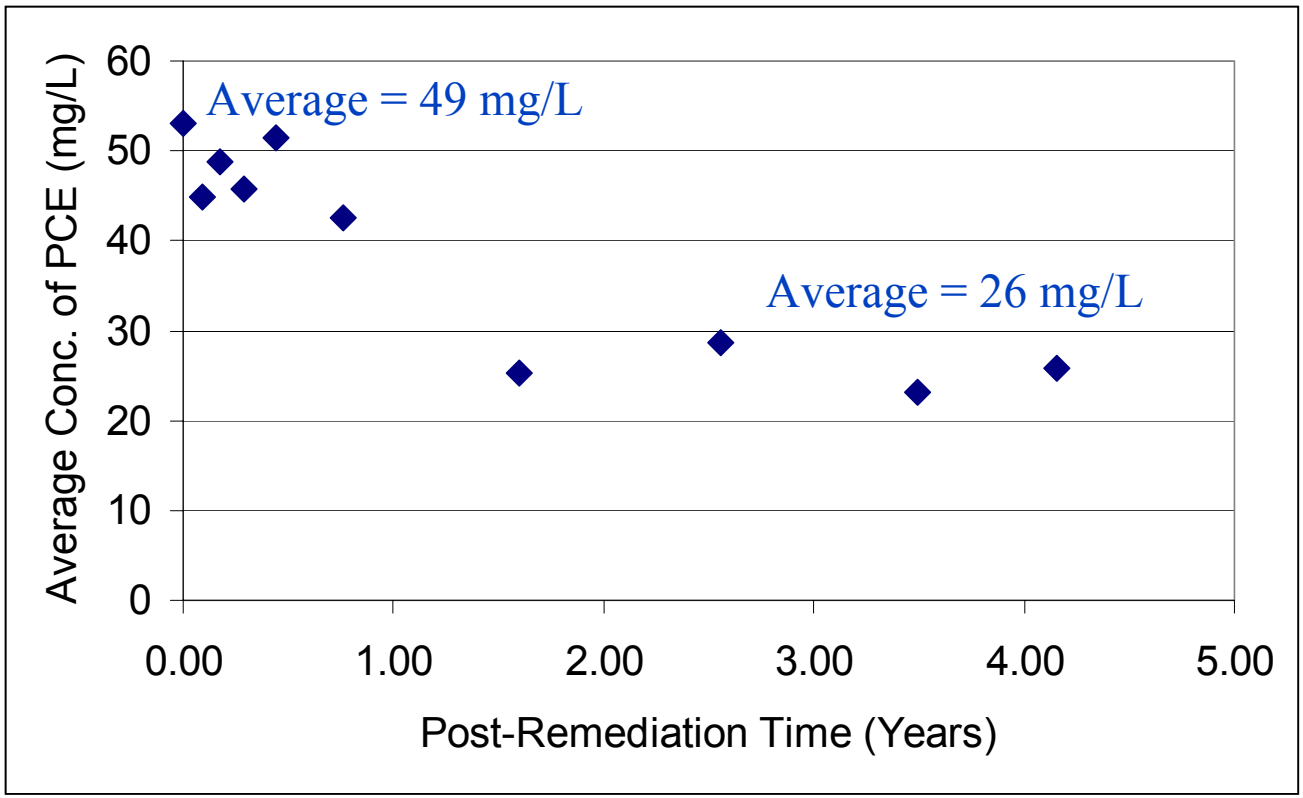
Summary of In-situ Flushing Remediation Effectiveness

	Fraction of mass removed
• Hill AFB cosolvents (1994-1995)	~82%
• Hill AFB microemulsions (1996)	~90%
• CFB Borden cosolvents (1997)	~70%
• Dry cleaner site, Jacksonville, FL (1998)	~64%
• Dover AFB cosolvents (1998-1999)	~62%
• Dover AFB surfactants (2000)	~68%

What is the result of In-Situ Flushing?

- Source Zone Response
- Plume Response

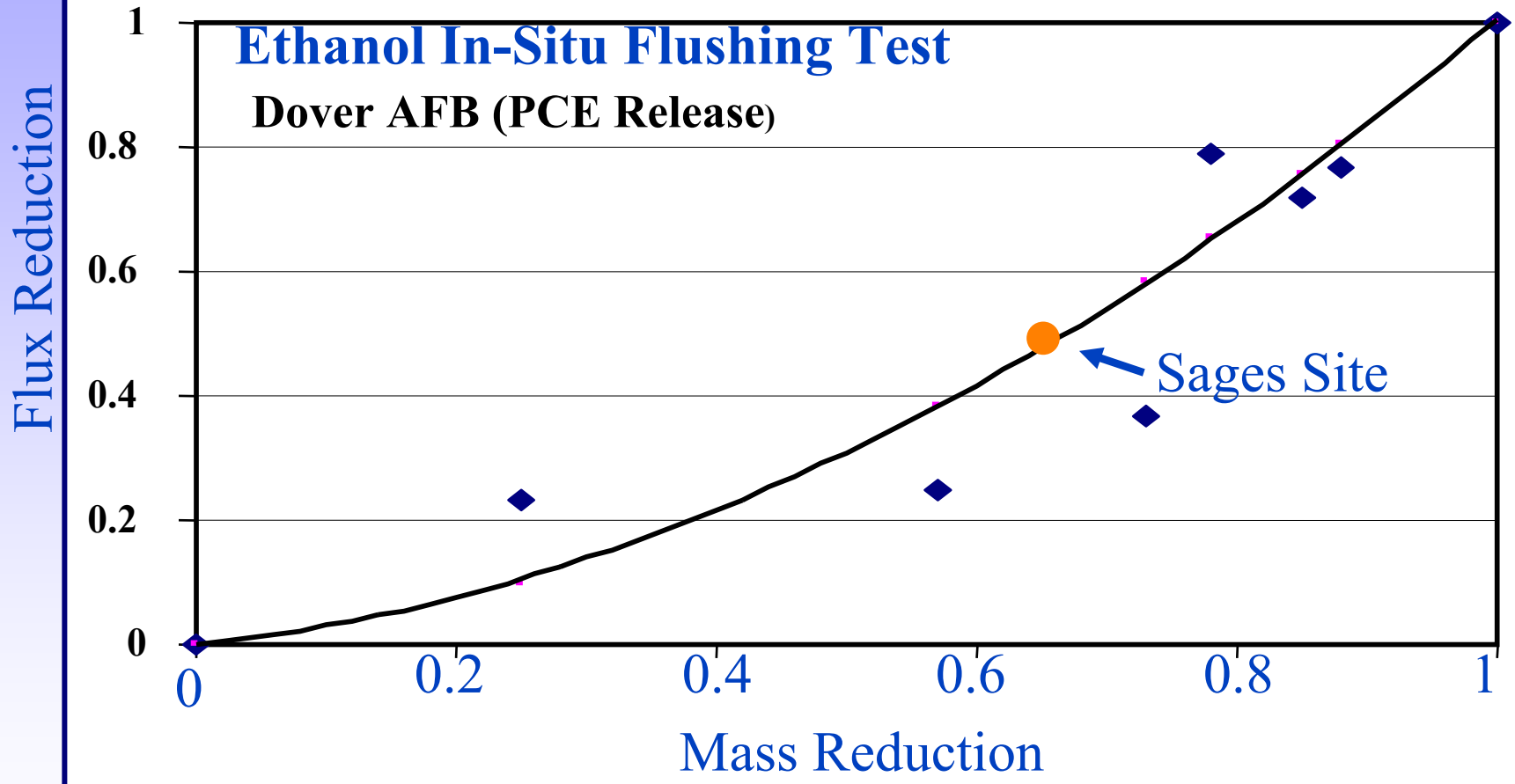
Concentration (or Flux) Reduction in the Source Zone



Mass Reduction = 64% : Flux Reduction = 47%

n = 35 sampling locations

Dover AFB: Controlled PCE Release



Brooks et al., 2003

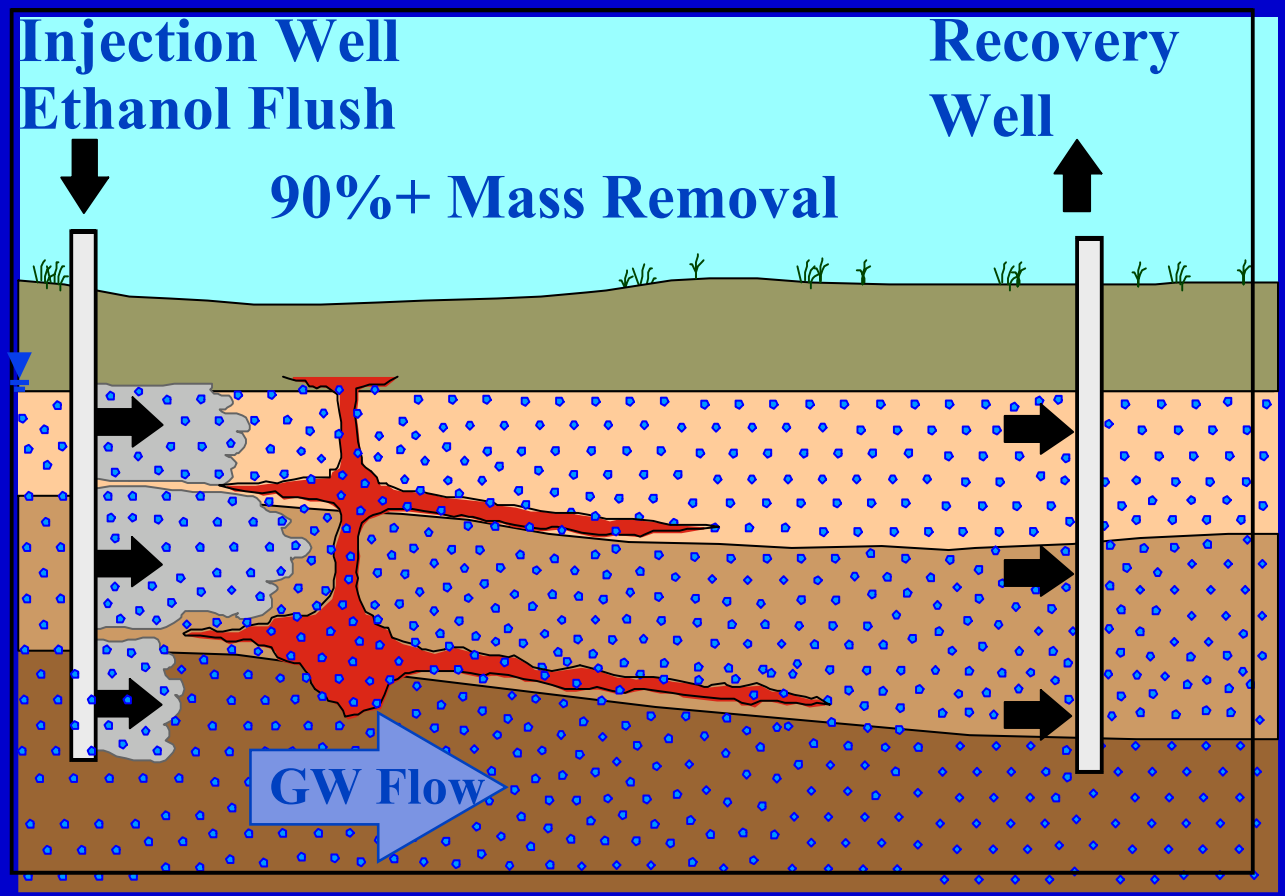
Solvent Extraction Residual Biotreatment (source management)

- Remove more accessible fraction of DNAPL, lower dissolved concentrations/flux. Reduce time/distance needed to meet GW quality objectives.
- Activate reductive bio-transformations in high redox environments.
- Insure supply of e- donor, accelerate process and reduce uncertainty.
- Meet regulatory requirements.

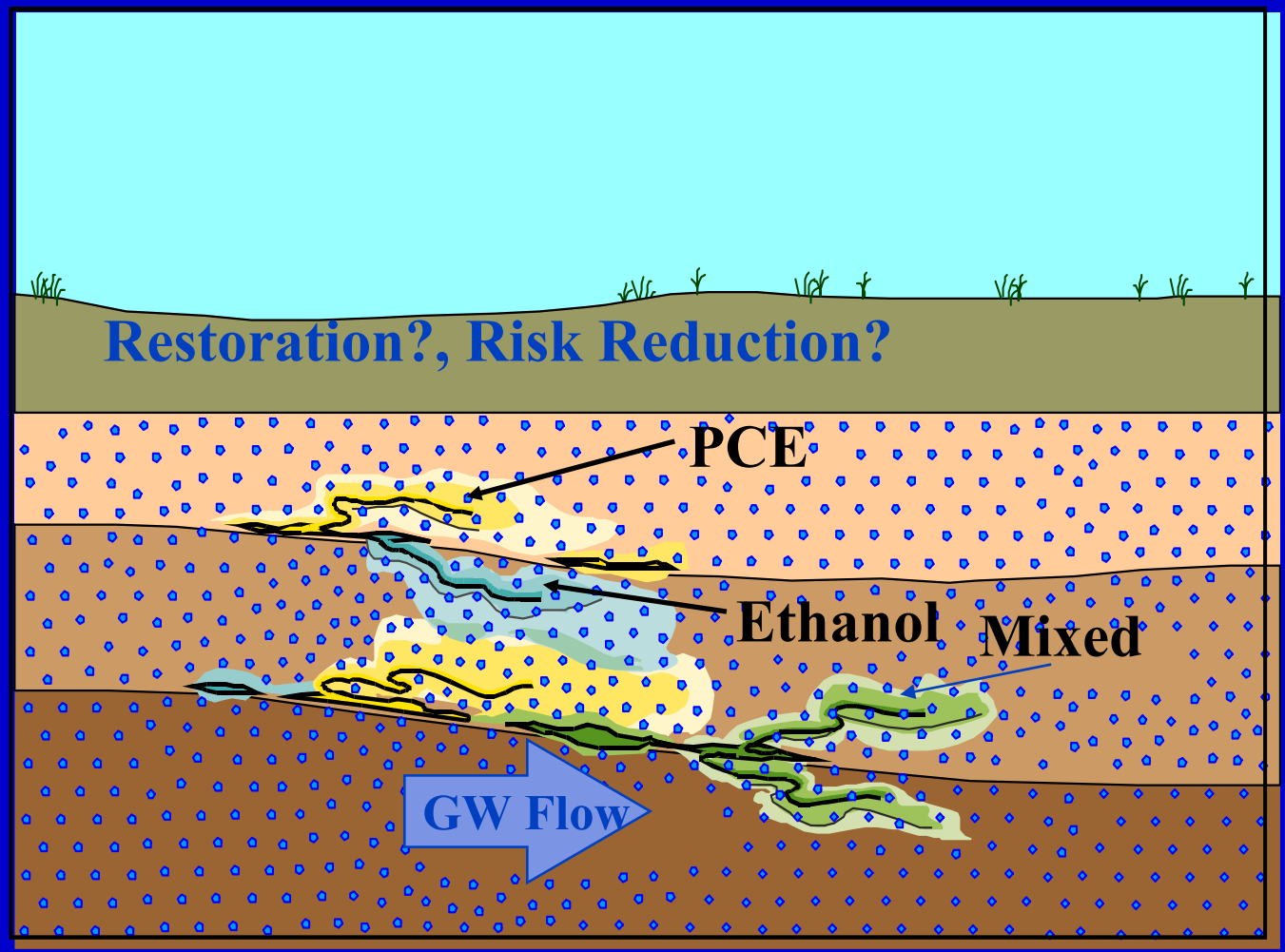
Plume Response
Pre-Cosolvent Flush
Site Characterization

- Aerobic Conditions
- Low levels of daughter products (TCE)

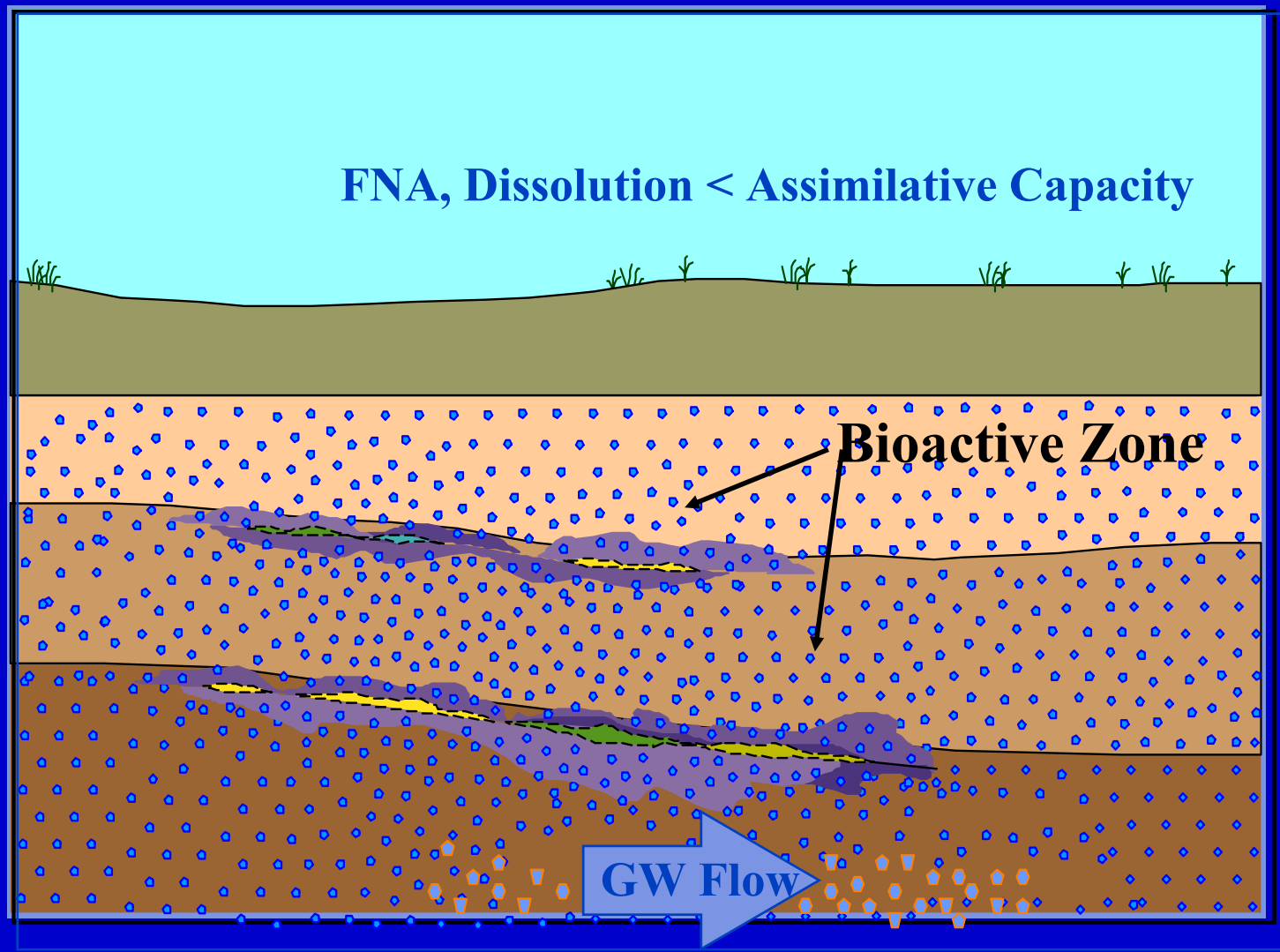
Cosolvent Extraction



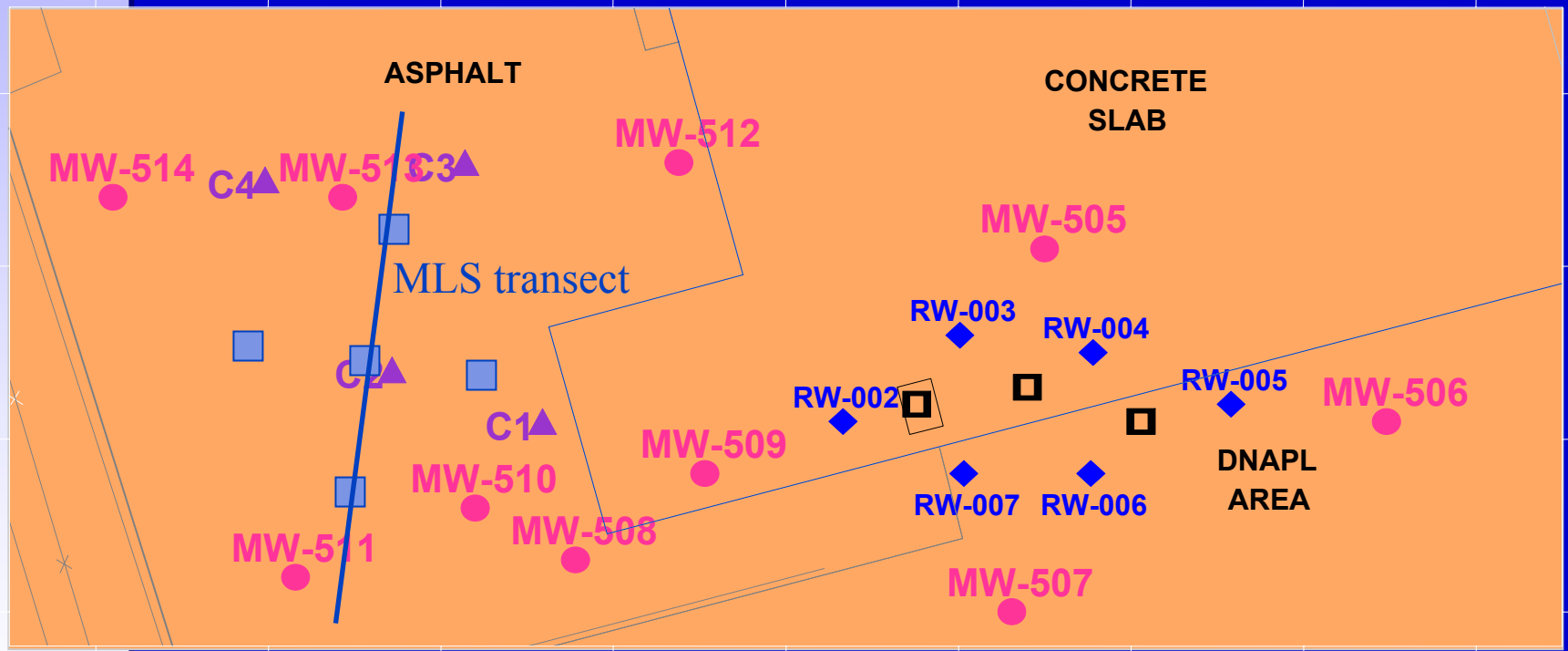
Residual Contaminants



Bioremediation

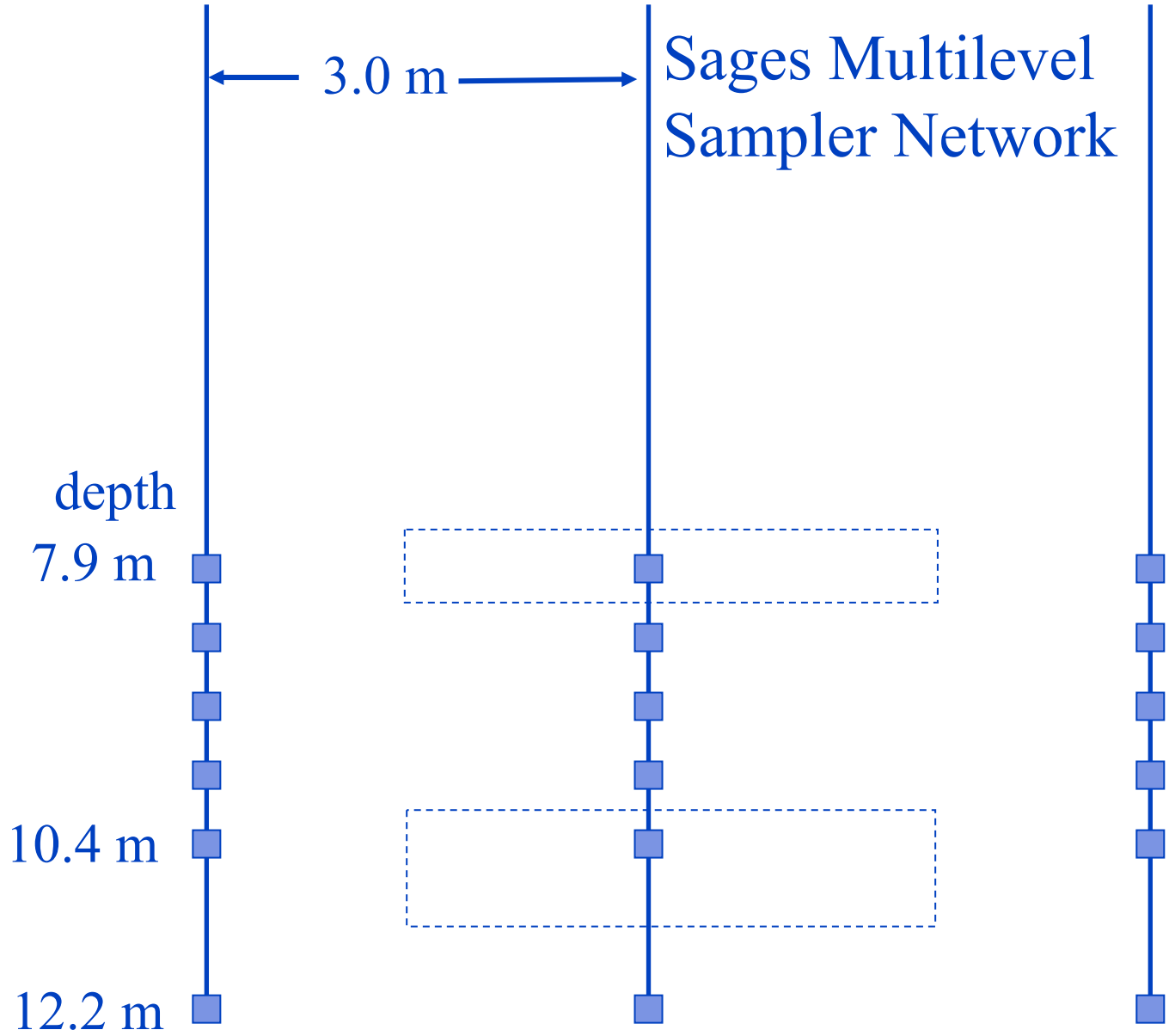


Sage's Dry Cleaner Site
Jacksonville, Florida

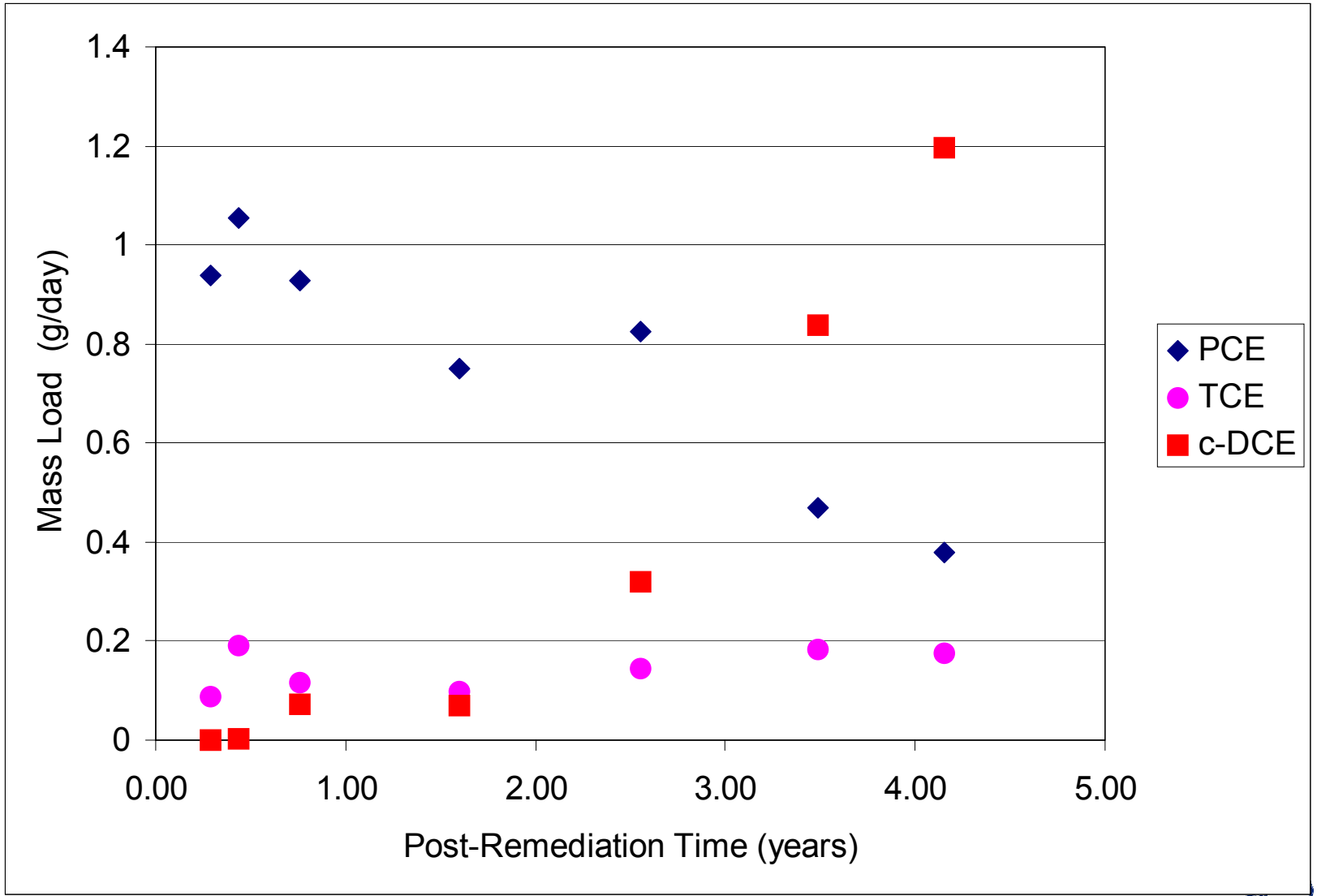


UNIVERSITY OF FLORIDA

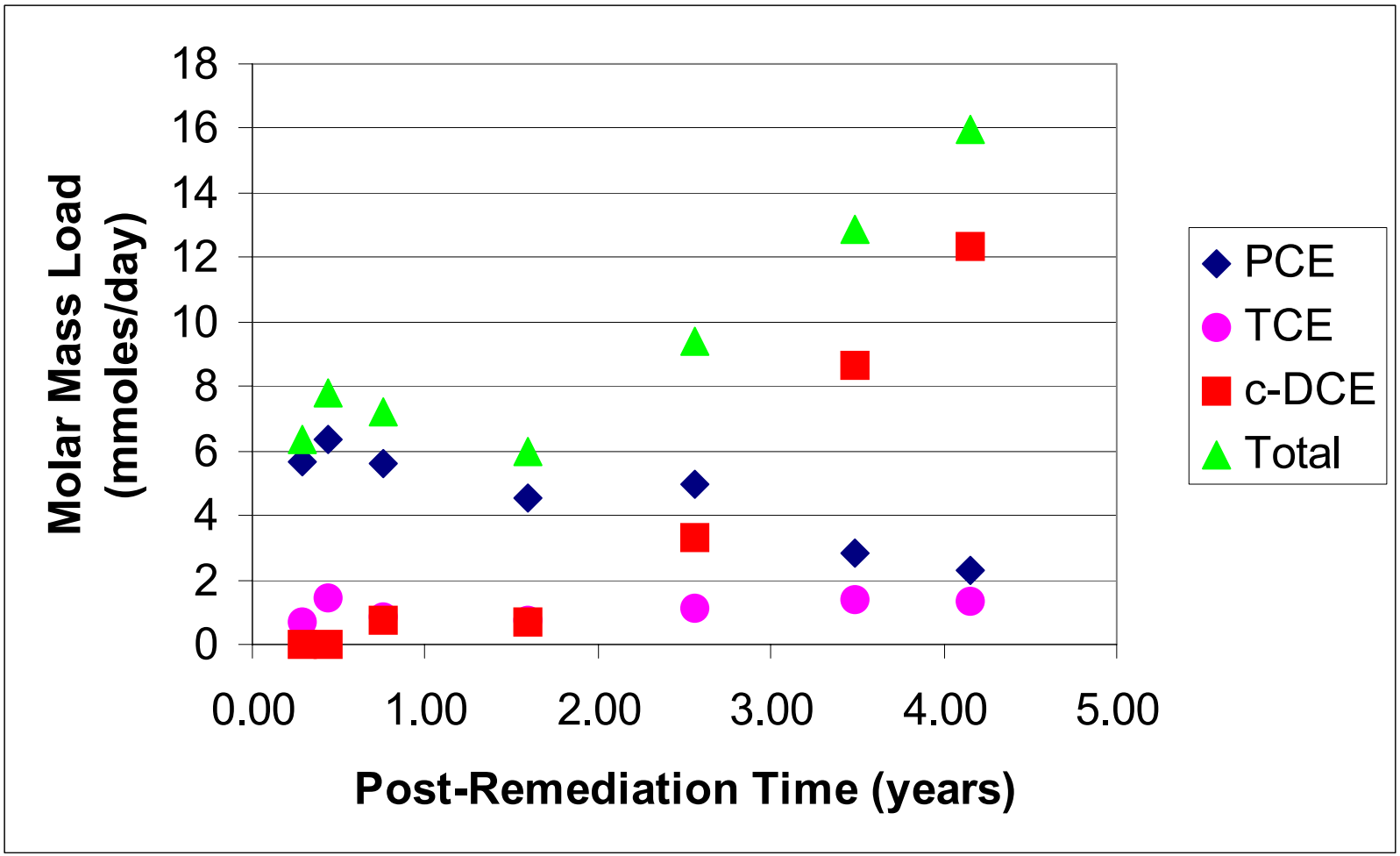
Engineering


3.0 m
Sages Multilevel
Sampler Network
depth
7.9 m
10.4 m
12.2 m

Total Plume Mass Load



Molar Based Total Load



Increased mass flux caused by enhanced dissolution?

Two years required to see response.

Alternative Flux Measurement Methods

Tubingen Method
Integral Pumping Test Method
(transect of wells pumped for a period of time measuring effluent contaminant concentrations)

Florida method
Flux Meter Borehole Method
(sorbent is placed in a well to collect contaminants and release tracers)

SUMMARY

Solvent Extraction:

43 L PCE Removed (Mass Recovery)

~64 % PCE Removed

Source Zone Flux

47% reduction in PCE concentration in the source zone multilevel sampler network

PCE Daughter Product Formation

Significant increase in *cis*-DCE mass

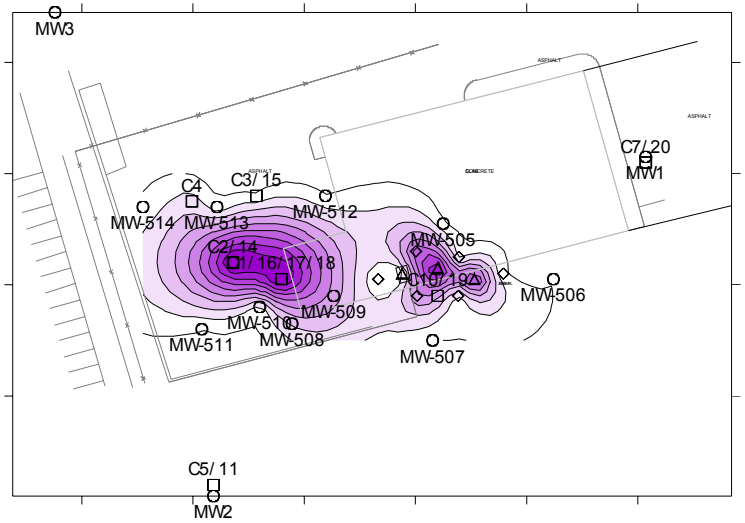
Significant time required to Observe Plume Response

PCE

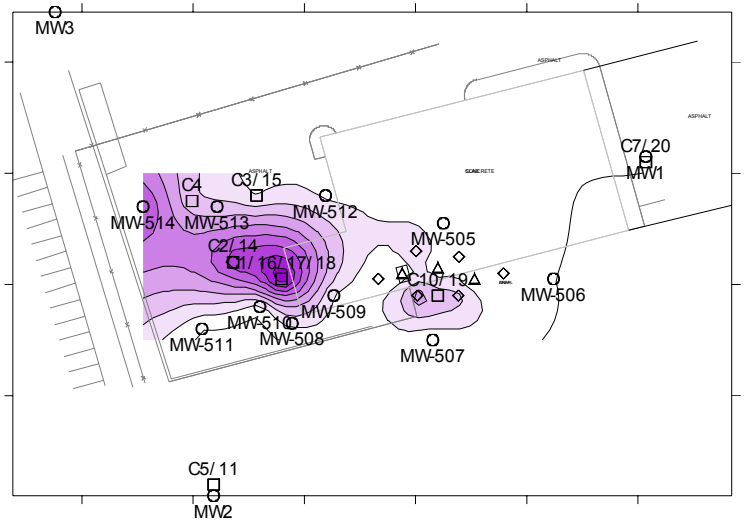
80,000 µg/l = 480 µM

80000 ug/L
70000 ug/L
60000 ug/L
50000 ug/L
40000 ug/L
30000 ug/L
20000 ug/L
10000 ug/L
0 ug/L

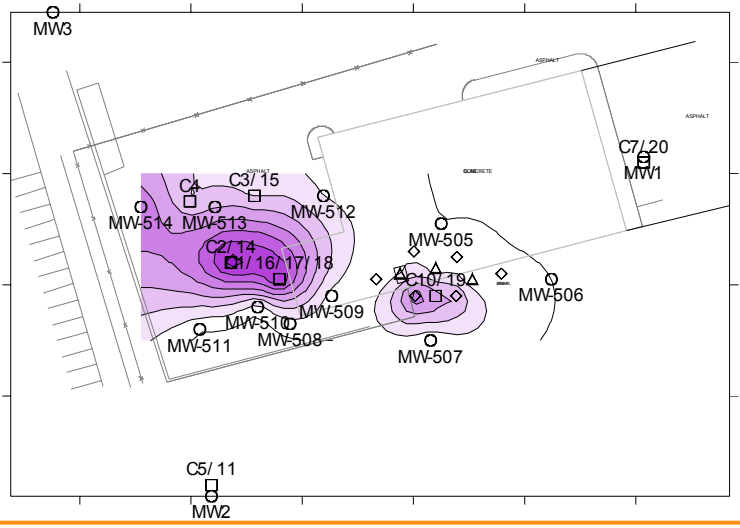
Pre-Ethanol Flush (with Day 29 data)



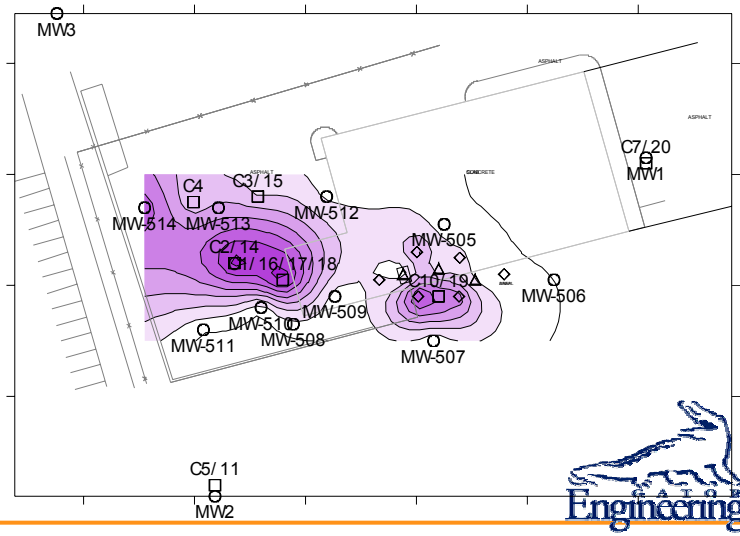
~1 Month Post-Flush



~2.5 Months Post-Flush



~4 Months Post-Flush



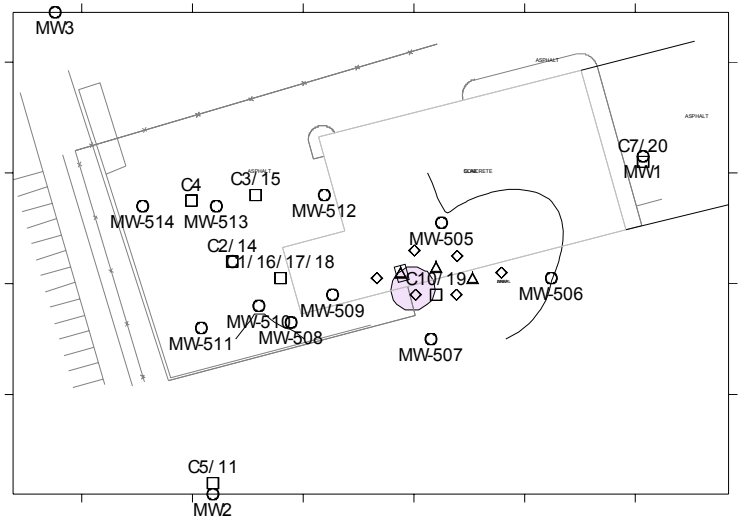
UNIVERSITY OF FLORIDA

Engineering

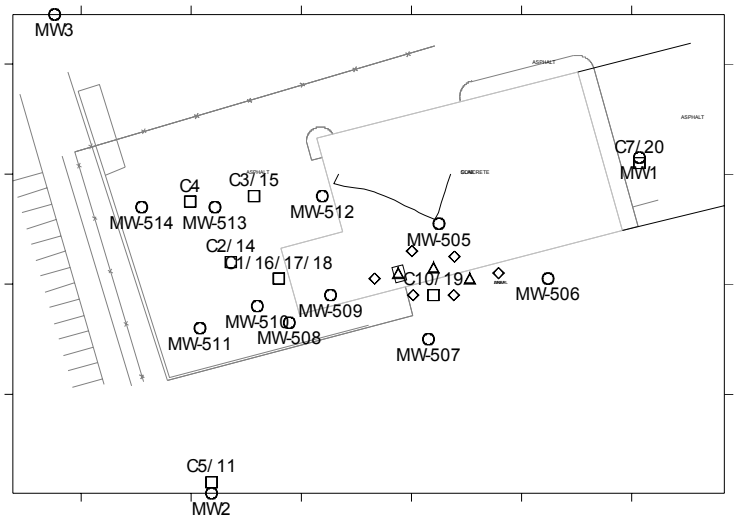
PCE

80000 ug/L
70000 ug/L
60000 ug/L
50000 ug/L
40000 ug/L
30000 ug/L
20000 ug/L
10000 ug/L
0 ug/L

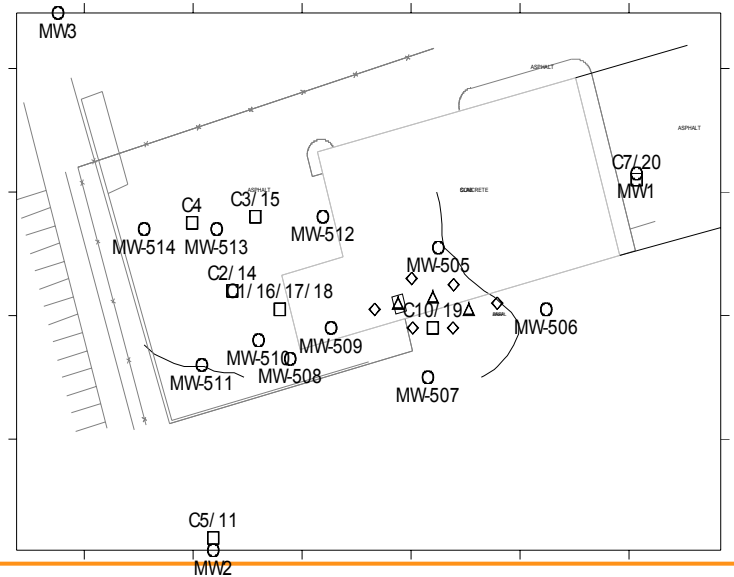
~25 Months Post-Flush



~28 Months Post-Flush



~31 Months Post-Flush



UNIVERSITY OF FLORIDA

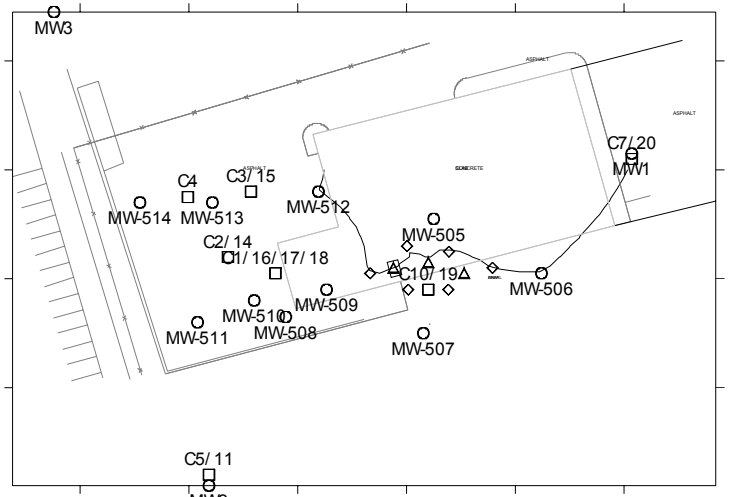
Gator Engineering

cis-DCE

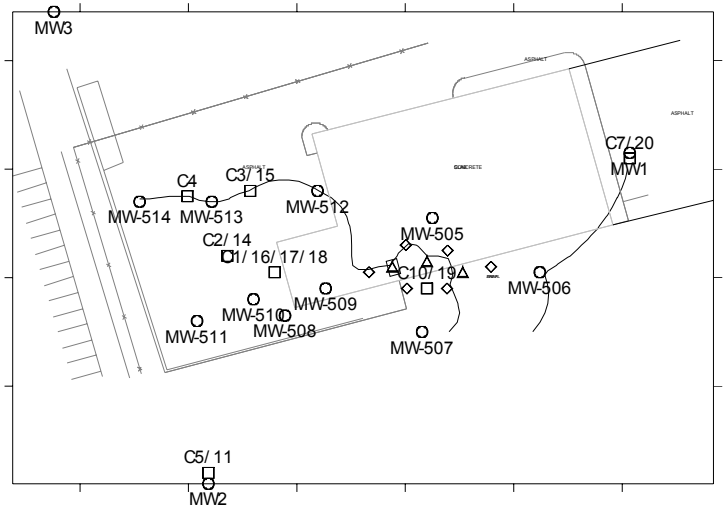
16,000 µg/l = 165 µM

16000 ug/L
14000 ug/L
12000 ug/L
10000 ug/L
8000 ug/L
6000 ug/L
4000 ug/L
2000 ug/L
0 ug/L

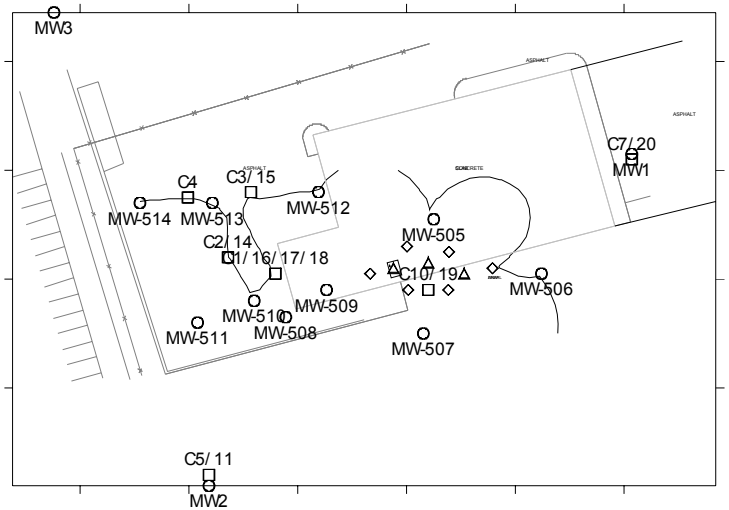
Pre-Ethanol Flush (with Day 29 data)



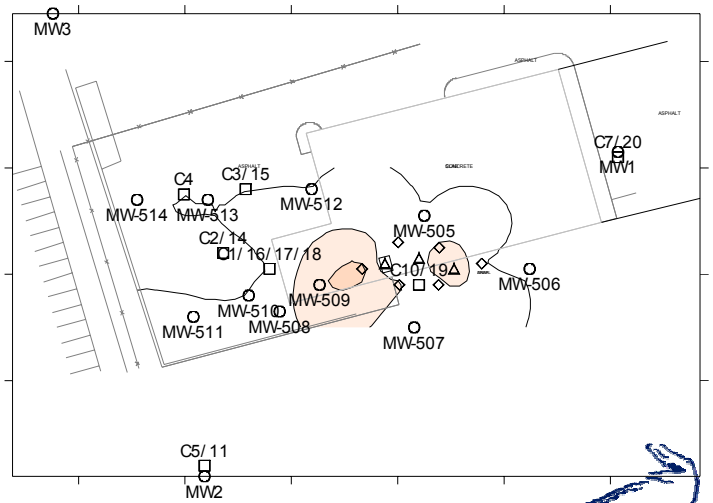
~1 Month Post-Flush



~2.5 Months Post-Flush



~4 Months Post-Flush



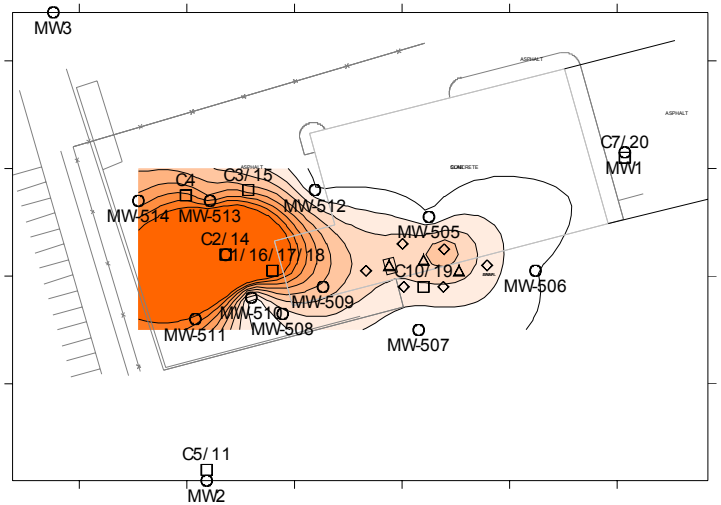
UNIVERSITY OF FLORIDA

Gator Engineering

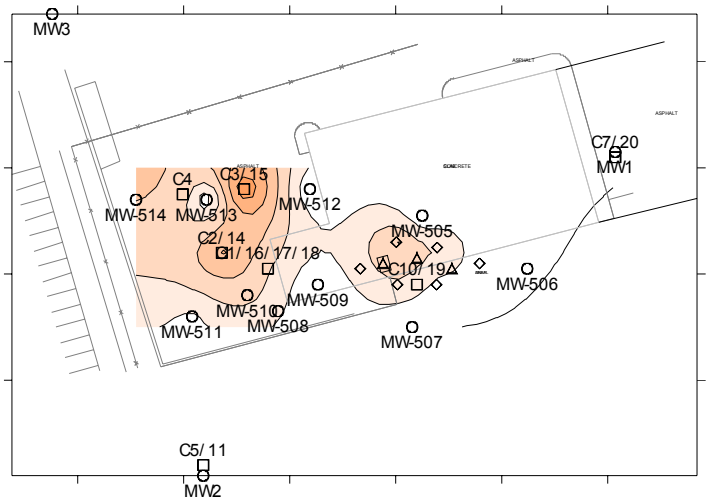
cis-DCE

16000 ug/L
14000 ug/L
12000 ug/L
10000 ug/L
8000 ug/L
6000 ug/L
4000 ug/L
2000 ug/L
0 ug/L

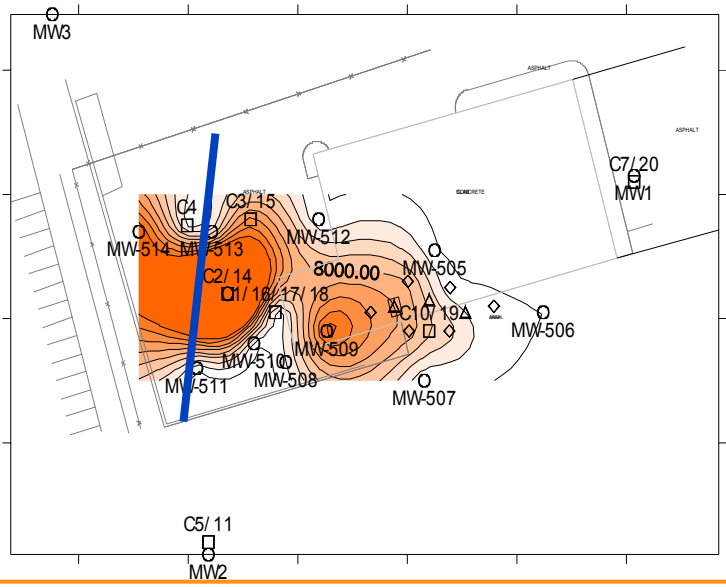
~25 Months Post-Flush



~28 Months Post-Flush

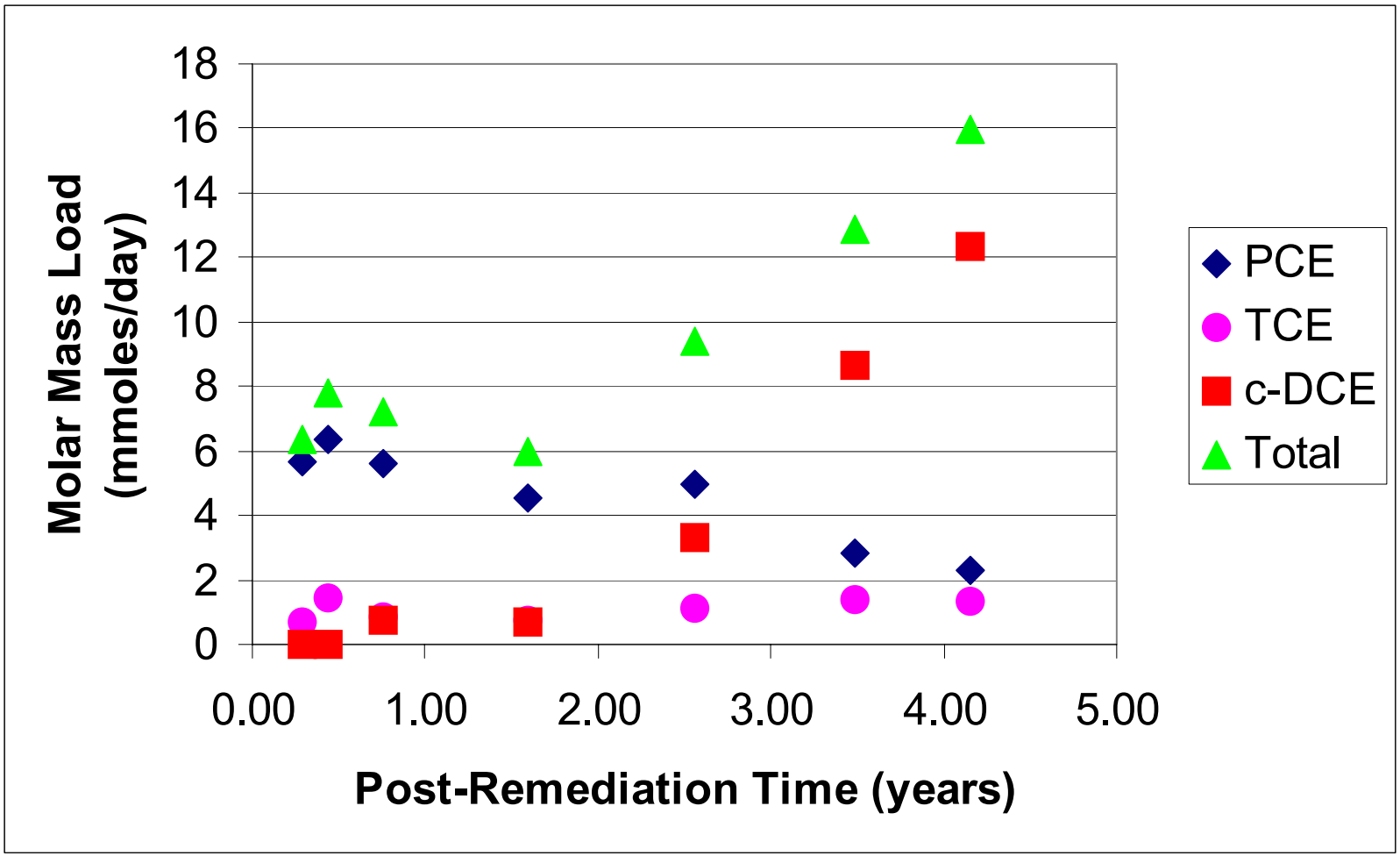


~31 Months Post-Flush



Next look at flux across a multilevel sampler transect

Molar Based Total Load



Increased mass flux caused by enhanced dissolution?