A Multi-Site Performance Review of Liquid Activated Carbon for Groundwater Treatment

Doug Davis – Director of Remediation Design,
Central/East Region Technical Services Manager

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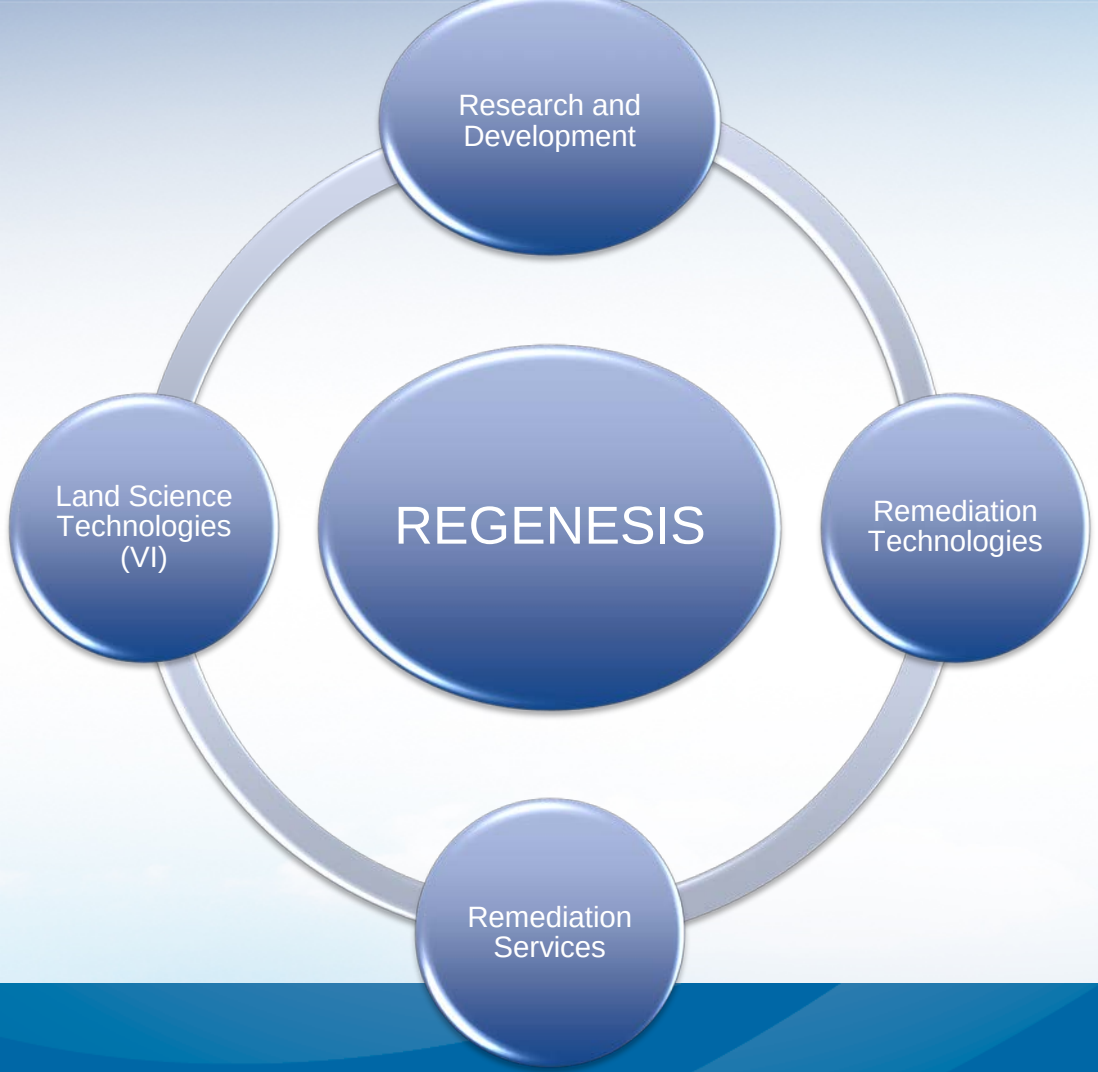
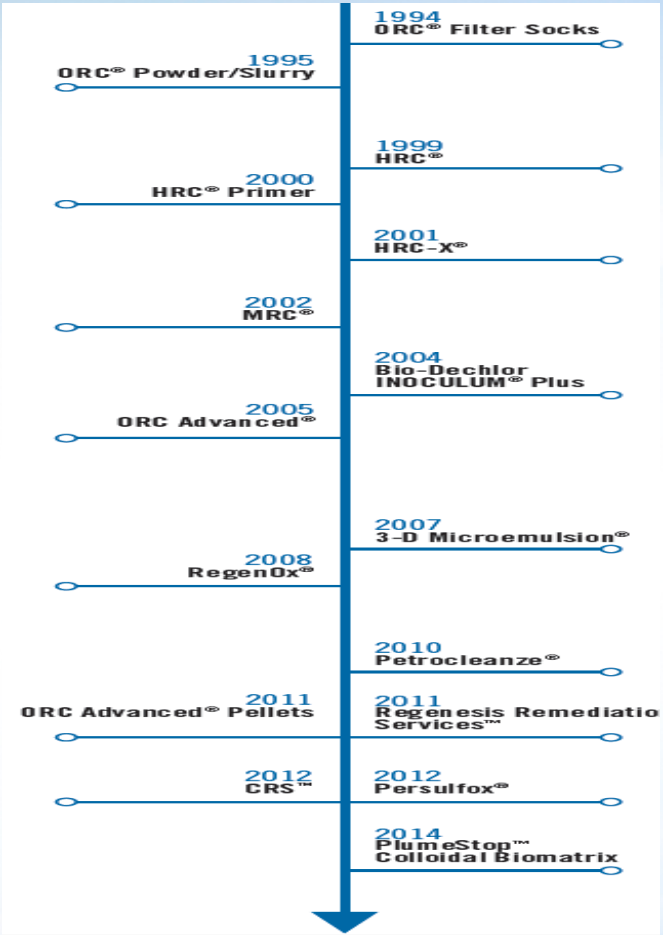
Technology-Based Solutions for the Environment

Outline

- Introduction
- Background on Technology Development
- Technology Functionality Basics
- Usage Statistics and Aggregate Field Performance
- Case Studies
- Q&A


Research and Development
Land Science Technologies (VI)
REGENESIS
Remediation Technologies
Remediation Services


1994
ORC® Filter Socks
1995
ORC® Powder/Slurry
1999
HRC®
2000
HRC® Primer
2001
HRC-X®
2002
MRC®
2004
Bio-Dechlor INOCULUM® Plus
2005
ORC Advanced®
2007
3-D Microemulsion®
2008
RegenOx®
2010
Petrocleanze®
2011
ORC Advanced® Pellets
2011
Regenesis Remediatio Services™
2012
CRS™
2012
Persulfox®
2014
PlumeStop™ Colloidal Biomatrix

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REMEDIATION SERVICES

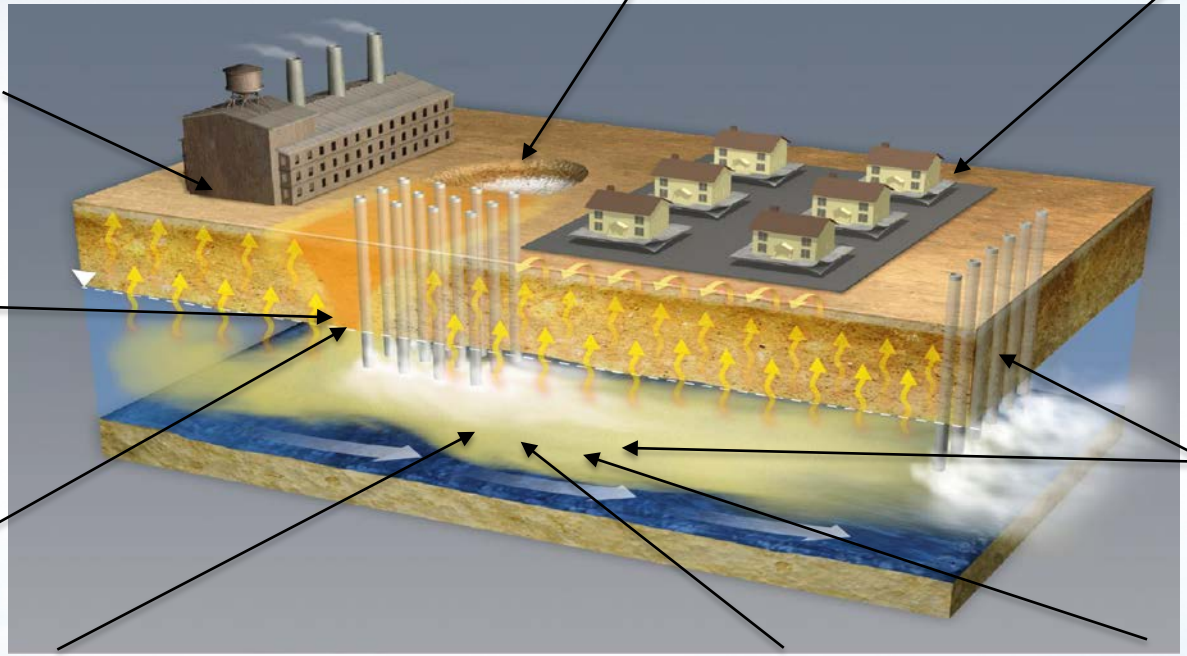
Aerobic Bio — ORC ADVANCED PELLETS — OXYGEN RELEASE COMPOUND

VI-New Construction — Geo-Seal Vapor Intrusion Barrier

VI-Existing Structures — Retro-Coat™ Vapor Intrusion Coating

Chemical Oxidation — REGEN Ox — PERSULF Ox

Enhanced Desorption — PETRO CLEANZE™ Enhanced Desorption



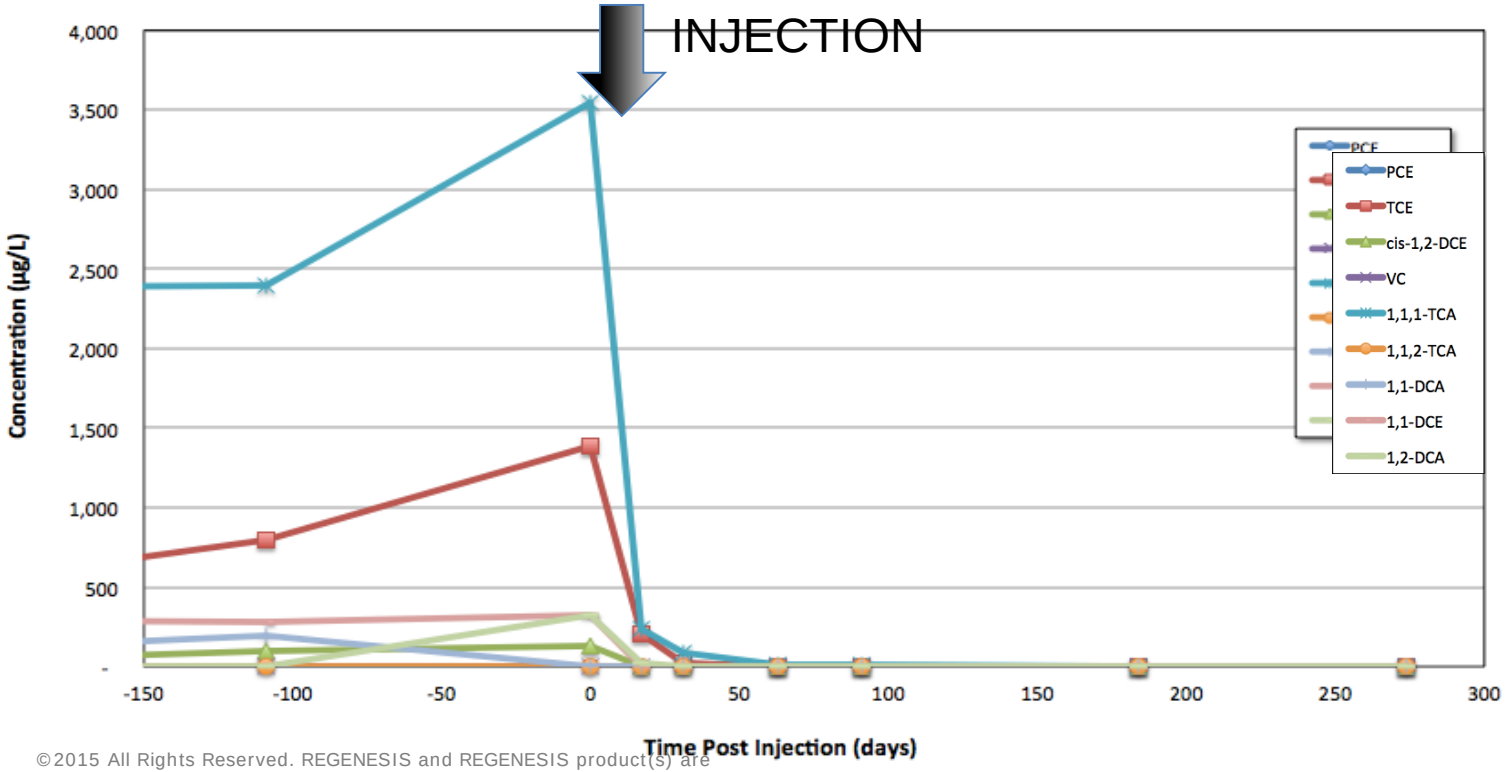
Sorption-Liquid Activated Carbon — PLUME STOP® Liquid Activated Carbon

Anaerobic Bio — 3-D MICROEMULSION — BDI PLUS BIO-DECHLOR INOCULUM

Aerobic Bio — ORC ADVANCED OXYGEN RELEASE COMPOUND

ISCR — CRS CHEMICAL REDUCING SOLUTION

VOC Groundwater Concentrations Following PlumeStop™ and HRC® Injection



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PLUME STOP™
Liquid Activated Carbon

Established Fact: Concentrations can be Reduced Quickly Through Sorption!

Challenge to REGENESIS®

Develop:

- ***Dispersible*** sorbent technology
- Stimulate rapid sorption of contaminants
- Permanently biodegrade contaminants

Challenge to REGENESIS®

Why a ***Dispersible*** sorbent?

Granular activated carbon >1,000 µm

Powdered > 40 µm but agglomerates back to 1,000 µm

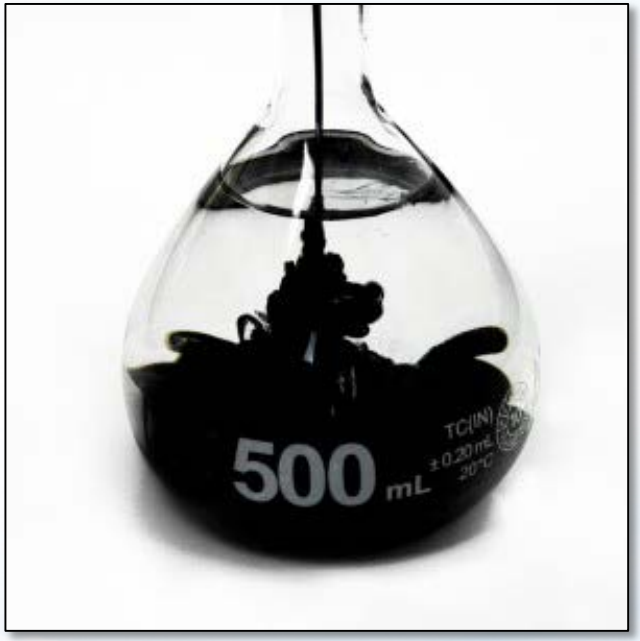
Pore Throat Diameter-sand/silt 5-30 µm

GACs/PACs do not disperse!!

The Reagent – Timeline

PLUME STOP®
Liquid Activated Carbon

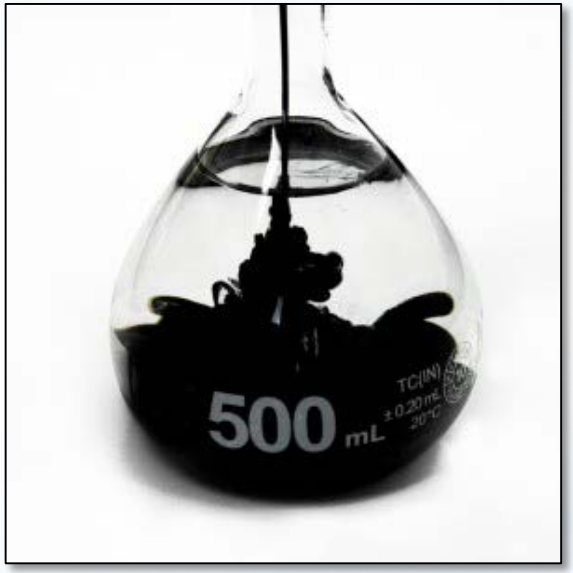
- R&D stages 2007 – 2013
  - Ongoing ancillary research
- Field beta tests 2013 – 2014
  - Early tests still running for long term data
- Commercial launch May 2014
  - Battelle Monterey
- Commercial applications since launch
  - Reviewed in this presentation



The Reagent – What Is It?

PLUME STOP®
Liquid Activated Carbon

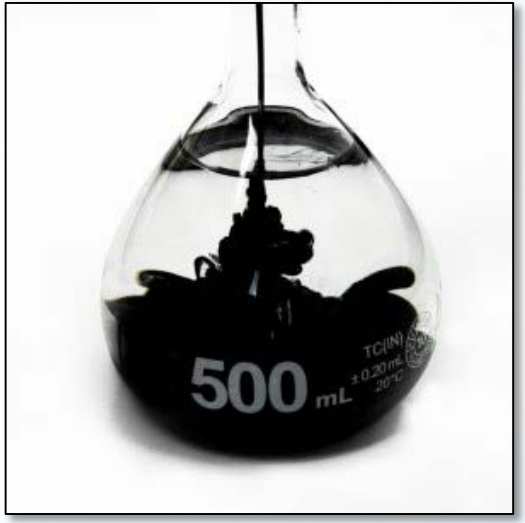
- A highly dispersive and injectable sorbent and microbial growth matrix
- Sorbent
  - Rapid drop in contaminant concentration
  - Immediate Risk Reduction
- Microbial Growth Matrix
  - Accelerated biological destruction of sorbed mass – bacteria grows well on carbon
  - Ability to secure cleanup to much lower targets



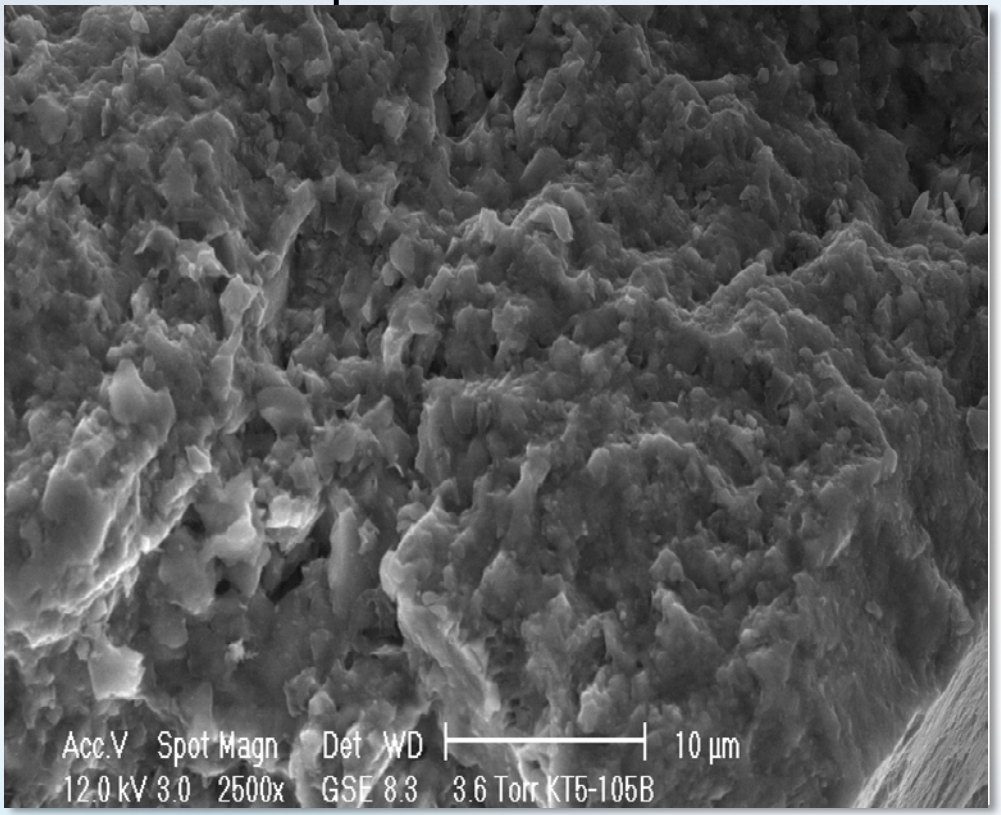
The Reagent – What Is It?

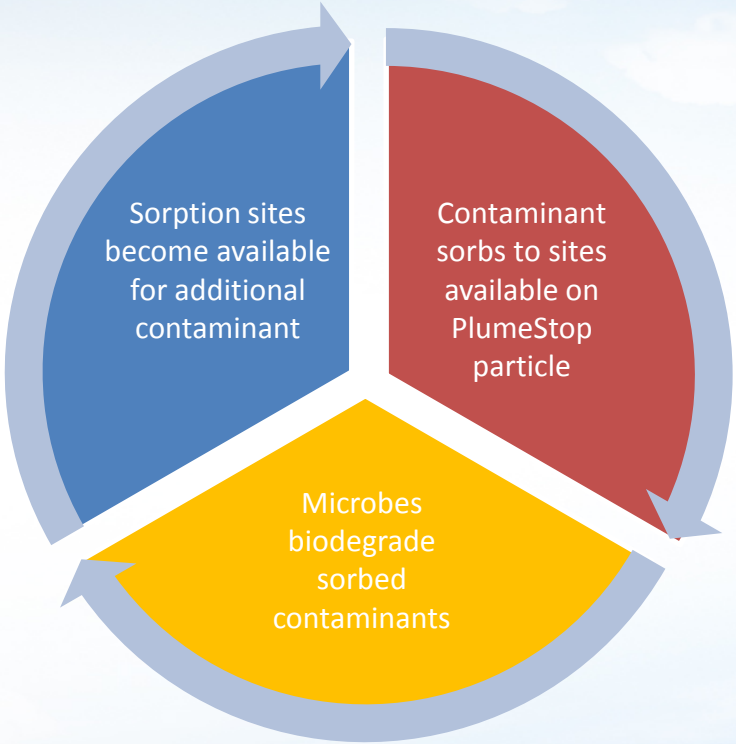
PLUME STOP®
Liquid Activated Carbon

- Colloidal Activated Carbon
  - Size – 1-2 µm
  - Size of a bacterium
  - Huge Surface Area – extremely fast sorption
- Proprietary Anti-Clumping/Distribution Supporting Surface Treatment
  - Core Innovation
  - Wide Area, Low-Pressure Distribution through soil without Clogging



PlumeStop Mode of Action





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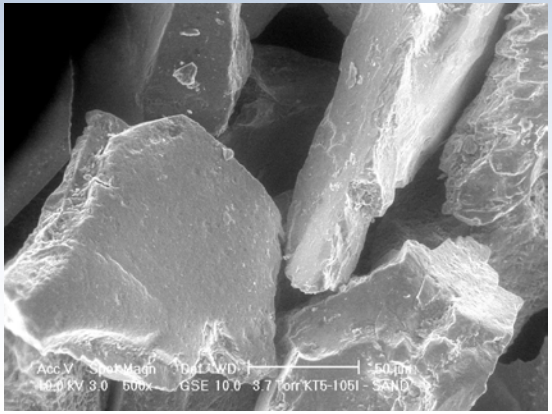

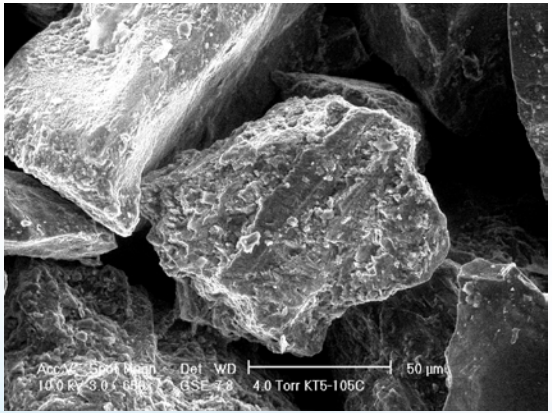

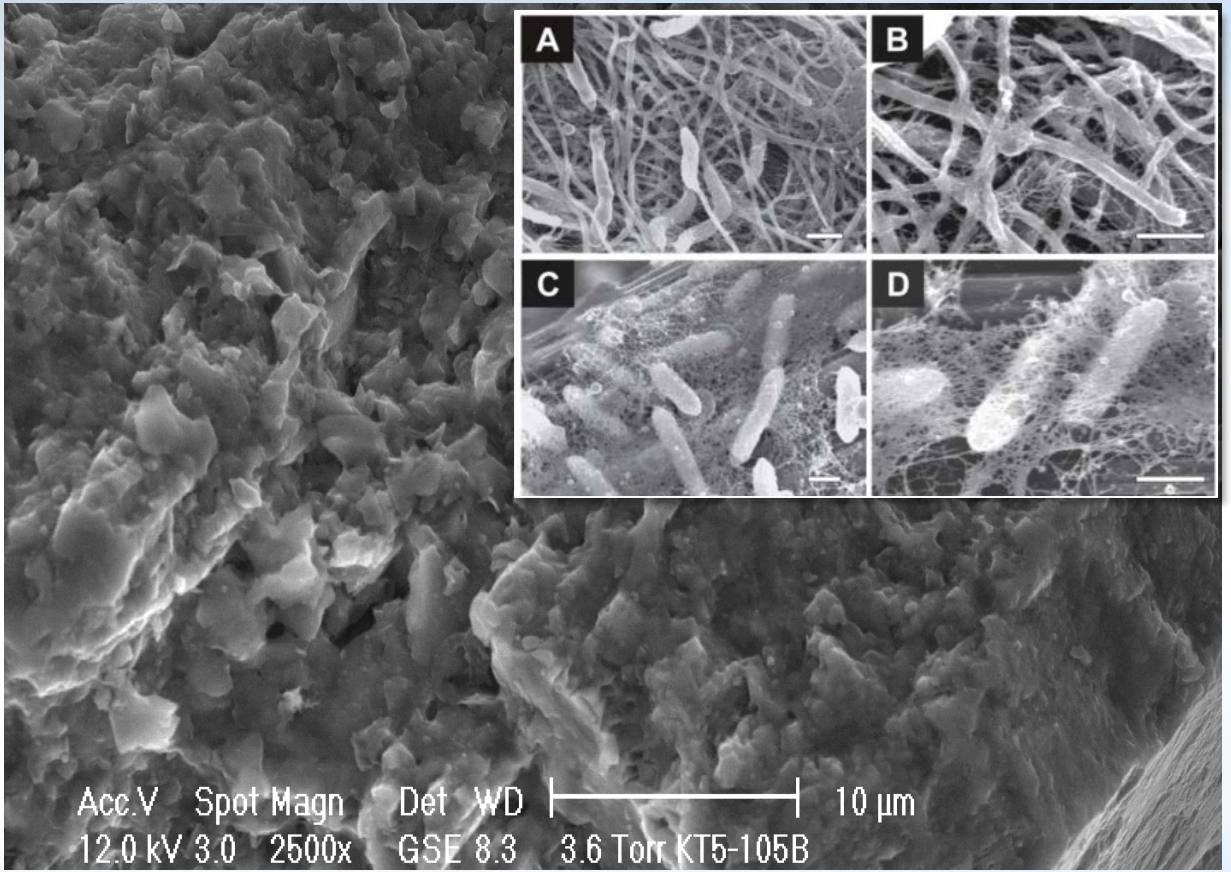

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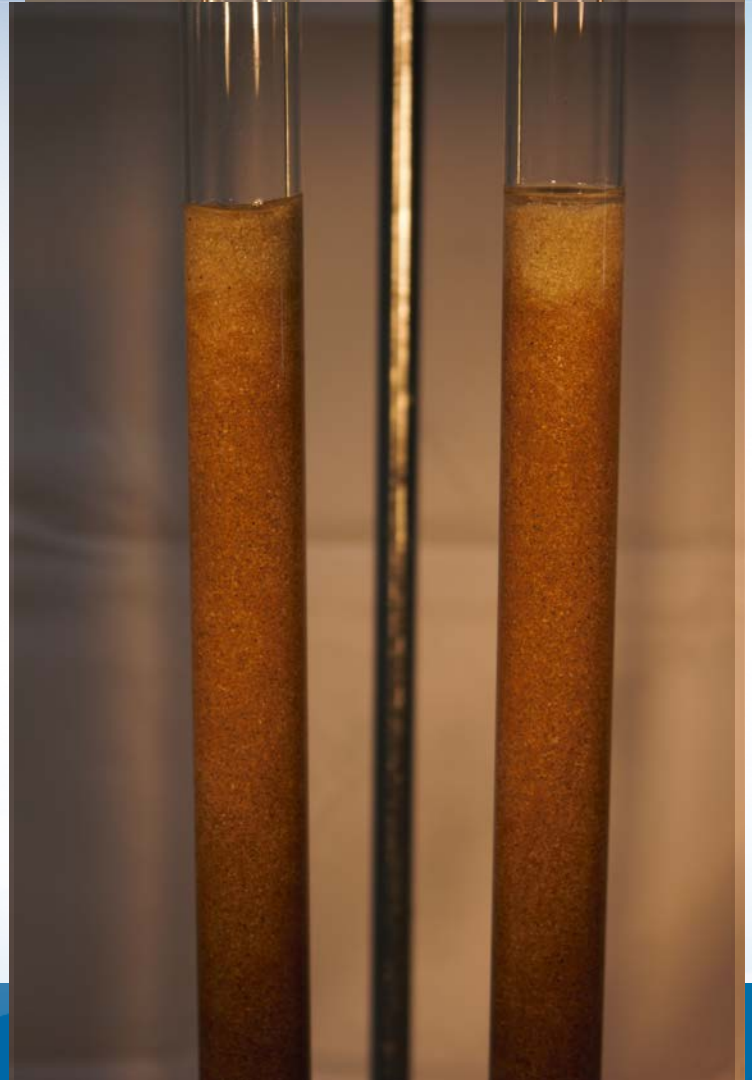
PlumeStop



Powdered Activated Carbon

repeat

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Evidence of Dispersive Flow (low pressure application)

Pre-app

Post-app

- Distribution of PlumeStop through target zone visually apparent
- Even dispersion evident through permeable strata

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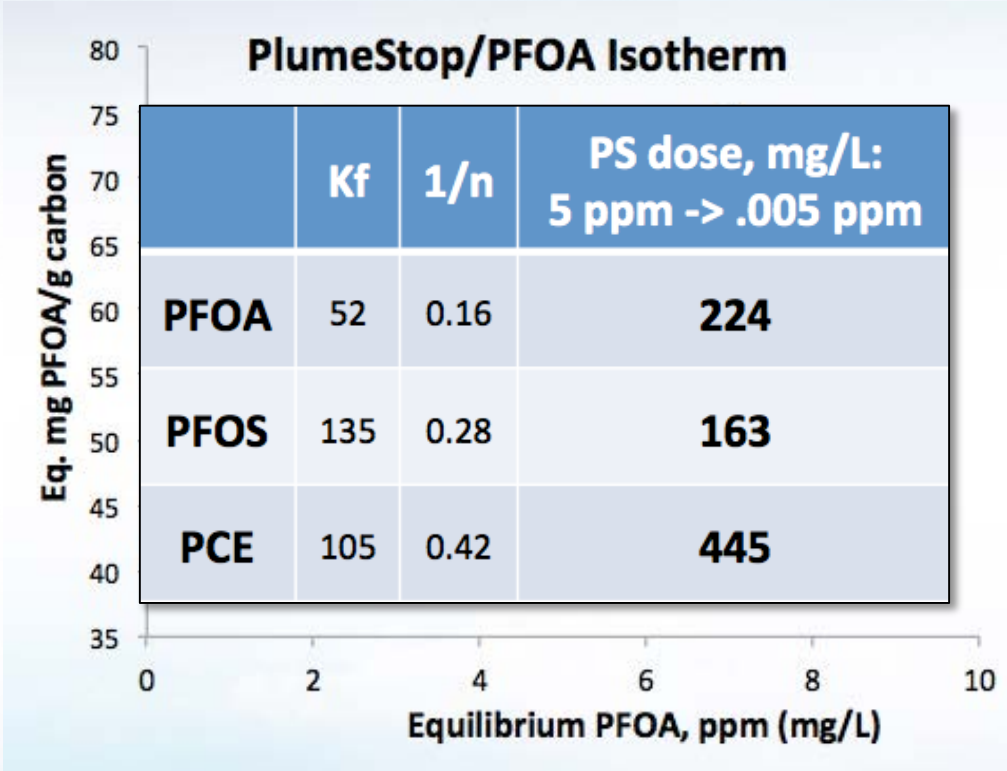
Liquid Activated Carbon

What it Treats

- CVOCs including ethenes and ethanes
- Petroleum Hydrocarbons (TPH, BTEX, etc.)
- Polynuclear Aromatics (PAHs)
- MTBE
- Pesticides
- PFCs
- Other Sorptive Contaminants



	Kf	1/n	PS dose, mg/L: 5 ppm -> .005 ppm
PFOA	52	0.16	224
PFOS	135	0.28	163
PCE	105	0.42	445

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Liquid Activated Carbon

How Do We Determine PlumeStop Dosage?

From the isotherms we know how much PlumeStop is needed to secure a concentration in groundwater (static system).

We then set the static system in motion given the groundwater velocity and contaminant mass flux.

We then factor in potential contaminant leaching from soil (matix back-diffusion).

Our pre-remedial design efforts are thus focused on identifying contaminant transport zones, quantifying mass flux and evaluating leaching potential

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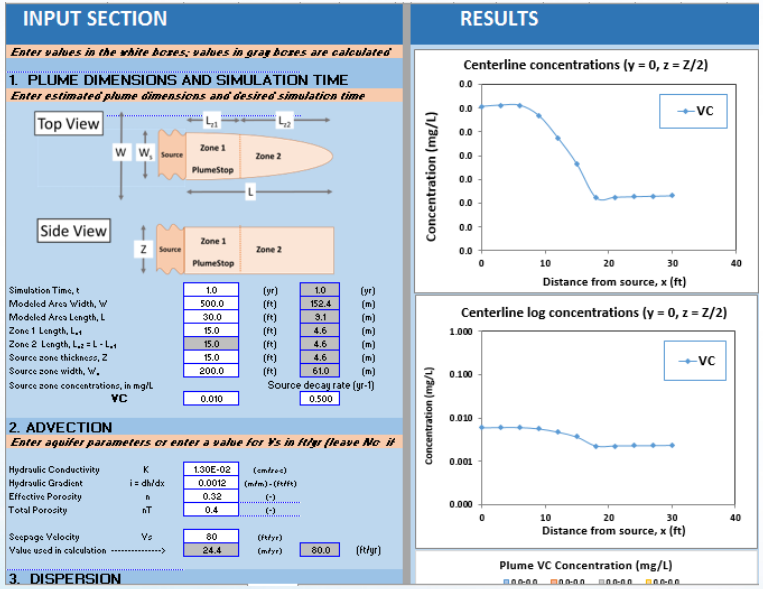
PLUME STOP™
Liquid Activated Carbon

PlumeStop-Biochlor Model Development



Developed by Professor Arturo Keller - UCSB

PlumeStop isotherms hot-wired into model

Through this effort we can now engineer the fraction organic carbon (foc) requirement to achieve a target concentration at a point of compliance

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Contaminants Sorbed, Now What?

3 Primary Methods of Contaminant Destruction

- **Aerobic Treatment**
  - Electron Acceptor Addition, Sparging…
- **Anaerobic Treatment**
  - Slow release electron donors
  - Lactate, recirculation systems
- **Monitored Natural Attenuation/Intrinsic Remediation**

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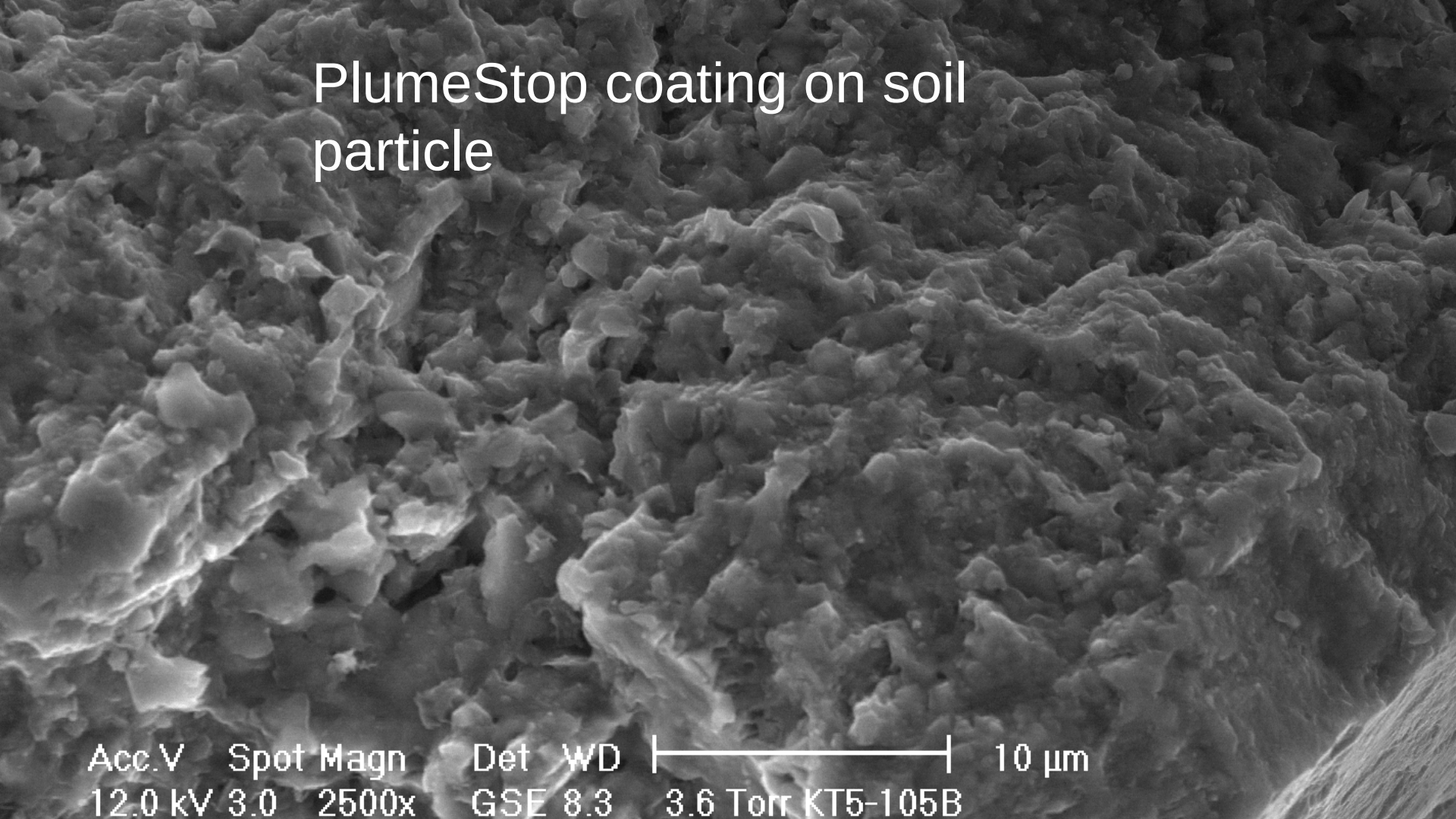
PlumeStop coating on soil particle
Acc.V Spot Magn Det WD 10 µm
12.0 kV 3.0 2500x GSE 8.3 3.6 Torr KT5-105B

When/Where to Use PlumeStop?

1. When time is critical
2. As a long-term barrier
3. To achieve stringent cleanup standards
4. To address matrix back diffusion
5. When remediation is “flat lining”

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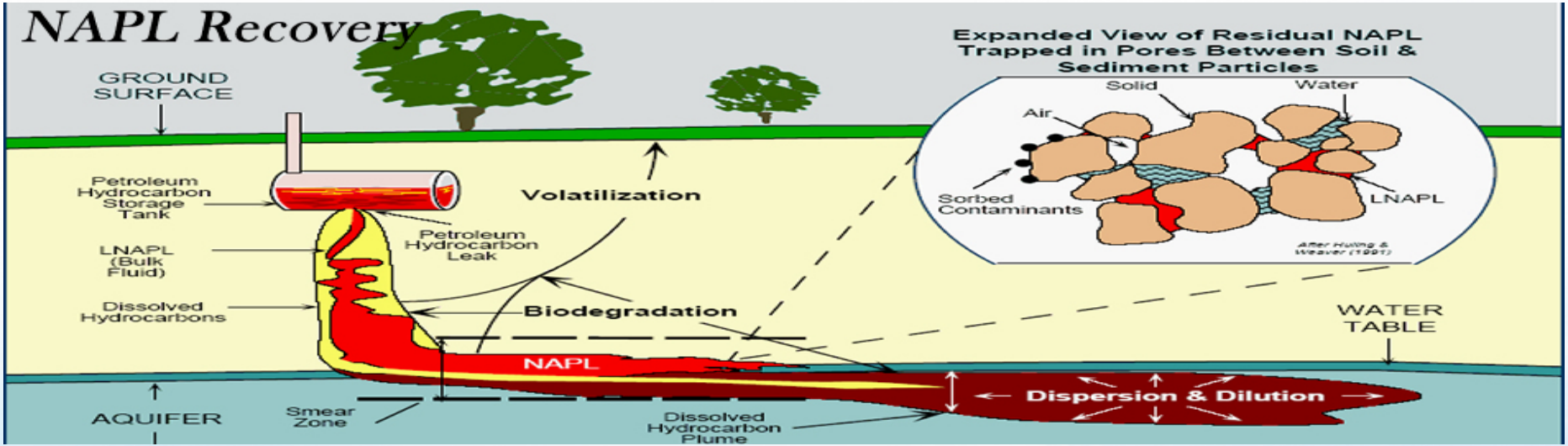
Pitfalls – Things to Avoid

- High mass/high concentration zones
  - NAPL – too much to sorb, too much to bio
- Low resolution sites
  - Design Verification



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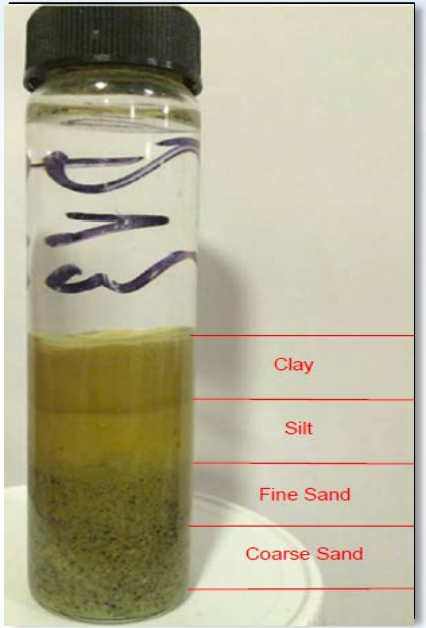
Design Verification Testing (DVT)

- Why is it necessary?
  - Site investigations typically focus on liability and risk assessment
    - Emphasis on contaminant identification, plume dimensions and migration pathways
- What is DVT?
  - **DVT focuses on efficient reagent-contaminant contact**
    - Emphasis on identification of principal impacted strata, contaminant mass distribution and reagent delivery
  - Field-verification of remedial design parameters
  - ID contaminant transport and storage zones
  - Regenesis personnel will perform and/or team w/ consultant to do the work
  - Enables accurate placement of reagents ***for maximum interception of contaminant flux***



Design Verification Testing (DVT)

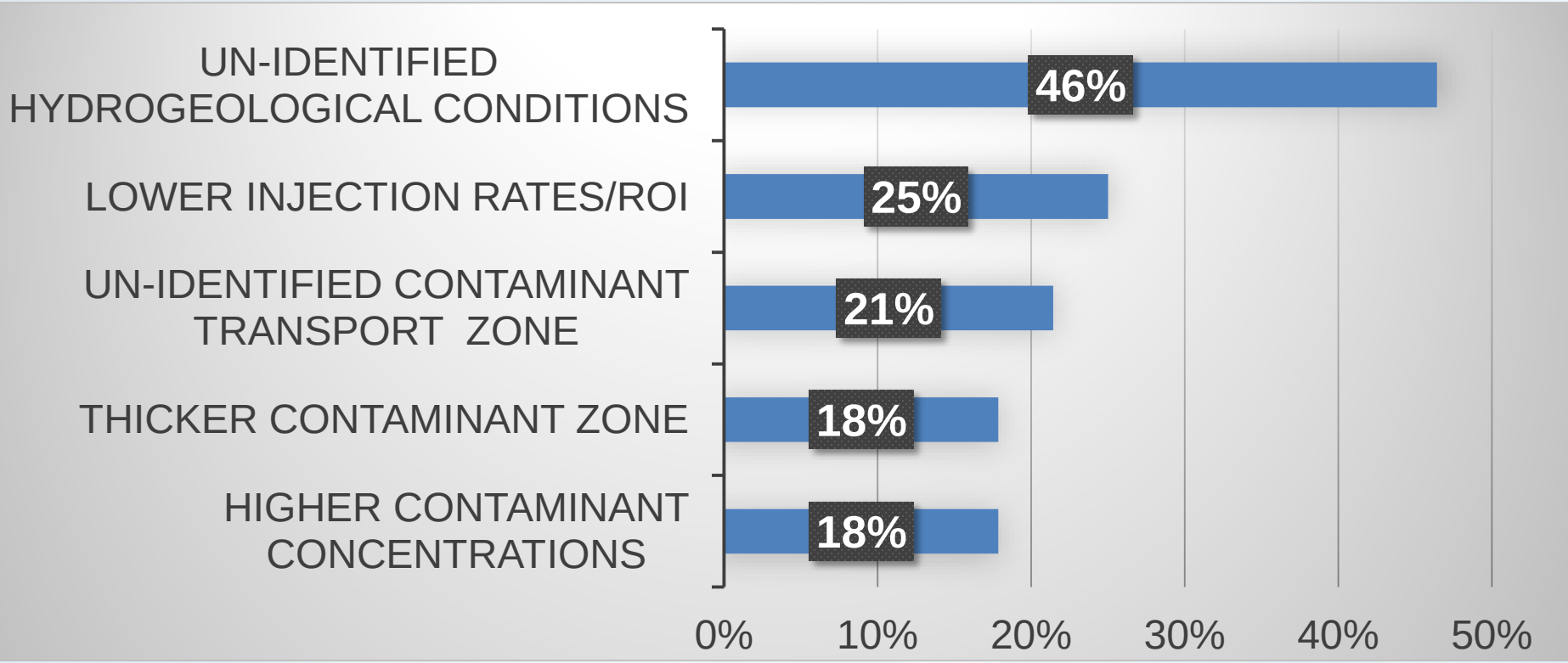
- DVT can Include Injection Testing for High Volume Delivery Systems

Regenesis DVT

- When is it undertaken?
  - Prior to planned application
    - Allows time for data analysis and design refinement
- What is the outcome?
  - 80% of tests to date have found unanticipated results
    - $^{2}/_{3}$ of preliminary designs have been modified / refined
  - 80% of design changes have been cost-neutral

Regenesis PlumeStop® strategy of 100% success

TECHNICAL BLIND SPOTS IDENTIFIED DURING DVT



- performance analytics -

Where Applied? PlumeStop Applications – as of July 2016

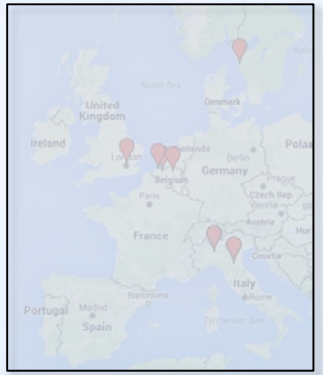
- Number of sites = 67
- Number of states = 24
- Number of countries = 7
- States
  - CA, CO, FL, GA, IA, IL, IN, KY, MA, MI, MO, NC, NE, NJ, NM, OH, PA, PR, SC, TX, UT, WA, WI, WV
- Countries
  - USA, Canada, Italy, Belgium, UK, Sweden, Netherlands
- Scale
  - Pilot 26 (39%)
  - Full 41 (61%)

PlumeStop Applications – July 2016

- Principally Hydrocarbons (aerobic bio) = 32
- Principally Solvents (anaerobic bio) = 31

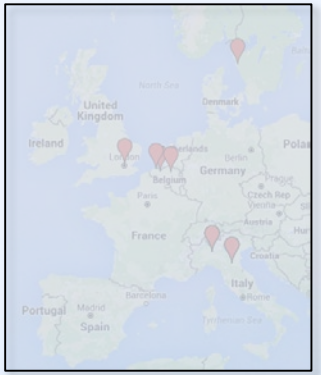
- Comingled / no dominant class = 4

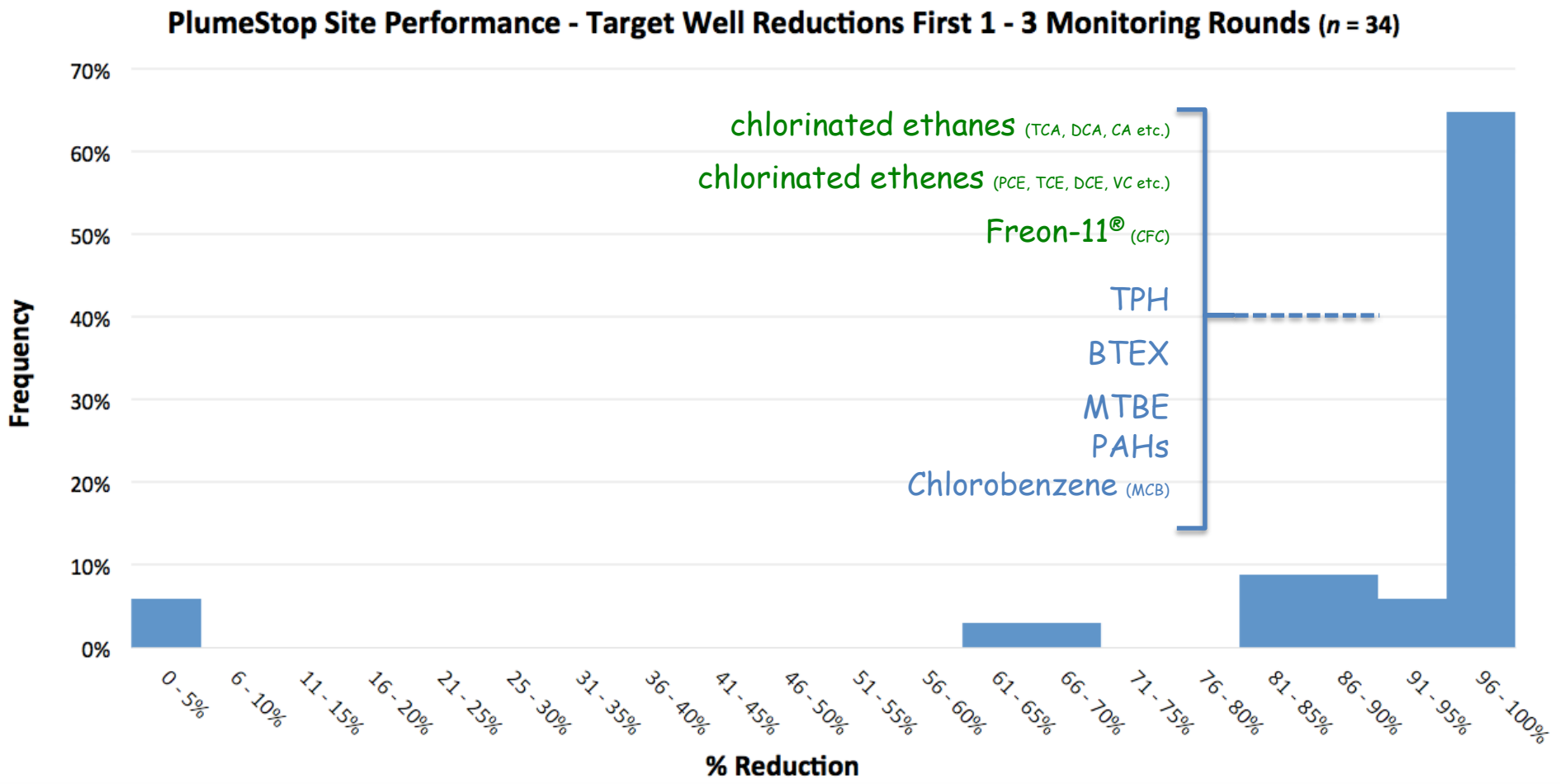
- Other contaminants of note
  - PAH, freon-11, MtBE, TBA, chlorobenzene



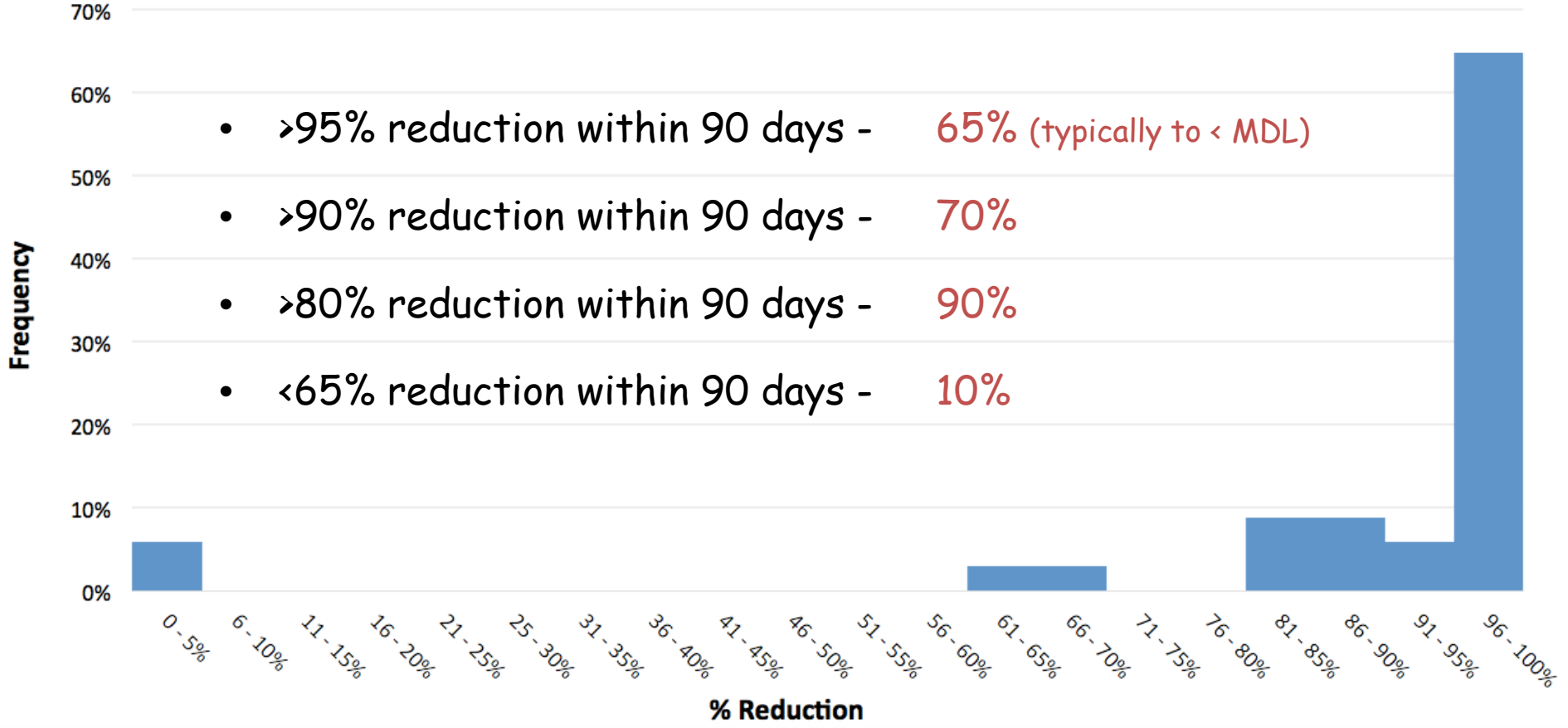
Data Set Reviewed

- 24 Project Site Data Sets Reviewed
  - All That We Have Access To Thus Far
  - More Coming/Continuous Feed
- Wells Within Zone of Anticipated Impact
- Total Contaminant Reduction
- Full Data Set Histogram
  - Histogram 1 – Contaminant Capture – Initial 1 to 3 rounds
  - Histogram 2 – Stability to Date – Ongoing (Average 200 days)




PlumeStop Site Performance - Target Well Reductions First 1 - 3 Monitoring Rounds (n = 34)
Frequency
70%
60%
50%
40%
30%
20%
10%
0%
chlorinated ethanes (TCA, DCA, CA etc.)
chlorinated ethenes (PCE, TCE, DCE, VC etc.)
Freon-11® (CFC)
TPH
BTEX
MTBE
PAHs
Chlorobenzene (MCB)
0 - 5%
6 - 10%
11 - 15%
16 - 20%
21 - 25%
25 - 30%
31 - 35%
36 - 40%
41 - 45%
46 - 50%
51 - 55%
56 - 60%
61 - 65%
66 - 70%
71 - 75%
76 - 80%
81 - 85%
86 - 90%
91 - 95%
96 - 100%
% Reduction

PlumeStop Site Performance - Target Well Reductions First 1 - 3 Monitoring Rounds (*n* = 34)



- >95% reduction within 90 days - 65% (typically to < MDL)
- >90% reduction within 90 days - 70%
- >80% reduction within 90 days - 90%
- <65% reduction within 90 days - 10%

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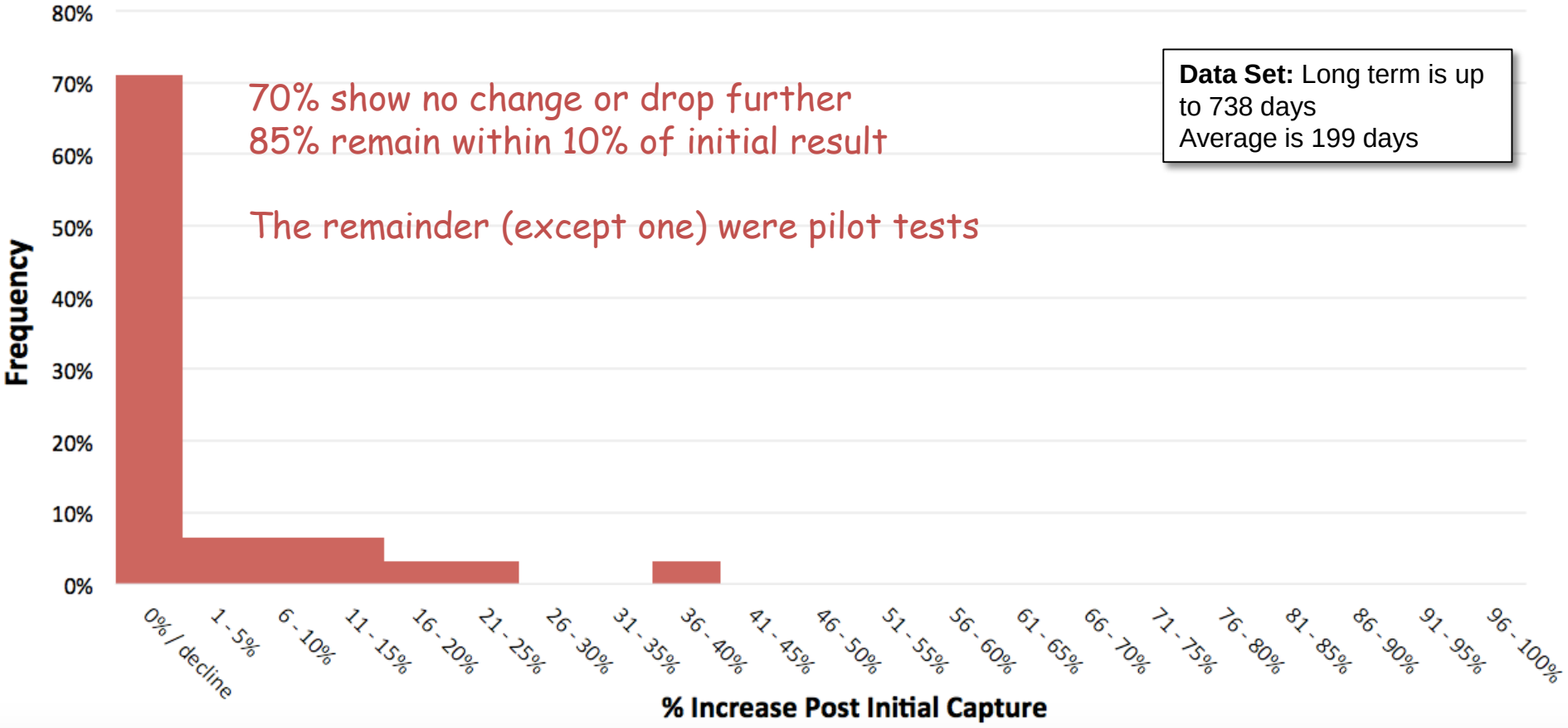
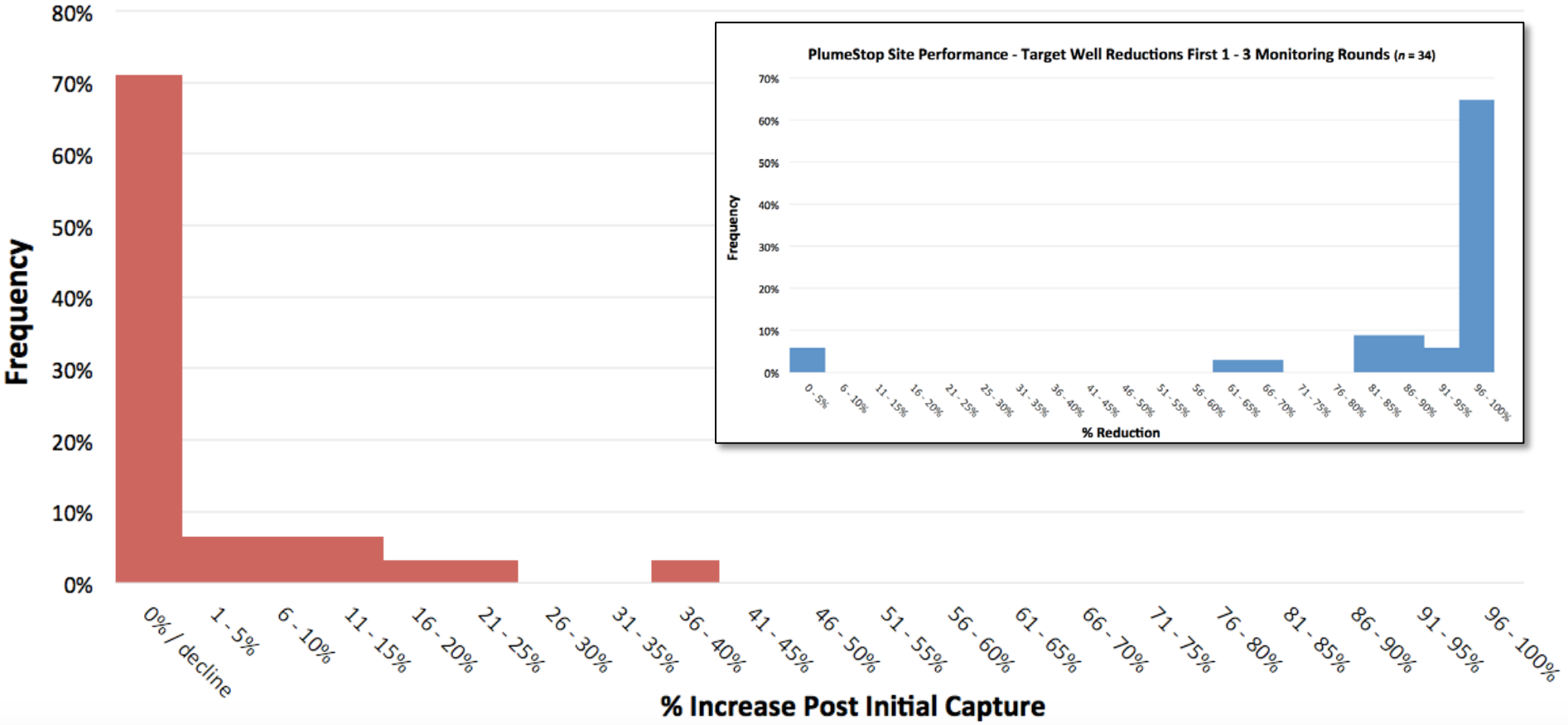
How Stable is this Reduction?
Will there be Rebound?

PlumeStop Long Term Performance - April 2016 (*n* = 31)



PlumeStop Long Term Performance - April 2016 (*n* = 31)



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Field Performance

How fast does it work?
How long does it last?
Is biodegradation occurring?

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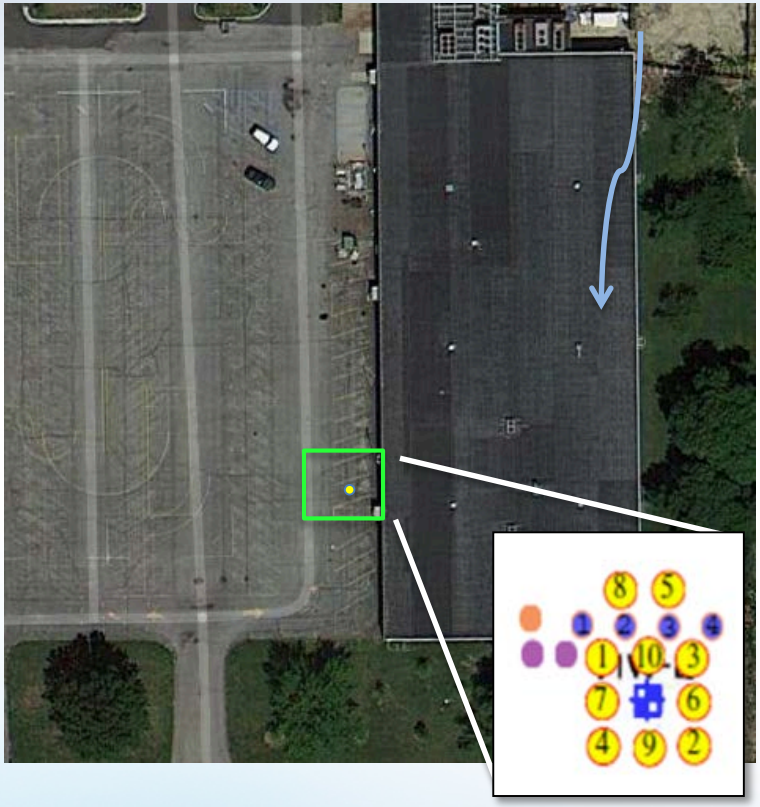
Midwest Chlorinated VOC Site



Former electronics facility

Contaminants: TCA, TCE, etc.

- TCE 1,390 µg/L
- TCA 3,550 µg/L

Treatment Area:

- Plume area only, no NAPL
- PlumeStop: 10-pt low pressure injection grid around MW-6
- HRC electron donor applied up-gradient

Site Characteristics:

- Sandy to silty sand; v = 12 ft/yr
- DTW = 10-13 ft bgs

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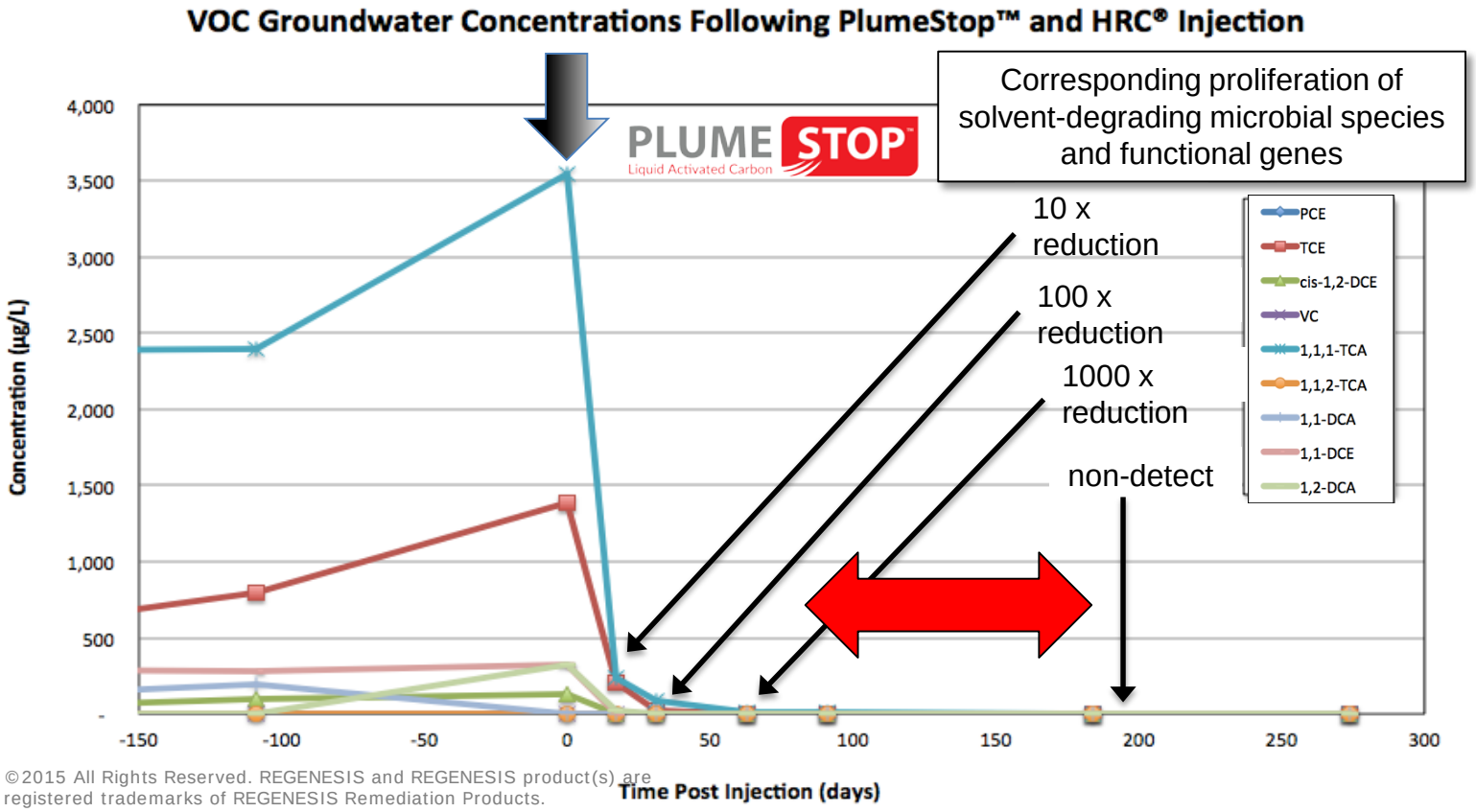

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Liquid Activated Carbon

Field Performance

How fast does it work? 92% Reduction in 2 weeks, ND 6 months

How long does it last? 2 years and counting

Is biodegradation occurring? Yes. Sorption saturation should have occurred at 8.3 months due to upgradient contaminant mass flux

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Liquid Activated Carbon

Field Performance

- Chlorinated solvents
- Post-sorption biodegradation
- Lines of evidence

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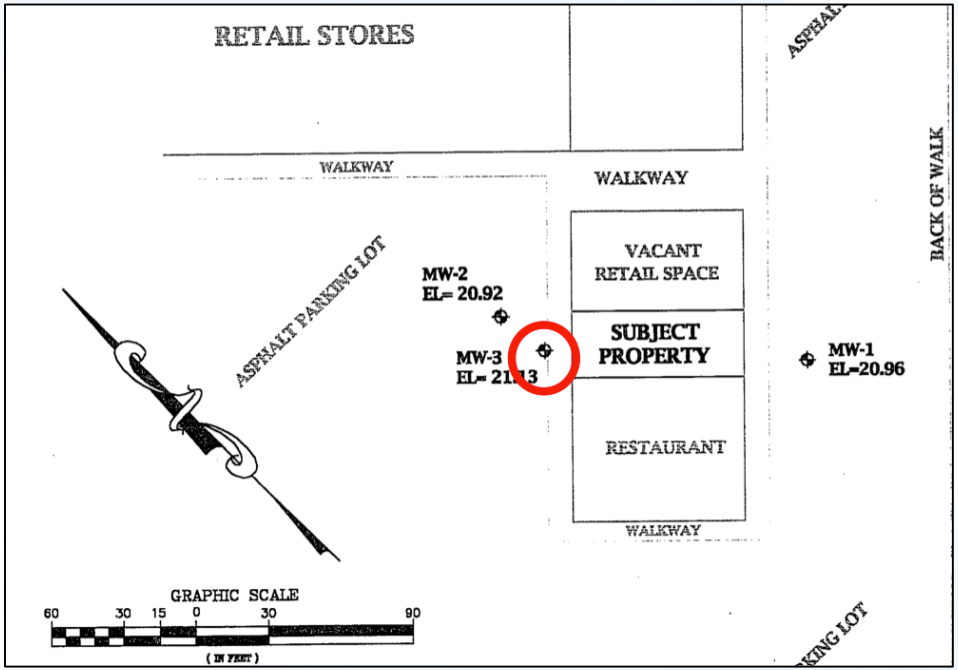
California Site

- ‘Dune Sand’ formation
- 33 ft/year groundwater flow
- High redox conditions (aerobic)
- No attenuation evident
- PCE 550 µg/L
- No daughter products
- PlumeStop
- Electron donor and bacteria



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Historic Data

MW-3 (ppb)

Year	PCE	TCE	VC	1,2 Cis	VC
2001	156	0	0	0	0
2002	94	0	0	0	0
2002.5	242	0	0	0	0
2003	174	0	0	0	
2004	147	0	0	0	
2005	122	0	0	0	
2006	203	0	0	0	
2007	584	0	0	0	
2008	310	0	0	0	
2009	587	0	0	0	
2010	330	0	0	0	
2011	501	0	0	0	0
2012	499	0	0	0	0

Steadily increasing PCE

No daughter products

(aerobic conditions)

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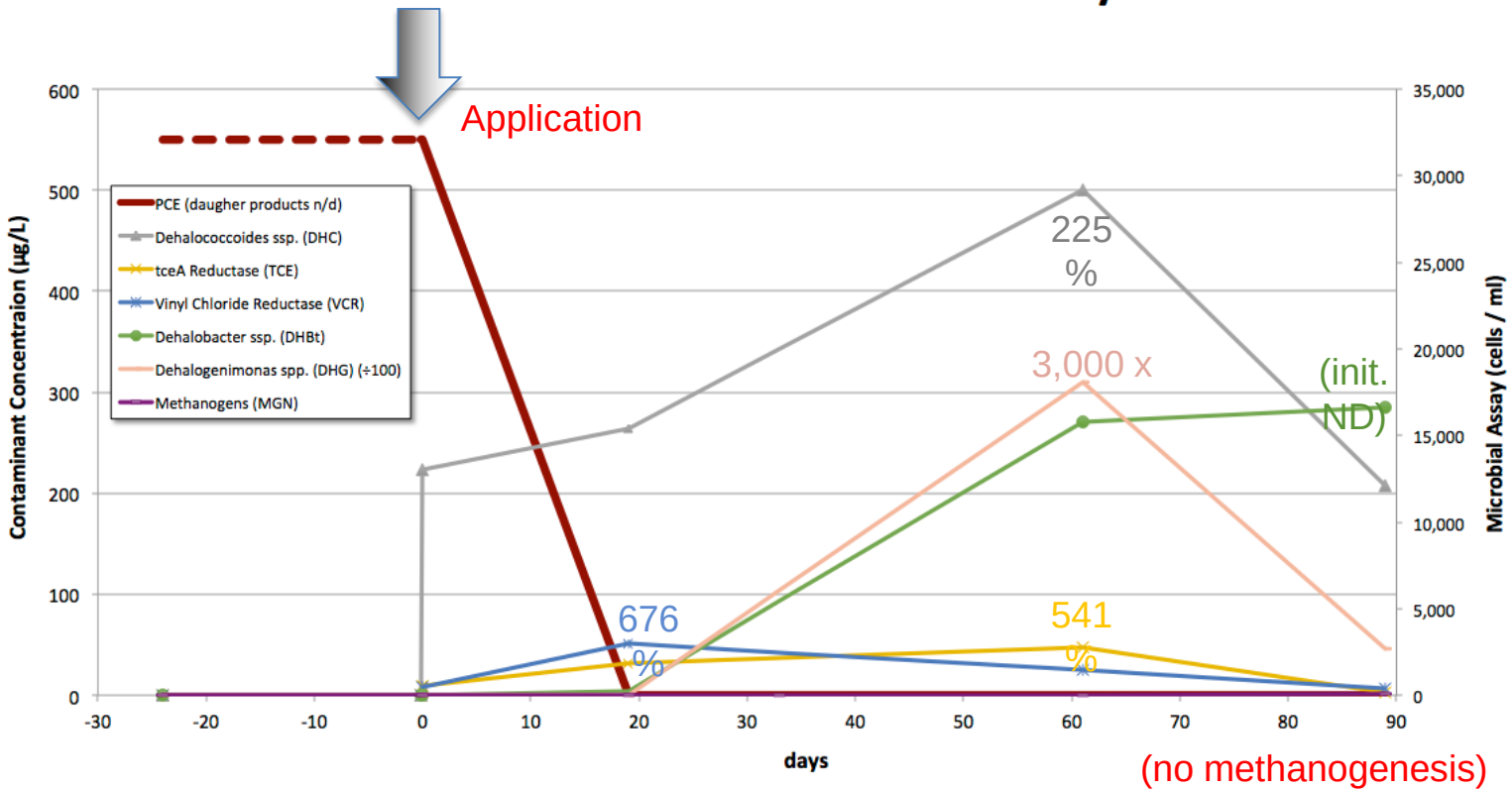
Contaminant and Dechlorination Microbial Assay Trends



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Data Summary

- >99% (two OOM) PCE concentration reduction within 14 days
  - 550 µg/L to non-detect (<5 µg/L)

- Optimal dehalorespiration conditions established
  - Redox from +254 mV to -150 mV ‘sweet spot’
  - Competing electron acceptors depleted

- Post-inoculation microbial trends
  - Increase then decrease in dechlorination species and enzymes
  - Consistent with solvent metabolism and depletion

Case Study: Real Estate Development – Time Pressure

- Neighborhood of McCormick Place – Central Chicago
  - New Sports Stadium
  - New Hotel Complex

- Solvent residues
- Tight time window
- High cost implications of delay
- Key remediation requirement: FAST

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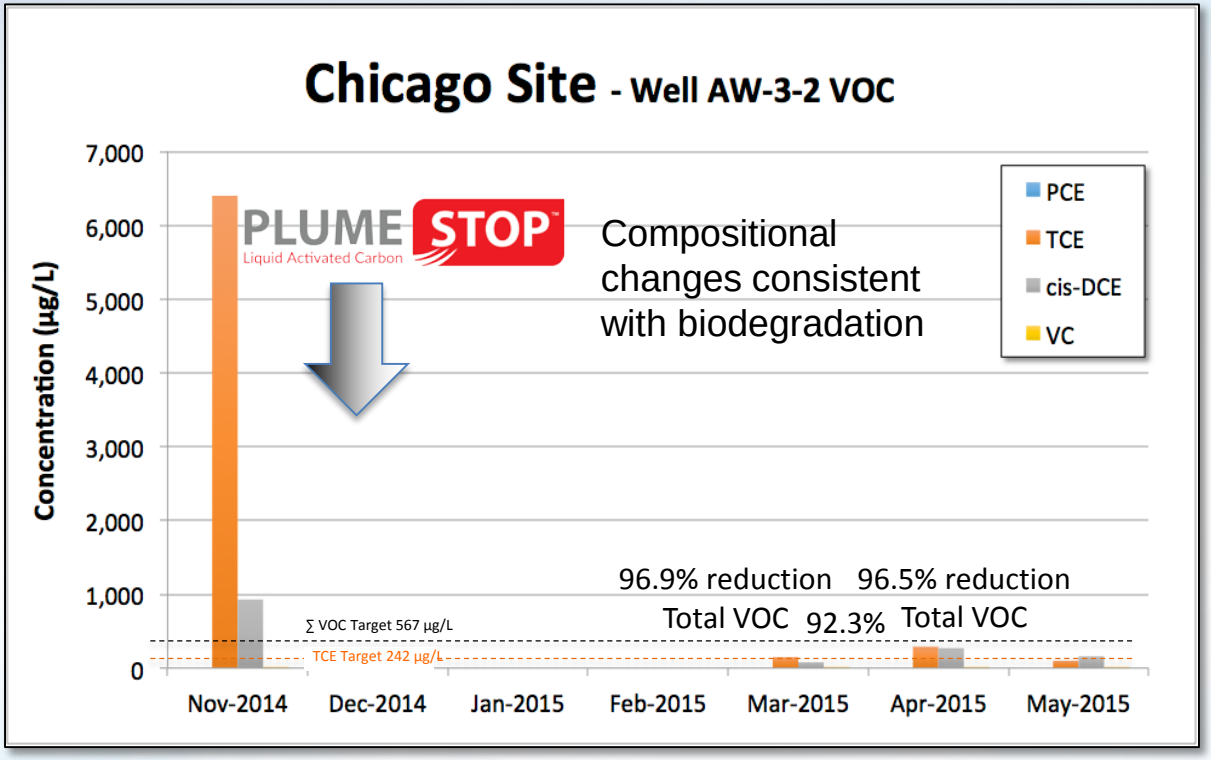
Site Details

- PCE and TCE – up to 7,440 µg/L
- Sand formation over clay
  - Treatment area: ~25,000 sf
  - Treatment Zone (10’ – 22’)

Enhanced bio: HRC®, BDI®

  - Sufficient to address the contamination
- PlumeStop
  - Rapid risk reduction and bio process acceleration
  - Take the bio process out of the groundwater phase
- 17 days’ fieldwork on site (Chicago winter)
  - 138 direct-push injections – no resident equipment



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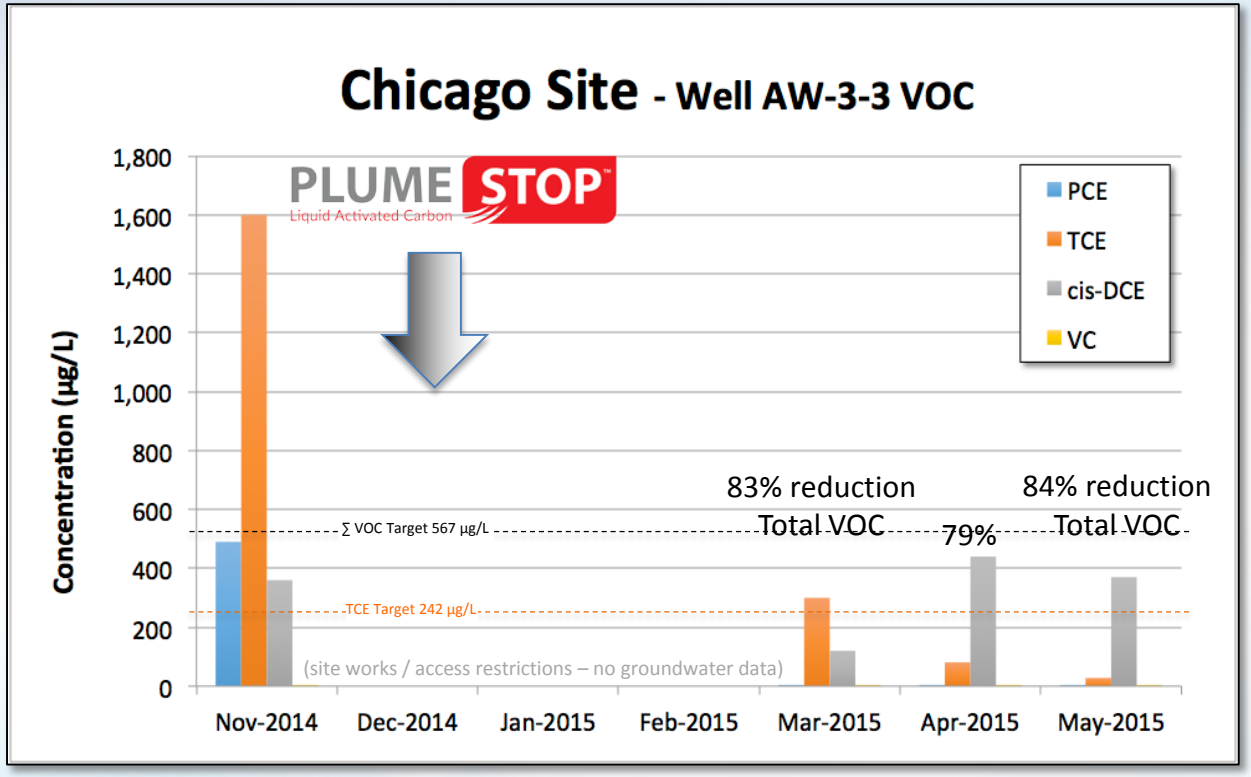

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Chicago Site – Status (June 2015)

- Rapid reduction in groundwater contamination
  - 80 – 97% from first sampling interval (total solvents)
- Bio conditions established (redox, TOC, microbial numbers)
  - Parent/daughter compound ratio shifts (dissolved phase)
  - (consistent with biodegradation)
- Targets met – third sampling interval (May 2015)
- Evaluating potential for closure (June 2015)

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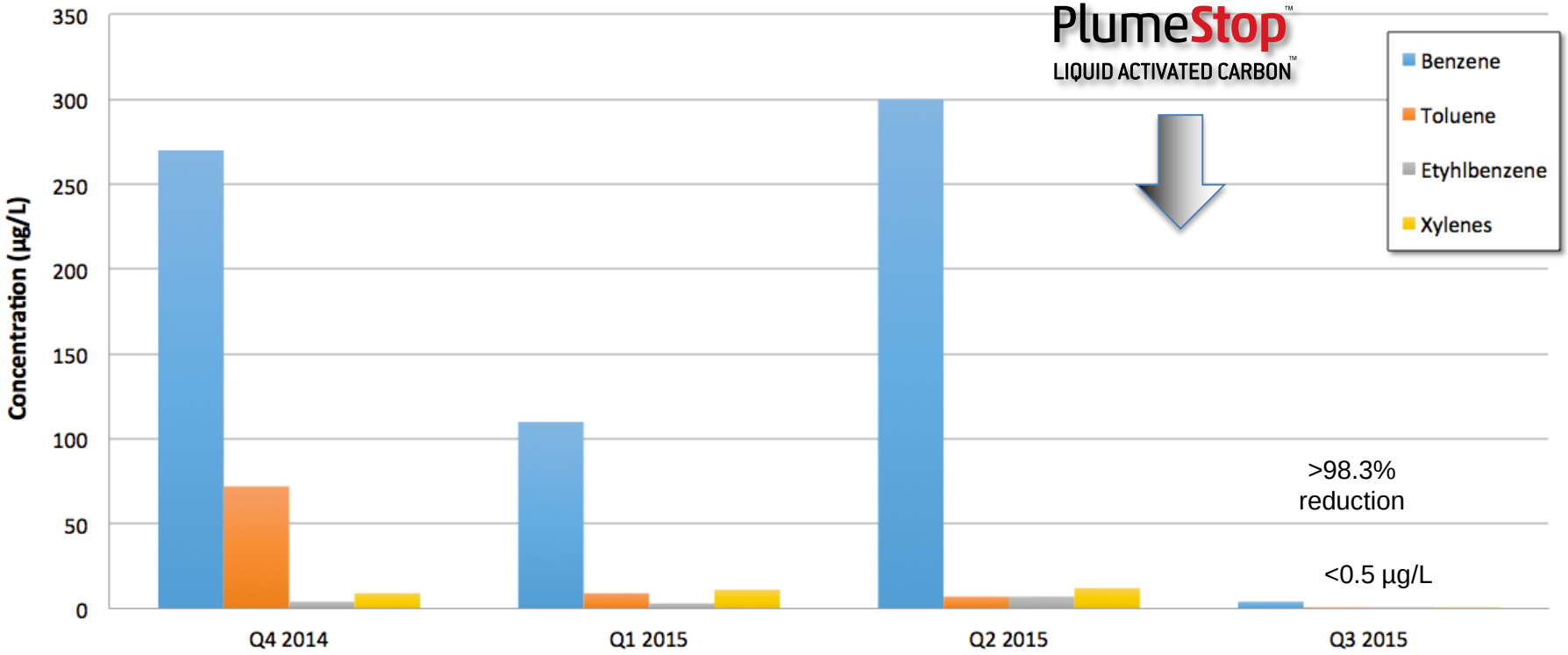
Case Study
- Filling Station – BTEX Residues -

Pennsylvania

PlumeStop™ - Filling Station

- Former Filling Station
- BTEX residues
- Tight formation
- 9’ – 15’ below grade
- Clay with Sand (*ca*. 3.53x10^{-7} cm/sec)
- Seepage Velocity Zero
- PlumeStop™ and ORC Advanced

BTEX - Well MW-6R



Case Study
- Manufactured Gas Plant / PAHs -

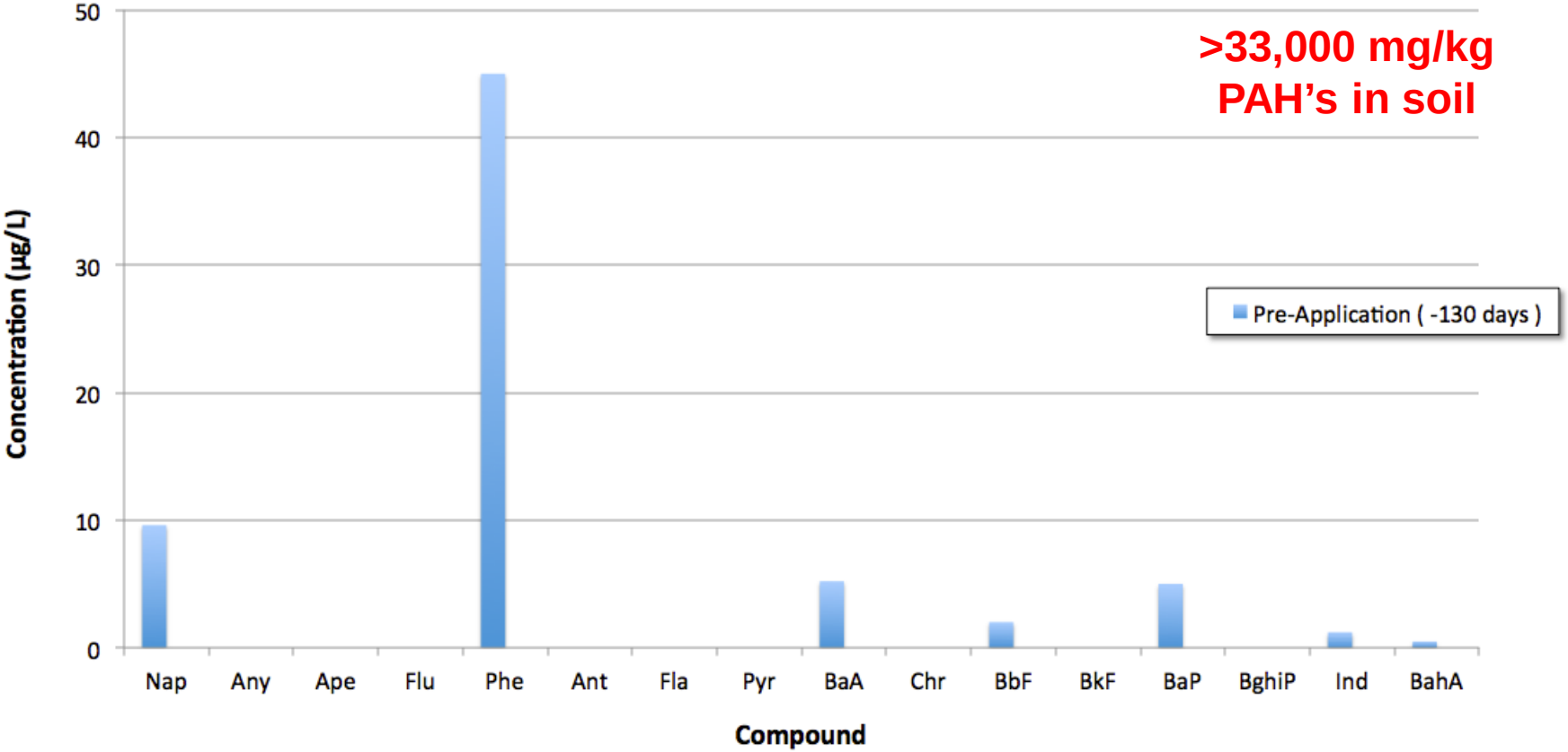
(skip to next)

PlumeStop™ MGP

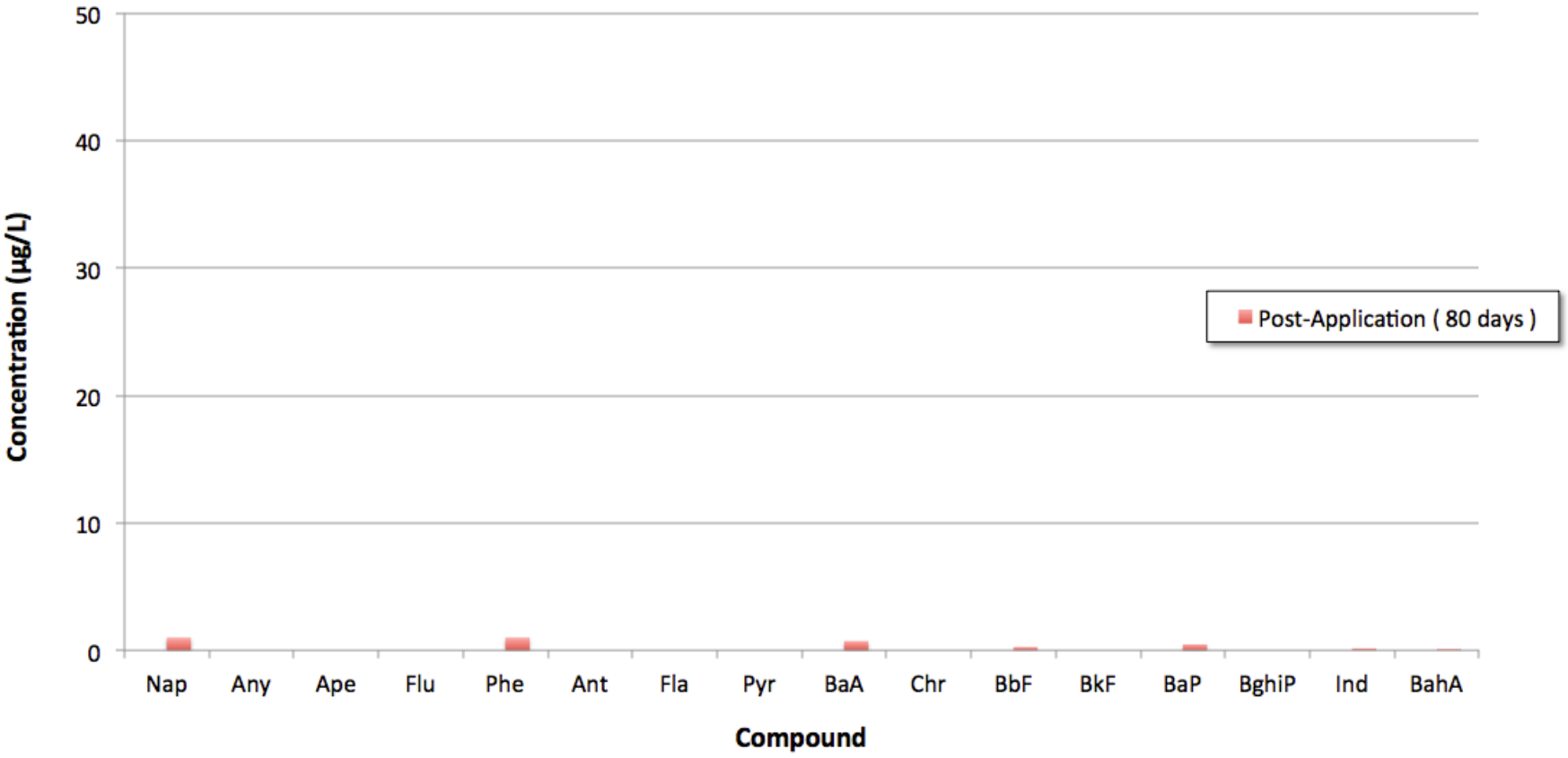
- Silty clay loam transitioning to sand and gravel
- Injection 13.0” – 22” fbgs

- PlumeStop™
- ORC-Advanced®

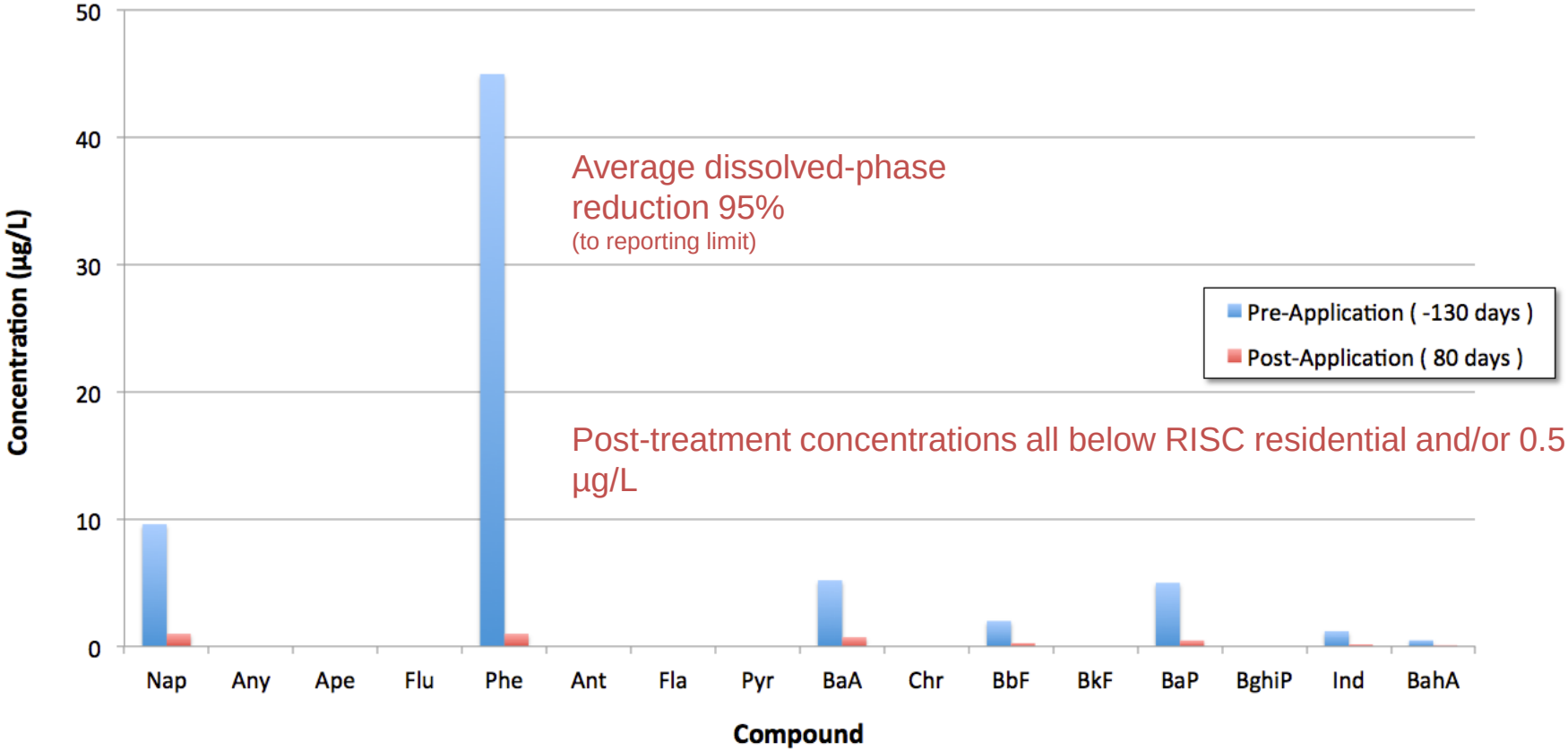
PlumeStop™ MGP Pilot - initial PAH Results



PlumeStop™ MGP Pilot - initial PAH Results



PlumeStop™ MGP Pilot - initial PAH Results



PLUME STOP™
Liquid Activated Carbon

How fast does it work?:

Generally > 80% reduction within 90 days at 90% of sites.

How long does it last?

Indefinitely if electron donor/acceptors present.

Is biodegradation occurring?

Multiple lines of evidence indicate complete biodegradation.

REGENESIS

A Multi-Site Performance Review of Liquid Activated Carbon for Groundwater Treatment

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REGENESIS

Technology-Based Solutions for the Environment