

MULTI-SITE PERFORMANCE REVIEW OF LIQUID ACTIVATED CARBON FOR GROUNDWATER TREATMENT



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REGENESIS

Carbon - Acronyms/Definition

- CBI – Carbon Based Injectates
- GAC – Granular Activated Carbon
- PAC – Powdered Activated Carbon
- LAC – Liquid Activated Carbon



Principal Technology Features

- **Rapid reduction of groundwater concentrations**
 - Multiple order of magnitude concentration reductions in days / weeks
- **Acceleration of contaminant biodegradation**
 - Elimination of low-concentration performance tailing
 - Ability to secure stringent clean-up targets
- **Wide subsurface dispersion**
 - Efficient fieldwork
 - Ability to address areas of restricted access, deep plumes etc.
- **Long-term efficacy**
 - The reagent is not consumed – it regenerates *in situ*

The Reagent – what it is

- Colloidal activated carbon (1 – 2 μm)
 - Size of a bacterium – suspends as ‘liquid’
 - Huge surface area – extremely fast sorption
- A highly dispersive, injectable **sorbent** and **microbial growth matrix**
- Sorbent
 - Rapid drop in dissolved-phase contaminant concentration
 - Immediate risk-reduction
- Microbial growth matrix
 - Accelerated bio-destruction of sorbed mass
 - Ability to secure clean-up to much lower targets

PLUME STOP
Liquid Activated Carbon



Technical Challenge – How do we Distribute Carbon In Situ?

Physical Differences Between PAC vs LAC

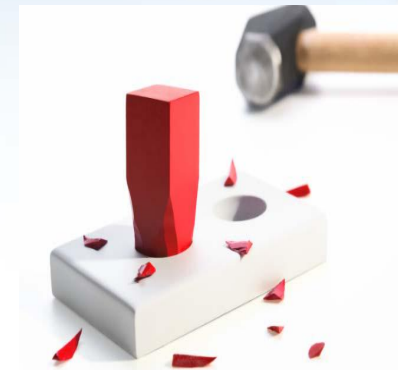
Carbon Type	Particle Size (micrometers)
Granular Activated Carbon (GAC)	400-1000
Powdered Activated Carbon (PAC)	50-250
Liquid Activated Carbon (LAC)	1-2



Technical Challenge – How do we Distribute Carbon In Situ?

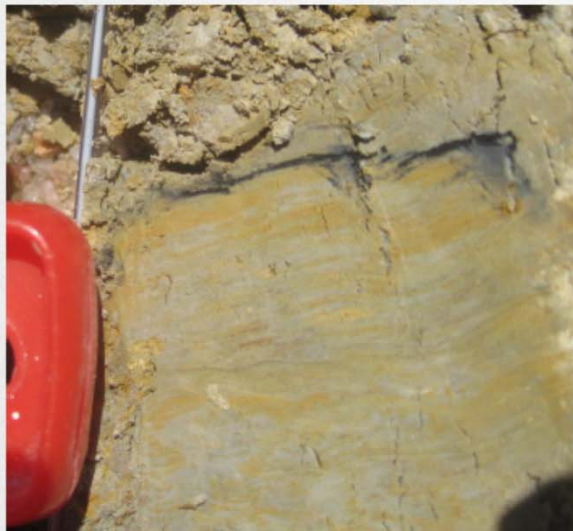
<u>Grain Size</u>	<u>Pore Throat Diameter (micrometers)</u>
Medium Sand	8-50
Fine Sand	5-20
Silt	3-8

*Pore throat diameters of typical aquifer materials range (Nelson, 2009):

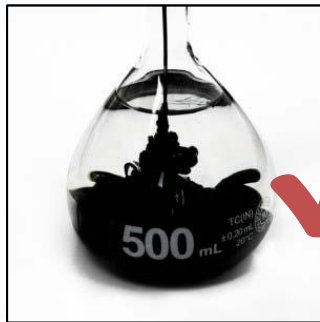


CBI Product Type	Particle Size (microns)	Application Pressure Required	Results in Aquifer Fracturing?
Granular Activated Carbon (GAC)	400-1000	High Pressure (>60 psi)	YES
Powdered Activated Carbon (PAC)	50-250	High Pressure (>60 psi)	YES
Liquid Activated Carbon (LAC)	1-2	Low Pressure (<60 psi)	NO

Emplacement-thin veins

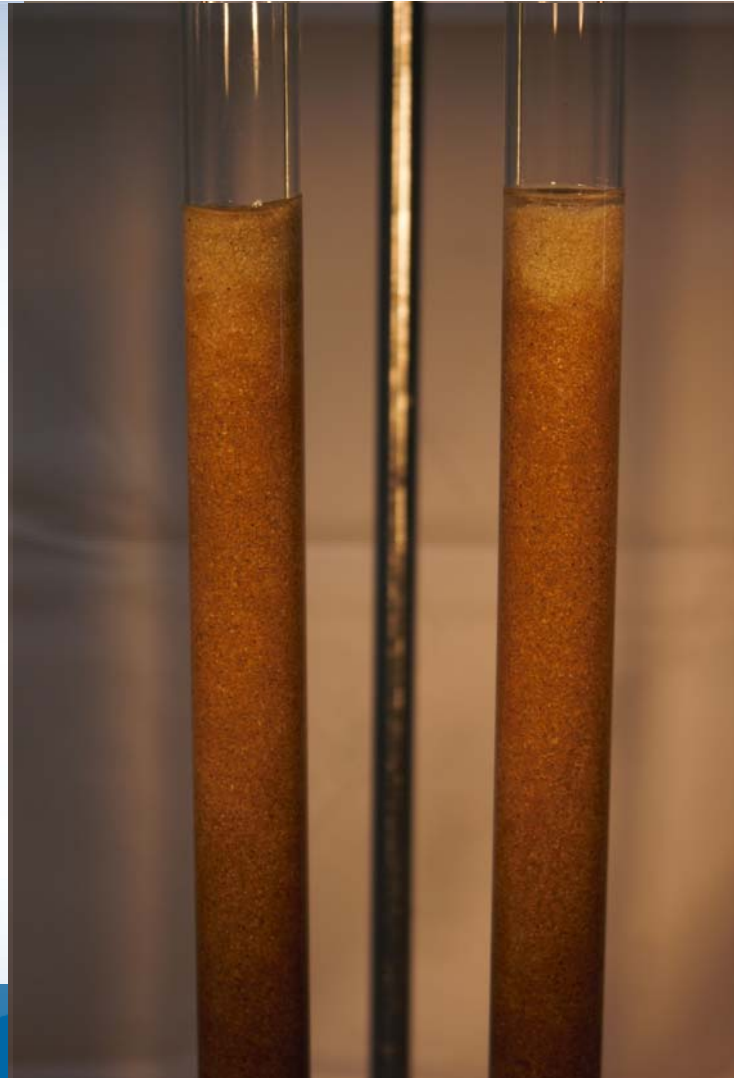


PlumeStop



PLUME STOP
Dark Activated Carbon

repeat



Powdered Activated Carbon



 **REGENESIS**

Evidence of Dispersive Flow (low pressure application)

Pre-app



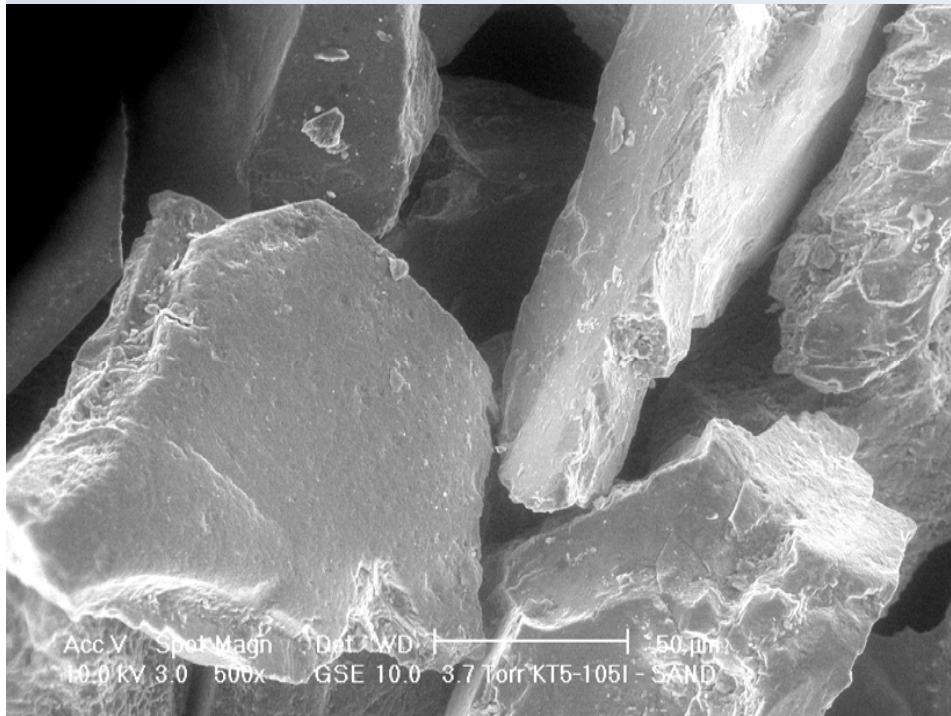
Post-app



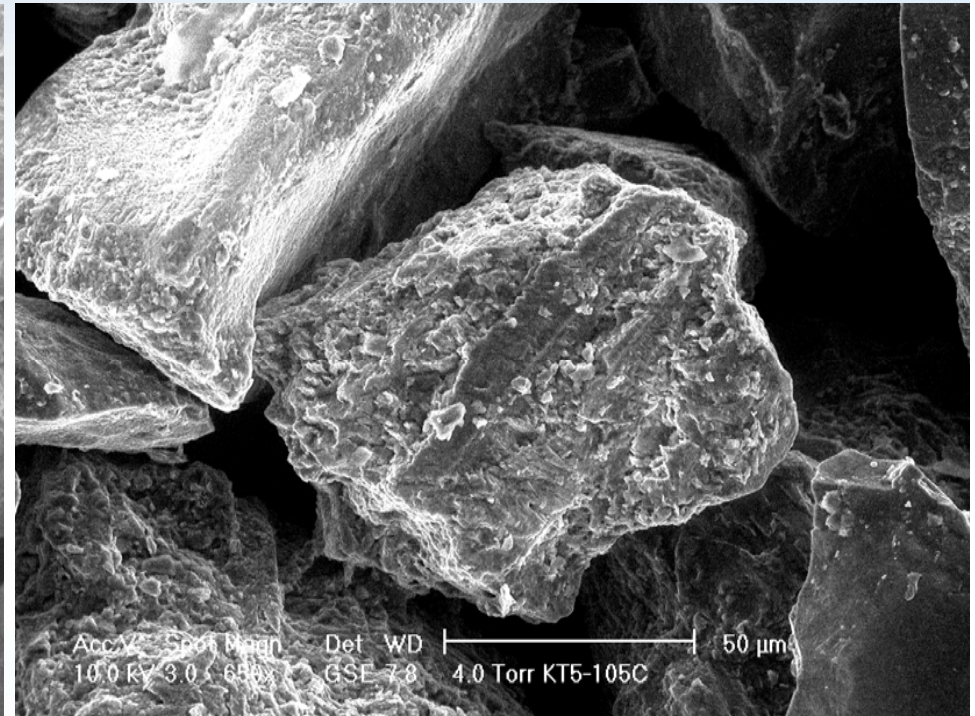
- Distribution of PlumeStop through target zone visually apparent
- Even dispersion evident through permeable strata



Electron Microscopy (SEM) of Soil Particles

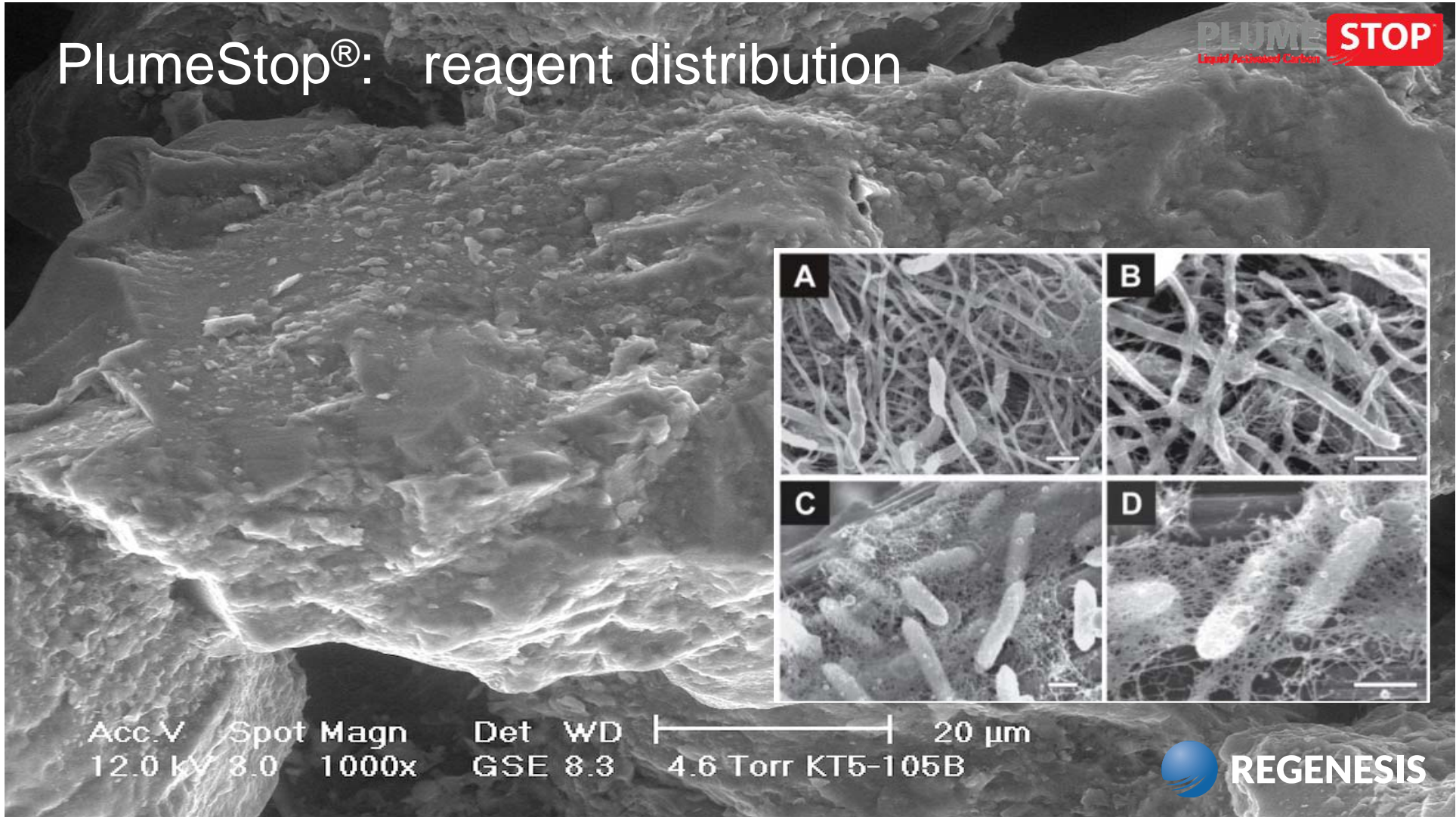


Before PlumeStop



After PlumeStop

PlumeStop[®]: reagent distribution



Acc.V Spot Magn Det WD |-----| 20 μm
12.0 kV 8.0 1000x GSE 8.3 4.6 Torr KT5-105B

Contaminants Sorbed, Now What?

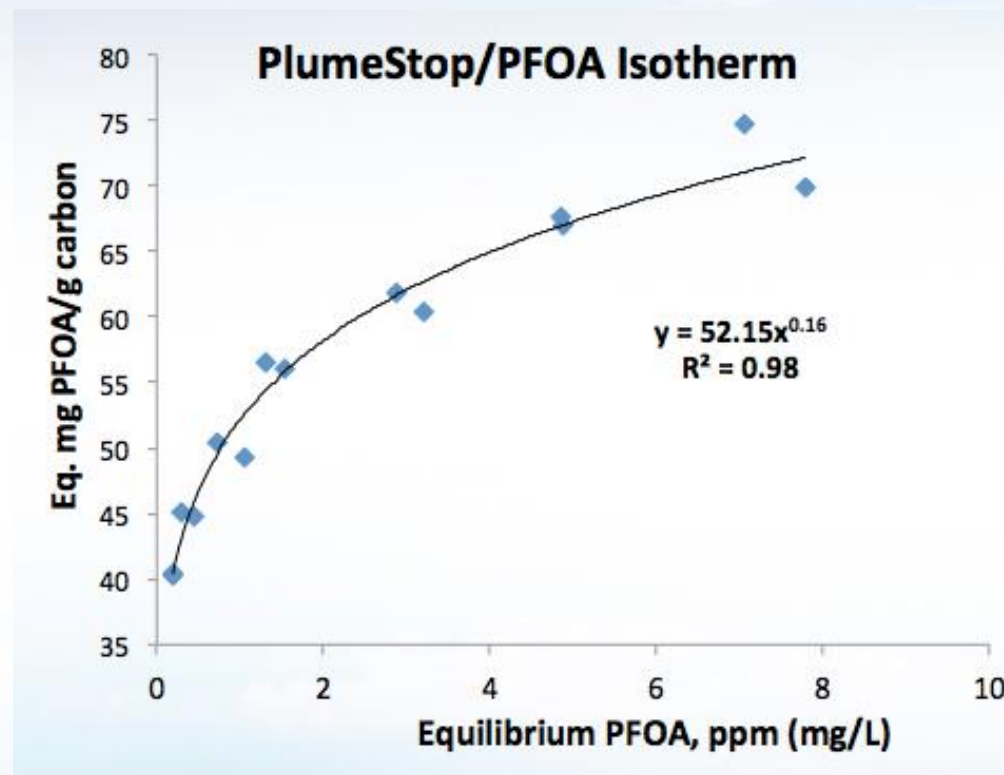
3 Primary Methods of Contaminant Destruction

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



What it Treats?

- ✓ CVOCs including ethenes and ethanes
- ✓ Petroleum Hydrocarbons (TPH, BTEX, etc.)
- ✓ MTBE
- ✓ Pesticides
- ✓ PFCs



PlumeStop + PFOA/PFOS: retardation factor

Example:

- PlumeStop® barrier width 16' (single application at mid-range dose)
- 160' per year seepage velocity
- 100 µg/L influent concentration

This is at 100 µg/L

At lower influent concentrations, the retardation quickly becomes **much** greater.

- Groundwater transit time 36.5 days
- PFOA transit time* = 20,800 days (57 years)
- PFOS transit time* = 73,000 days (200 years)

* transit time peak based on individual components

PlumeStop Applications – July 2017

- Numbers

- Sites = 112
- States = 28
- Countries = 6 (USA, Canada, Italy, Belgium, UK, Sweden)

- Scale

- Pilot 25 (22%)
- Full 87 (78%)

- Contaminants

– Principally Hydrocarbons (aerobic bio) = 43

– Principally Solvents (anaerobic bio) = 50

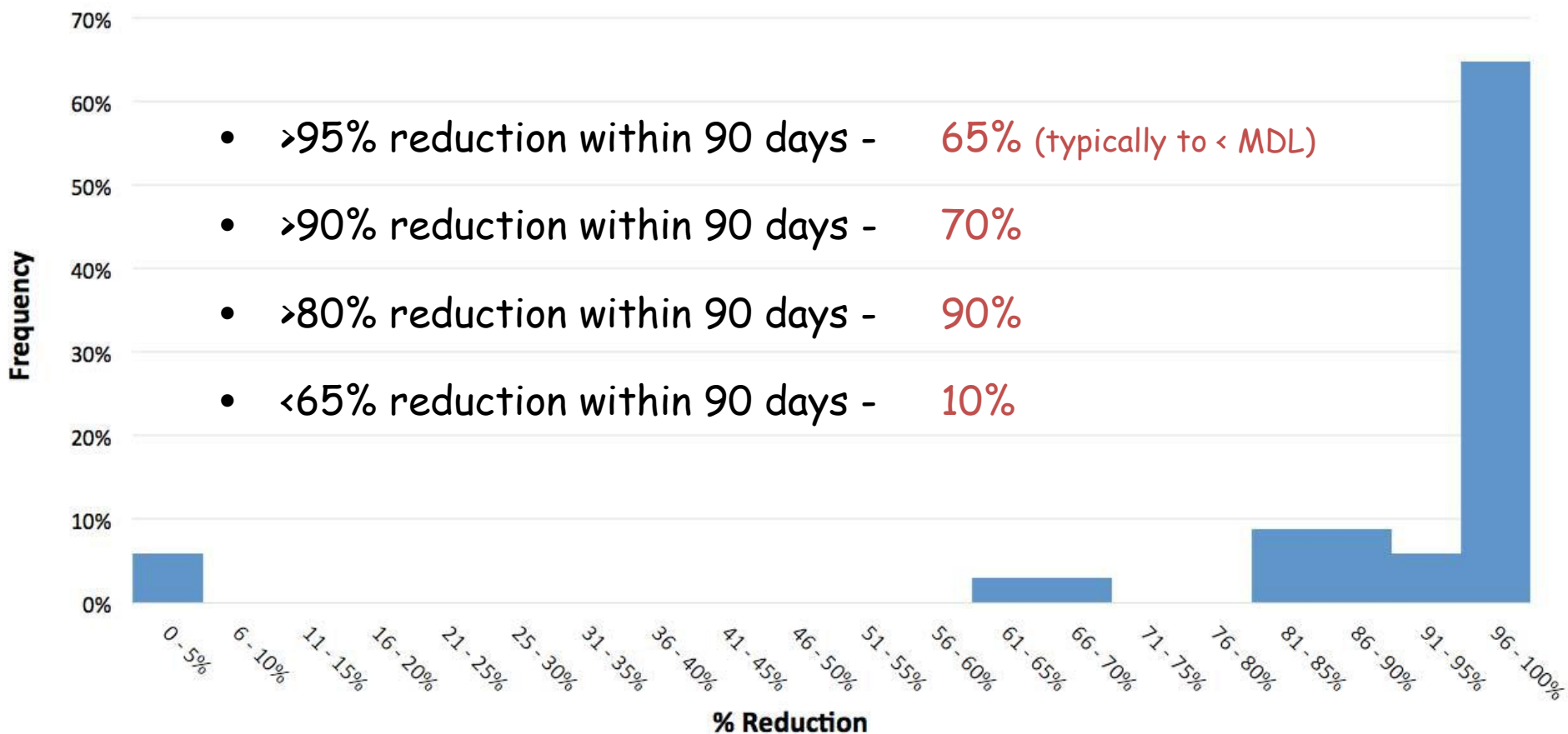
– Mixed / no dominant class = 6

– Other contaminants of note:

- PAH, freon-11, MtBE, TBA, chlorobenzene, PFAS

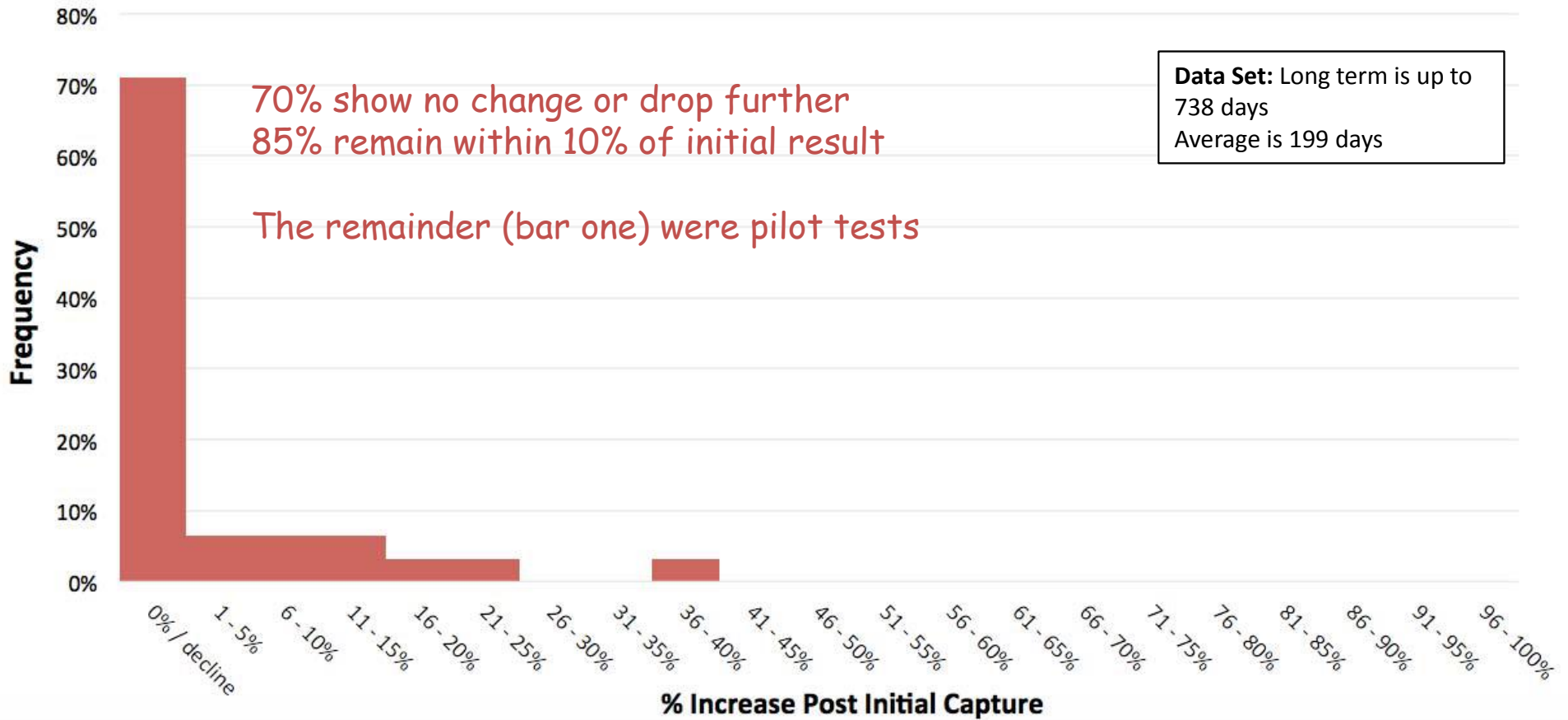
(close)

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



Stability to date?

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



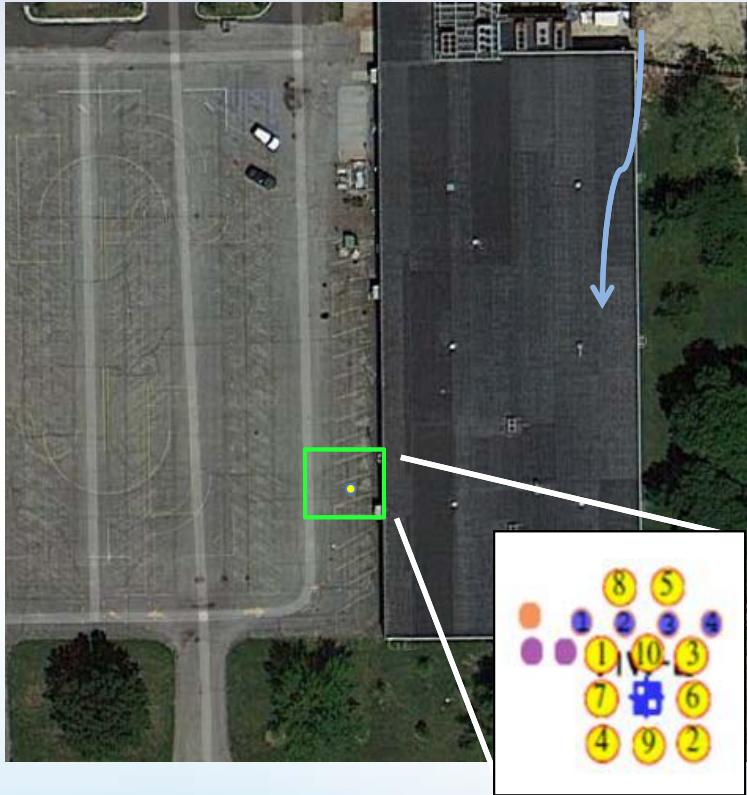
Field Performance

How fast does it work?

How long does it last?

Is biodegradation occurring?

Midwest Chlorinated VOC Site



Former electronics facility

Contaminants: TCA, TCE, etc.

- TCE 1,390 $\mu\text{g/L}$
- TCA 3,550 $\mu\text{g/L}$

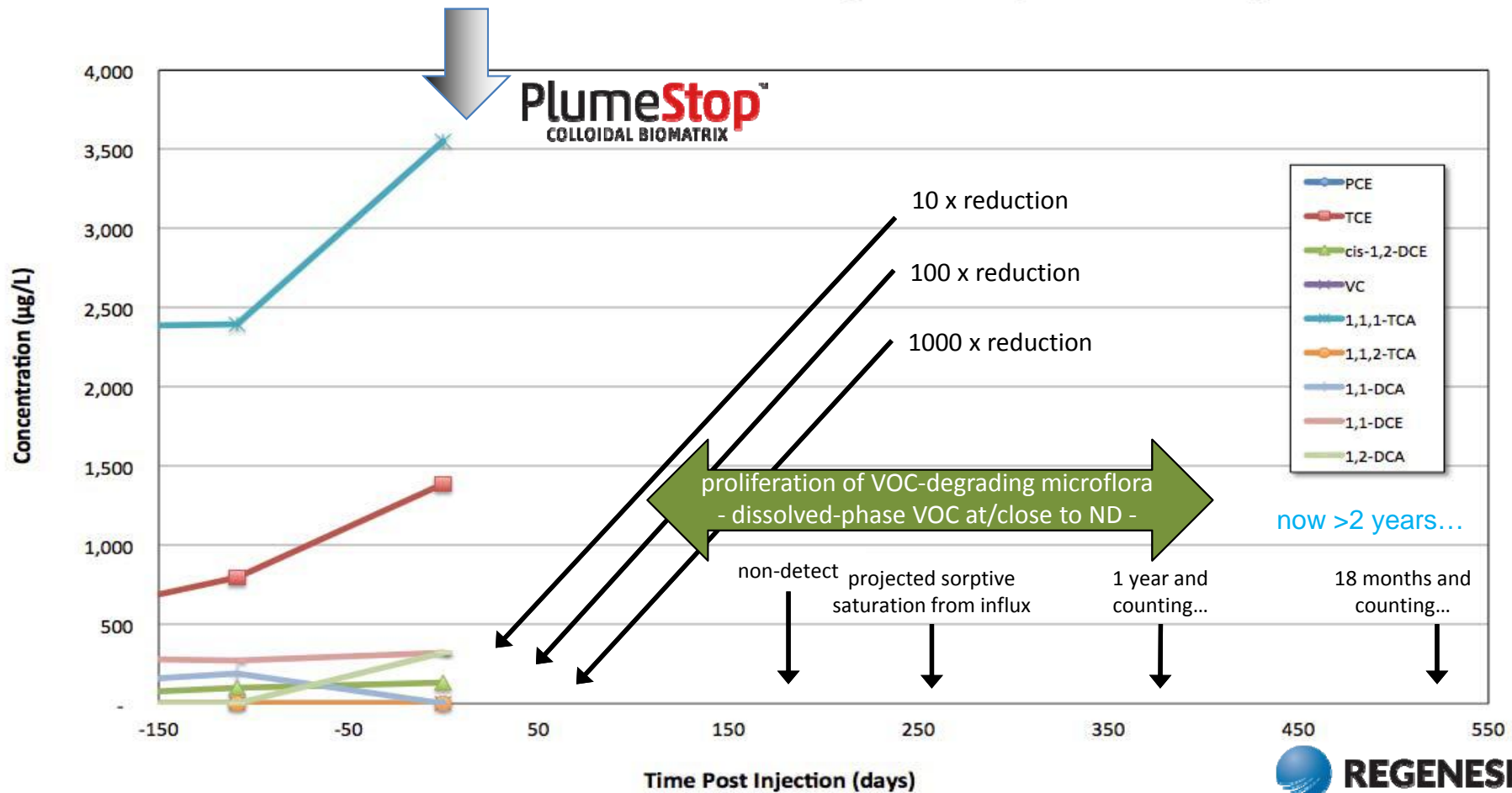
Treatment Area:

- 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; $v = 12 \text{ ft/yr}$
- DTW = 10-13 ft bgs

VOC Groundwater Concentrations Following PlumeStop™ and HRC® Injection



Constituent	RISC Residential Closure Criteria ¹	Industrial Closure Criteria ¹	MW-6						MW-6				
			Sep-13	Dec-13	Mar-14	Jun-14	Sep-14	Dec-14	Mar-15	Jun-15	Sep-15	Dec-15	Mar-16
1,1-Dichloroethane	990	10,000	254	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)
1,2-Dichloroethane	5	31	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)
1,1-Dichloroethene	7	5,100	350	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)
cis-1,2-Dichloroethene	70	1,000	147	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)
trans-1,2-Dichloroethene	100	2,000	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)
Methylene chloride	5	380	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)
Tetrachloroethene	5	55	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)
1,1,1-Trichloroethane	200	29,000	3,860	16.6	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)
1,1,2-Trichloroethane	5	50	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)
Trichloroethene	5	31	1,420	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)
1,2,3-Trichlorobenzene	NL	NL	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)
Trichlorofluoromethane	1,700	31,000	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)
Vinyl chloride	2	4	ND (2)	ND (2)	ND (2)	ND (2)	ND (2)	ND (2)	ND (2)	ND (2)	ND (2)	ND (2)	ND (2)

Field Performance

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

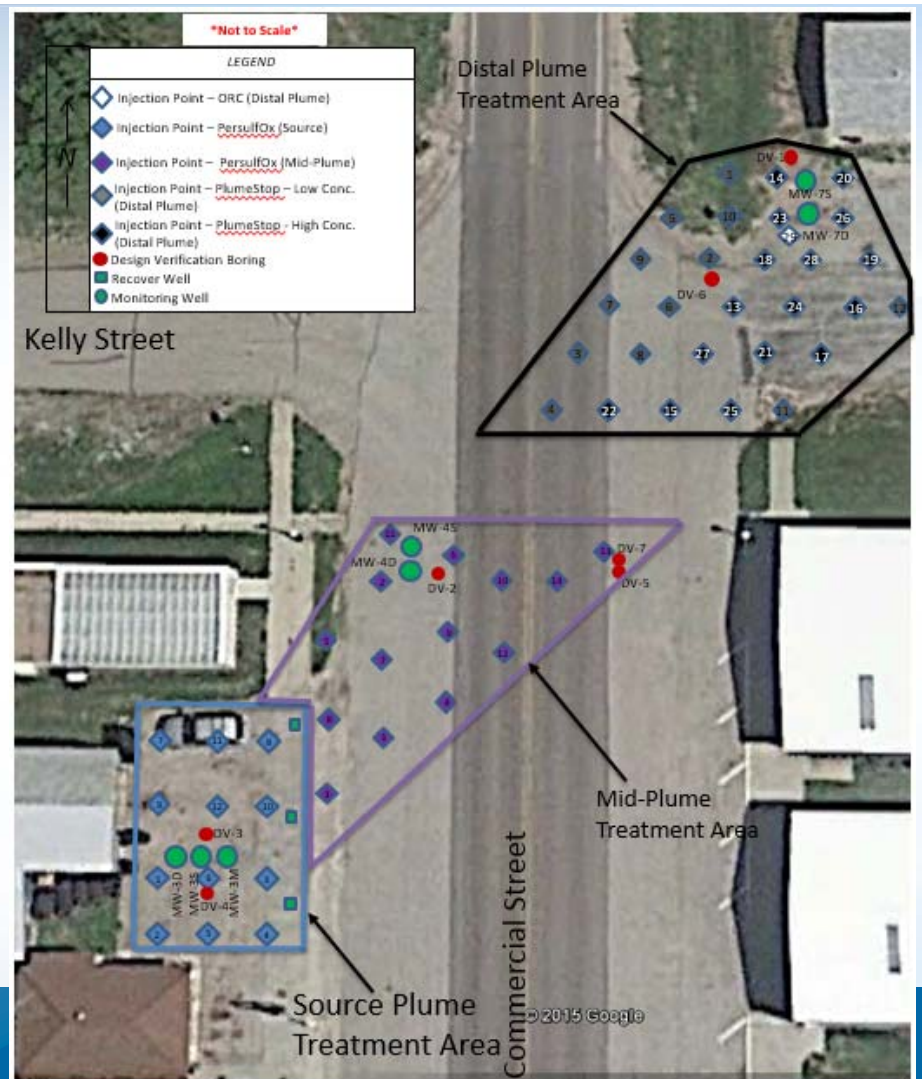
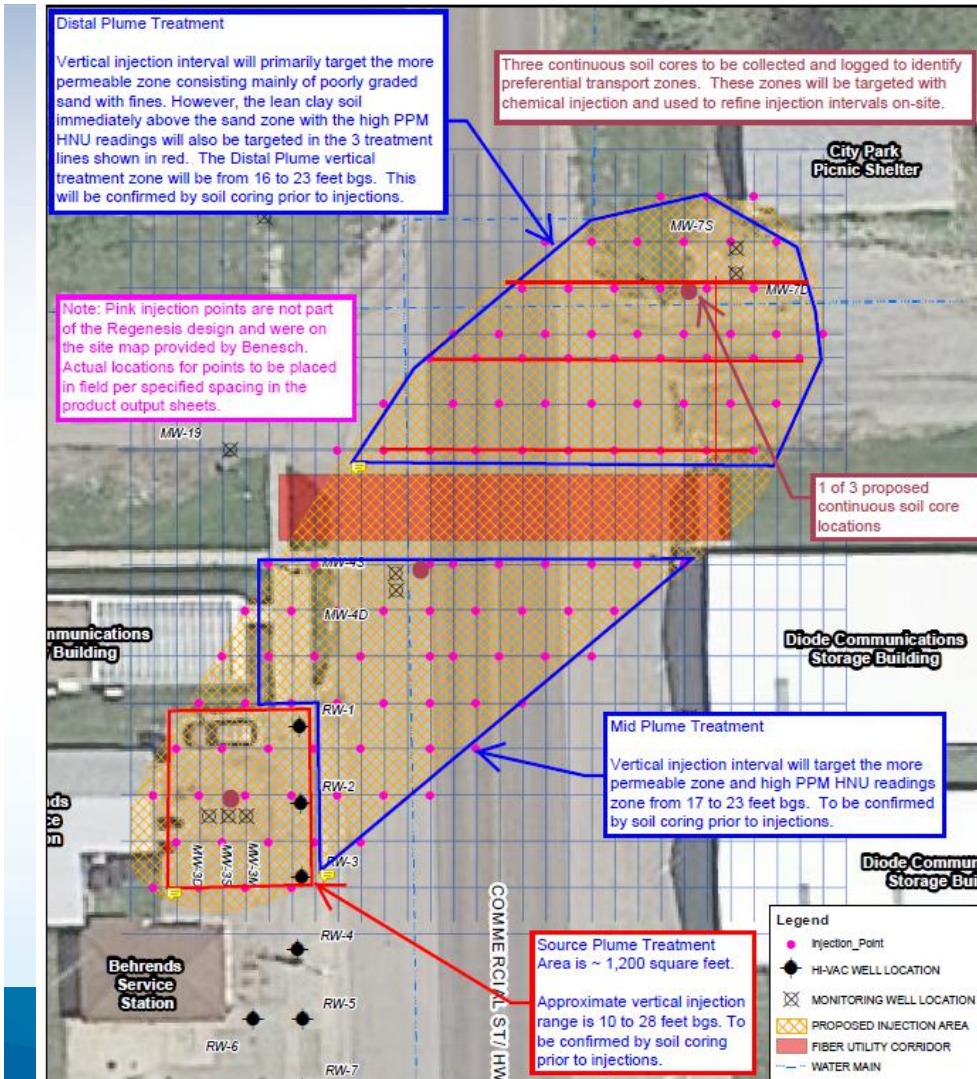
How long does it last? **>2 years and counting**

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

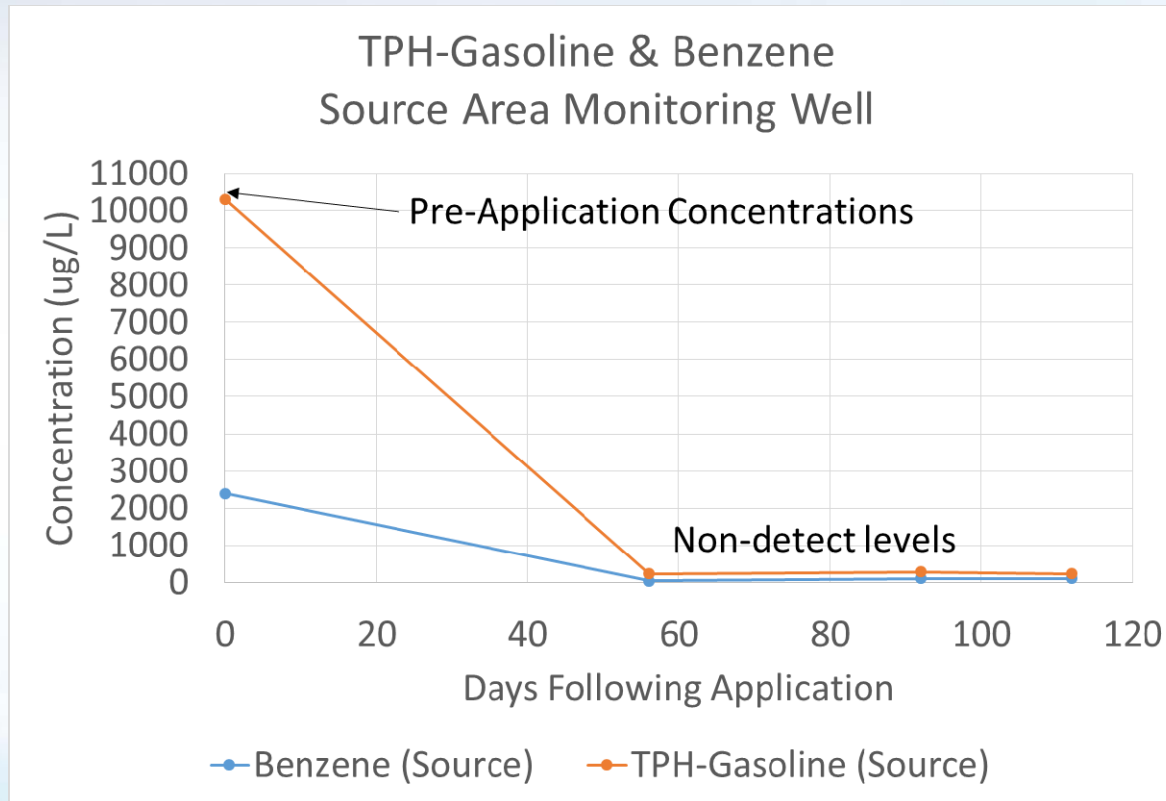
CASE STUDY: PETROLEUM RELEASE SITE, NEBRASKA

- **UST Site:** TPH/BTEX
- **Remedial Strategy:**
 - PersulfOx[®]-source/mid-plume
 - PlumeStop/ORC-distal plume/barrier
- **Concerns for Remedial Injections:**
 - Identify permeable zones/target injection intervals
 - Confirm injection rates
 - Confirm contaminant mass

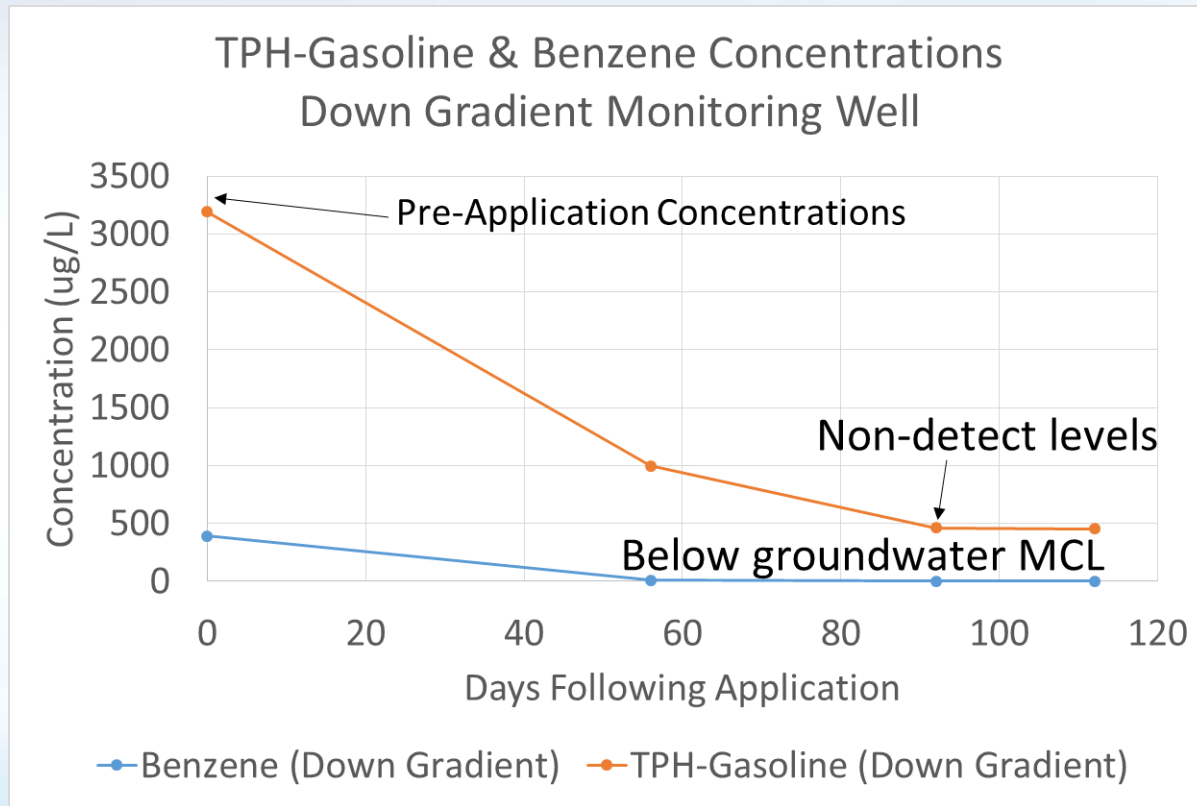




CASE STUDY: POST APPLICATION RESULTS



CASE STUDY: POST APPLICATION RESULTS



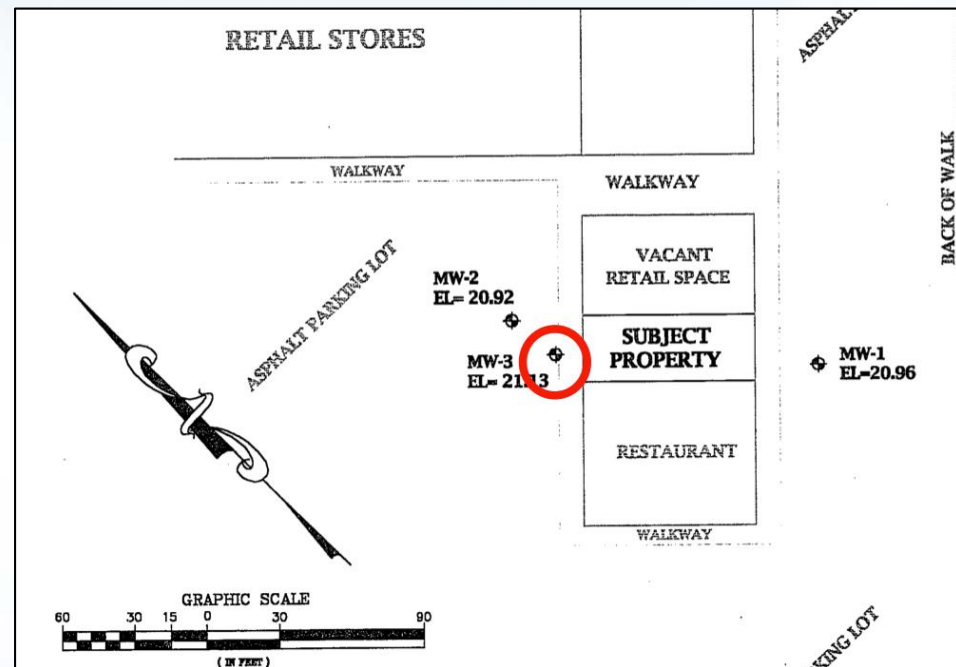
Field Performance

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



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 (DHC)



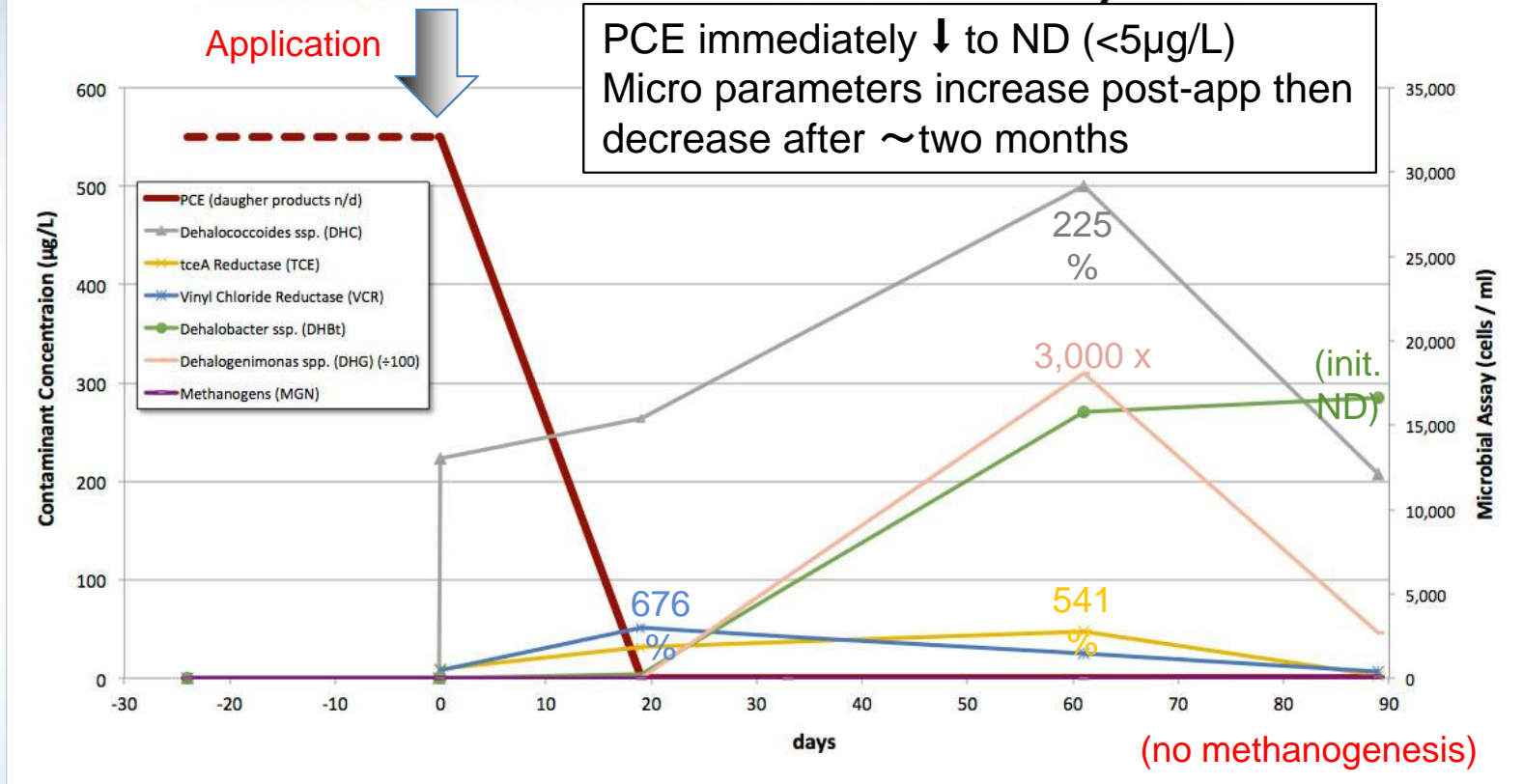
Historic Data

MW-3 (ppb)

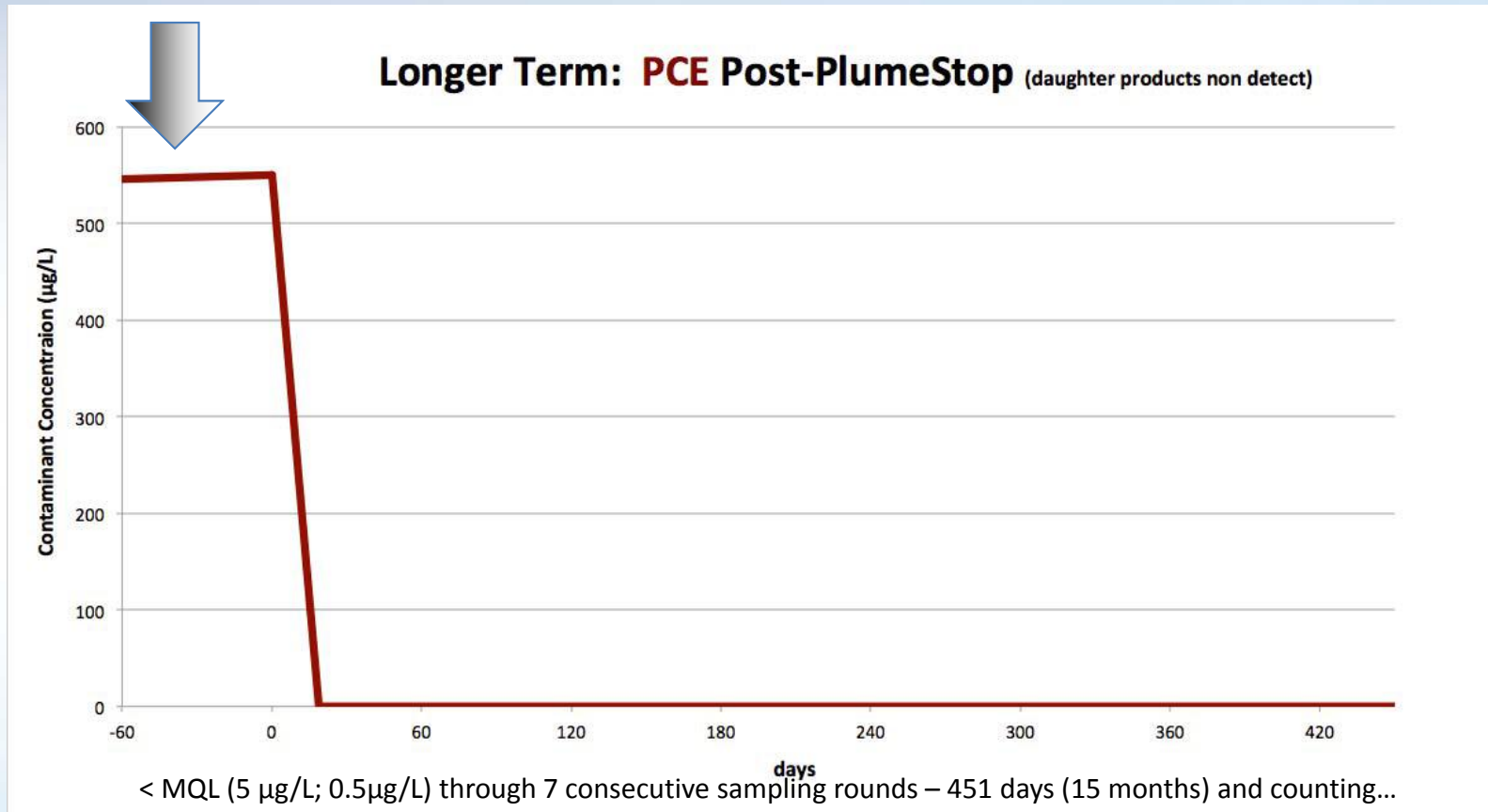
Year	PCE	TCE	VC	1,2 Cis	VC
2001	156	0	0	0	0
2002	94	0	0	0	0
2002.5	242	0	0	0	0
2003	174	0	0	0	0
2004	147	0	0	0	0
2005	122	0	0	0	0
2006	203	0	0	0	0
2007	584	0	0	0	0
2008	310	0	0	0	0
2009	587	0	0	0	0
2010	330	0	0	0	0
2011	501	0	0	0	0
2012	499	0	0	0	0

Steadily increasing PCE
No daughter products
(aerobic conditions)

Contaminant and Dechlorination Microbial Assay Trends



Application



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 (± 30 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

Thank You!

Questions?

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