

The Gift that Keeps on Giving: Post-Bioremediation Sustained Treatment



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Acknowledgements

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- › Projects CU-1292, ER-201120, and ER-201429

- › **Project Team**

- › Kenneth Walker, PE, PG

- › David Adamson, PhD, PE

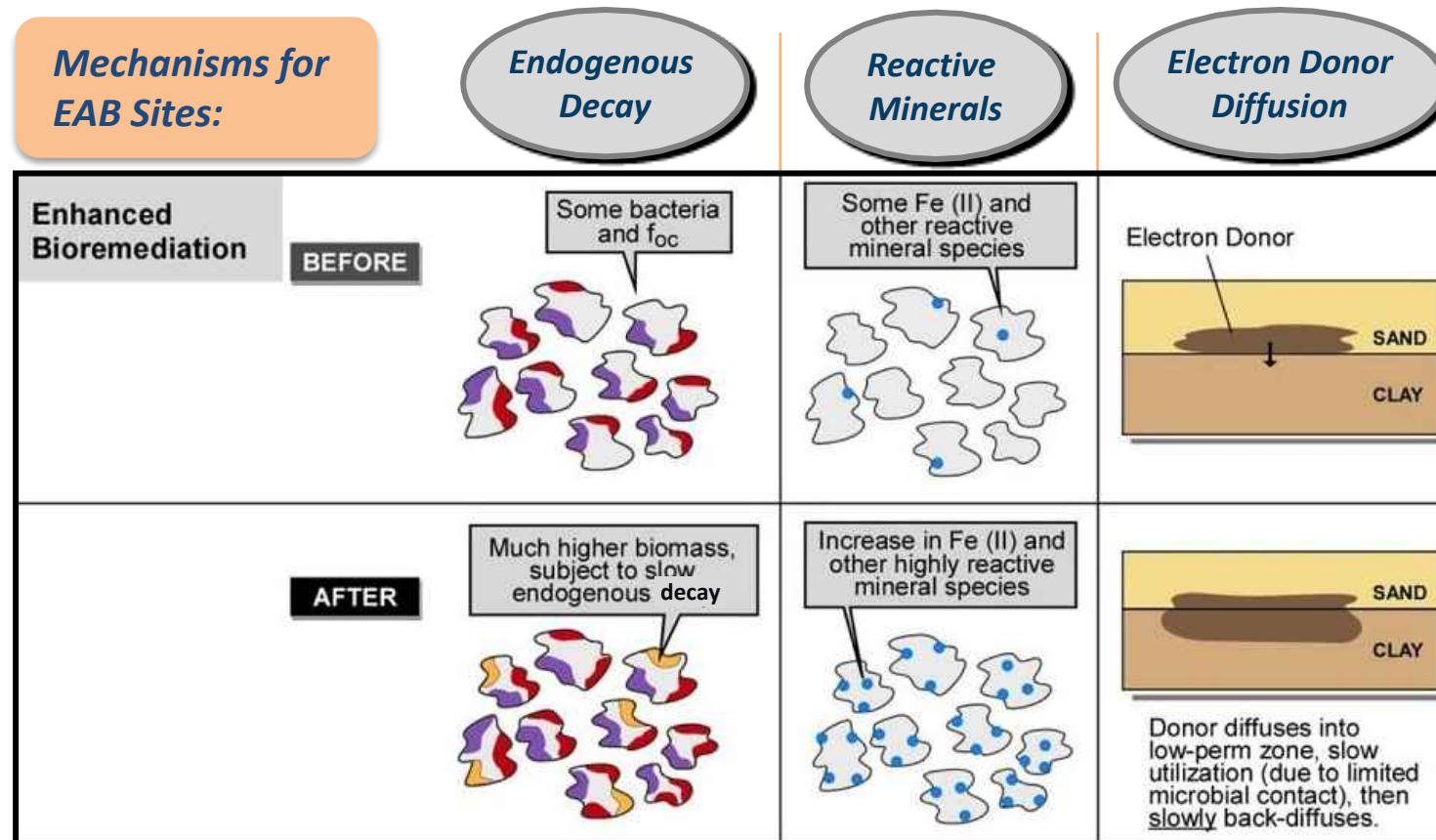
- › Charles Newell, PhD, PE

- › Objectives & Key Concepts
- › Lab: Experimental Observations
- › Desktop: Data Mining Remediation Performance
- › Field: Extended Long-Term Monitoring
- › Key Findings & Fact Sheets for Assessing Your Site

- › Expand our understanding of ***sustained treatment*** following enhanced anaerobic bioremediation at chlorinated solvent sites
 - › Enhanced Anaerobic Bioremediation (EAB) typically involves:
 - › Substrate injections (e.g., emulsified oils, molasses, lactate, etc.)
 - › Permeable reactive barriers (e.g., mulch biowalls)
 - › May also include bioaugmentation
 - › Objective of EAB is to promote reductive dechlorination of chlorinated compounds to innocuous end-products

What is Sustained Treatment?

- Enhanced or maintained **attenuation** capacity within the treatment zone after active treatment (injection period)

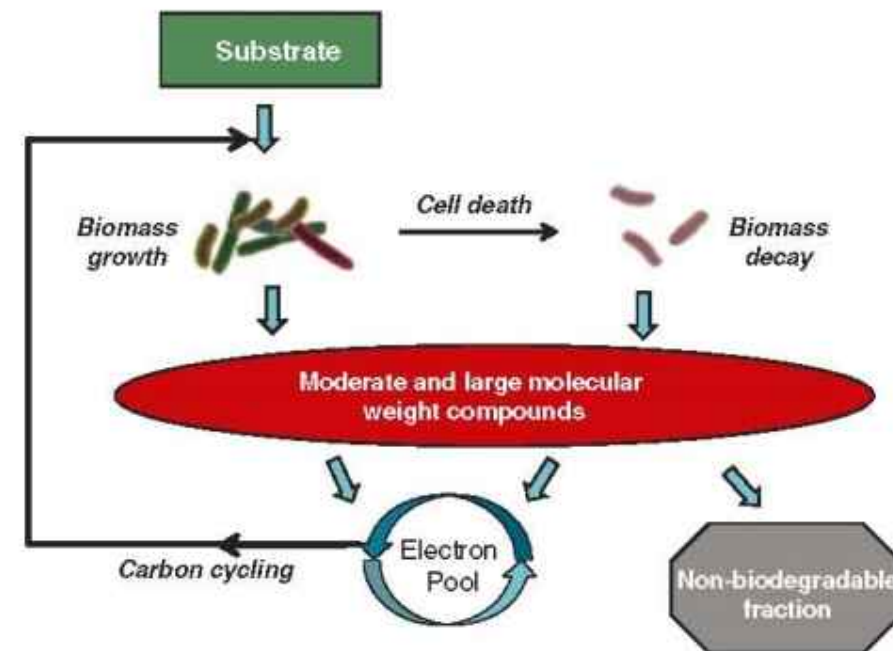


What is Sustained Treatment?

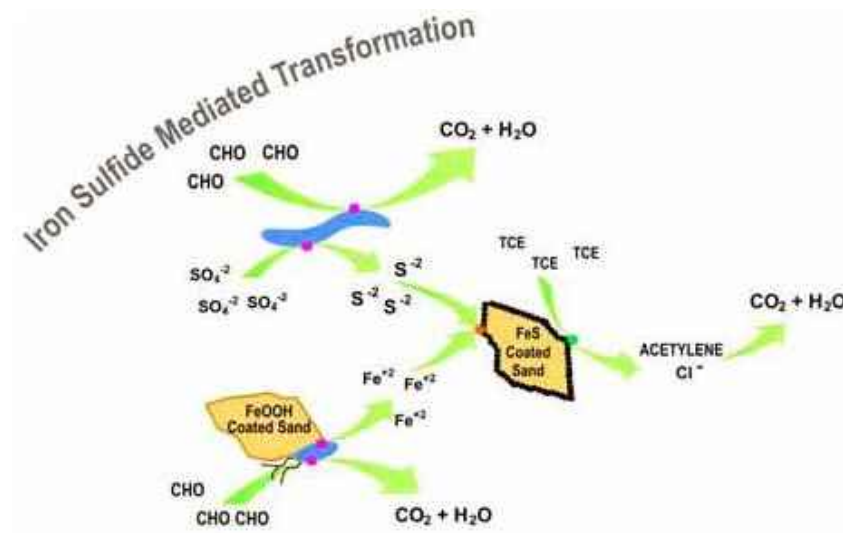
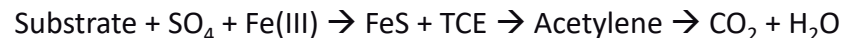
› Endogenous decay (biomass recycling)

“Carbon substrate selection and injection timing can be tuned to promote pseudo-self sustaining reactive zones... during late-stage treatment.”

(Suthersan et al. 2012)



› Reactive mineral generation



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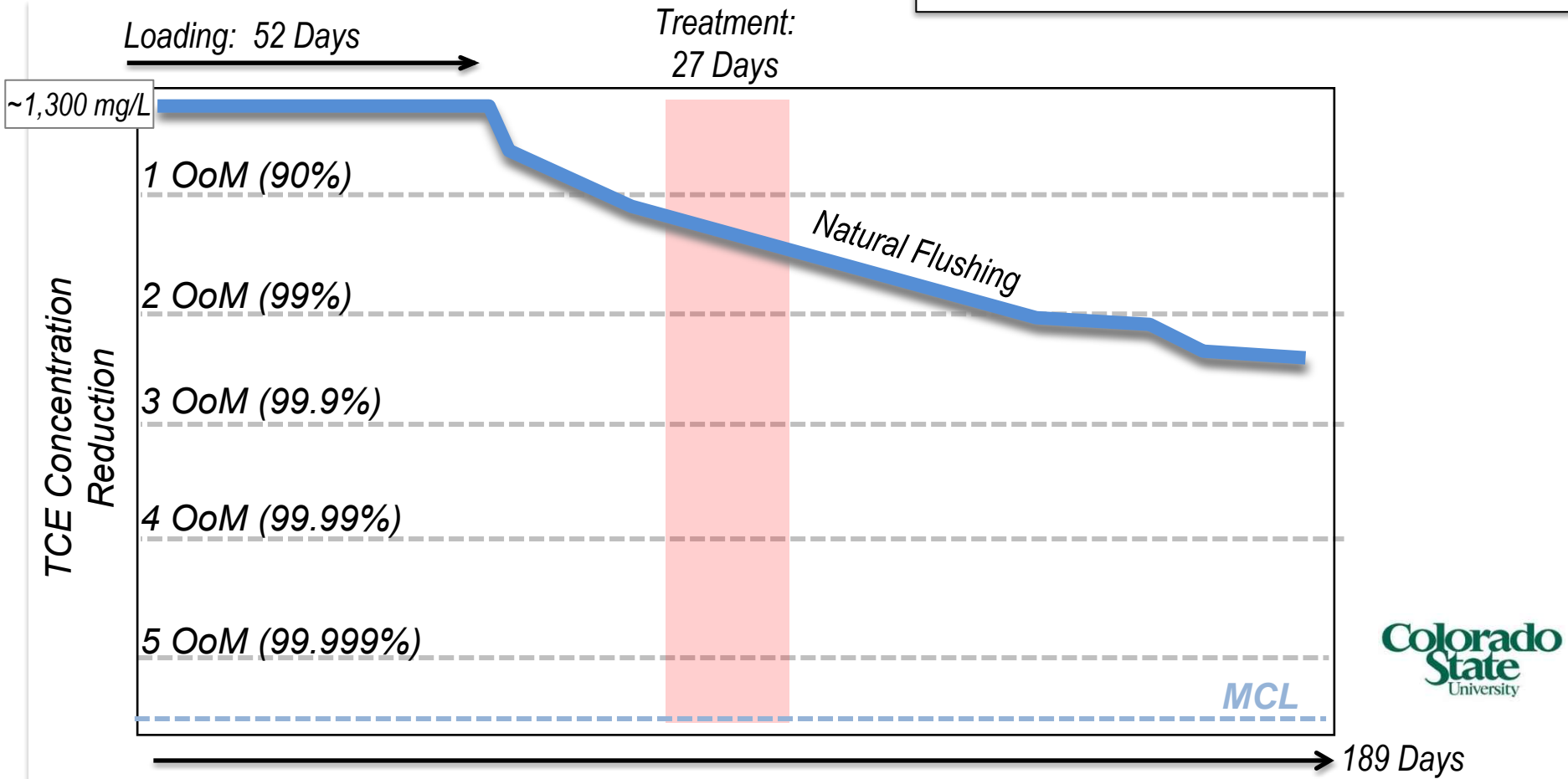
Lab Studies

CSU Matrix Diffusion Tank Experiments



Tank / Experiment

1. Control (45 PVs after loading ended)



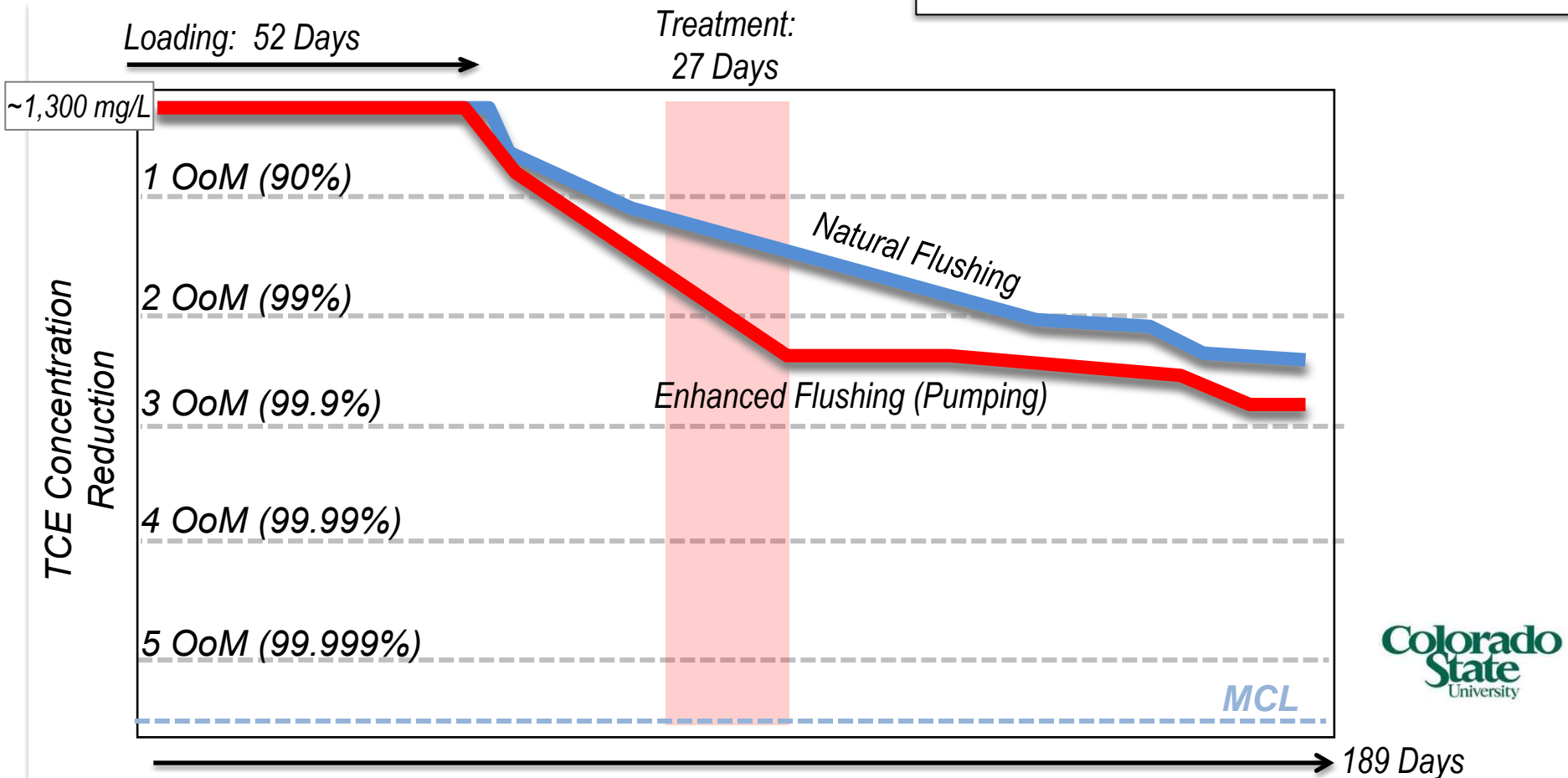
Lab Studies

CSU Matrix Diffusion Tank Experiments



Tank / Experiment

1. Control (45 PVs after loading ended)
2. Enhanced flushing (81 PVs after loading)



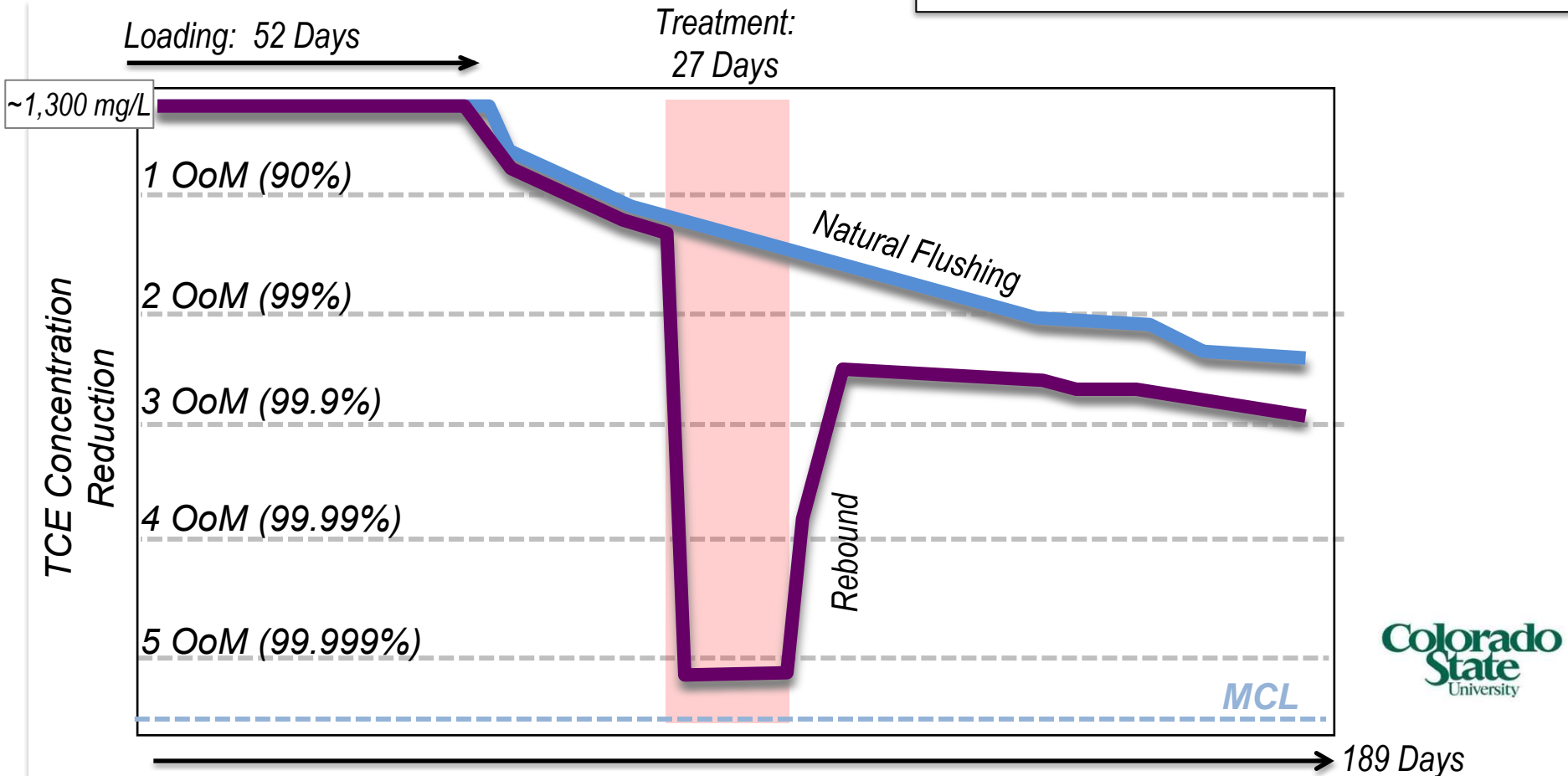
Lab Studies

CSU Matrix Diffusion Tank Experiments



Tank / Experiment

1. Control (45 PVs after loading ended)
3. Chemical oxidation (45 PVs after loading)



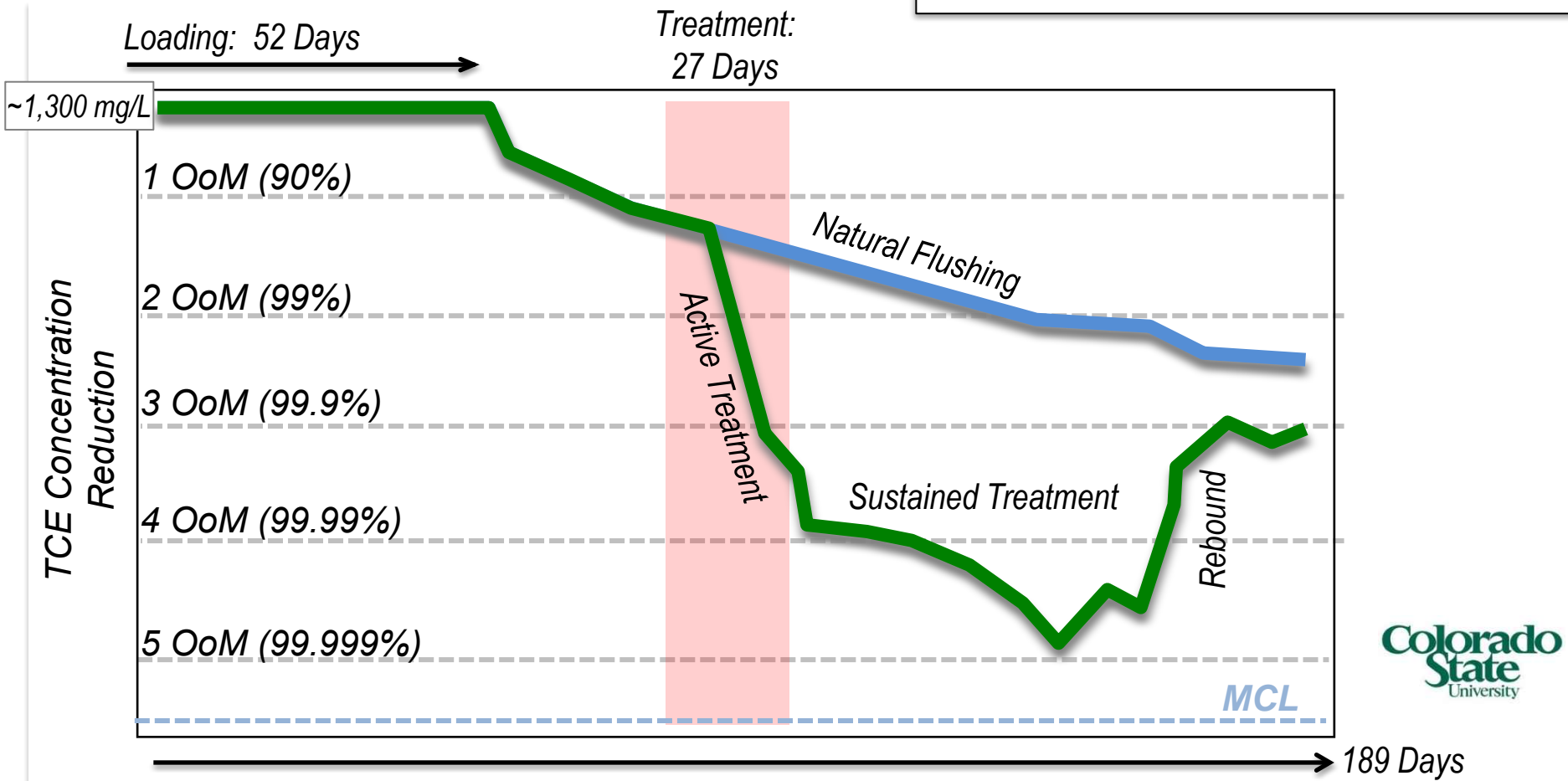
Lab Studies

CSU Matrix Diffusion Tank Experiments



Tank / Experiment

1. Control (45 PVs after loading ended)
4. Bioremediation (45 PVs after loading)



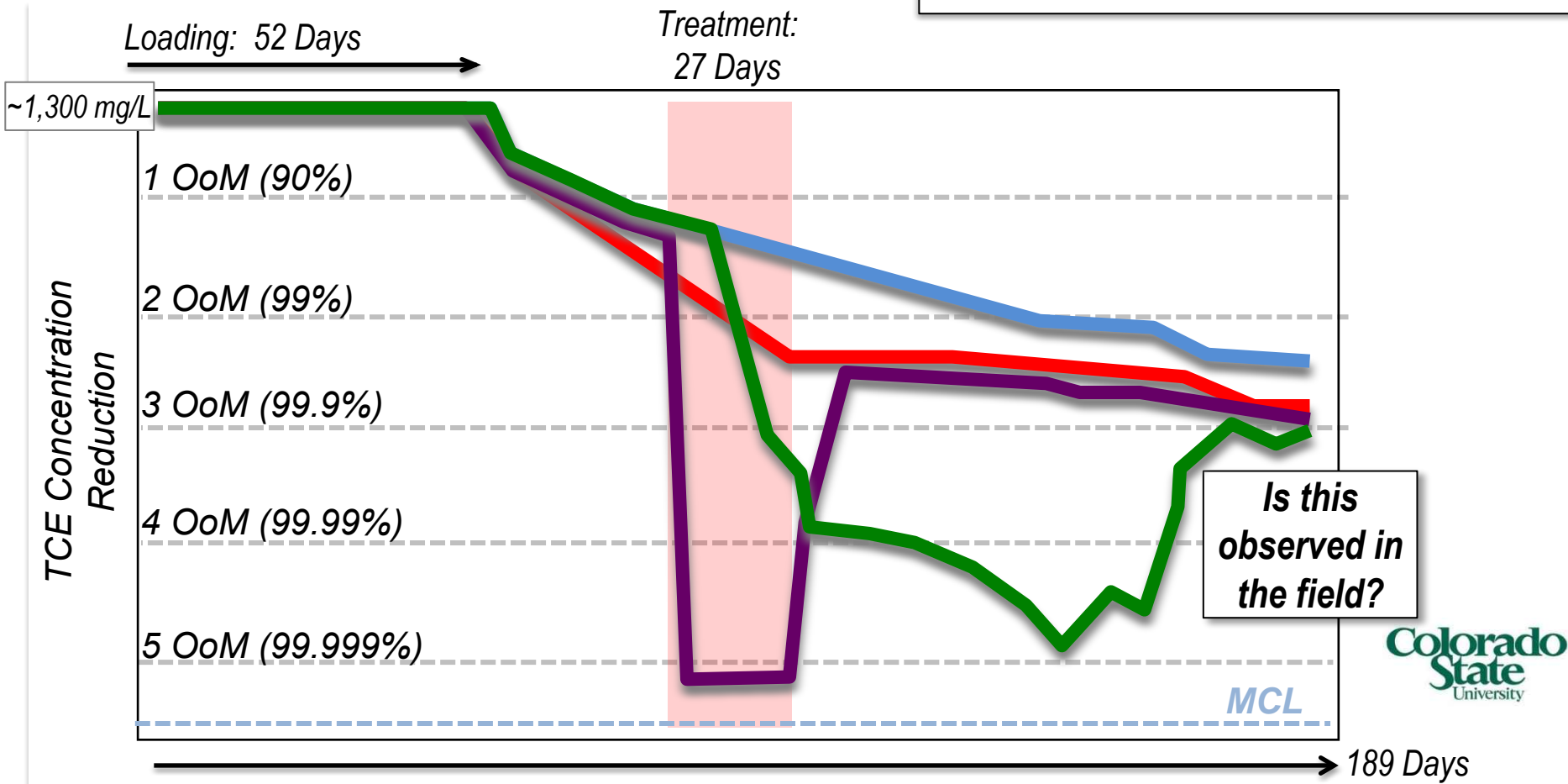
Lab Studies

CSU Matrix Diffusion Tank Experiments



Tank / Experiment

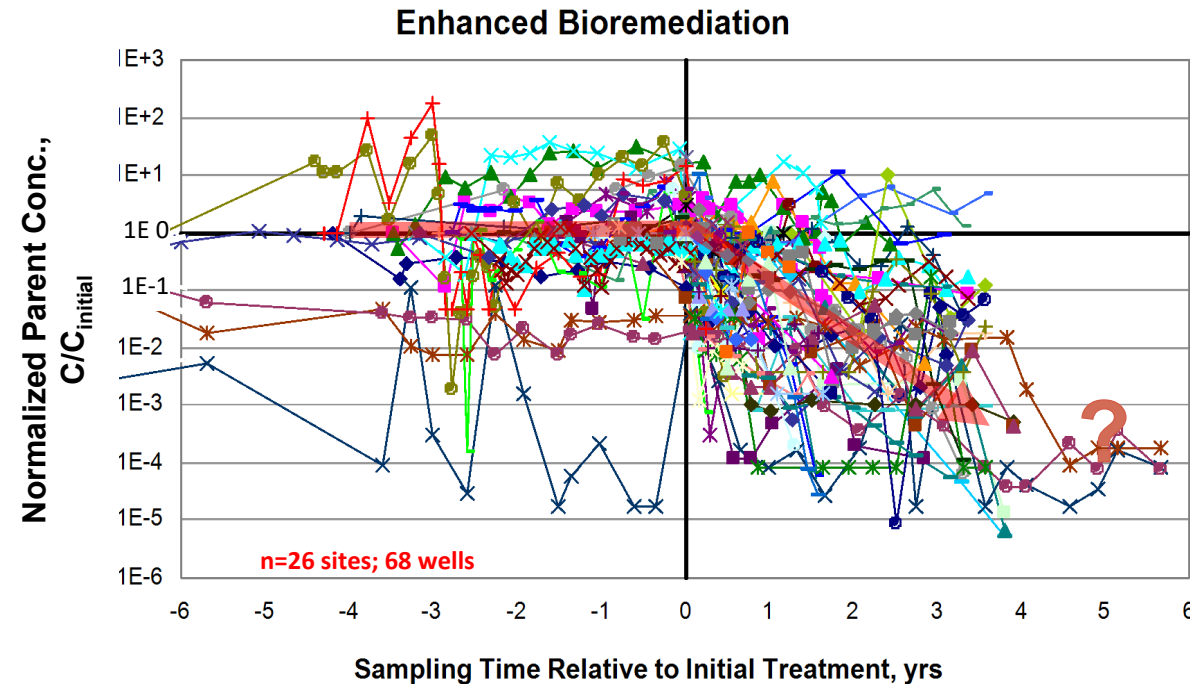
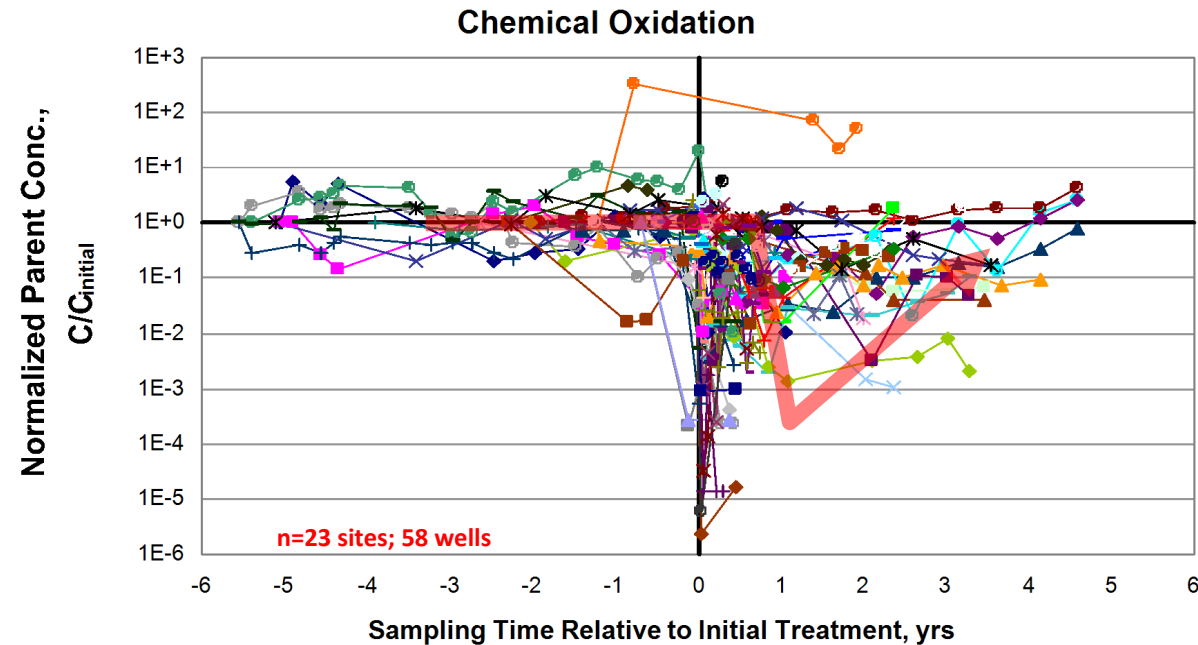
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Data Mining

- › 2002 SERDP project compiled remediation performance data from **59 sites**
- › Results suggested a continued decline in concentrations following treatment with EAB



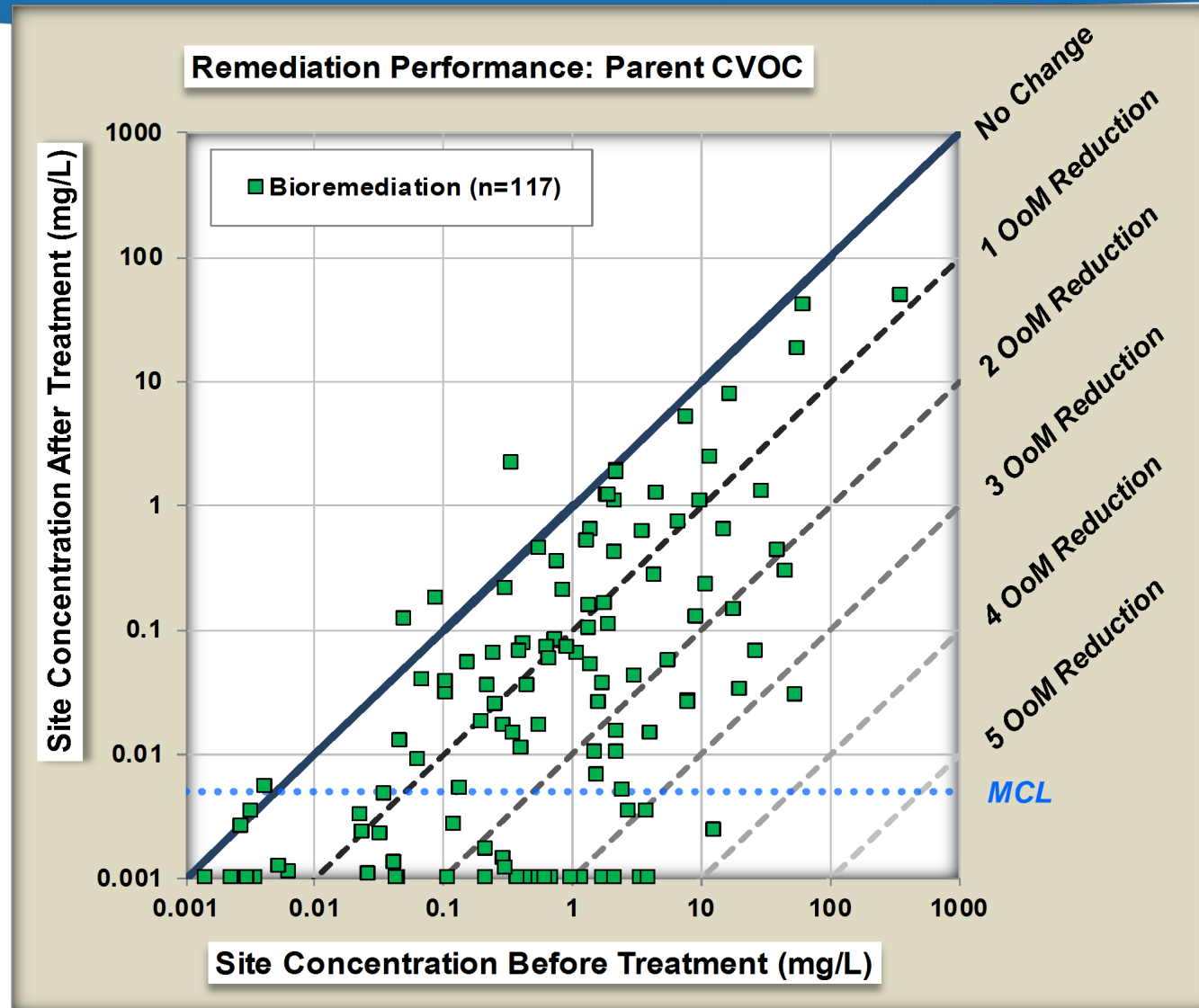
Additional Data Mining on Performance

- › Expanded the remediation performance dataset to **235 sites**, with **117 EAB sites**

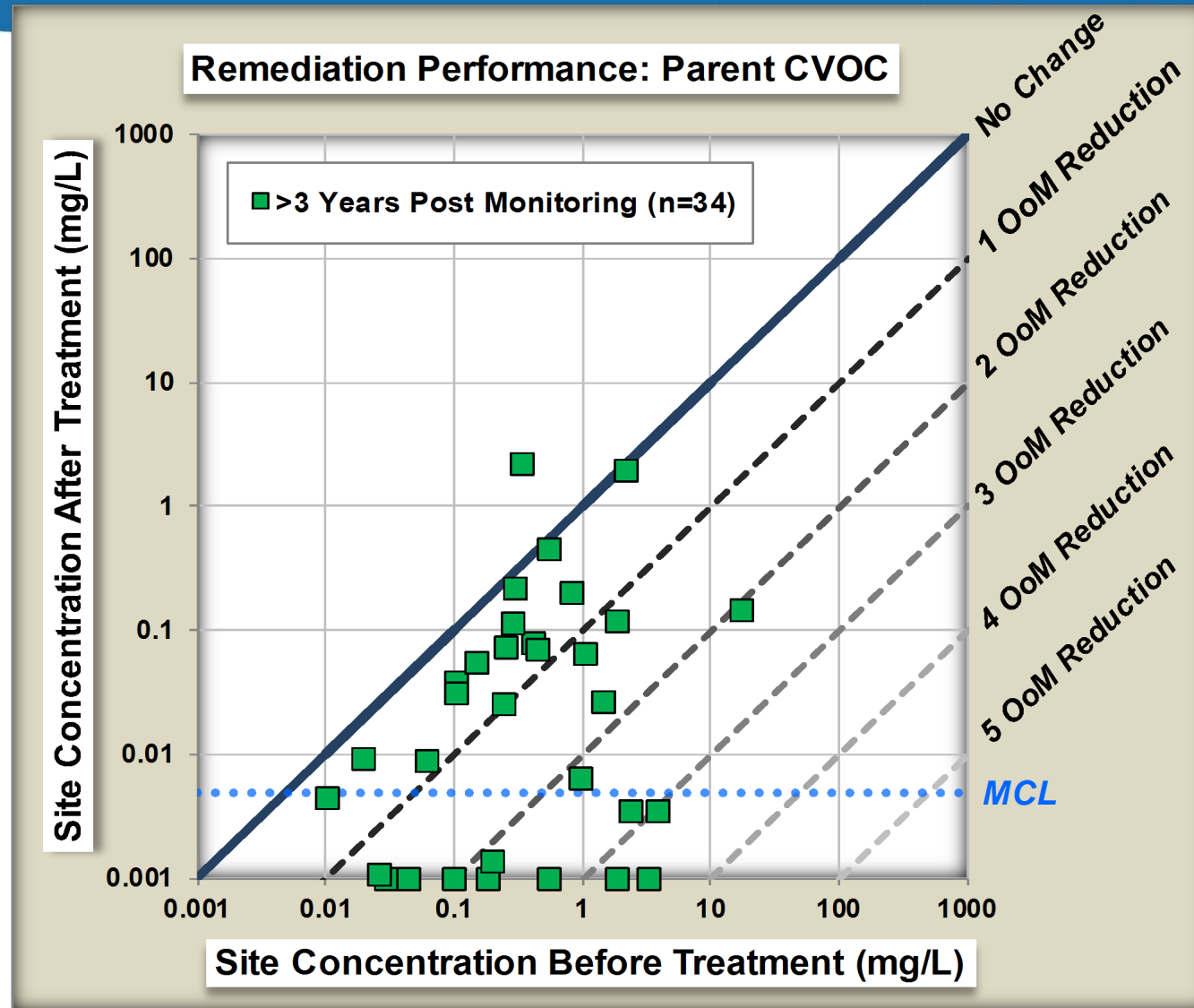
Database by the Numbers:

- ⇒ 280 Chlorinated Solvent Groundwater Sites
 - 235 In-Situ Remediation Sites
 - 45 Untreated (MNA) Sites
- ⇒ 796 Wells
- ⇒ 11,965 Sampling Events
- ⇒ 48,594 Chlorinated Compound Concentrations
- ⇒ ~ \$120,000,000 at \$10,000 per event

Additional Data Mining on Performance



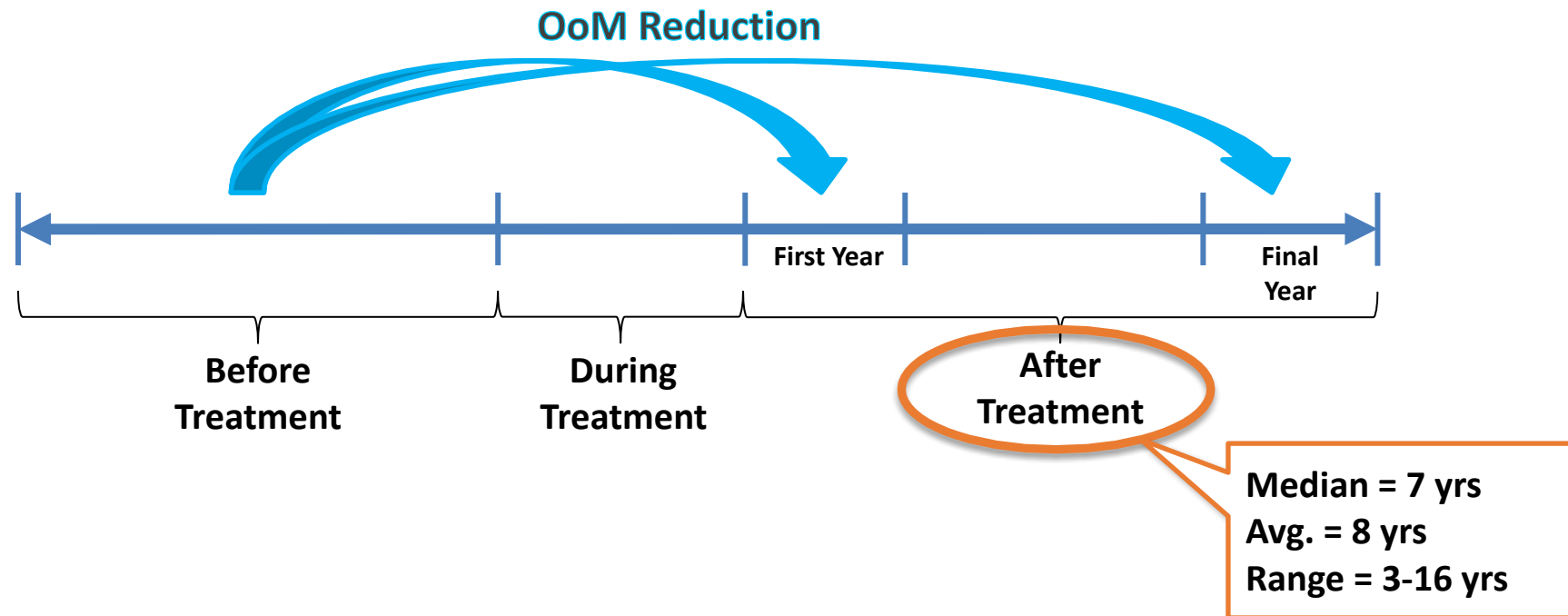
Additional Data Mining on Performance



Sustained Treatment Data Analysis

Key Metric: Order of Magnitude (OoM) Concentration Reduction

$$\text{OoM Reduction} = -\log\left(\frac{C_{Post}}{C_{Pre}}\right)$$

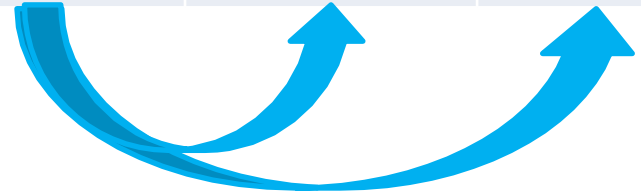


Sustained Treatment Data Analysis

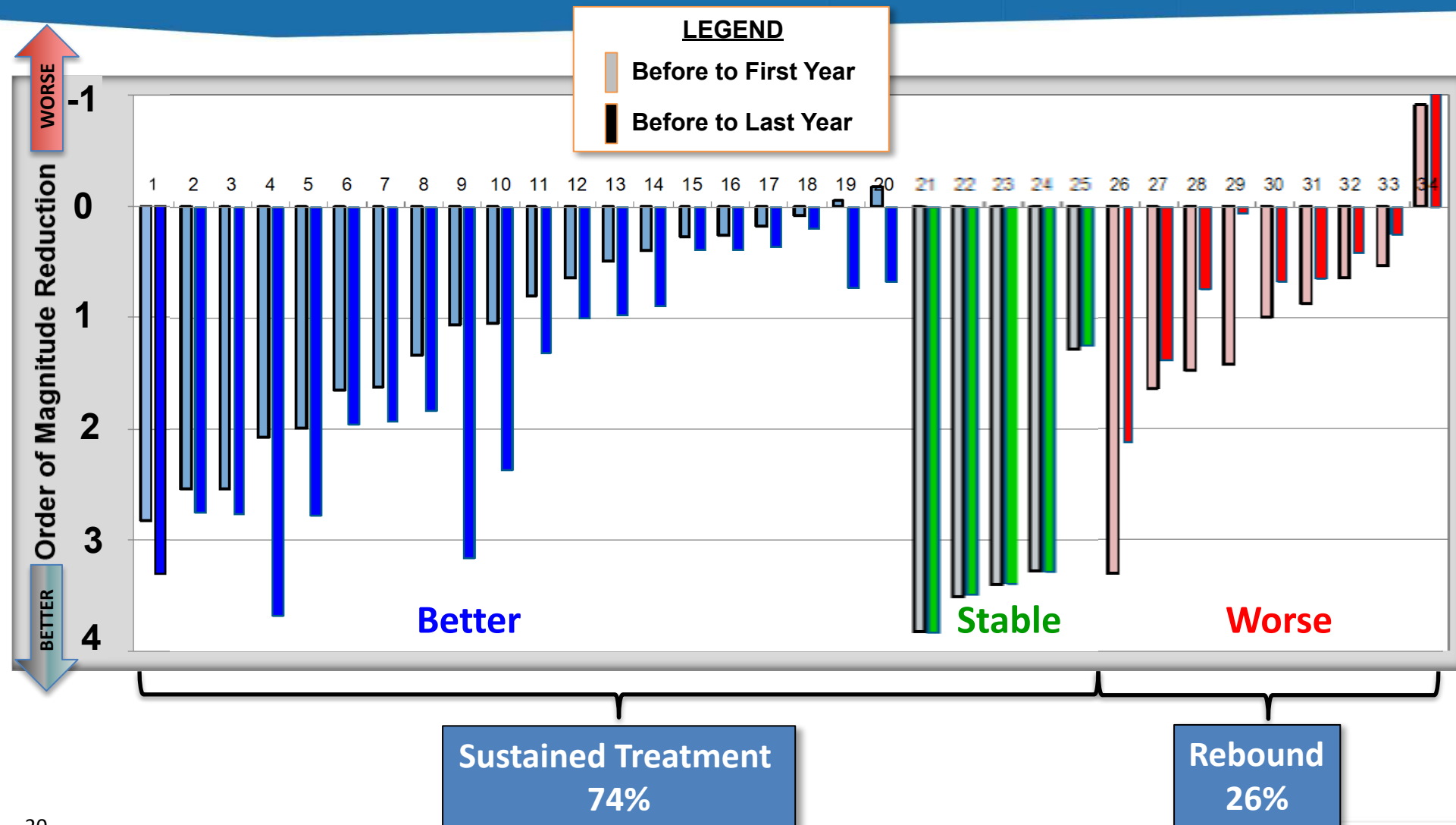
EXAMPLE:

PCE (mg/L)	Geomean Conc. Before Treatment	Geomean Conc. First Year After Trmt.	Geomean Conc. Last Year After Trmt.
MW-1	1.5	0.1	0.005
MW-2	0.8	0.08	0.008
MW-3	0.05	0.01	0.01
Site Conc. (Median)	0.8	0.08	0.008

$$\text{OoM Reduction} = -\log (0.08/0.8) = 1$$


$$\text{OoM Reduction} = -\log (0.008/0.8) = 2$$

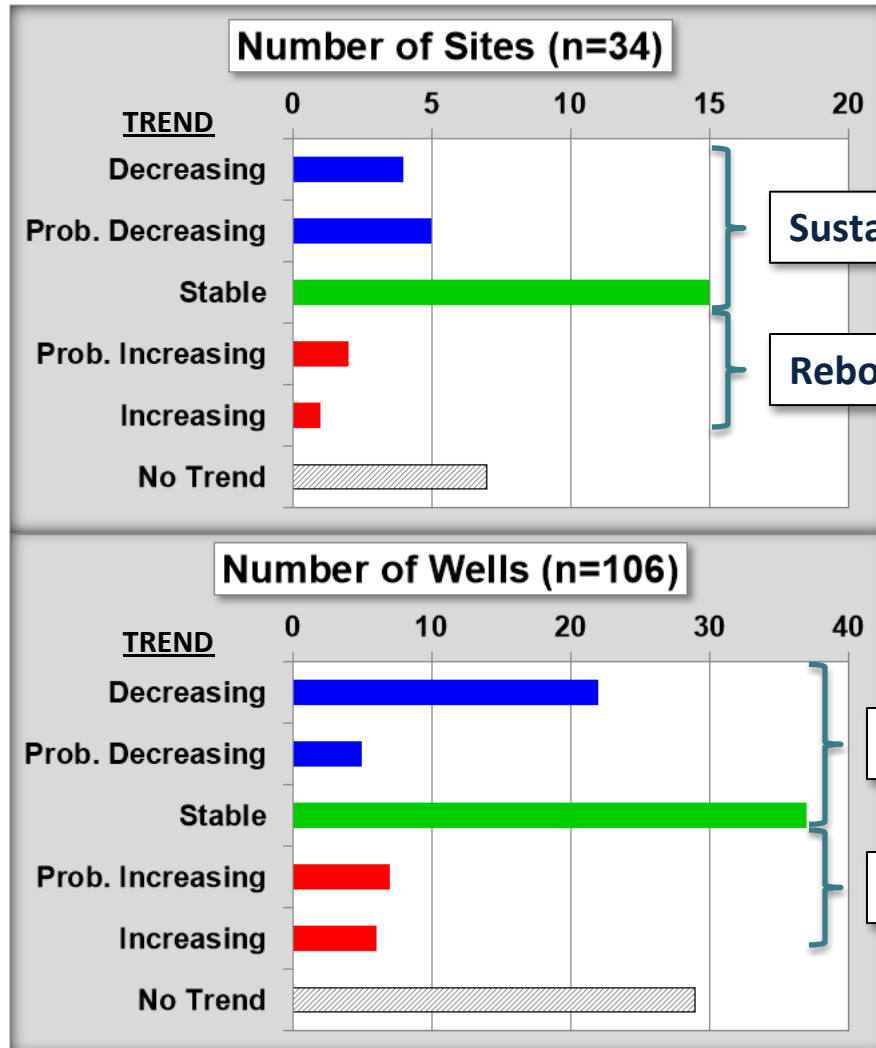
Results: *OoM Reduction by Site* (3 to 16 years after treatment)



Results: *Trend Analysis Post-Treatment*

(3 to 16 years after treatment)

Mann-Kendall Trend Analysis over Post-Treatment Period



Sustained Treatment (89%)

Rebound (11%)

KEY POINT:

Sustained treatment indicated at majority of sites/wells

Sustained Treatment (83%)

Rebound (17%)

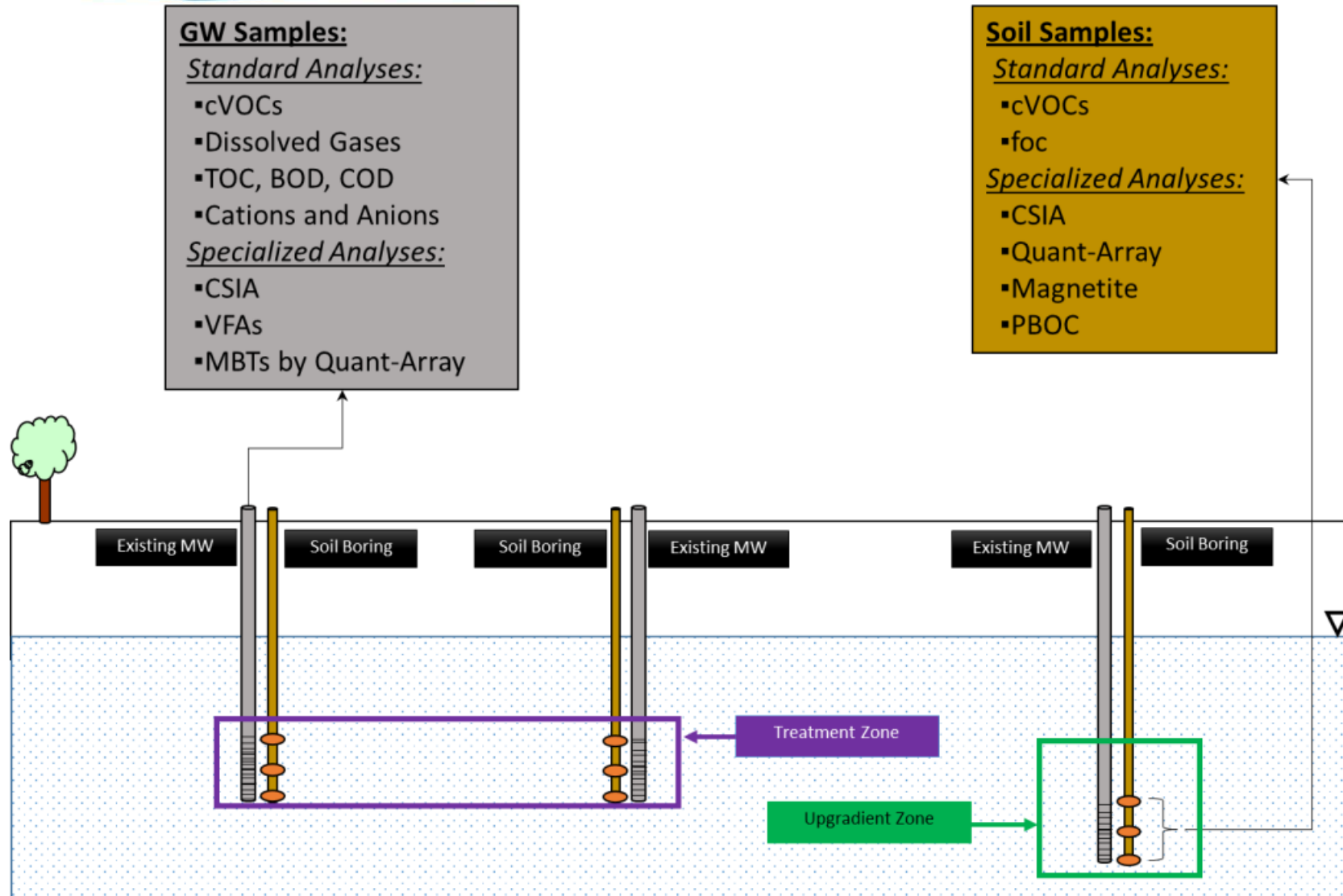
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Field Demonstration

Conducted extended monitoring of 6 projects:

SITE	SUBSTRATE	YEARS AFTER TREATMENT
Tinker AFB, OK	Lactate (fast-release)	9
Tinker AFB, OK	Emulsified Oil (slow-release)	9
Altus AFB, OK	Emulsified Oil (slow-release)	5
Altus AFB, OK	Mulch (Biowall)	10
NTC Orlando, FL	Emulsified Oil (slow-release)	5
Kelly AFB, TX	Emulsified Oil + Microbes (slow-release)	5

Field Demonstration – Testing Plan



Field Demonstration – Example Results

Kelly AFB

***Upgradient GW vs.
Treatment Zone GW:***

Parameter	Upgradient Well	Average Treatment Zone
PCE, mg/L	0.0085	<0.000372
DCE+VC, mg/L	0.0822	0.202
Ethene, mg/L	<0.00426	0.047
Methane, mg/L	0.0083	5.89
Σ VFAs, mg/L	0.76	0.77
BOD, mg/L	<3.33	<3.33
TOC, mg/L	0.85	2.15
DHC, cell/mL	5	63,000
Σ Red.Dech., cell/mL	1,000	115,000
EBAC, cell/mL	190,000	865,000
¹³ C DCE, δ13C (‰)	-19.50	+34.16
¹³ C VC, δ13C (‰)	ND	-2.74
Mag. Susc., mg/kg	3.8 E-7	2.0 E-7
f _{oc} , mg/kg	6,350	2,980
PBOC, mg/kg	68	62

Field Demonstration – Example Results

NTC Orlando

*Upgradient GW vs.
Treatment Zone GW:*

Parameter	Upgradient Well	Average Treatment Zone
TCE, mg/L	<0.000398	0.005
DCE+VC, mg/L	0.0011	0.38
Ethene, mg/L	<0.00426	0.0076
Methane, mg/L	0.59	12.8
Σ VFAs, mg/L	1.32	0.47
BOD, mg/L	7.8	12.9
TOC, mg/L	12.6	8.4
DHC, cell/mL	<25	106
Σ Red.Dech., cell/mL	380	3,310
EBAC, cell/mL	534,000	137,400
¹³ C DCE, δ13C (‰)	ND	-19.5
¹³ C VC, δ13C (‰)	ND	-21.1
Mag. Susc., mg/kg	8.6E-09	4.0E-09
f _{oc} , mg/kg	1,810	1,980
PBOC, mg/kg	440	530

- › Objectives & Key Concepts
- › Lab: Experimental Observations
- › Desktop: Data Mining Remediation Performance
- › Field: Extended Long-Term Monitoring
- › **Key Findings & Fact Sheets for Assessing Your Site**

- › Data mining indicates sustained treatment occurrence at about 67% to 75% of enhanced bioremediation sites up to 16 years after treatment
- › Field data suggests the influence of enhanced bioremediation for at least 5 to 10 years after treatment

KEY POINT:

A generally well-designed and implemented EAB project will most likely benefit from sustained treatment for a period of at least 3 years to more than 15 years after treatment.

Assessing Sustained Treatment at Your Site using the ESTCP Fact Sheet

- › *Lines of Evidence* approach with Critical Values and parameter assessment guidelines
- › **Primary Lines of Evidence:**

Worksheet for Sustained Treatment Assessment for Post-ISB Sites

Parameter / Line of Evidence	Critical Value / Relationship	Site-Specific Results	Data Support Evidence of Sustained Treatment?
<i>Parent CVOC Concentration Change over Post-Treatment Monitoring Period</i>	Decrease in parent CVOC conc. from first year of post-treatment monitoring vs. last year of post-treatment monitoring	Concs. remain stable or decline	Yes
		Concs. increase	No
<i>CVOC Concentration Trend of Parent and Daughter Products</i>	Mann-Kendall trend from the most recent 4-8 monitoring events is same as (or better than) trend from first 4-8 post-treatment monitoring events	Trends improve or remain stable	Yes
		Trends worsen	No

Assessing Sustained Treatment at Your Site using ESTCP Fact Sheet

› Other Lines of Evidence:

Worksheet for Sustained Treatment Assessment for Post-ISB Sites

Parameter / Line of Evidence	Critical Value / Relationship	Site-Specific Results	Data Support Evidence of Sustained Treatment?
<i>TOC in Groundwater</i>	TOC > 20 mg/L (USEPA, 1998)		
<i>TOC in Groundwater</i>	Treatment Zone (TZ) > Upgradient (UG)		
<i>Ethene in Groundwater</i>	Ethene > 0.1 mg/L (USEPA, 1998)		
<i>Ethene in Groundwater</i>	Treatment Zone (TZ) > Upgradient (UG)		
<i>Methane in Groundwater</i>	Methane > 0.5 mg/L (USEPA, 1998)		
<i>Methane in Groundwater</i>	Treatment Zone (TZ) > Upgradient (UG)		

Assessing Sustained Treatment at Your Site using ESTCP Fact Sheet

› Other Lines of Evidence:

Worksheet for Sustained Treatment Assessment for Post-ISB Sites

Parameter / Line of Evidence	Critical Value / Relationship	Site-Specific Results	Data Support Evidence of Sustained Treatment?
<i>Dehalococcoides in Groundwater</i>	Treatment Zone (TZ) > Upgradient (UG)		
<i>Dehalococcoides in Groundwater</i>	> 10 ⁴ cells/mL (Lu et al., 2006)		
<i>Sum of Reductive Dechlorinators in GW</i>	> 10 ⁴ cells/mL		
<i>¹³C of CVOCs in Groundwater</i>	Enrichment of ¹³ C signature relative to upgradient monitoring locations		
<i>PBOC in Aquifer Sediment</i>	PBOC > 200 mg/kg (Chapelle et al., 2012)		

Wrap Up

- › Additional Fact Sheets available for:
 - › Assessing Sustained Treatment at Biowall sites
 - › Modeling MNA in low-permeability zones
- › <https://serdp-estcp.org/projects/details/3d847710-d6ae-4ef4-b97a-47cfe3a7160e>
- › Or search “ESTCP ER-201429”
- › Or email tmm@gsienv.com