

Field Performance of Colloidal Activated Carbon

Lessons Learned from Multiple Sites and Geological Settings

Jack Shore

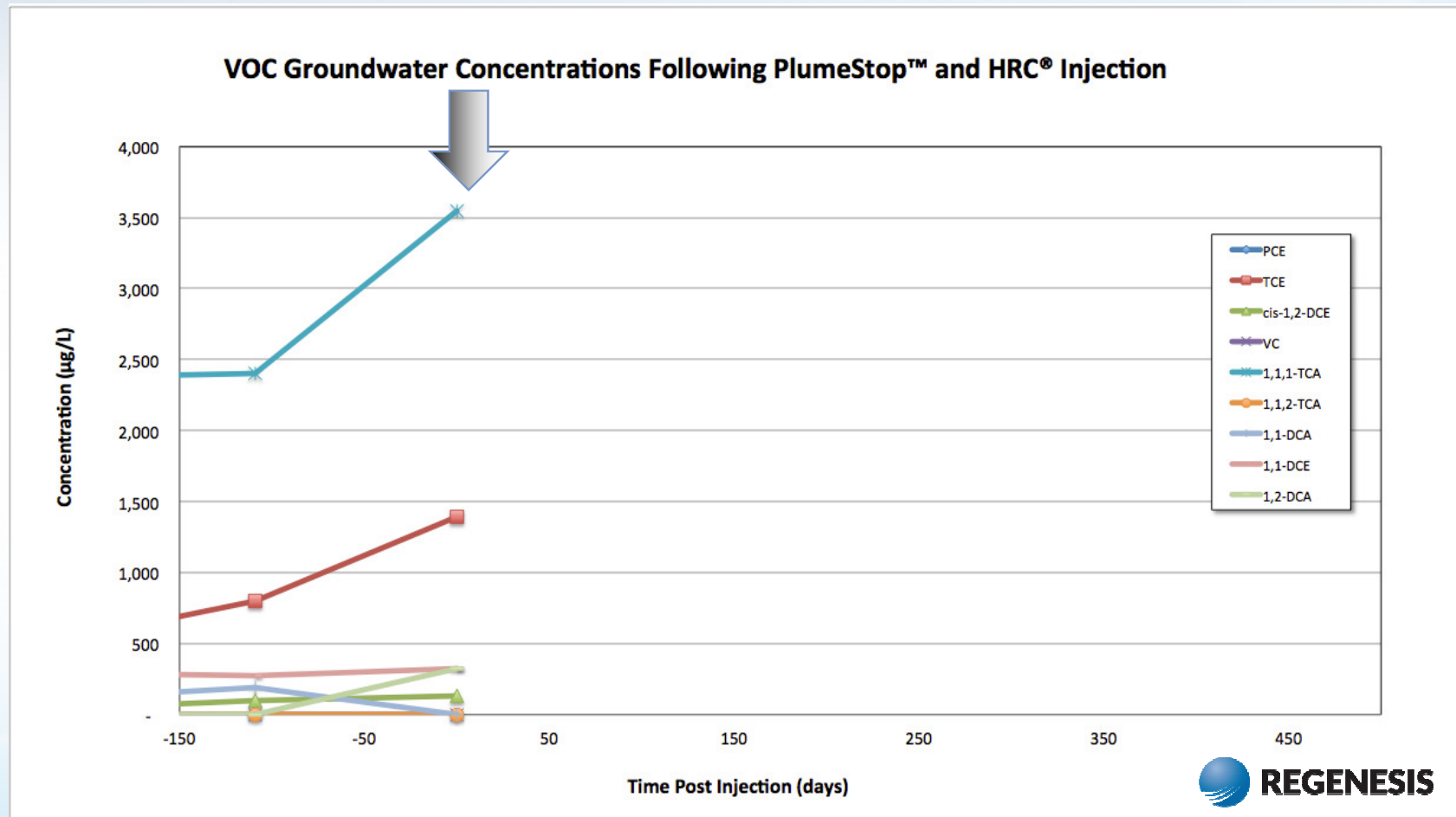
District Manager – UK and Scandinavia

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Introduction

- What is Colloidal Activated Carbon (PlumeStop)
- How colloidal activated carbon behaves in heterogenous superficial geologies
- How PlumeStop mitigates against back diffusion
- Case study focus
- Composite data review from 34 sites across the US and EU

Typical Site Results?



PlumeStop

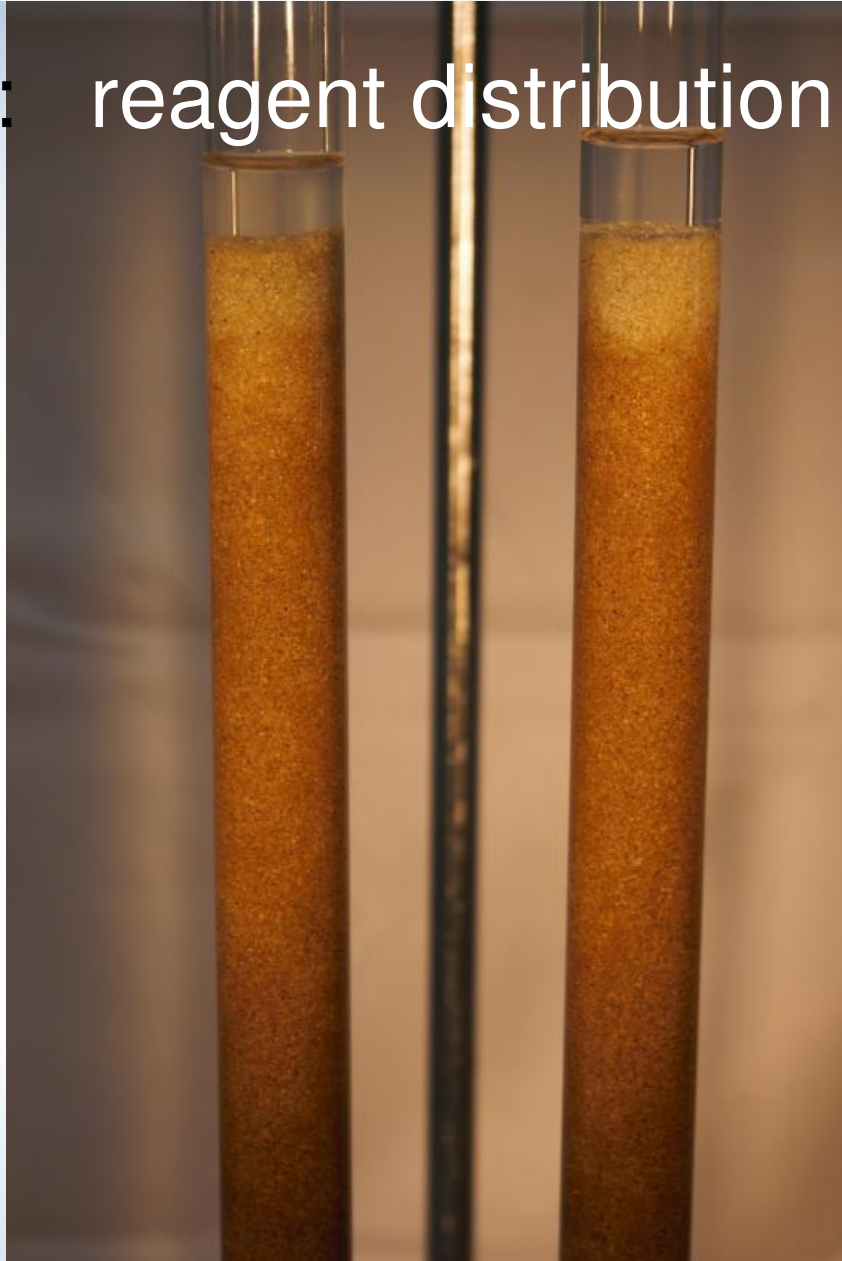
- Colloidal remediation agent
 - Liquid Activated Carbon
 - 1-2 micron colloids
 - polymer/dispersive agent
- Distributes widely in subsurface
 - No clogging pore-throats or clumping
- Adsorbs contaminants rapidly
 - Removed from aqueous phase
 - Concentrates contamination within biomatrix
- Accelerated biodegradation
 - Host to sedentary bacteria (biofilms)
 - Close contact with sorbed contaminant
- Rapid and sustained contaminant destruction
- Very low targets achieved

PLUME STOP[™]
Liquid Activated Carbon



PlumeStop™

reagent distribution



PlumeStop

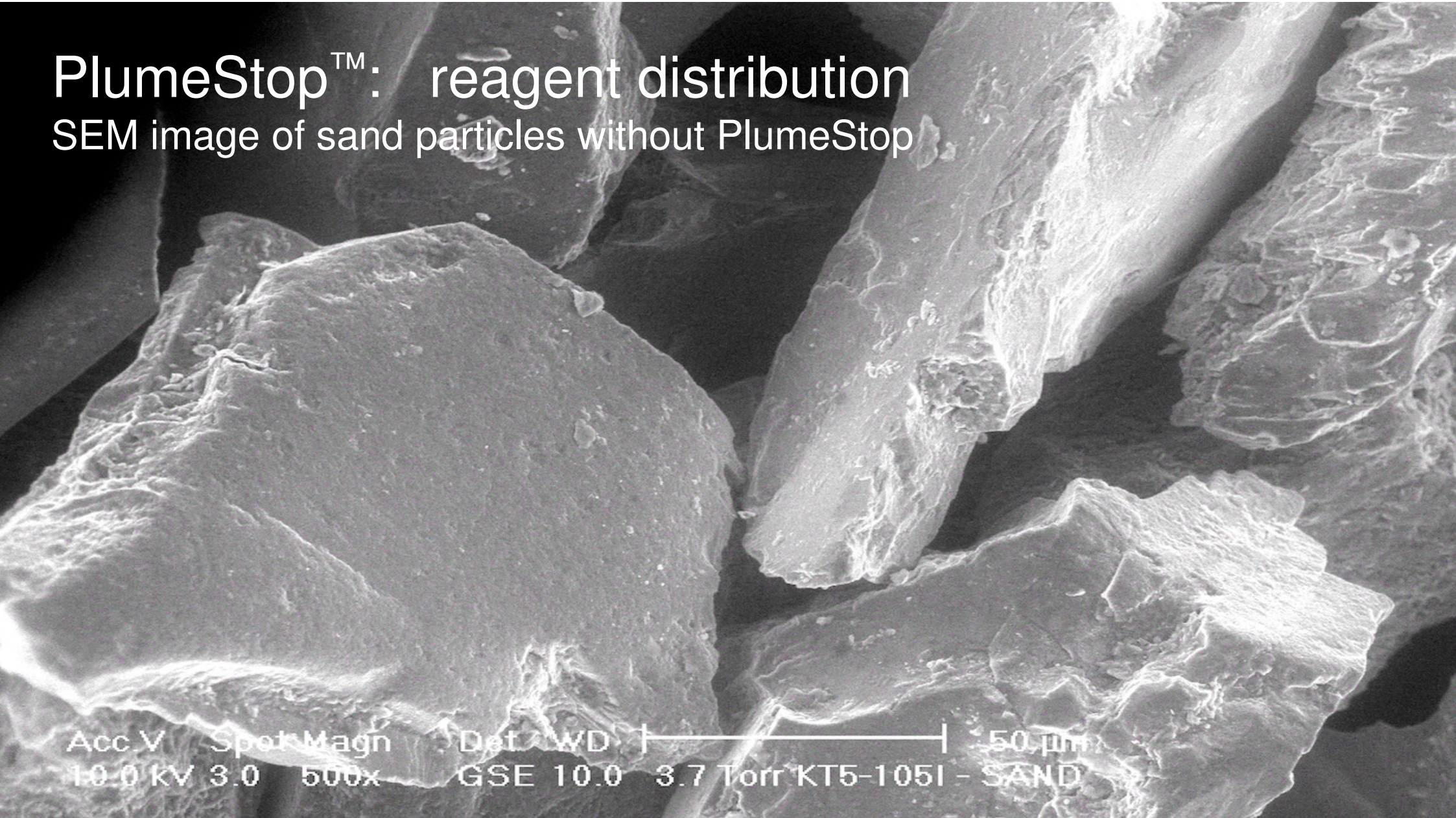


2 μ m Powdered Activated Carbon

repeat

PlumeStop™: reagent distribution

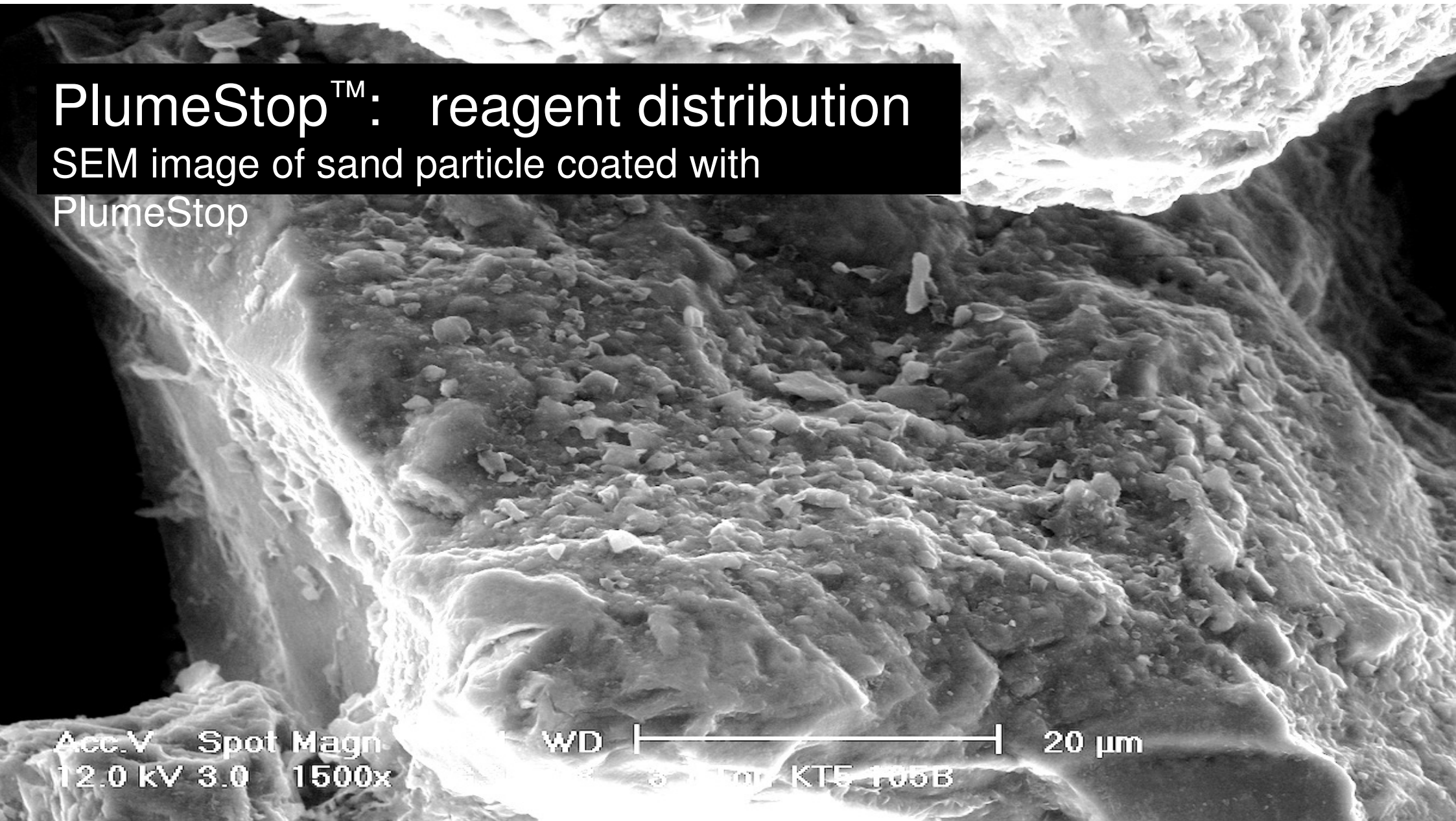
SEM image of sand particles without PlumeStop



Acc V Spot Magn Det WD |-----| 50 µm
10.0 kV 3.0 500x GSE 10.0 3.7 Torr KT5-1051 - SAND

PlumeStop™: reagent distribution

SEM image of sand particle coated with PlumeStop



Acc.V 12.0 kV Spot 3.0 Magn 1500x

WD

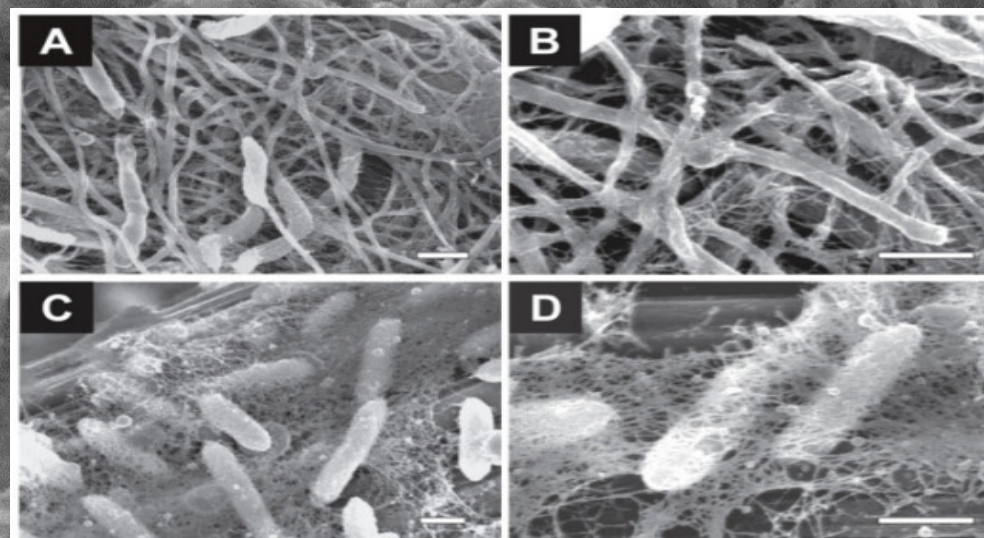


20 μm

15.0 μm KTE 105B

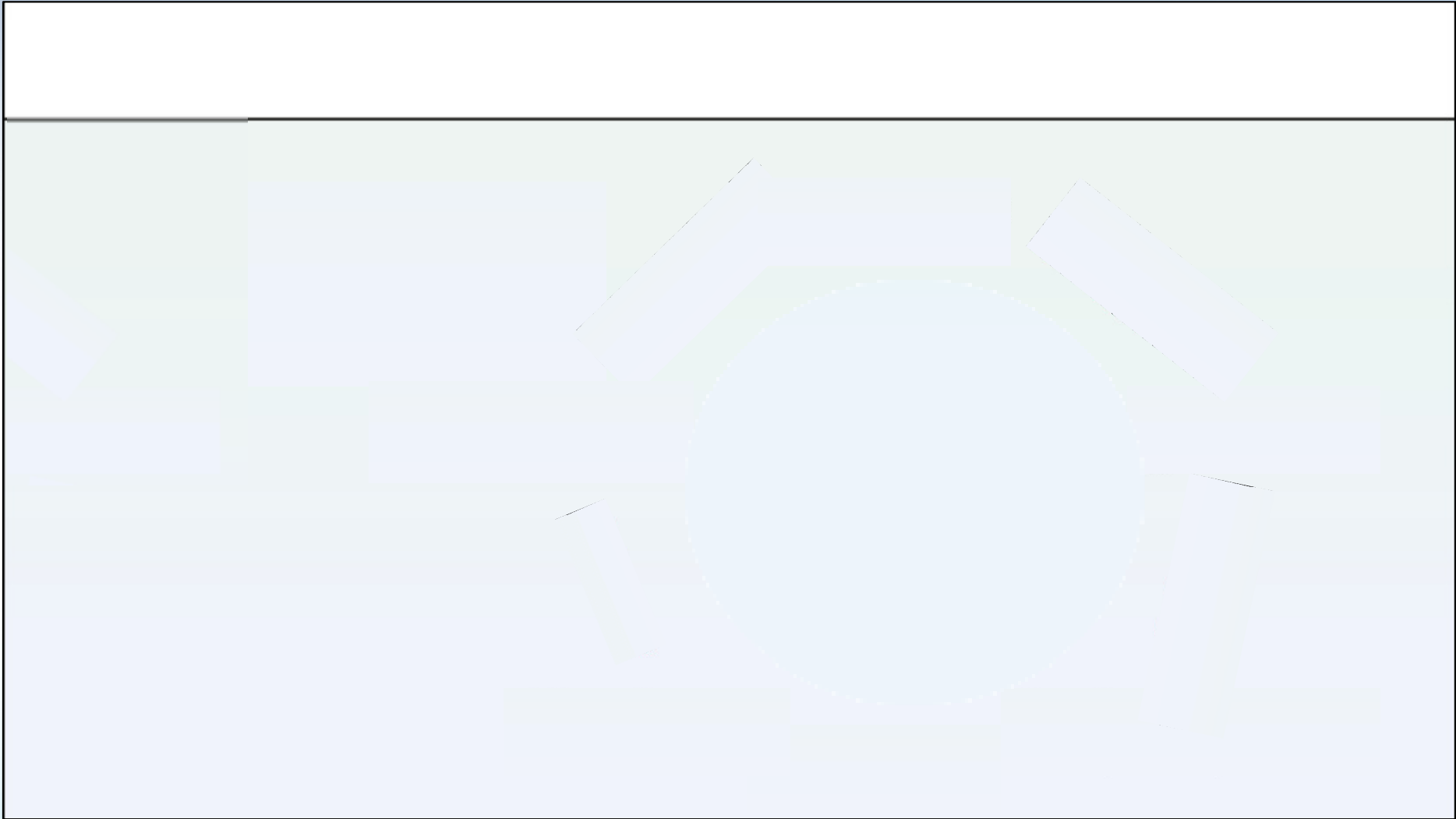
PlumeStop™: reagent distribution

SEM image of sand particle coated with PlumeStop



Acc.V Spot Magn Det WD |-----|
12.0 kV 3.0 2500x GSE 8.3 3.6 Torr KT5-105B

10 μm

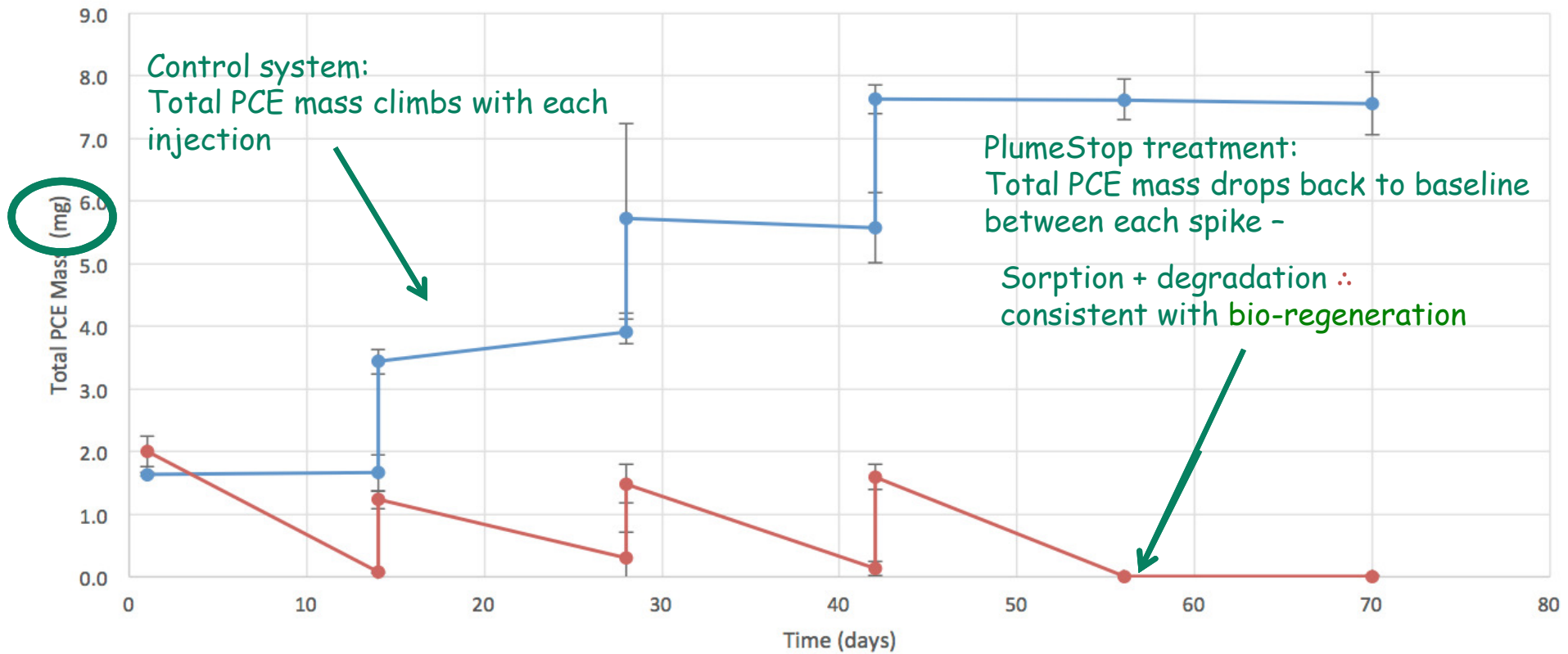


Bioregeneration

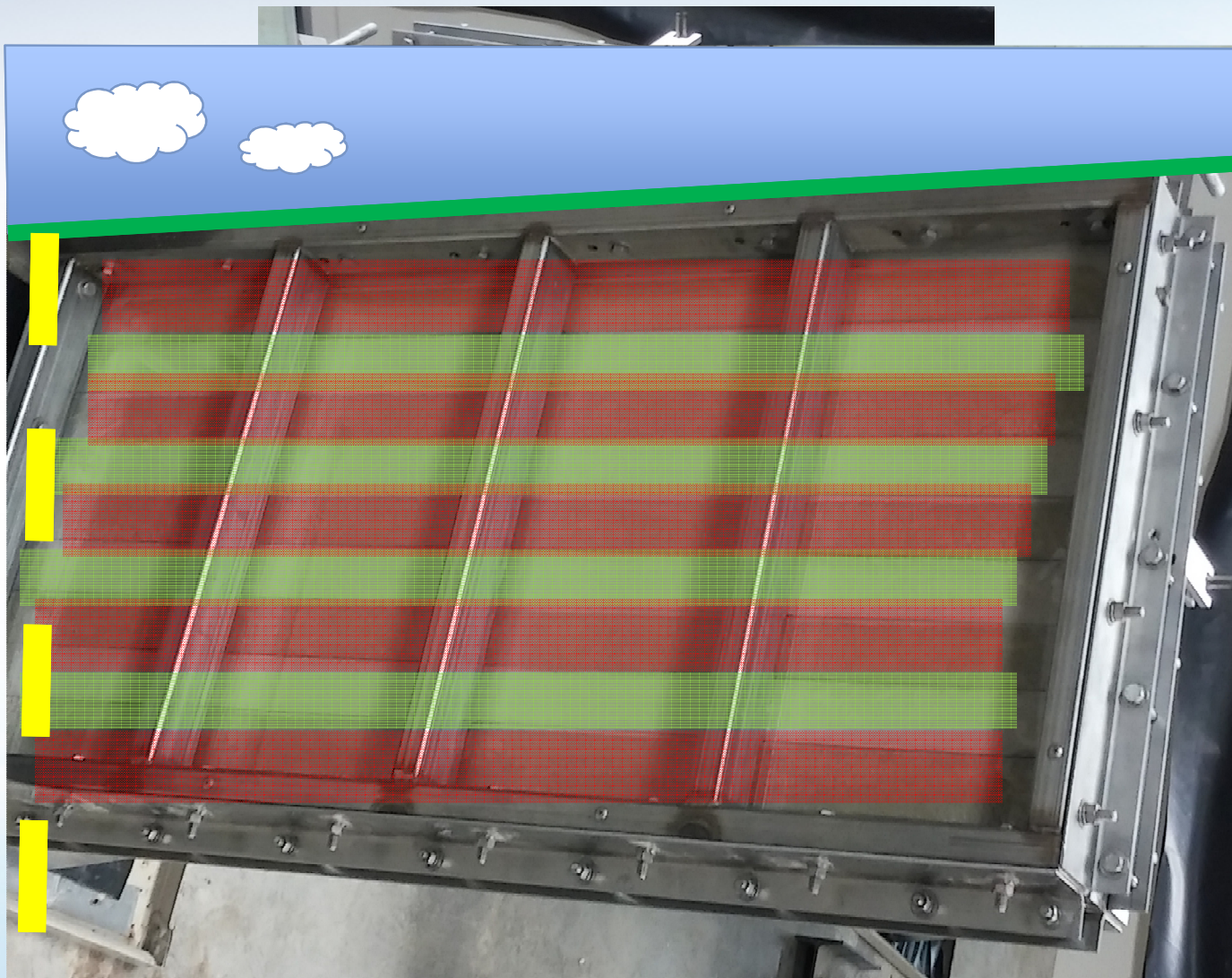
PCE in Total System Extract

(error bars signify +/- 1 standard deviation)

—●— Sterile Soil —●— Live Soil with PlumeStop



PlumeStop Installation into Contaminant Flux Zones - Model

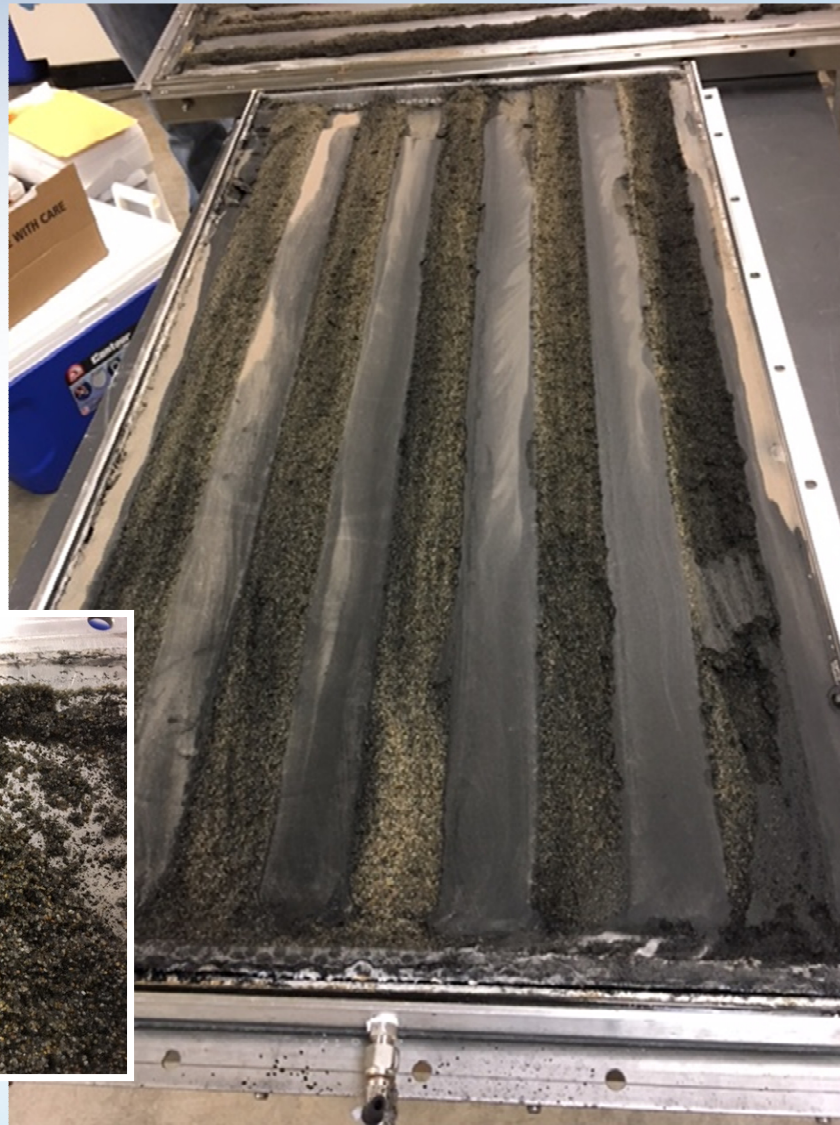


PlumeStop Installation into Contaminant Flux Zones - Model



PlumeStop Transport

Noticeable
penetration into
low k zones



Tank 2: PlumeStop only



Tank 4: PlumeStop + ERD





How does PlumeStop mitigate against back diffusion?

Back Diffusion

Colorado State University

**Civil and Environmental Engineering
Center for Contaminant Hydrology**

CCH

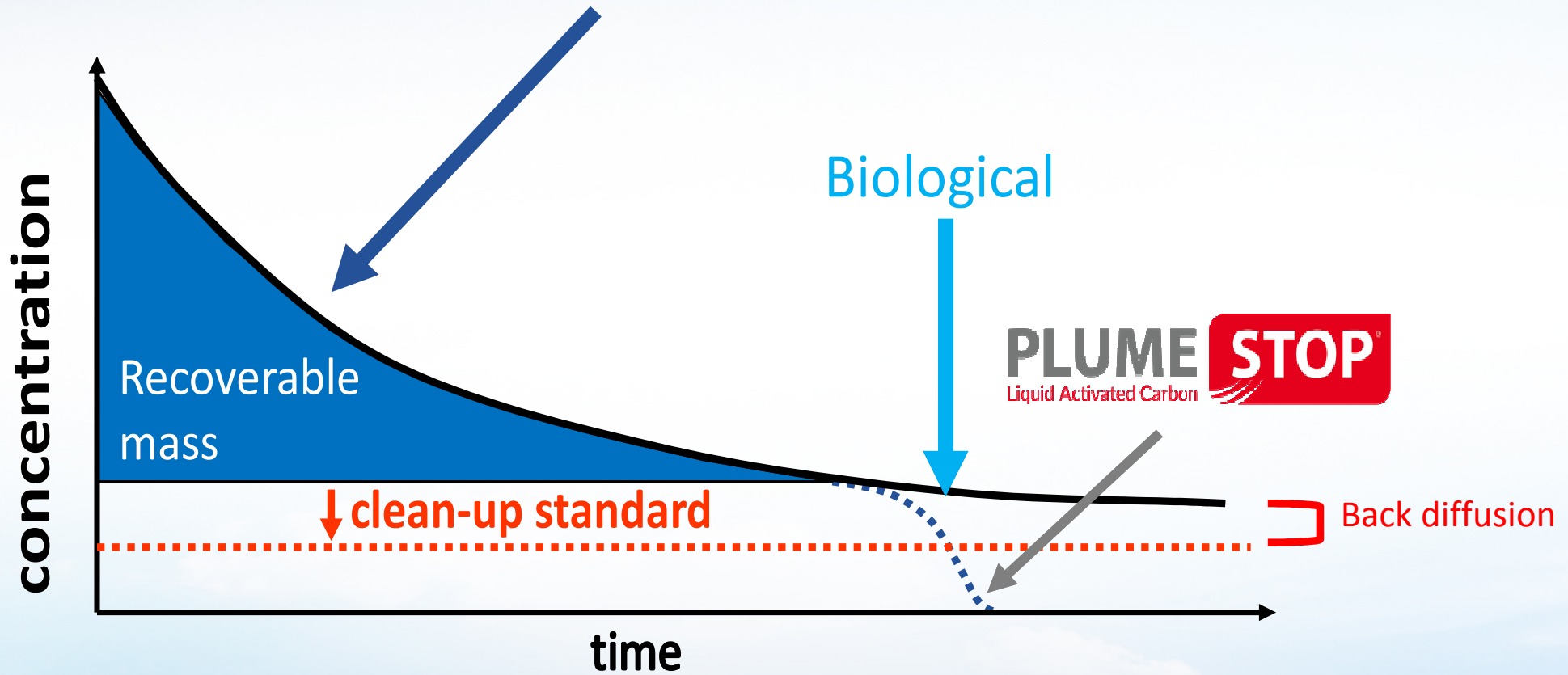


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Back Diffusion.. Continued

Physical Removal or Chemical Oxidation



PlumeStop and Back Diffusion – Lab study

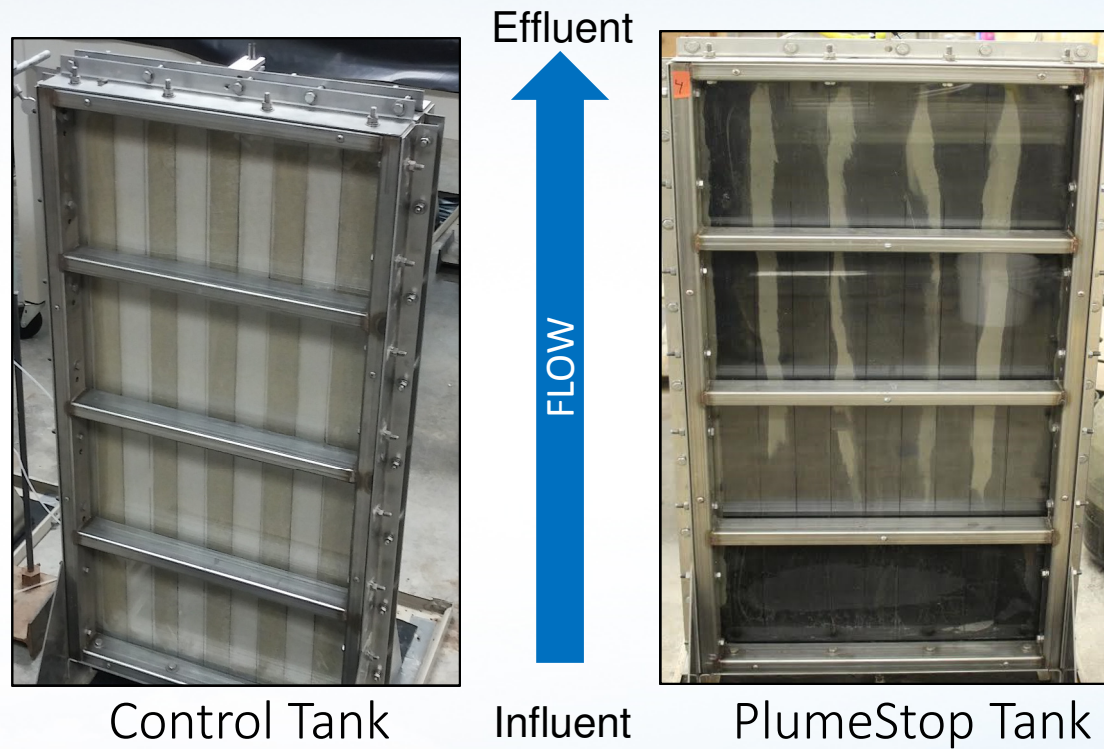
- Tank 1** Control, no treatment
- Tank 2** PlumeStop only
- Tank 3** ERD Treatment
➤ Lactate + DHC
- Tank 4** PlumeStop + ERD
➤ PlumeStop, lactate, DHC

1. “TCE Spill”
 - a. TCE saturated water flowed through tanks (~12 PV)
2. Back diffusion:
 - a. Influent switched to clean water until effluent TCE <5 mg/L
3. Inject remediation treatments

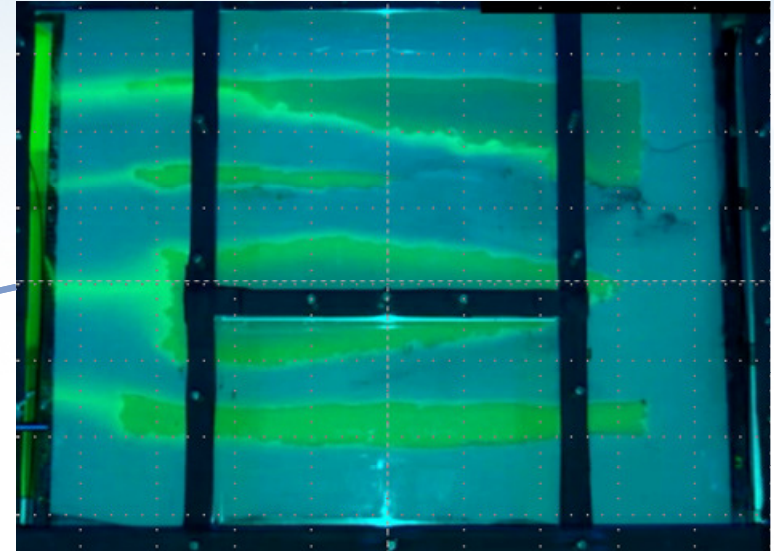
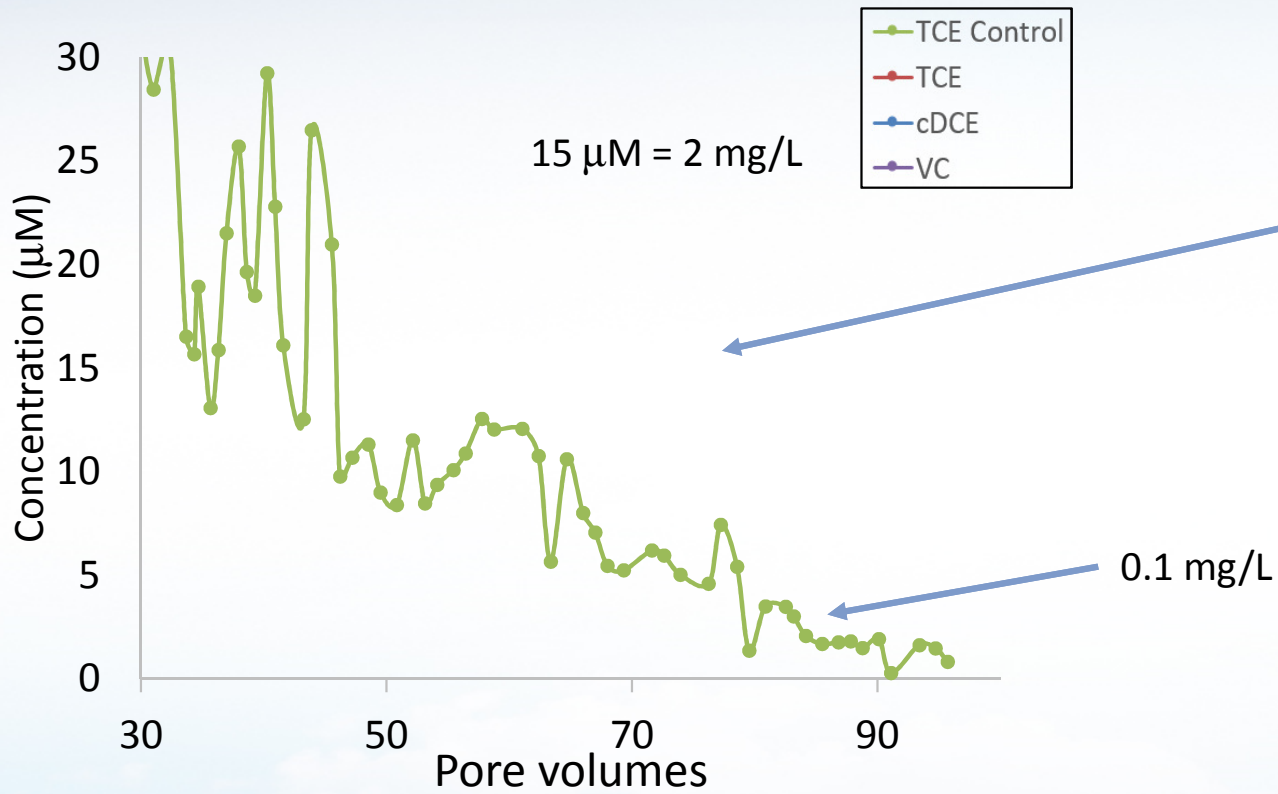


PlumeStop and Back Diffusion – Lab study - Analysis

- Effluent samples collected throughout experiment for VOCs
- qPCR analysis of water and soil upon completion of experiment



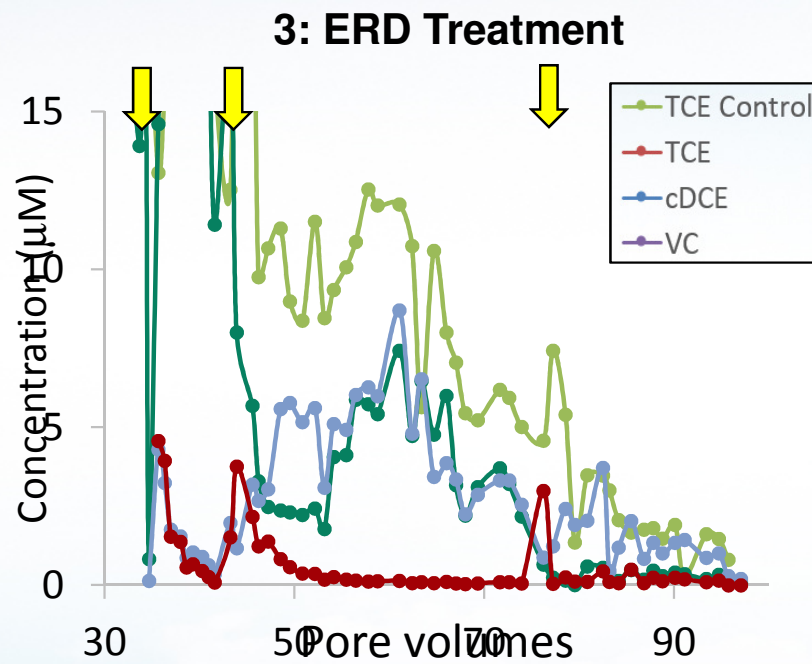
Effluent Results - Tank 1 (Control)



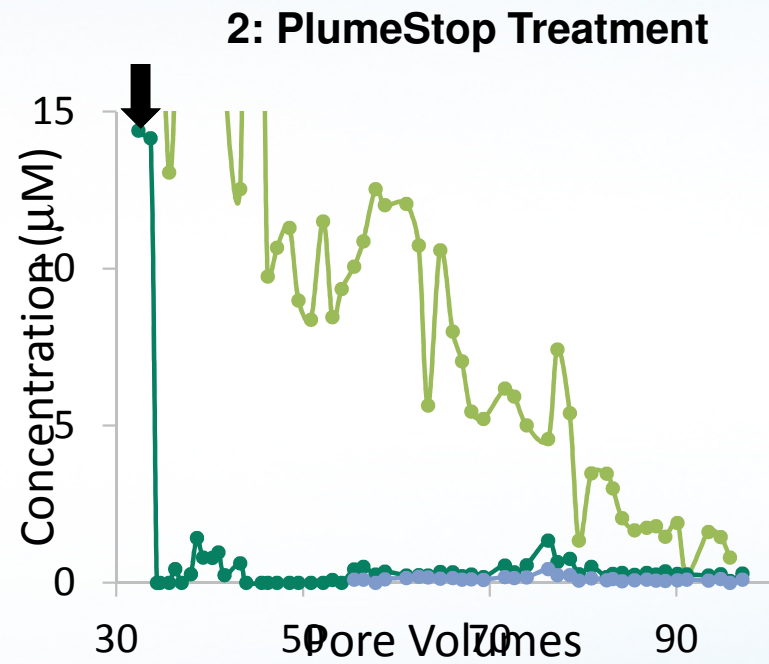
Note: Graph starts at time when amendments were applied

Effluent Results - Tank 3 (Donor) & Tank 2 (PlumeStop)

ERD Treatment: **No**
containment of total
VOCs

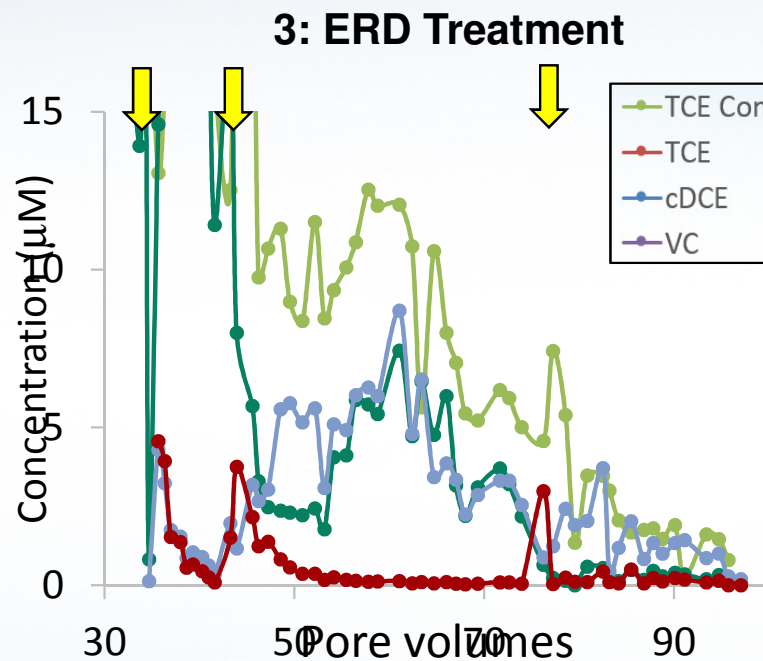


↓ = Lactate/DHC applications

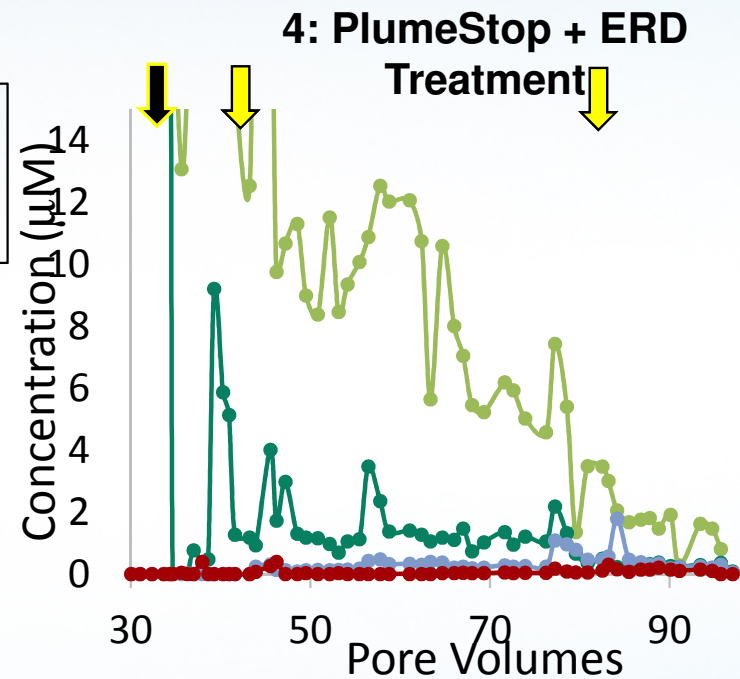


↓ = PlumeStop application

Effluent Results - Tank 3 (Donor) & Tank 4 (PlumeStop& Donor)

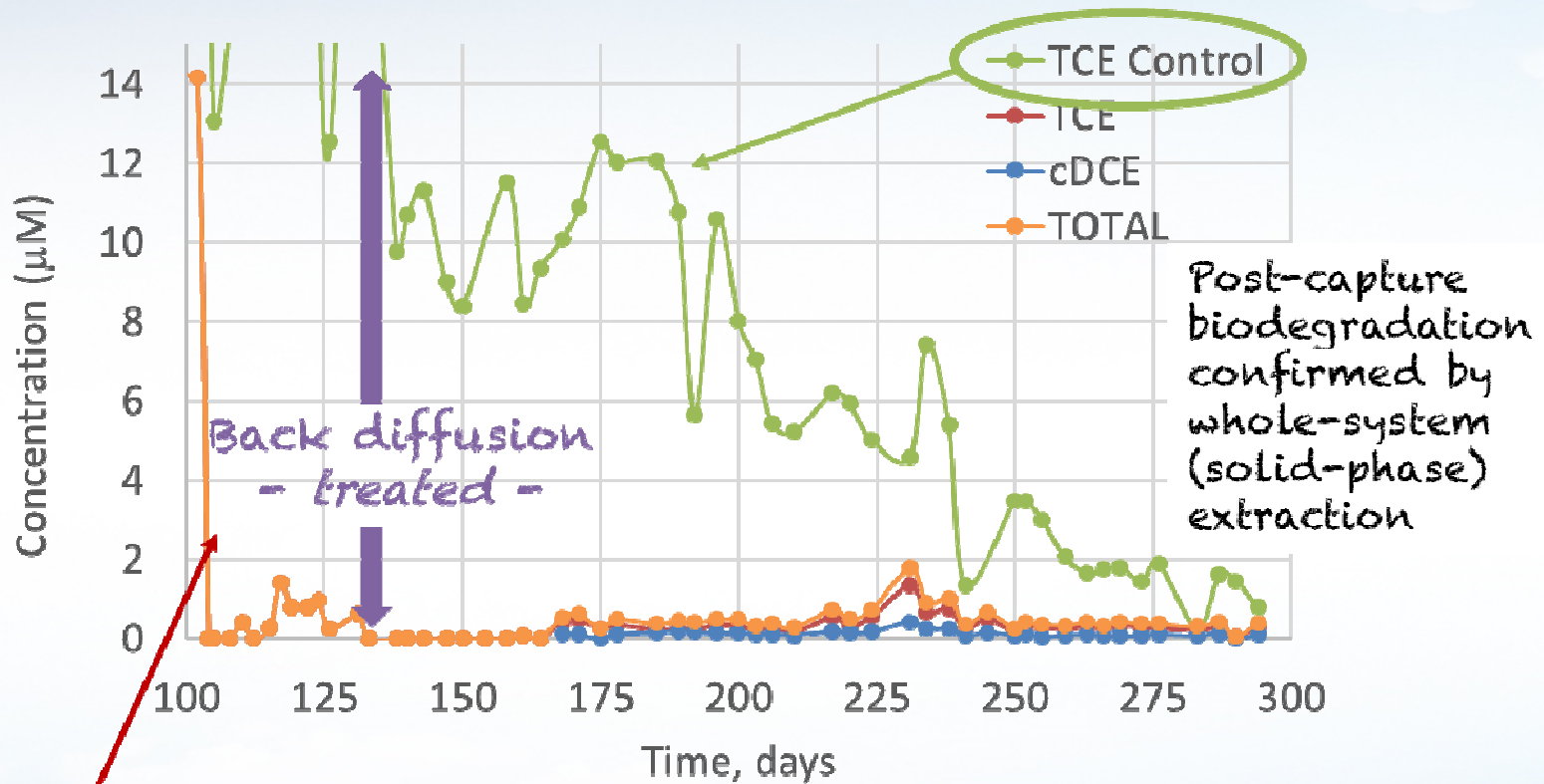


↓ = Lactate/DHC applications



↓ = PlumeStop application

Effluent Results - PlumeStop



PLUME STOP
Liquid Activated Carbon

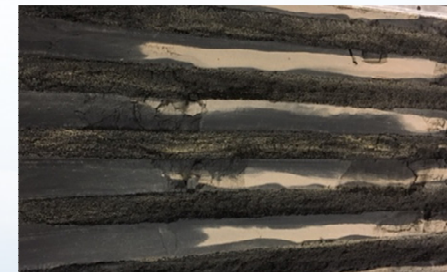
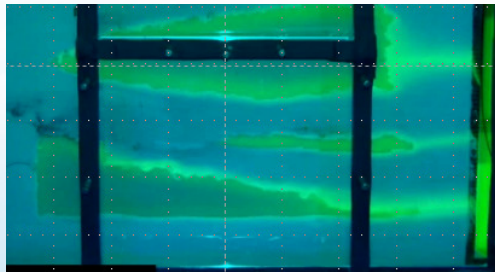
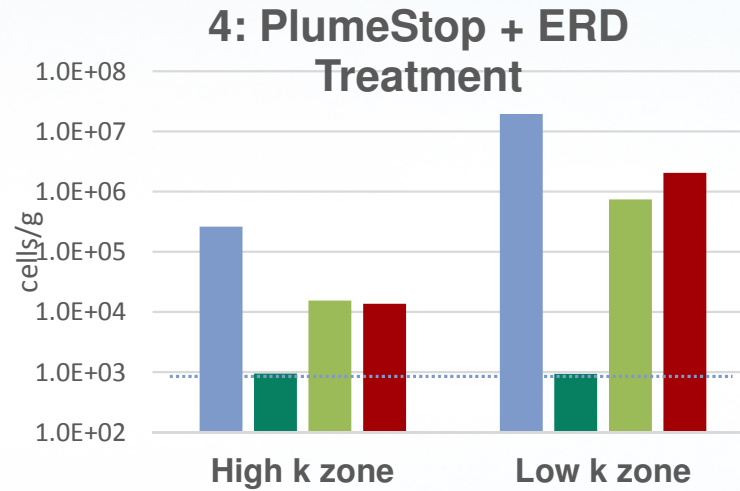
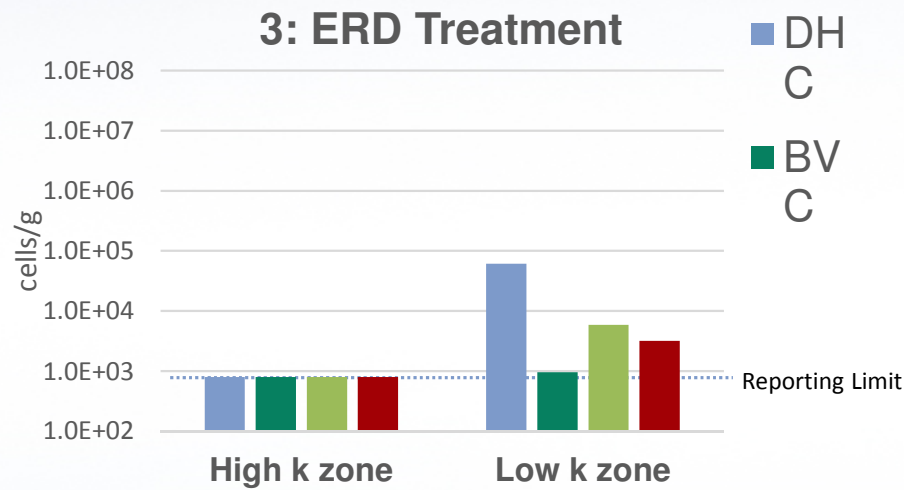
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Microbial Mass - Tank 3 (Donor) & Tank 4 (PlumeStop & Donor)

Over two orders of magnitude DHC population increases in presence of PlumeStop

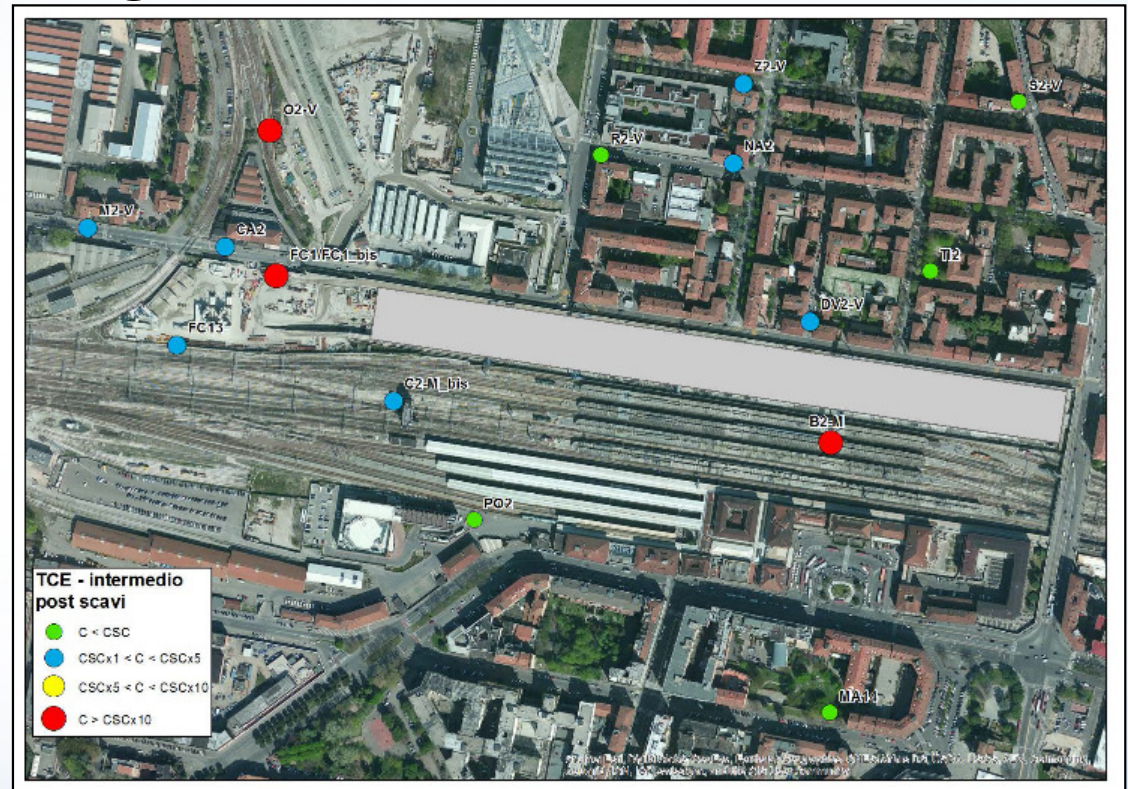


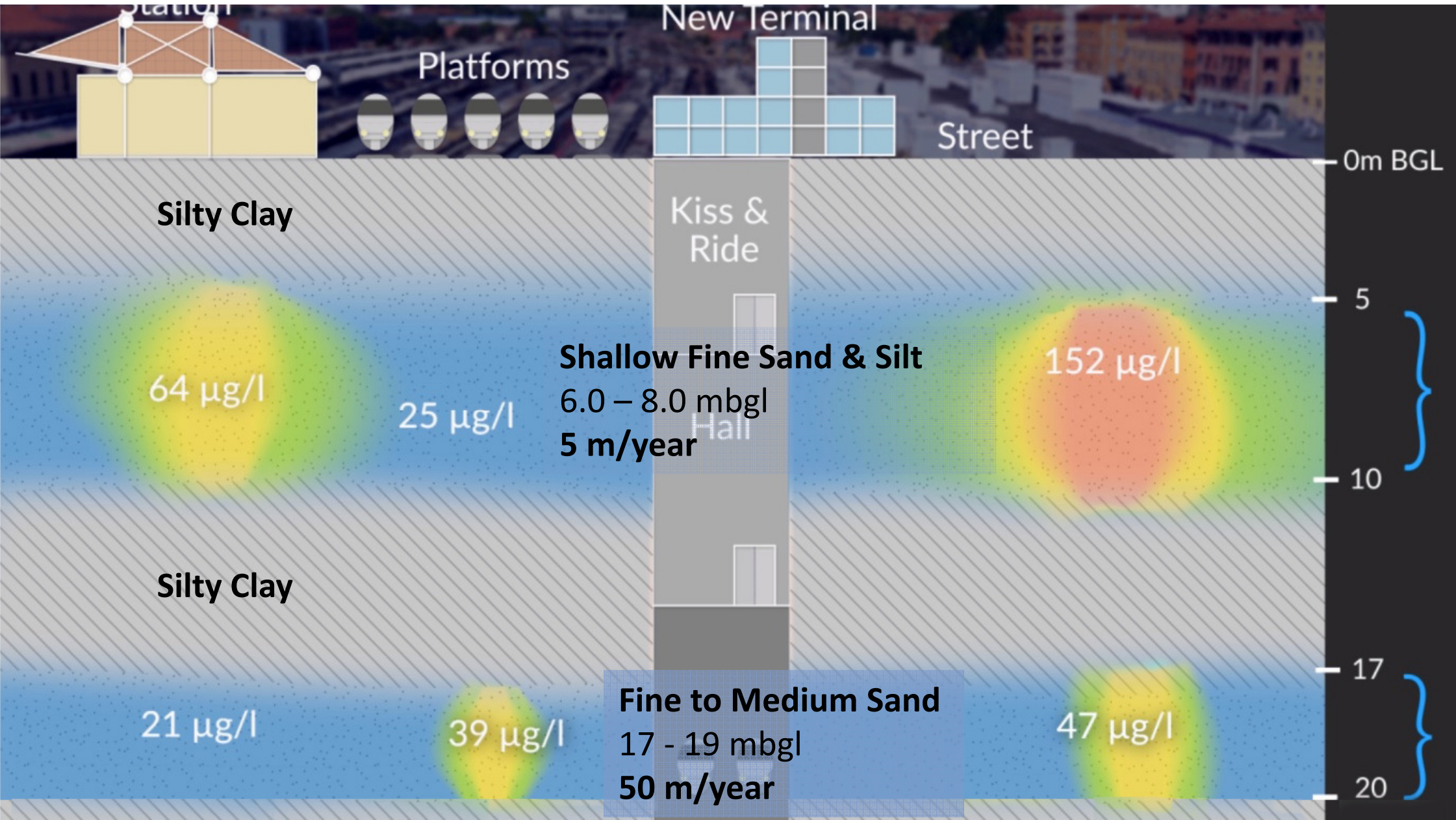


Case Study Focus – Bologna Train Station

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- Widespread CHC plume under train station
- Low concentrations; approx. 100ug/L
- Complex alluvial formation
 - Shallow Fine Sand + Silt
 - Low seepage velocity
 - Silty clay aquatard
 - Deeper Fine to Med Sand
 - High seepage velocity
- PlumeStop with HRC
- Hot Spot treatment
- Second phase





Silty Clay

64 $\mu\text{g/l}$

Silty Clay

21 $\mu\text{g/l}$

25 $\mu\text{g/l}$

Shallow Fine Sand & Silt
6.0 – 8.0 mbgl
5 m/year

152 $\mu\text{g/l}$

Fine to Medium Sand
17 - 19 mbgl
50 m/year

39 $\mu\text{g/l}$

47 $\mu\text{g/l}$

0m BGL

5

10

17

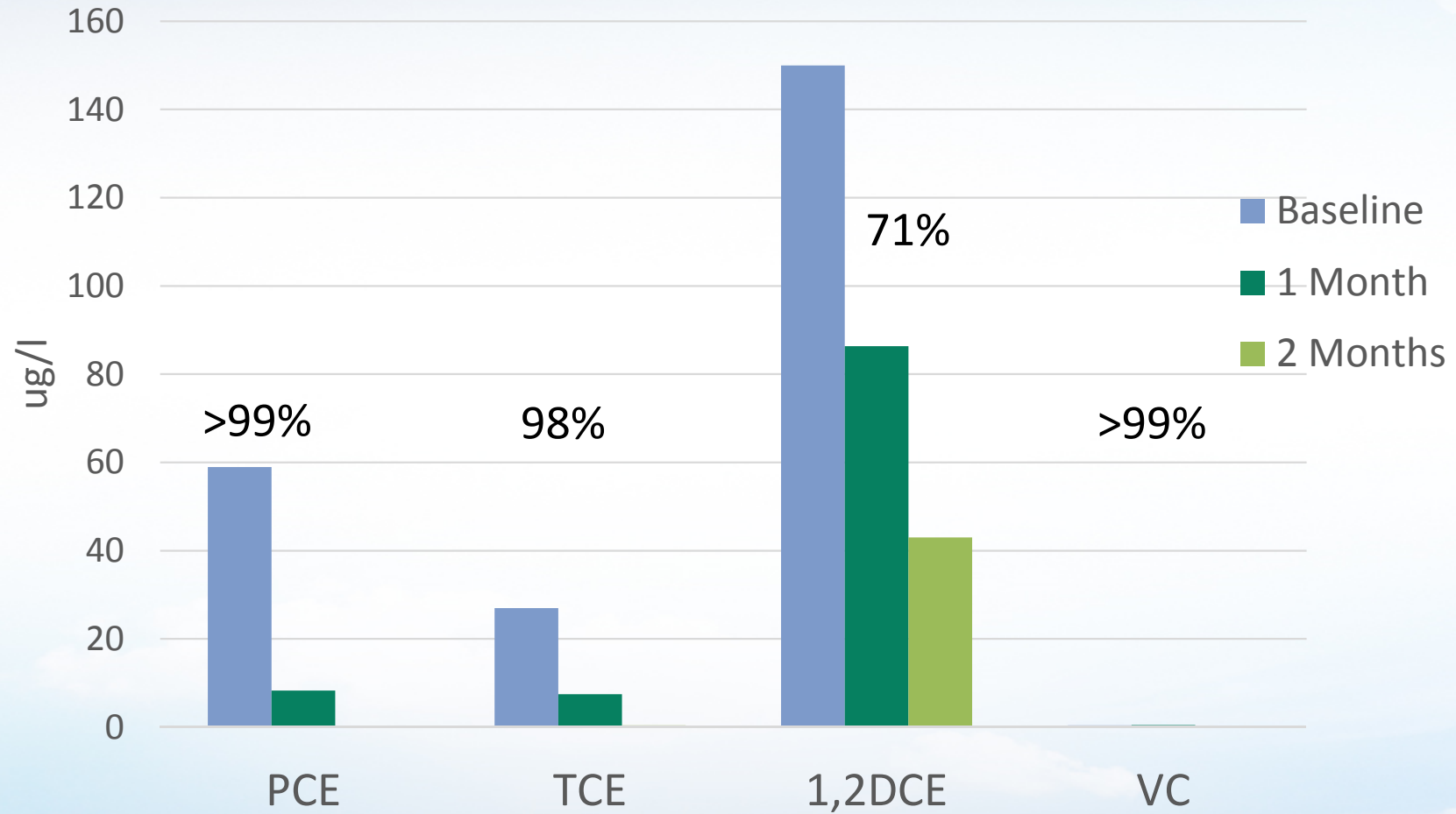
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Case Study Focus – Treatment Areas



Bologna Train Station – Initial Results

Mean Chlorinated Ethene Concentrations in Area OV



Long term results...

Fig. 8, Area 1 average CHC concentrations over time (superficial aquifer treatment)

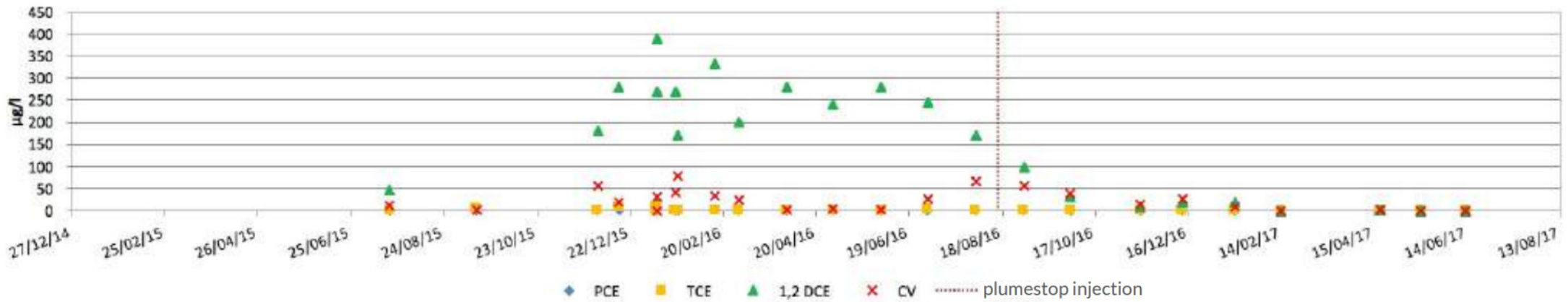
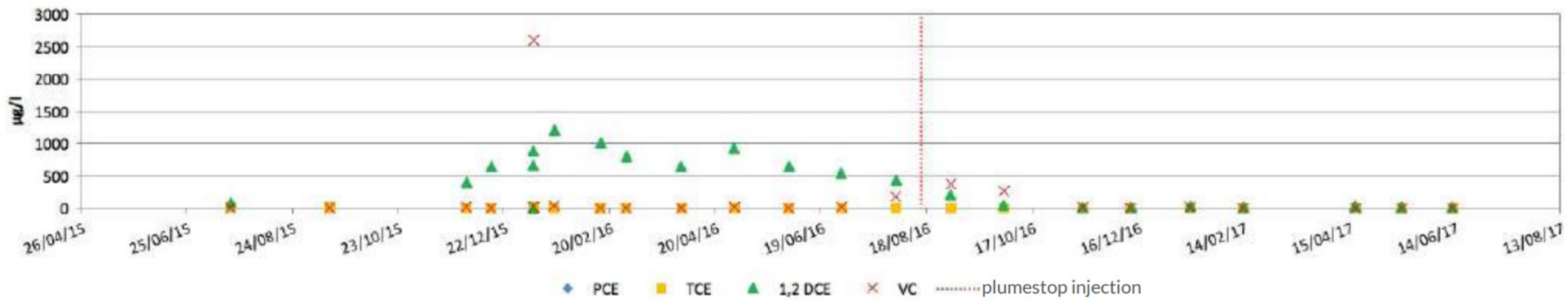


Fig. 9, Area 1 average CHC concentrations over time (deeper aquifer treatment)





But is that typical?

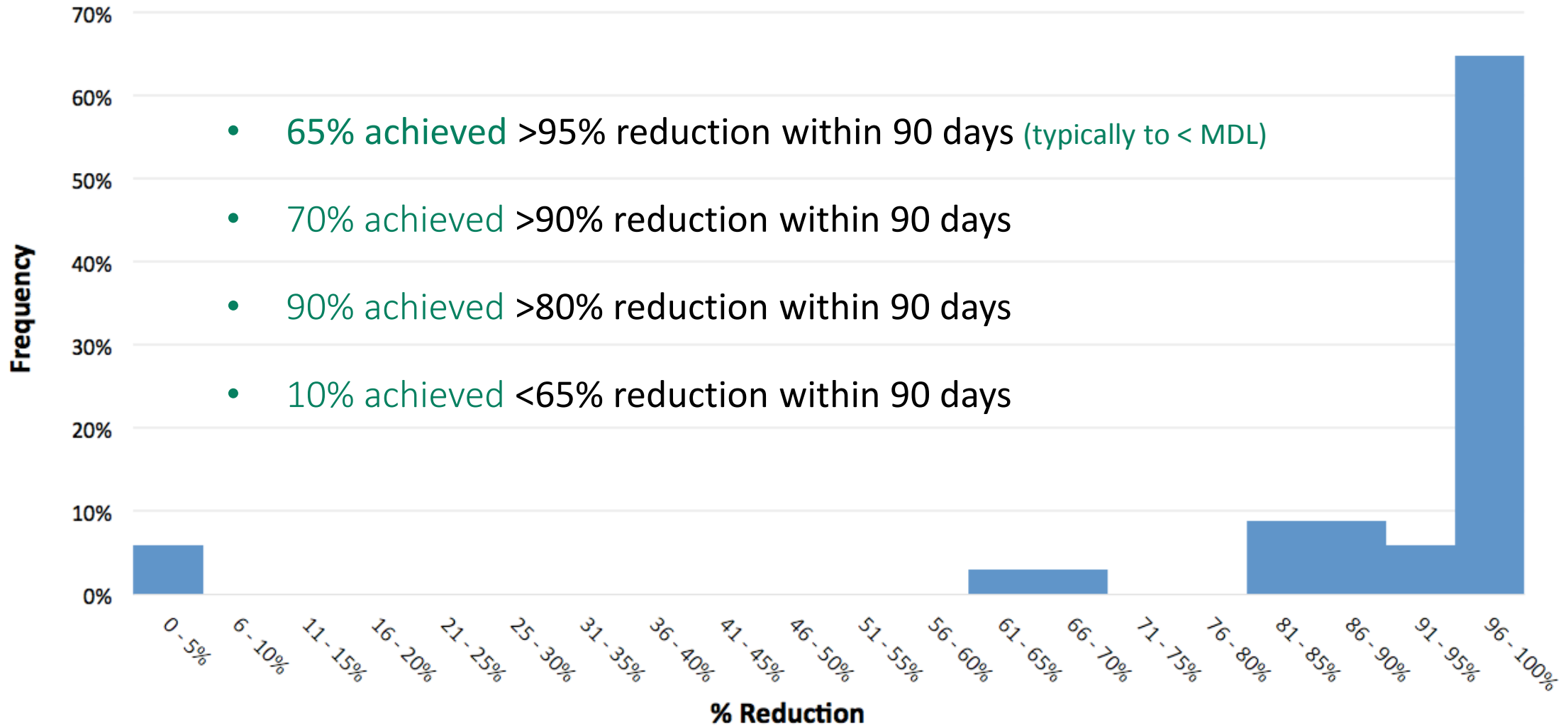
Project	Well	Months:								Accepted	Rejected	Latest	Latest (days)	Advection days	1° Comp.	Notes:	JB Verdict	Reason
		1 30	2 60	3 90	4 120	5 150	6 180	9 270	12 365									
5	DoD50427	MW-6R							97%	-	87%	352	8	BTEX	SB-231	Accept		
6	ToH52185	MW-4	58%		67%				-	67%	67%	80	2	CIS-1,2-DCE	upstream of the area / in border of injection zone / little injection wells involved?	Reject	Upgradient.	
		MW-5	87%		88%				88%	-	88%	80	4	CIS-1,2-DCE	central to injection array / in border of injection zone	Accept	Central to injection zone.	
		MW-7	96%		96%				96%	-	96%	80	2	PCE	central to injection array / in border of injection zone	Accept	Central to injection zone.	
7	DaP51392	MW-7	64%	46%	47%				47%	-	82%	213	2	TCE	central and between two injections lines, close of each one (< 16 ft)	Accept	DG / central of first injection line.	
		MW-8	98%	97%	95%				95%	-	92%	213	2	PCE	within injection array but decentred, between two injections lines, close of each one (< 14 ft)	Accept	DG / central of first injection line.	
		MW-8DR	-5%	0%	0%					-	0%	0%	79	2	(clean)	within injection array but decentred, between two injections lines, close of each one (< 16 ft)	Reject	Clean to start with. Deeper formation
		MW-12	0%	0%	0%				-	0%	0%	79	2	(clean)	within injection array but decentred, between two injections lines, close of each one (< 16 ft)	Reject	Clean to start with.	
		MW-18	0%	29%	29%				-	29%	29%	79	?	TCE	Well MW-18 no located	Reject	Not on map	
		MW-18C	0%	0%	0%				-	0%	0%	79	42	PCE	decentred / out of injection array / downstream of the two injection lines / far	Reject	Not on map	
		MW-19	93%	93%	95%				95%	-	95%	-153	2	TCE	central / out of injection array / downstream of the two injection lines / close	Accept	DG / central of both injection lines.	
		MW-22	0%	0%	0%				-	0%	0%	79	?	(clean)	Well MW-22 no located	Reject	Not on map	
		MW-22C	20%	20%	-712%			44%		-712%	44%	213	?	PCE	Well MW-22C no located	Reject	Not on map	
		MW-24	87%	87%	84%				84%	-	84%	79	3	TCE	central / out of injection array / downstream of the two injection lines / close	Accept	DG / central of both injection lines.	
8	ToH50766	MW-10S		69%	85%	86%			-	85%	86%	114		Gasoline	Well MW-10S unlocated	Reject	Location not shown	
		MW-7D		88%	85%	68%			85%	-	68%	114	24	Gasoline	central / within array injection	Accept	Within treatment zone	
		MW-3M		66%	62%	-61%			-	62%	-61%	114	24	Gasoline	central / within array injection	Reject	PersulfOx application	
		9	DoD51265	PMW-01	100%	100%	100%			100%	-	100%	93	4	TCE	central (within array)	Accept	Pilot test well
				PMW-03	88%	78%	79%	75%			79%	-	75%	126	4	TCE	central (within array) (daughter products increasing)	Accept
		10	DoD52594	SSC-12			62%			62%	-	59%	80	100	TCE, DCE	decentred but within inject be carefull with advection years	Accept	Within south grid
				SSC-13			84%			84%	-	81%	80	100	TCE, DCE	central but out of injection array - distance estimated because very close of injection array	Accept	Peripheral but close to N grid.
				SSC-32			67%			67%	-	66%	80	1400	TCE, DCE	outside injection array	Accept	Peripheral but close to N grid.
SSC-46					97%			-	97%	87%	81		DCE	Well SSC-46 unlocated	Reject	Location not shown		
SSC-65					-1755%			-	-1755%	65%	80		TCE	Well SSC-65 unlocated	Reject	Location not shown		
11	BaP46530	MW-1		65%				65%	-	65%	66	3	DCE	outside injection array	Accept	Peripheral but close to N grid.		
								65%	-	65%	66	3	DCE	central / within injection line	Accept	Only PlumeStop monitoring well.		
12	DaP45825	MW-1	91%	91%	91%		91%	91%	91%	91%	362	21	GRPH	central (within array)	Accept	Central and only well.		
13	DoD27646	MW-5-5	-19%		-25%			-25%	-	-57%	175	61	DCE	Down-gradient of PlumeStop and 3DME?	Accept	Down-gradient of PlumeStop barrier		
		WC-1	73%		89%			89%	-	71%	175	4	PCE	PlumeStop Zone?	Accept	Upgradient/adjacent to PlumeStop zone		
14	DoD50939	MW-3		98%				98%	-	98%	61	9	TPH, BTEX	central within injection array	Accept	Accept Within Grid. All reduced		
		MW-7		98%				98%	-	98%	61	5	TPH, BTEX	decentred within injection array	Accept	Accept Within Grid. All reduced		
		MW-9		98%				98%	-	98%	61	7	TPH, BTEX	central within injection array	Accept	Accept Within Grid. All reduced		
15	ScM49964	AW3-2		97%	92%	96%		92%	-	96%	141	3	TCE	not to scale on the map / distance from injection array estimated	Accept	Used in case study		
		AW3-3		83%	79%	84%		79%	-	84%	135	15	TCE	not to scale on the map / distance from injection array estimated	Accept	Used in case study		
		MW-321-1	-3%	-70%	-27%			-27%	-	-27%	100	15	TCE	not to scale on the map / distance from injection array estimated	Accept	Rogue data. Middle of injection grid		
		MW-321-2	0%	0%	0%			-	0%	0%	100	15		not to scale on the map / distance from injection array estimated	Reject	Clean to start with		
		MW-321-3	0%	0%	0%			-	0%	0%	100	61		not to scale on the map / distance from injection array estimated	Reject	Clean to start with		
16	DaP51157	PMW-1	99.24%		100%		99.9%	99.6%	100%	-	100%	257	9	PCE	central and within the line injection / downstram of the main injection array	Accept	In grid	
		PMW-2	98%		99%		98.4%	96.2%	99%	-	96%	257	21	TCE	decentred and within the line injection / downstram of the main injection array	Accept	In grid	
17	BaP44216	MW-016			85%			85%	-	85%	82	1	PAH	central and within injection array	Accept	Baseline >300 days, but it's still all well		
				96%	96%	96%		91%	89%	90%	91%	-	74%	738	PCE	Central within injection array	Accept	Beta test well
20	BaP48883	MW-18	92%	93%	89%		94%	94%	89%	-	68%	465	12	TCA	central within injection array	Accept	Data increasingly dominated by chlor	
21	BaP40759	BL-55-II	99%	99%		94%	97%	94%	-	97%	198	3	TCE	Distance from injection array estimated	Accept	In test array		
		BL-59-II	100%	100%		100%	100%	100%	-	100%	198	3	TCE	BL-59-II is downstream of BL-55-II (420 ft)	Accept	In test array		
22	DrB52004	MW-4R	41%		65%			65%	-	65%	84	10	PCE	DG of barrier - slow advection - impact increasing over time - distance estimated	Accept	Immediately down-gradient of barrier		
		MW-24S	100%		100%			-	100%	100%	84	61	PCE	Distance from injection array estimated, but further DG than MW-4R	Reject	DG of barrier, but not within advection		
24	ScM50091	DW-12			98%		93%	96%	98%	-	97%	443	13	PCE	central / out of / downstream injection array	Accept	In injection zone	
		DW-13			95%		97%	97%	95%	-	97%	259	13	PCE	central within injection array	Accept	In injection zone	
		DW-15			99%		100%	100%	99%	-	100%	443	15	PCE	central within injection array	Accept	In injection zone	

Project	Well	Months:								Accepted	Rejected	Latest	Latest (days)	Advection days	1 ^o Comp.	Notes:	JB Verdict	Reason
		1 30	2 60	3 90	4 120	5 150	6 180	9 270	12 365									
5	DoD50427									97%	-	87%	352	8	BTEX	SB-231	Accept	
6	ToH52185									97%	67%	67%	80	2	CIS-1,2-DCE	upstream of the area / in border of injection zone / little injection wells involved?	Reject	Upgradient.
	MW-4	58%		67%						-	67%	67%	80	2	CIS-1,2-DCE	central to injection array / in border of injection zone	Accept	Central to injection zone.
	MW-5	91%		96%						88%	-	88%	80	4	PCE	central to injection array / in border of injection zone	Accept	Central to injection zone.
7	DaP51392									95%	-	82%	213	2	TCE	central and between two injections lines, close of each one (< 16 ft)	Accept	DG / central of first injection line.
	MW-7	64%	46%	77%						95%	-	92%	213	2	PCE	within injection array but decentred, between two injections lines, close of each one (< 14 ft)	Accept	DG / central of first injection line.
	MW-8	98%	97%	95%						92%	-	0%	79	2	(clean)	within injection array but decentred, between two injections lines, close of each one (< 16 ft)	Reject	Clean to start with. Deeper formation
	MW-8DR	-5%	0%	0%						-	0%	0%	79	2	(clean)	within injection array but decentred, between two injections lines, close of each one (< 16 ft)	Reject	Clean to start with.
	MW-12	0%	0%	0%						-	0%	0%	79	2	(clean)	within injection array but decentred, between two injections lines, close of each one (< 16 ft)	Reject	Clean to start with.
	MW-18	0%	29%	29%						-	29%	29%	79	?	TCE	Well MW-18 no located	Reject	Not on map
	MW-18C	0%	0%	0%						-	0%	0%	79	42	PCE	decentred / out of injection array / downstream of the two injection lines / far	Reject	Not on map
	MW-19	93%	93%	95%						95%	-	95%	-153	2	TCE	central / out of injection array / downstream of the two injection lines / close	Accept	DG / central of both injection lines.
	MW-22	0%	0%	0%						-	0%	0%	79	?	(clean)	Well MW-22 no located	Reject	Not on map
	MW-22C	20%	20%	-712%			44%			-	-712%	44%	113	?	PCE	Well MW-22C no located	Reject	Not on map
8	ToH50766									85%	-	86%	114	24	Gasoline	central / within array injection	Reject	Per BuilOx application
	MW-10S		69%	85%	86%					-	85%	86%	114	24	Gasoline	central / within array injection	Accept	Within treatment zone
	MW-7D		88%	85%	68%					85%	-	68%	114	24	Gasoline	central / within array injection	Reject	Per BuilOx application
	MW-3M		66%	62%	61%					-	62%	61%	114	24	Gasoline	central / within array injection	Accept	Per BuilOx application
	PMW-01	100%	100%	100%						100%	-	100%	114	24	TCE	central / within array injection	Accept	In test well
	PMW-03	98%	78%	91%	76%					75%	-	76%	114	24	TCE	central / within array injection	Accept	In test well
	SSC-12			62%						62%	-	59%	80	100	TCE, DCE	decentred but within injec be careful with advection years	Accept	Within south grid
	SSC-13			84%						84%	-	81%	80	100	TCE, DCE	central but out of injection array / distance estimated because very close of injection array	Accept	Peripheral but close to N grid.
9	DoD5126									91%	-	81%	80	100	TCE, DCE	outside (between) of the two injection lines	Accept	Peripheral but close to N grid.
	SSC-32			91%					91%	-	81%	80	100	TCE, DCE	Well SSC-32 unlocated	Reject	Location not shown	
	SSC-46			91%					91%	-	81%	80	100	TCE, DCE	Well SSC-46 unlocated	Reject	Location not shown	
	SSC-65			-1755%					-	-1755%	-	65%	80	TCE	Well SSC-65 unlocated	Reject	Location not shown	
	SSC-114			95%					95%	-	95%	81	3200	TCE	outside injection array	Accept	Peripheral but close to N grid.	
11	BaP46530		65%						65%	-	65%	66	3	DCE	central / within injection line	Accept	Only PlumeStop monitoring well.	
	DaP45825		91%	91%	91%		91%	91%	91%	-	91%	362	21	GRPH	central (within array)	Accept	Central and only well.	
13	DoD27646									-25%	-	-57%	175	61	DCE	Down-gradient of PlumeStop and 30ME7	Accept	Down-gradient of PlumeStop barrier
	WC-1		19%	25%					73%	-	73%	175	61	DCE	PlumeStop barrier	Accept	Upgradient/adjacent to PlumeStop zone	
14	DoD50939									98%	-	98%	61	5	TPH, BTEX	central within injection array	Accept	Accept Within Grid. All reduced
	MW-3		98%						98%	-	98%	61	5	TPH, BTEX	decentred within injection array	Accept	Accept Within Grid. All reduced	
	MW-7		98%						98%	-	98%	61	7	TPH, BTEX	central within injection array	Accept	Accept Within Grid. All reduced	
15	ScM49964									92%	-	96%	141	3	TCE	not to scale on the map / distance from injection array estimated	Accept	Used in case study
	AW3-2		97%	92%	96%				92%	-	84%	135	15	TCE	not to scale on the map / distance from injection array estimated	Accept	Used in case study	
	AW3-3		83%	79%	84%				79%	-	84%	135	15	TCE	not to scale on the map / distance from injection array estimated	Accept	Used in case study	
	MW-321-1		-3%	-70%	-27%				-27%	-	-27%	100	15	TCE	not to scale on the map / distance from injection array estimated	Accept	Rogue data. Middle of injection grid	
	MW-321-2		0%	0%	0%				0%	-	0%	100	15	TCE	not to scale on the map / distance from injection array estimated	Reject	Clean to start with	
16	DaP51157									99%	-	99%	257	9	PCE	central and within the line injection / downstram of the main injection array	Accept	In grid
	PMW-1	99.24%		100%		99.9%	99.6%		100%	-	100%	257	21	TCE	decentred and within the line injection / downstram of the main injection array	Accept	In grid	
	PMW-2	98%		99%		99%	96.2%		99%	-	99%	257	21	TCE	decentred and within the line injection / downstram of the main injection array	Accept	In grid	
	PMW-3	-71.41%		-108%		-17.4%	-45.5%		-	-108%	-46%	257	24	PCE	central / out of / downstream of the line injection	Reject	Outside treatment zone	
17	BaP44216									85%	-	85%	82	1	PAH	central and within injection array	Accept	Baseline >300 days, but it's still all well
	MW1		96%	96%		91%	89%	90%	91%	-	74%	738	15	PCE	central within injection array	Accept	Beta test well	
20	BaP48883									92%	-	92%	45	3	TCE	central within injection array	Accept	Data increasingly dominated by chlor
	BaP40759									99%	-	99%	128	3	TCE	Distance from injection array estimated	Accept	In test array
21	BaP40759									99%	-	99%	128	3	TCE	Distance from injection array estimated	Accept	In test array
	BL-59-II		100%	100%	100%				100%	-	100%	198	3	TCE	BL-59-II is downstream of BL-55-II (420 ft)	Accept	In test array	
22	DrB52004									41%	65%	65%	84	10	PCE	DG of barrier - slow advection - impact increasing over time - distance estimated	Accept	Immediately down-gradient of barrier
	MW-24S		100%	100%					-	100%	100%	84	61	PCE	Distance from injection array estimated, but further DG than MW-4R	Reject	DG of barrier, but not within advective	
24	ScM50091									98%	-	97%	443	13	PCE	central / out of / downstream injection array	Accept	In injection zone
	DW-12			98%		93%		96%	95%	-	97%	259	13	PCE	central within injection array	Accept	In injection zone	
	DW-13			95%		97%		97%	95%	-	97%	259	13	PCE	central within injection array	Accept	In injection zone	
	DW-15			99%		100%		100%	99%	-	100%	443	15	PCE	central within injection array	Accept	In injection zone	

Multi-Site Data Review

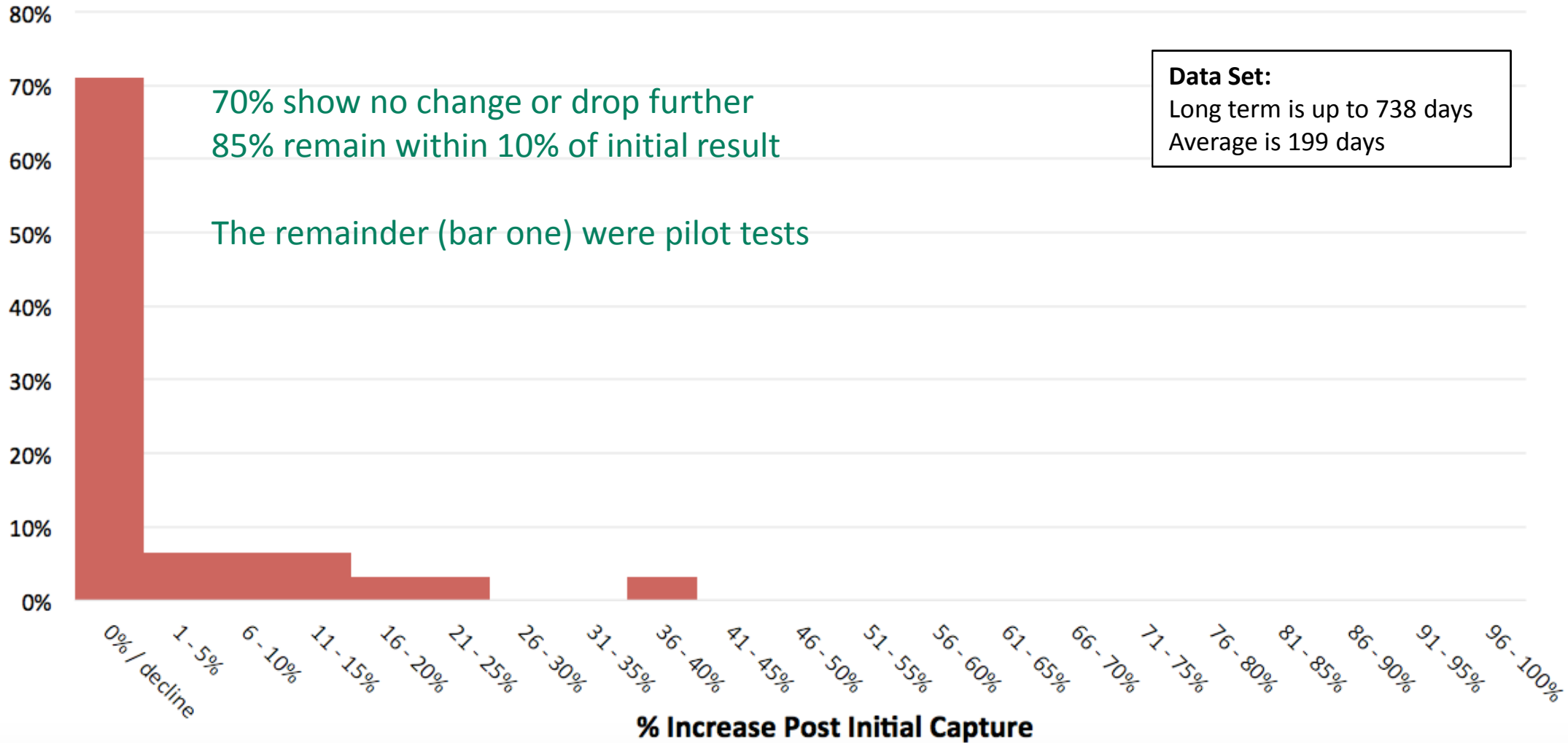
- All available site performance data pooled – 34 sites
- Wells within expected zone of impact highlighted and assessed – i.e. those wells within treatment grid and/or advective distance
- Total contaminant reductions monitored over time
- Performance histograms created – full data set
- Initial reduction
- Stability (rebound – or lack thereof) to date

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

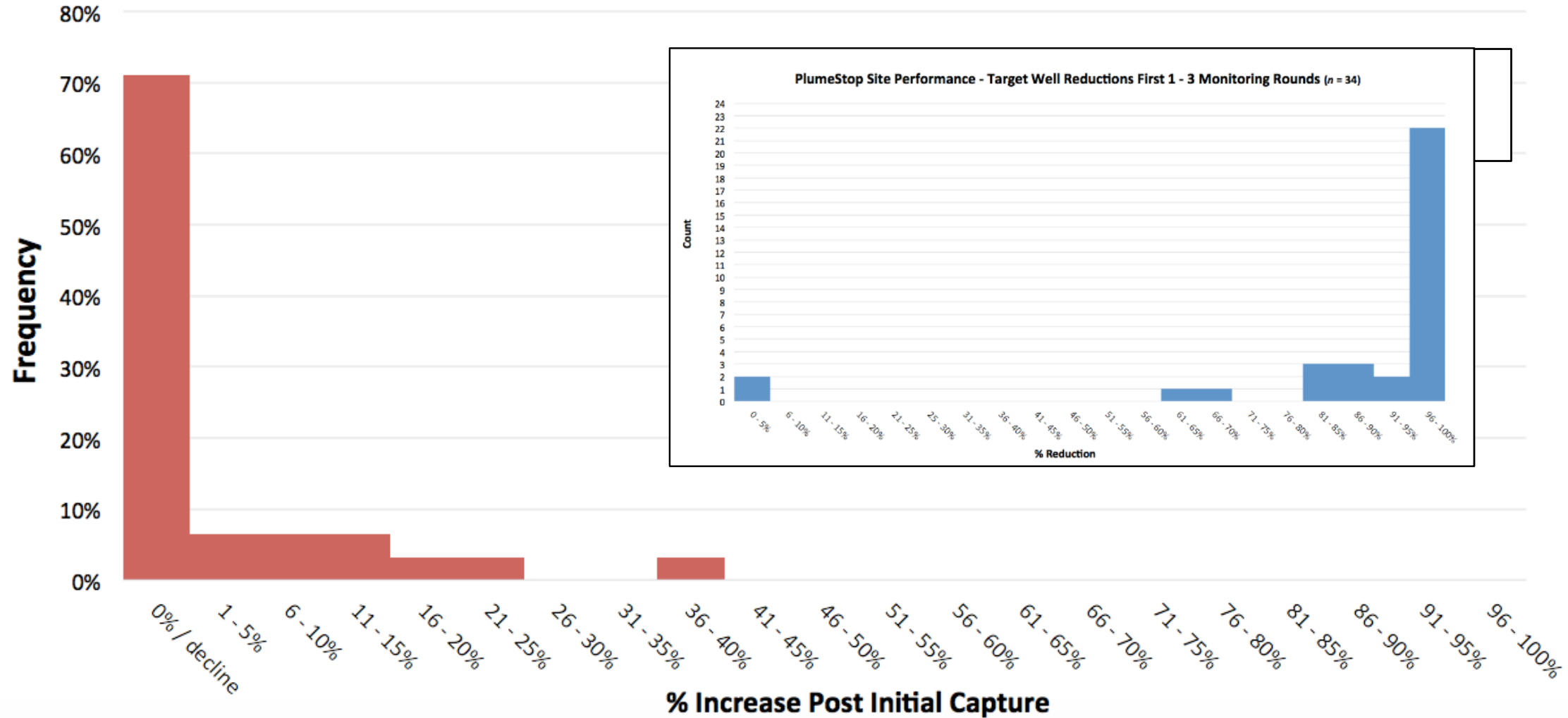


- 65% achieved >95% reduction within 90 days (typically to < MDL)
- 70% achieved >90% reduction within 90 days
- 90% achieved >80% reduction within 90 days
- 10% achieved <65% reduction within 90 days

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

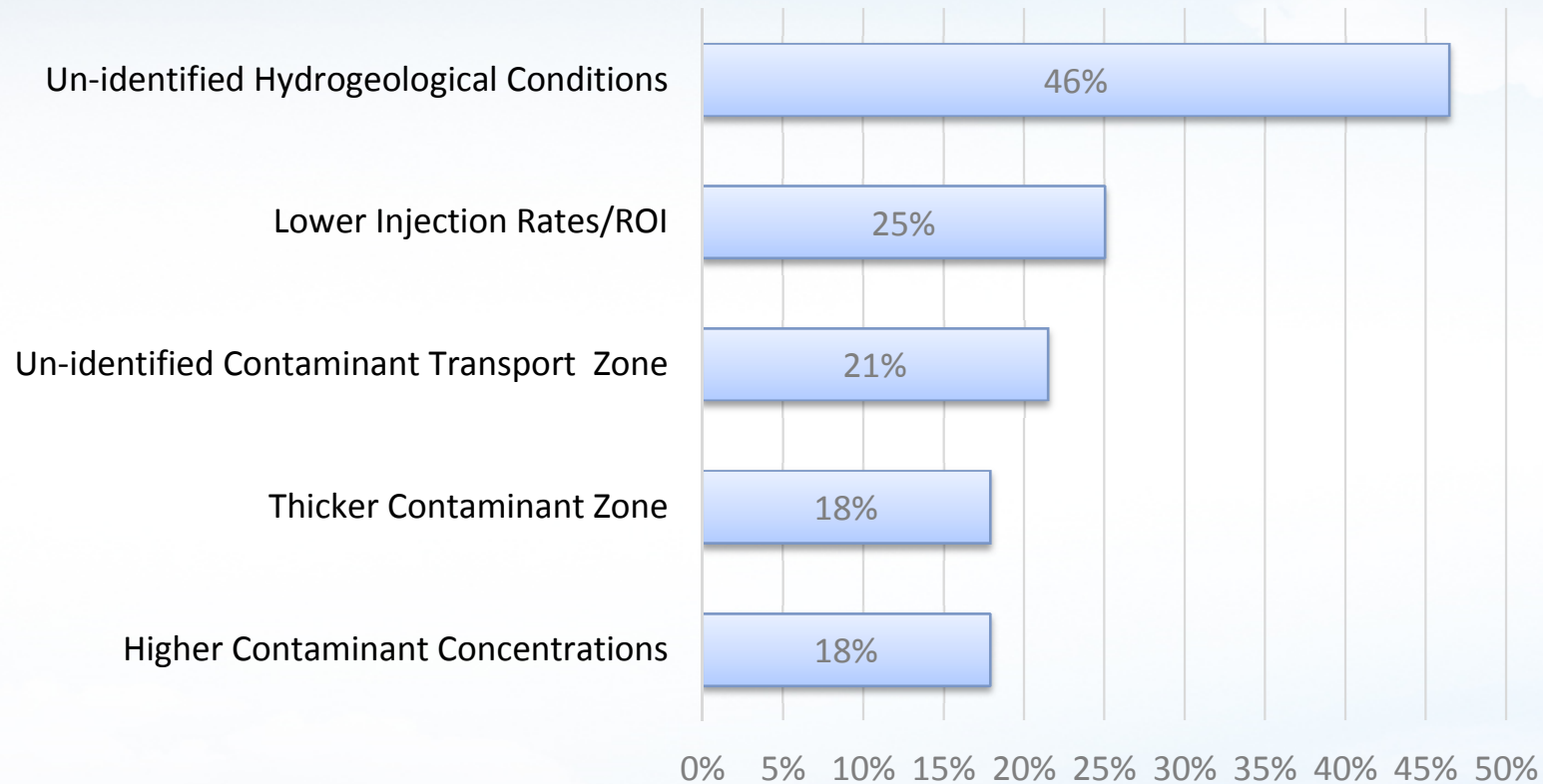


PlumeStop Long Term Performance - April 2016 (n = 31)



Pilot Trials – Technical Blind Spots

- 80% of tests to date have found unanticipated results (technical blind spots)
- $\frac{1}{3}$ of preliminary designs have been modified / refined
- Design changes generally have been cost-neutral





Working with you

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To achieve the best in-situ
remediation solution for
your site.