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International Symposium on Bioremediation and Sustainable Environmental Technologies

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Adjusting Amendment Delivery Vertically and Horizontally Based on Targeted Compounds – *Translating Assumptions to Field Implementation*

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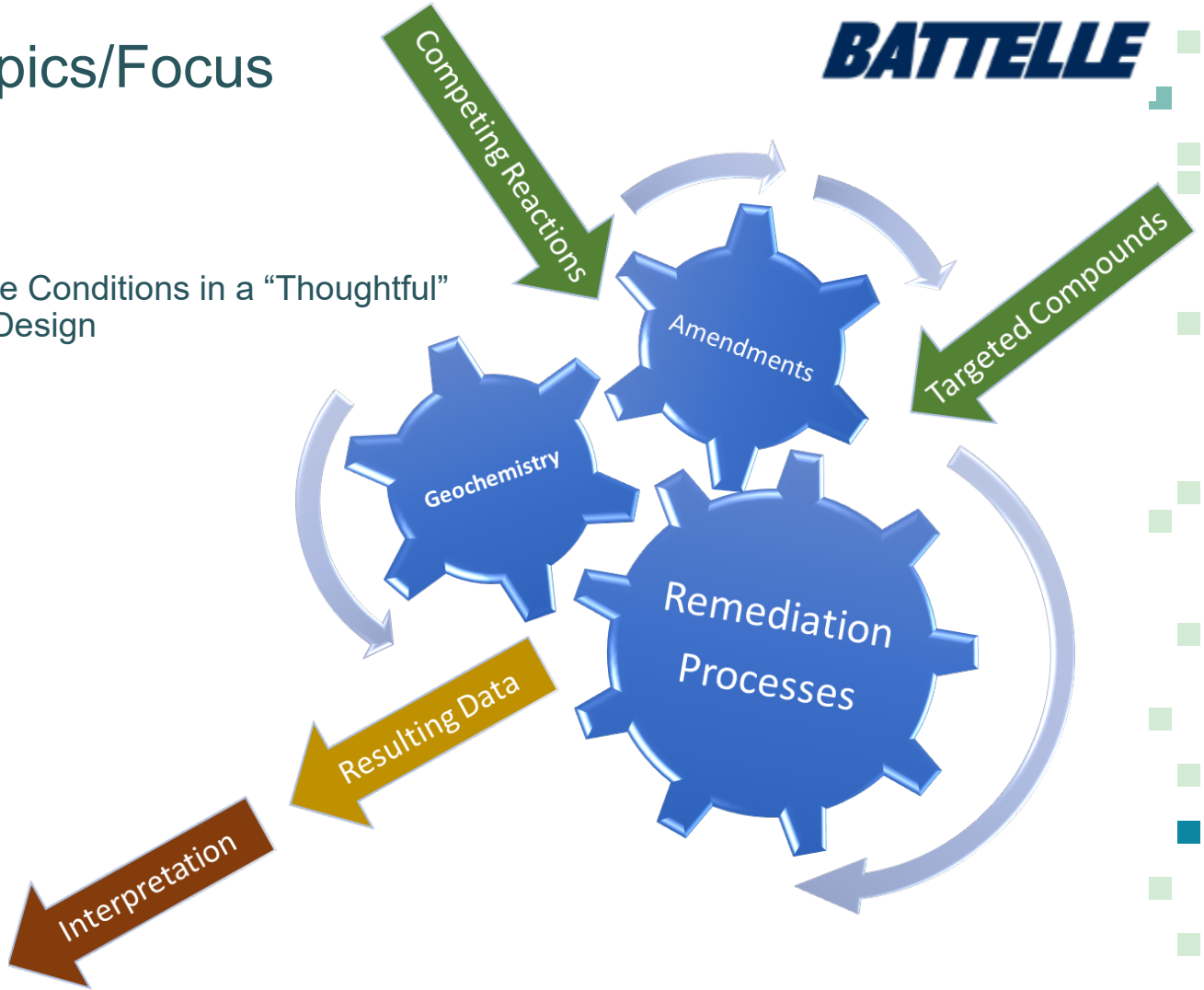
Outline Topics/Focus

- Amendments
- Geology
- Geochemistry
- Integrating Site Conditions in a “Thoughtful” Remediation Design



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Amendments
Treatment of CVOCs

- Zero Valent Iron
- Organic Hydrogen Donors
- Essential Nutrients
- Micro Nutrients
- EZVI

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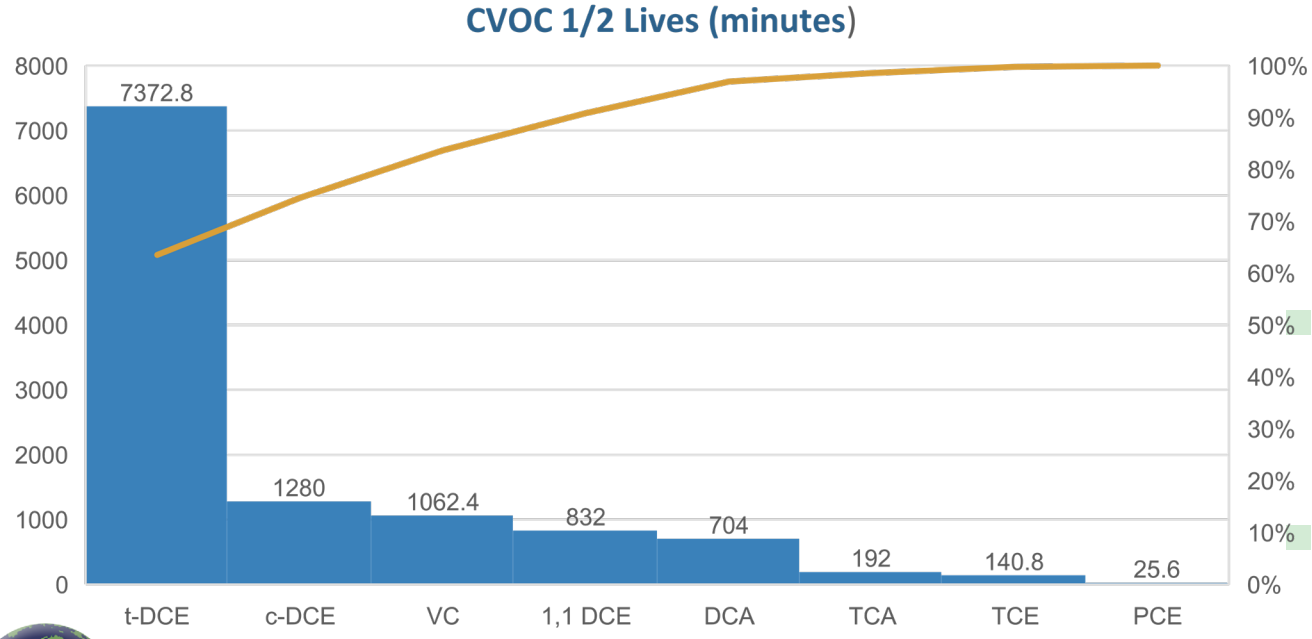
Zero Valent Iron



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Zero Valent Iron

VS.

Diameter (microns)	Surface Area (FT^2/lb)	$/Lb	$/1,000 Ft^2
1	18695.12315	9.5	0.508154
2	9346.37759	8	0.855947
3	6232.49704	7	1.123145
4	4674.37278	6.5	1.390561
5	3739.02463	6.25	1.671559
25	748.27852	3.25	4.343303
50	374.13926	2.35	6.281084
100	187.06963	1.25	6.682004
200	92.35083	0.75	8.121205
400	47.3594	0.45	9.50181
800	23.6797	0.25	10.55757

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Organic Hydrogen Donor

Acetate	$C_2H_3O_2^- + 4H_20 \Rightarrow 2CO_2^- + 2H_2O + 4H_2$ *acetate fermentation*
Butyrate	$C_4H_7O_2^- + 2H_20 \Rightarrow 2C_2H_3O_2^- + H^+ + 2H_2$ *butyrate fermentation to acetate*
Propionate	$C_3H_5O_2^- + 3H_20 \Rightarrow C_2H_3O_2^- + CO_2^- + H_2O + 3H_2$ *propionate fermentation to acetate*
Lactate	$C_3H_5O_3^- + 2H_2O + \Rightarrow C_2H_3O_2^- + CO2^- + H_2O + 2H_2$ *lactate fermentation to acetate*

1 milligram (mg) of H_2 →

- 21 mg of PCE to ethene
- 22 mg of TCE to ethene
- 24 mg of DCE to ethene
- 31 mg of VC to ethene

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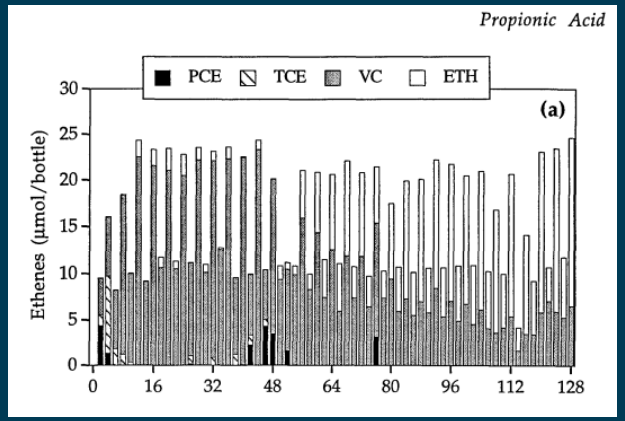
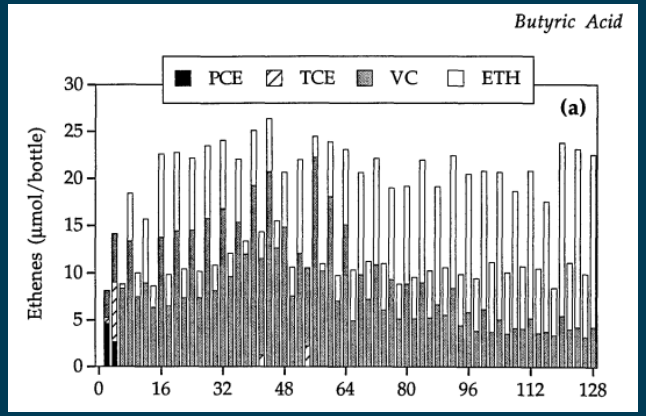
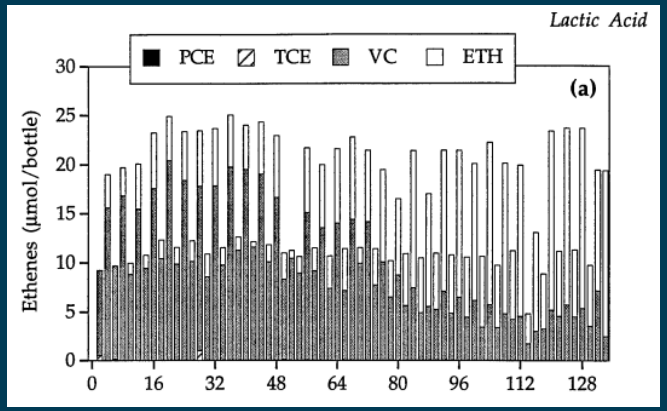
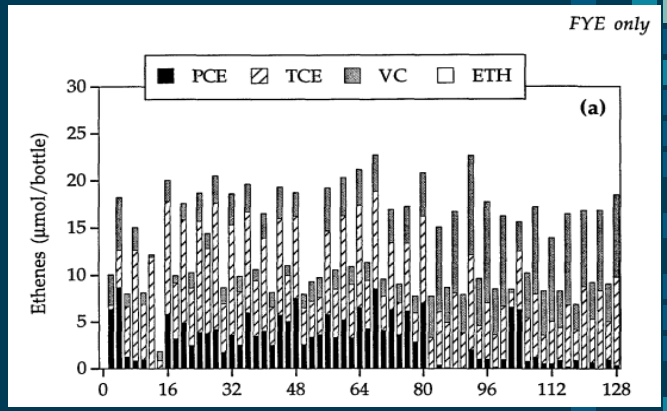
Organic Hydrogen Donor









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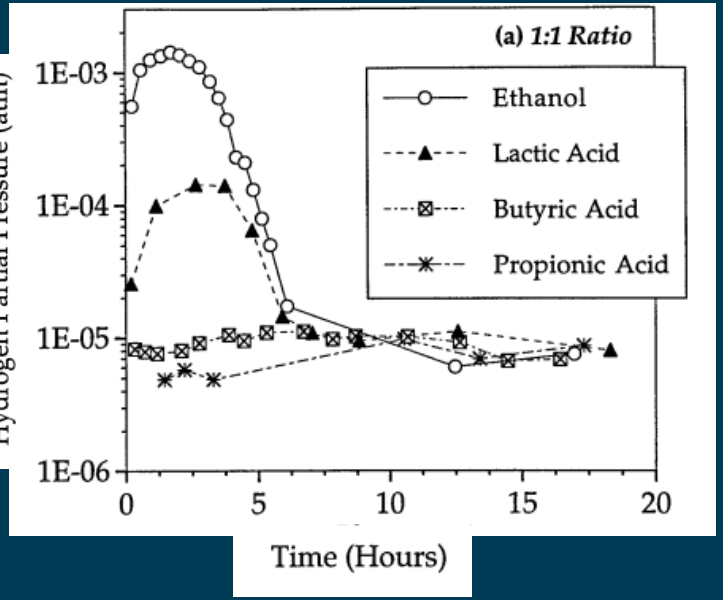
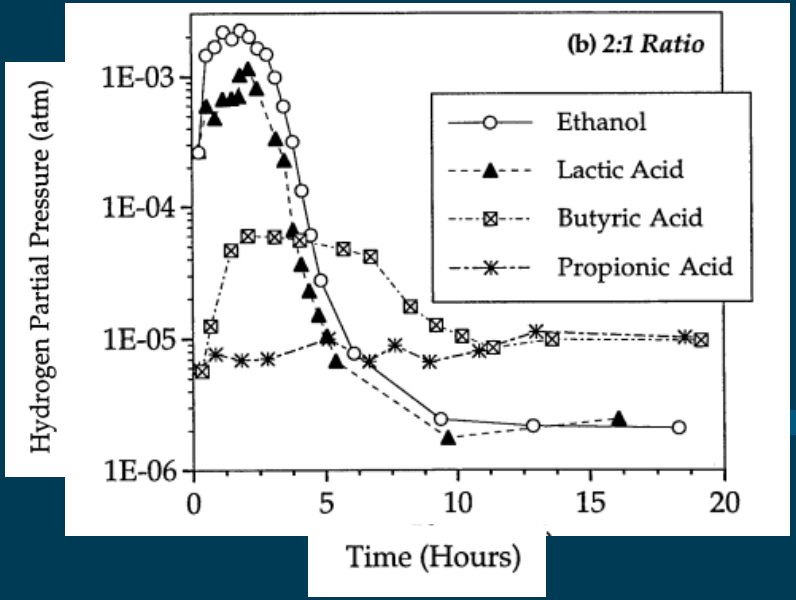
Organic Hydrogen Donor





"Sometimes less is MORE!"

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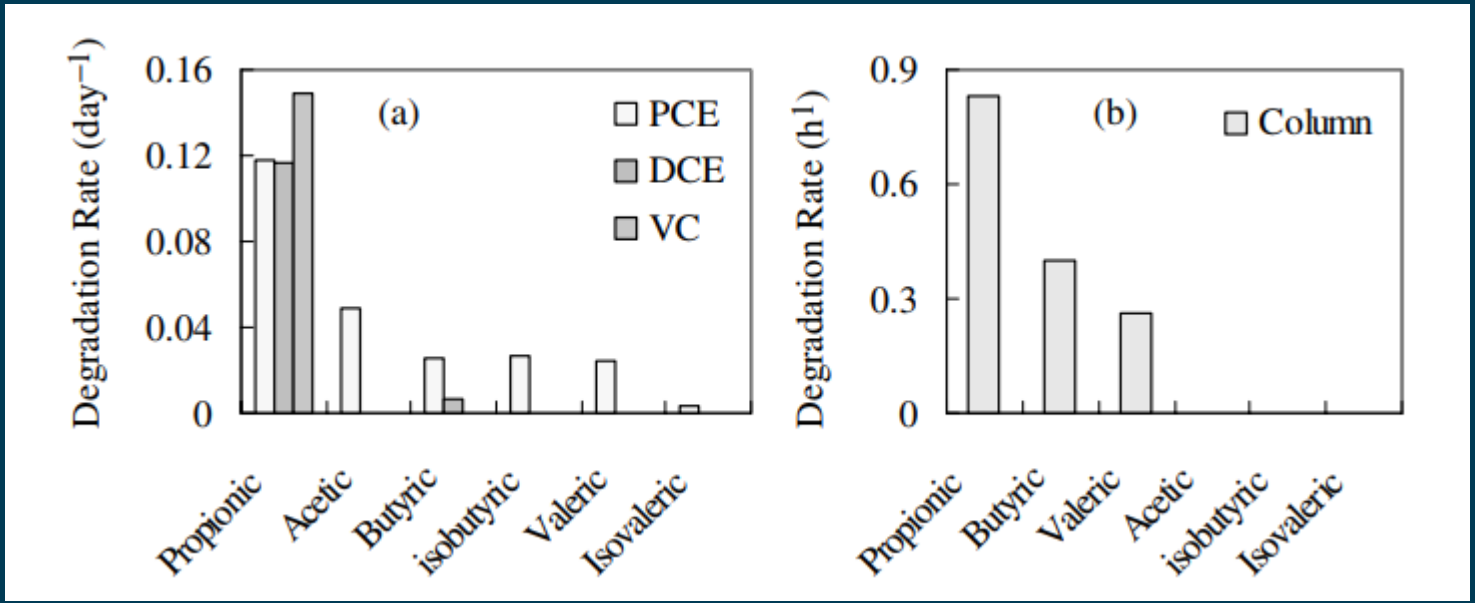
Organic Hydrogen Donor



"Sometimes less is MORE!"

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Organic Hydrogen Donor - Utilization

COMPETITION FOR EVOLVED HYDROGEN

The rate of hydrogen evolution from donor fermentation, the ultimate aqueous phase concentration that it attains, the affinity that each set of organisms has for hydrogen, and the populations of hydrogen users are the parameters that determine the rate and extent of dechlorination or hydrogenotrophic methanogenesis that occurs.

Scroll over.....

HYDROGEN

HYDROGEN

DECHLORINATION

DECHLORINATION

METHANE FROM HYDROGEN

METHANE FROM HYDROGEN

DECHLORINATOR BIOMASS

DECHLORINATOR BIOMASS

HYDROGENOTROPHIC METHANOG

HYDROGENOTROPHIC METHANOGEN BIOMASS

ACETATE

The hydrogen donors also produce acetate upon fermentation. Acetate may accummulate or be converted to methane by acetoclastic methanogens. The acetate concentration effects the thermodynamics and favorability of donor fermentation.

ACETATE

ACETATE

METHANE FROM ACETAT

METHANE FROM ACETATE

ACETOTROPHIC METHAN

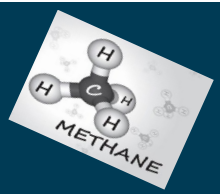
ACETOTROPHIC METHANOGEN BIOMASS

FERMENTED YEAST EXTRACT

Fermented yeast extract (FYE) is a nutritional supplement added to dechlorinating cultures to supply trace nutrients. FYE also contains acetate, propionate, butyrate, and longer-chained VFAs, and it coentributes a significant amount of extra reducing equivalents over

FERMENTED YEAST EXTRACT

FERMENTED YEAST EXTRACT



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Essential Nutrients

Under natural conditions, the aquifer may contain suitable amounts of trace nutrients for microbial growth; however, the nutritional demand imposed by rapid microbial growth in response to addition of an organic substrate may exceed the capacity of the aquifer system (Chamberlain, 2003).

In addition to the abiotic transformations, when an impacted aquifer is amended with carbon under low pH or nutrient limiting conditions the fermentable organic matter may be converted to a variety of ketones, including acetone or methyl ethyl ketone (MEK; 2-butanone).

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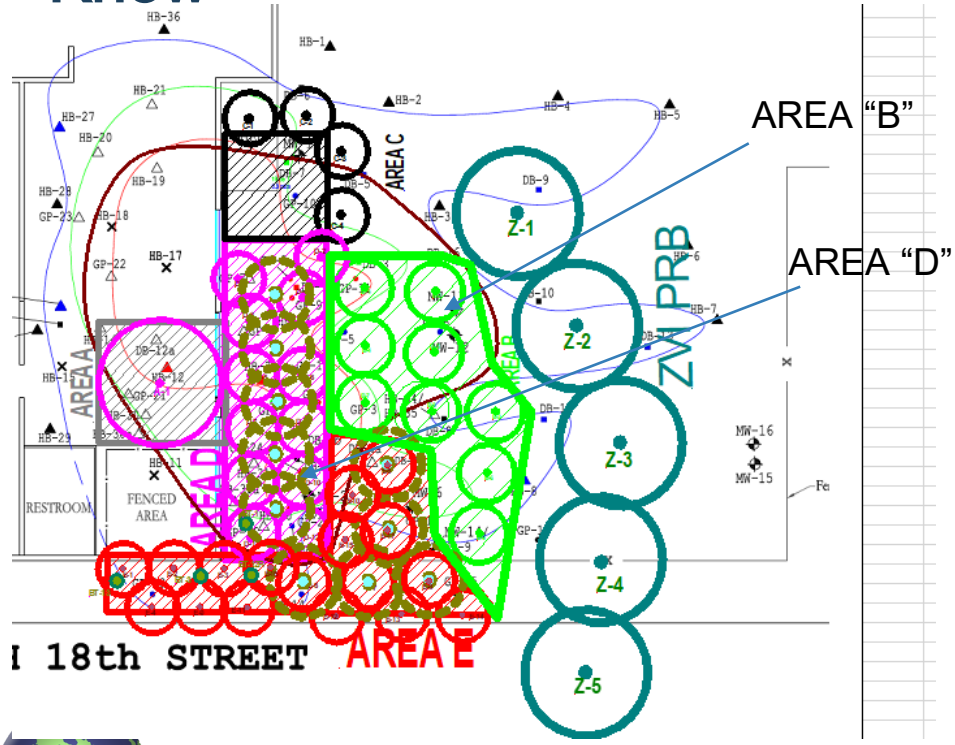
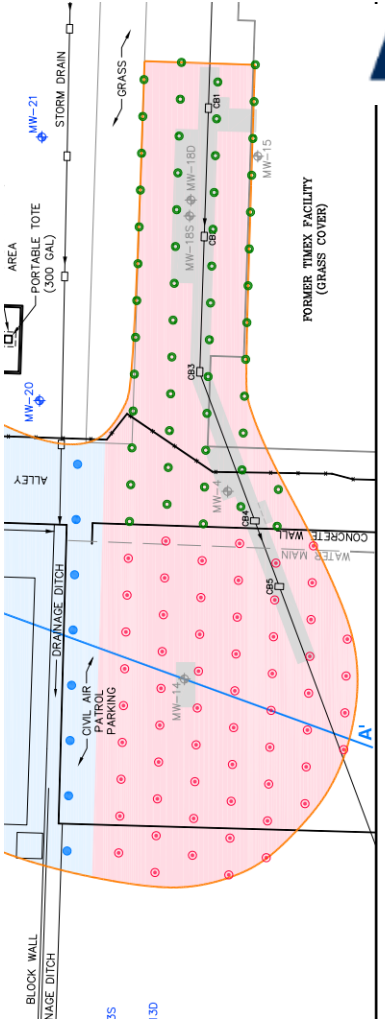
Applying What we "Know"



VS.



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Applying What we "Know"

Area "B"

Site Name		Charles Beseler		
Area B				
Parameters	Units	Assumptions		
Target Area	Ft.X Ft.	1040		
Soil Absorbsion Correction for GAC Constant	%	30		
Area of influence of Remediation Injection(s)	Sq. Ft.	95.0330975		
Estimated Number of Injections to Treat Area	# Injections	9		
vertical impacted zone	Ft.	10		
Total Volume Targeted	Cu. Yd.	385.1851852		
Porosity	%	20.00%		
Groundwater Flow Velocity	Ft/Yr	10.00		
Injection Depth	Ft - bgs	18-28		
Volatile Organic Compounds in Water				
PCE	ppb	1	0.001	ppm
TCE	ppb	37000	37	ppm
c-DCE	ppb	65000	65	ppm
t-DCE	ppb	1	0.001	ppm
1-1 DCA	ppb	1	0.001	ppm
1,1 DCE	ppb	1	0.001	ppm
VC	ppb	1000	1	ppm
			0	
Injection Parameters			0	
Anticipated Radius of Influence	Ft	5.5		

Intervals	3		
Area B			
Injection Summary:	Injection #1	Injection #2	Injection #3
Depth of Injection	18-20'	22-24'	26-28'
Grams B2/inj	33.73	33.73	33.73
Grams B12/inj	4.86	4.86	4.86
Grams RYR/inj	71.76	71.76	71.76
Pounds Yeast Extract/inj	2.00	2.00	2.00
Pounds Provectus IR/inj	25.00	25.00	25.00
Pounds of ZVI/inj	30.00	30.00	30.00
Pounds of Sulfite/inj	2.00	2.00	2.00
Pounds of Nutrient/inj	2.00	2.00	2.00
Kelp - Hydrolyzed	10.00	10.00	10.00
Propionate (Lipid)	16.67	16.67	16.67
Gallons of Sulfite/Nutrient/zvi	75.00	75.00	75.00

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Applying What we "Know"

Area "D"

Site Name		Charles Beseler		
Area D				
Parameters	Units	Assumptions		
Target Area	Ft.X Ft.	1200		
Soil Absorbsion Correction for GAC Constant	%	40		
Area of influence of Remediation Injection(s)	Sq. Ft.	95.0330975		
Estimated Number of Injections to Treat Area	# Injections	12		
vertical impacted zone	Ft.	13		
Total Volume Targeted	Cu. Yd.	577.7777778		
Porosity	%	20.00%		
Groundwater Flow Velocity	Ft/Yr	10.00		
Injection Depth	Ft - bgs	12-25		
Volatile Organic Compounds in Water				
PCE	ppb	1	0.001	ppm
TCE	ppb	10000	10	ppm
c-DCE	ppb	10000	10	ppm
t-DCE	ppb	1	0.001	ppm
1,1 DCA	ppb	50	0.05	ppm
1,1 DCE	ppb	50	0.05	ppm
VC	ppb	2000	2	ppm
			0	
Injection Parameters			0	
Anticipated Radius of Influence	Ft	5.5		

Area D				
Injection Summary:	Injection #1	Injection #2	Injection #3	Injection #4
Depth of Injection	12-14'	16-18'	20-22'	23-25'
Grams B2/inj	32.88	32.88	32.88	32.88
Grams B12/inj	4.74	4.74	4.74	4.74
Grams RYR/inj	69.96	69.96	69.96	69.96
Pounds Yeast Extract/inj	5.00	5.00	5.00	5.00
Pounds Provectus IR/inj	12.50	12.50	12.50	12.50
Pounds of ZVI/inj	25.00	25.00	25.00	25.00
Pounds of Sulfite/inj	2.50	2.50	2.50	2.50
Pounds of Nutrient/inj	2.50	2.50	2.50	2.50
Kelp - Hydrolyzed	5.50	5.50	5.50	5.50
Propionate (Lipid)	12.50	12.50	12.50	12.50
Gallons of Sulfite/Nutrient/zvi	75.00	75.00	75.00	75.00

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Applying What we "Know"

Area "B" vs. "D"

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		Area B	Area D		
Injection Depth		18-28	12-25	Ft - bgs	
Soil Absorbsion Correction for GAC Constant		30.00	40.00	%	
Targeted Compounds (GW)					
TCE		37000	10000	ppb	
c-DCE		65000	10000	ppb	
t-DCE		1	1	ppb	
1,1 DCA		1	50	ppb	
1,1 DCE		1	50	ppb	
VC		1000	2000	ppb	
		Injected Mass/Interval			Variance
B2		101.18	131.53	g	30.00%
B12		14.57	18.95	g	30.00%
Red Yeast Rice		215.27	279.85	g	30.00%
Yeast Extract		6.00	20.00	lbs	233.33%
Provectus IR		75.00	50.00	lbs	-33.33%
ZVI		90.00	100.00	lbs	11.11%
Sulfite		6.00	10.00	lbs	66.67%
Nutrient		6.00	10.00	lbs	66.67%
Kelp - Hydrolyzed		30.00	22.00	lbs	-26.67%
Propionate (Lipid)		50.00	50.00	lbs	0.00%

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Applying What we "Know"

Results 600 Days

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MW-12 (µg/L).							
Sampling Date	05/13/2015	12/11/2015	02/29/2016	05/26/2016	08/29/2016	12/21/2016	07/18/2017
TCE	36,900	46,900	13,100	1,060	1,790	550	<5.3
cis-1,2-DCE	65,200	95,000	73,500	73.400	58,600	76,600	5,420
Vinyl Chloride	1,100	3,060	7,860	7,000	11,300	19,300	2,710

MW-16(µg/L)							
Sampling Date	05/13/2015	12/11/2015	02/29/2016	05/26/2016	08/29/2016	12/21/2016	07/18/2017
TCE	8.1 J	14.0	2.1	<0.26	0.64 J	<2.6	<0.27
cis-1,2-DCE	1,240	14,300	1,200	195	535	1,540	49.5
Vinyl Chloride	453	8,000	1,410	122	1,100	13,400	247

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Results 600 Days

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MW-12							
Sampling Date	05/13/2015	12/11/2015	02/29/2016	05/26/2016	08/29/2016	12/21/2016	07/18/2017
Depth to GW (ft)	20.43	23.95	22.02	21.34	22.02	23.28	19.35
D.O. (mg/L)	3.72	<0.01	0.88	1.38	8.16	6.93	3.21
ORP (mV)	+113	-57	-54	-166	-99	-147	-106
Conductivity (uohms/Con)	2,310	2,390	967	2,460	2,360	2,340	2,220
pH	7.20	7.54	6.59	6.65	6.71	6.13	6.49
Sulfate (mg/L)	50.5	34.8	<10	<10	NA	<10	4.6
Total Iron (µg/L)	8,160	13,200	40,200	16,100	NA	30,000	4,900
Methane (µg/L)	12.9	3.5	4.7	1,600	NA	1,440	3,410
Ethane (µg/L)	0.82	0.26	0.56	86.7	NA	60.9	71.9
Ethene (µg/L)	1.8	0.79	1.6	348	NA	1,170	2,170

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Results 600 Days

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MW-16							
Sampling Date	05/13/2015	12/11/2015	02/29/2016	05/26/2016	08/29/2016	12/21/2016	07/18/2017
Depth to GW	18.45	22.20	20.00	19.52	20.37	21.82	17.75
D.O. (mg/L)	<0.01	7.23	1.61	1.27	2.68	2.82	1.41
ORP (mV)	-25	-128	-86	-105	-50	-176	-65
Conductivity (uohms/Con)	624	939	683	874	684	1,180	892
pH	5.76	8.93	6.78	6.70	6.93	6.41	6.48
Sulfate (mg/L)	26.5	11.4	12.4	<10	NA	20.2	5.0
Total Iron (µg/L)	3,310	2,650	52,100	10,400	NA	12,200	363
Methane (µg/L)	73.6	7.7	7.2	3,210	NA	7,200	6,710
Ethane (µg/L)	1.1	0.41	0.69	240	NA	351	226
Ethene (µg/L)	1.2	2.9	5.7	415	NA	3,780	729

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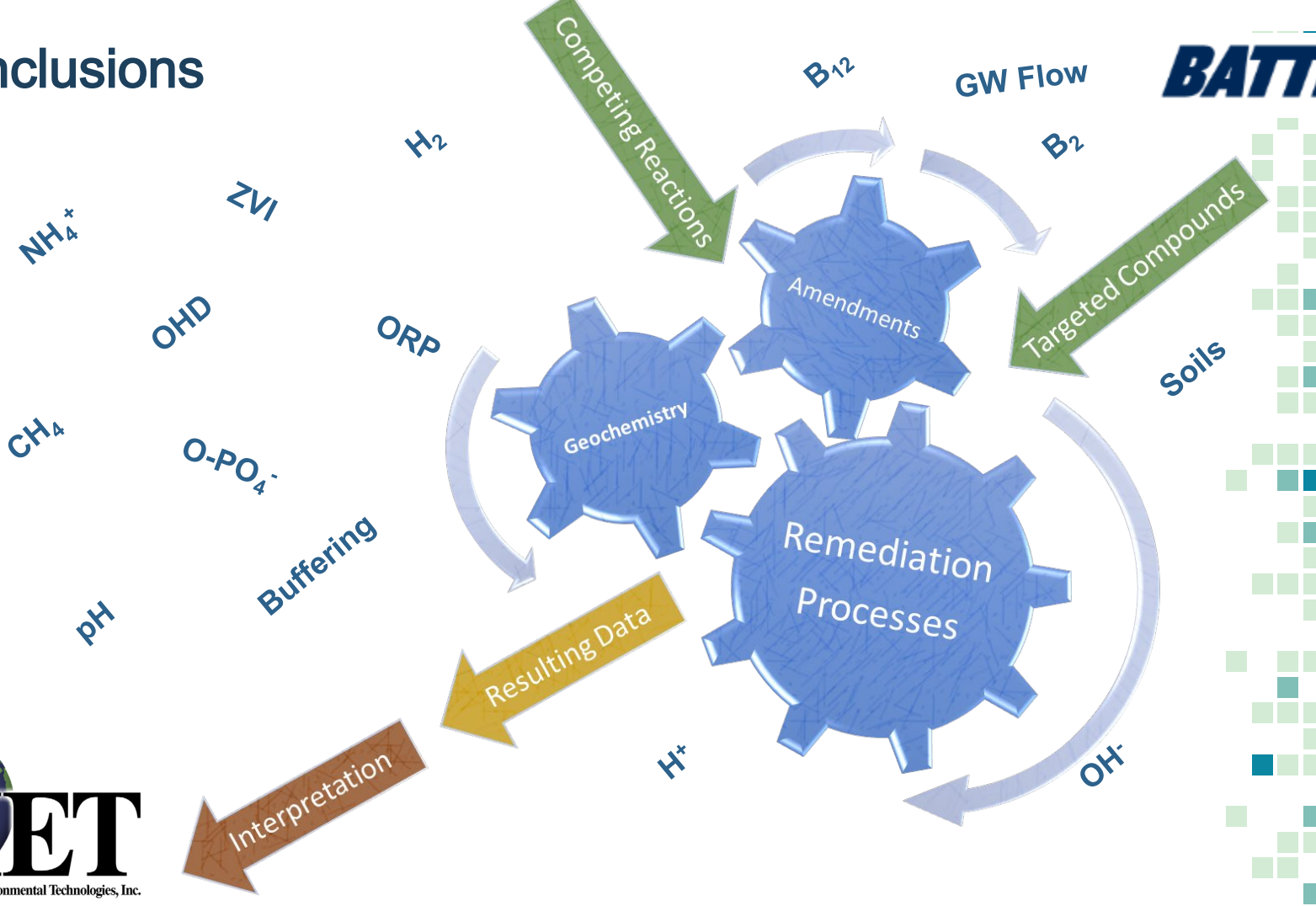
Conclusions



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Questions