Optimization Strategies for *In Situ* Bioremediation of a TCE Plume at a Complex Site Under a Regulatory Paradigm Shift



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Abstract #476, Session D3, Flagler Room, 2:40PM

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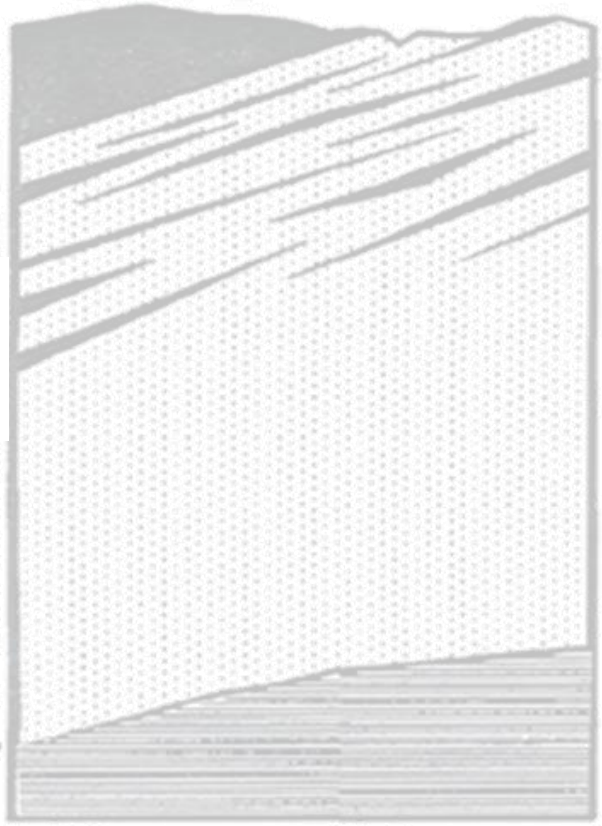
Miami, Florida, U.S.A.

Overview

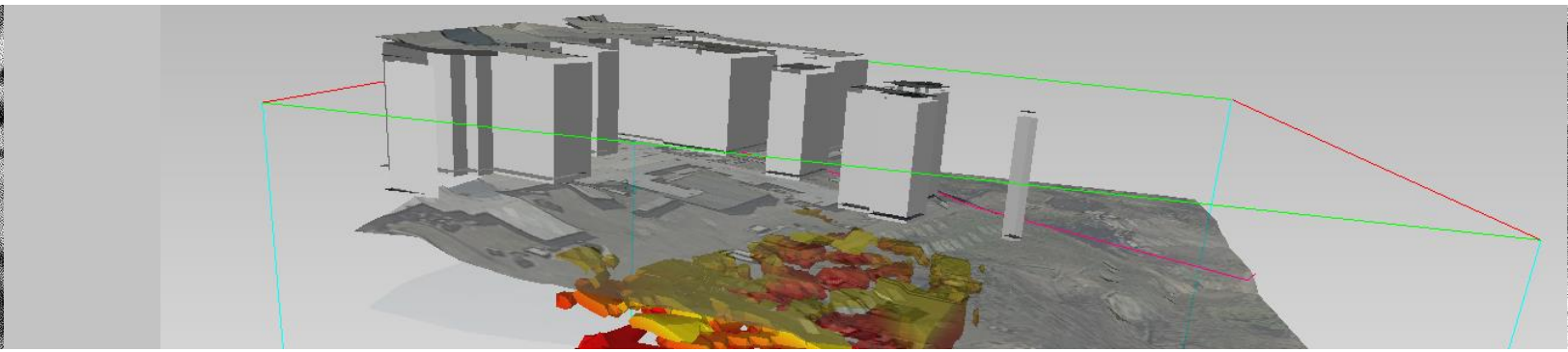
1. Site History
2. Site Conditions
3. Summary of Remediation Efforts
4. Analysis, Evaluation, and Conclusions

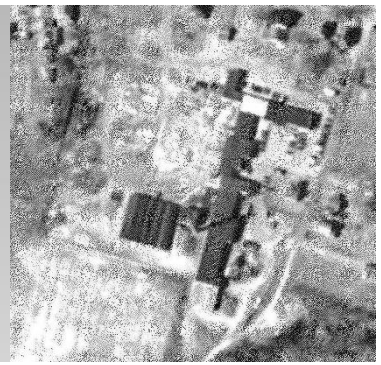


5. Expanded Investigation
6. On-going Remediation Efforts
7. Lessons Learned
8. Q&A

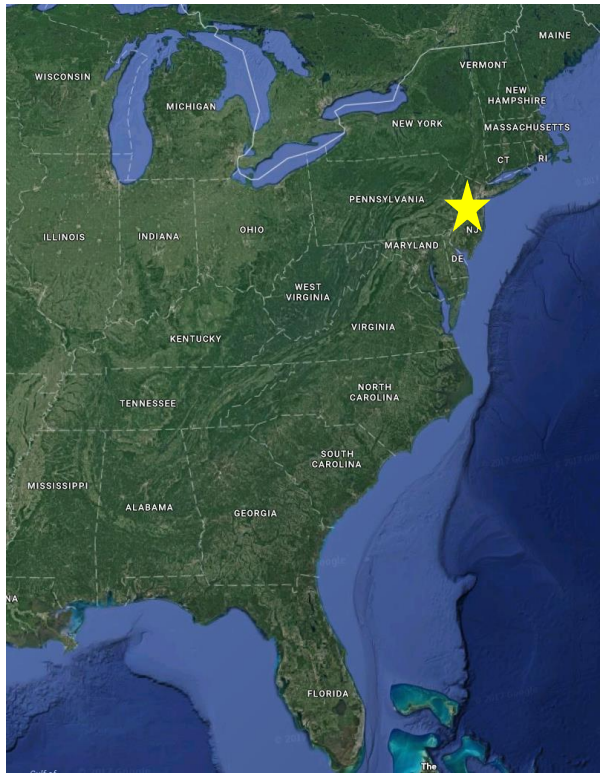
A Slow Release of TCE Over Time

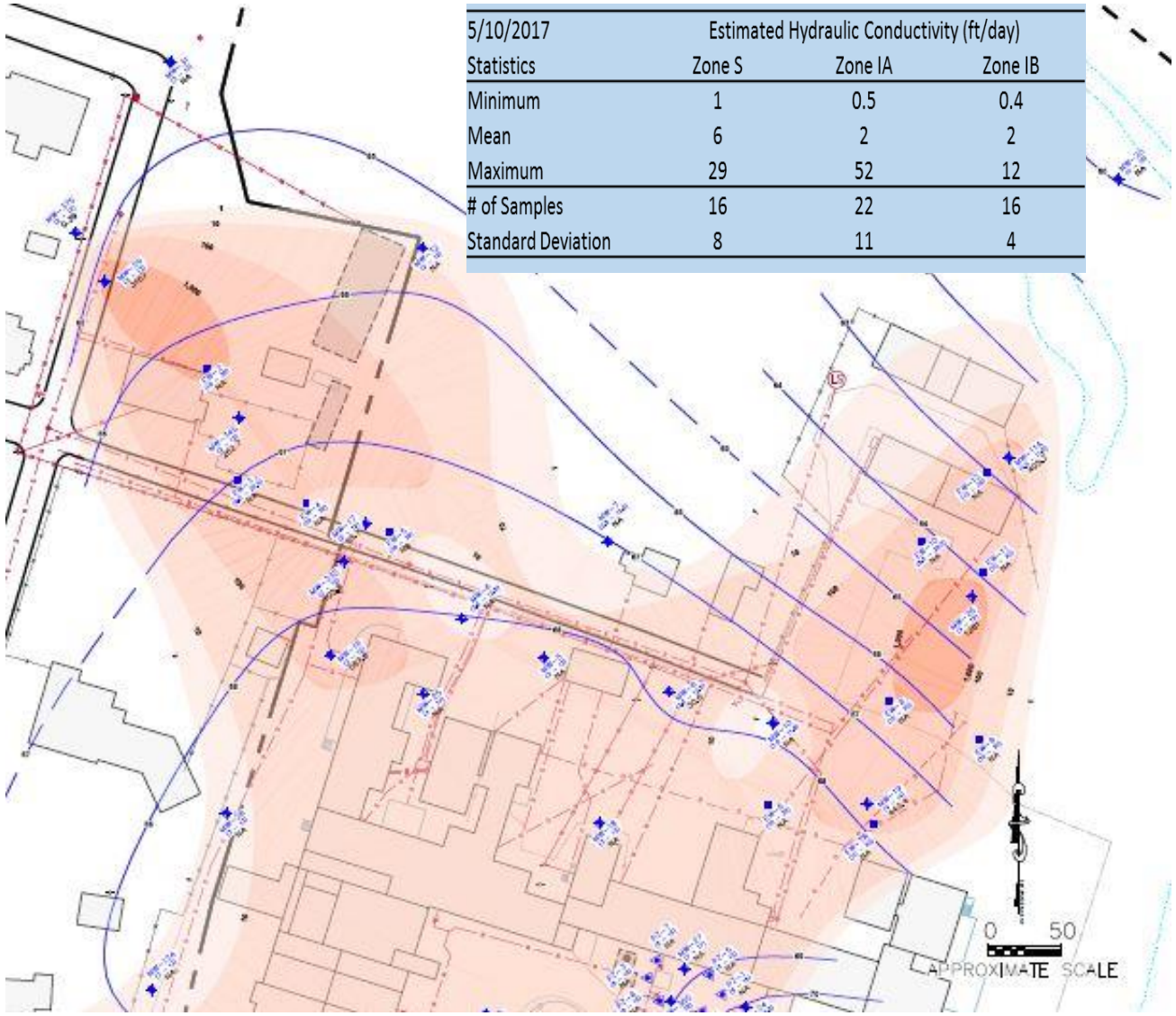
1. Cutlery manufacturing and distribution facility erected in the 1940s.
2. Source of contamination was never confirmed; on-site septic system and leach fields remain the most probable origin.
3. Investigative/remediation activities date back to mid-1980s;





Limits to Transport





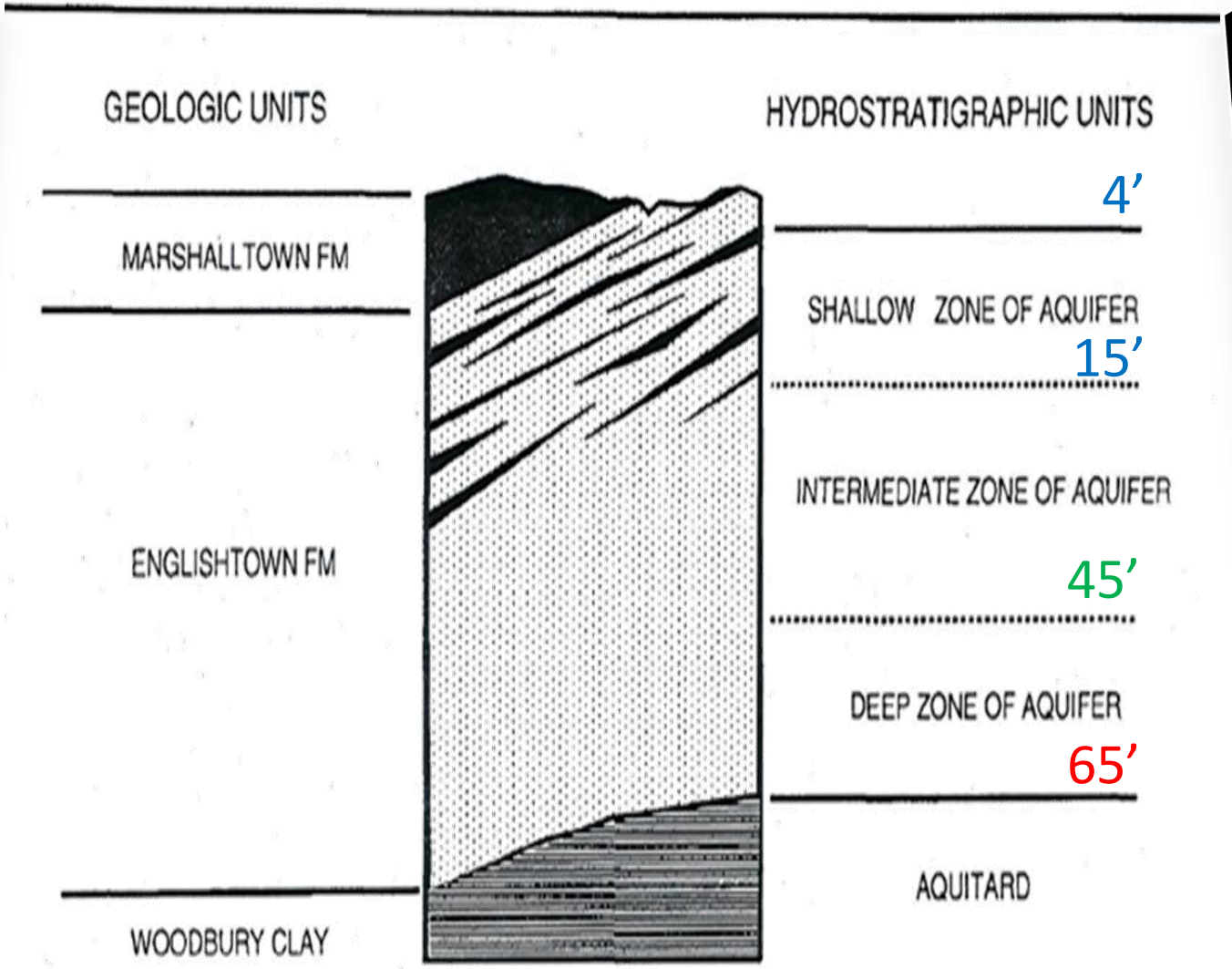
5/10/2017	Estimated Hydraulic Conductivity (ft/day)		
Statistics	Zone S	Zone IA	Zone IB
Minimum	1	0.5	0.4
Mean	6	2	2
Maximum	29	52	12
# of Samples	16	22	16
Standard Deviation	8	11	4

Heterogeneous and Acidic Aquifer

pH
4.1 – 6.1 su
Avg: 4.9 su

Dissolved O_2
0 – 7.1 mg/L
Avg: 1.2 mg/L

ORP
125 to 279 mV
Avg: 197 mV



TCE
Avg: 3,682 µg/L
Max: 74,500 µg/L

***cis*-1,2,-DCE**
Avg: 55 µg/L
Max: 200 µg/L

Vinyl Chloride
Avg: 6 µg/L
Max: 9 µg/L

EISB was selected as IRM

1. EISB was selected based on the site's complex hydrogeology, plume geometry and ongoing site operations.

2. A multi phased pilot test (Phase I & II) was conducted to design appropriate enhancement and amendment delivery strategy in light of
   - low pH levels;
   - clay interbedding;
   - limited freeboard (shallow groundwater); and
   - access constraints.

Detailed injection summary provided at end (Supplemental Slides)

The EISB Program

Biostimulation

pH Buffer

Bioaugmentation

IRM INJECTION SUMMARY

326 injection pts

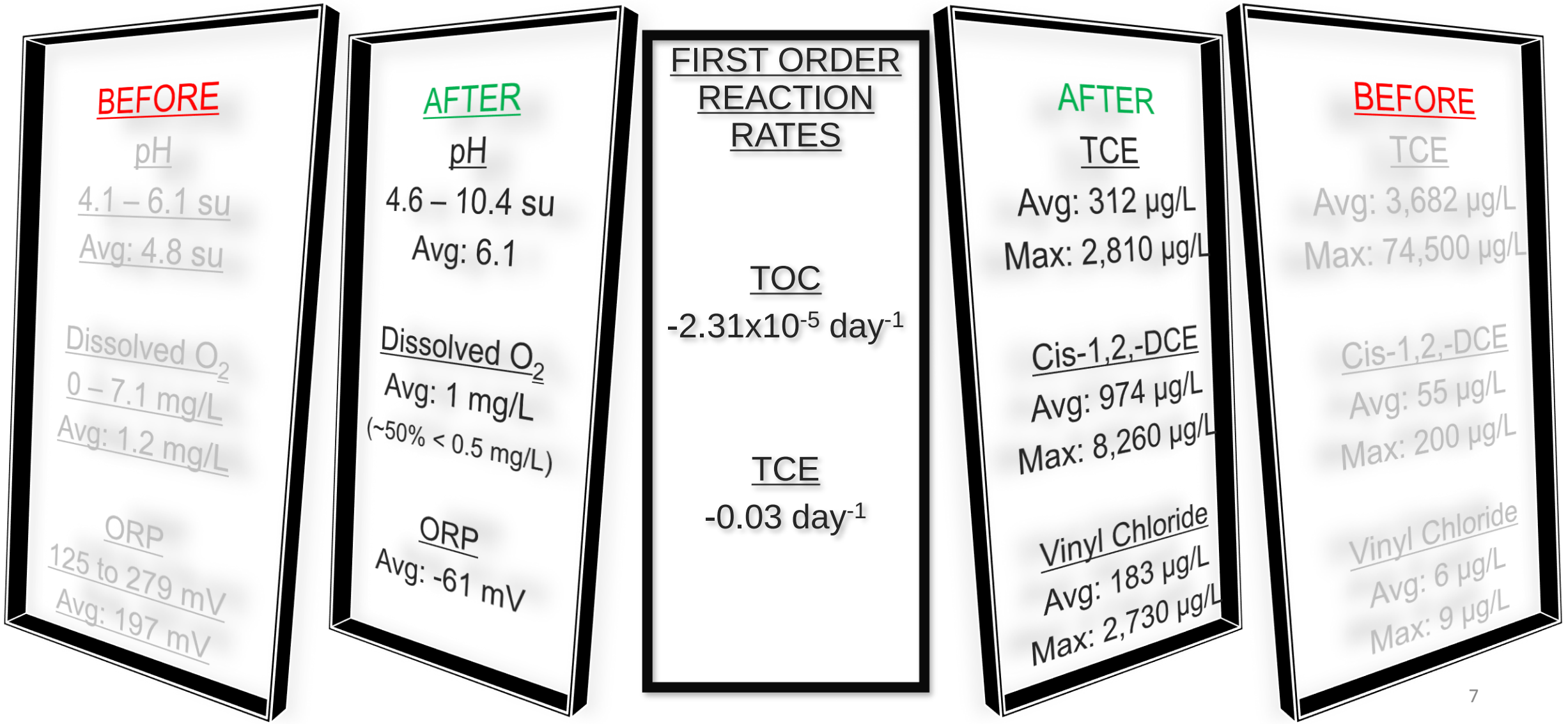
500K gal Total Vol.

23K gal of EVO

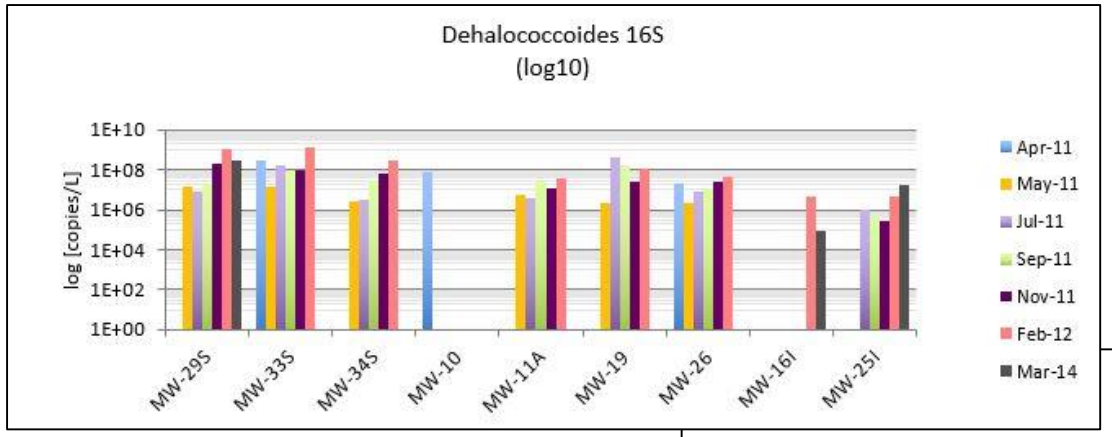
204K lbs NaBicarb

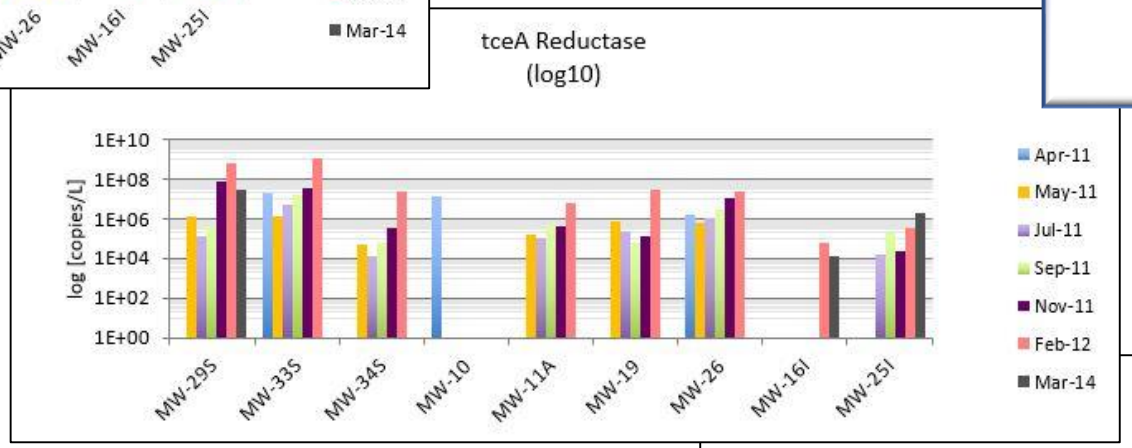
173 L of *DHC* culture

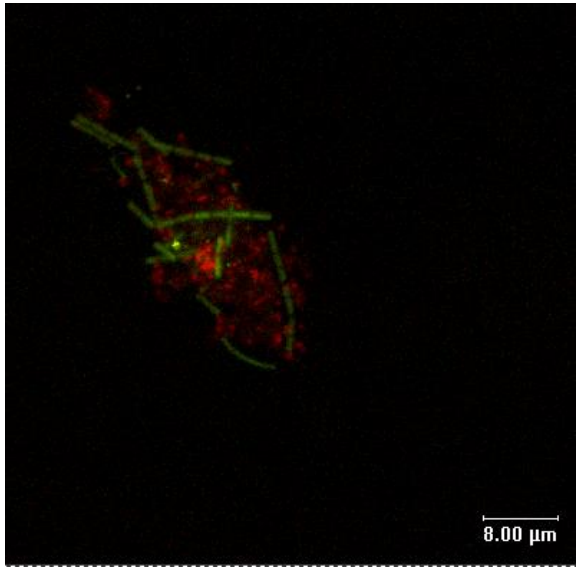
Shallow Zone Success

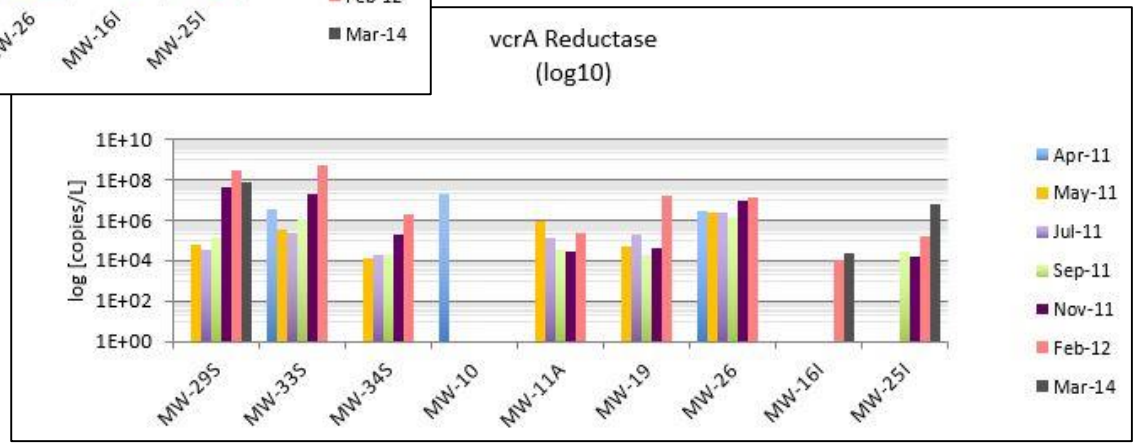


Bioaugmentation Showed Favorable Results









Bioaugmentation Injections in July 2011 and May 2012

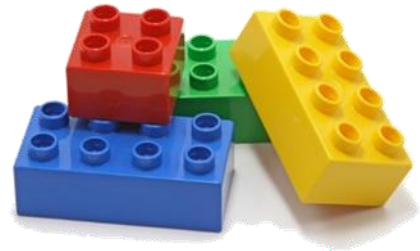
- DHC present in some locations before bioaug;
- DHC targets generally wide spread post-injection.

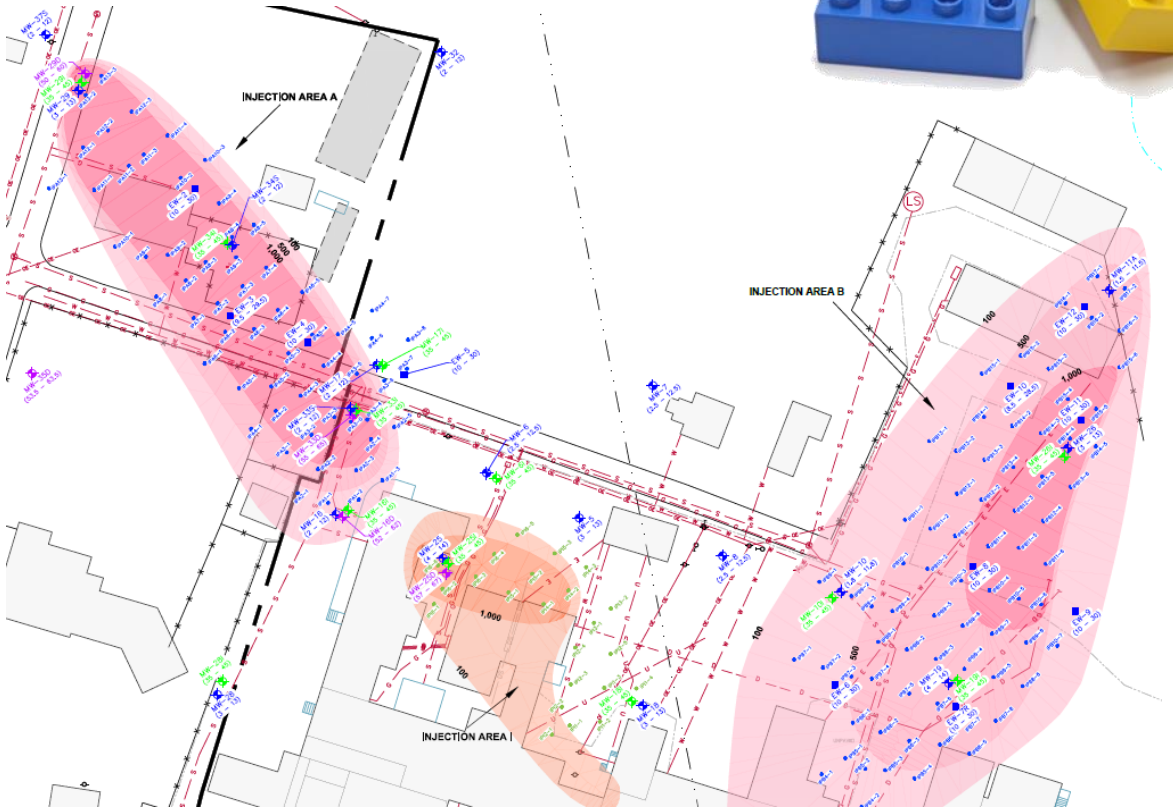
Phased Approach for Mass Reduction

1. The EISB program (Ph III) was conducted using direct push with the Primawave pulsing tool.

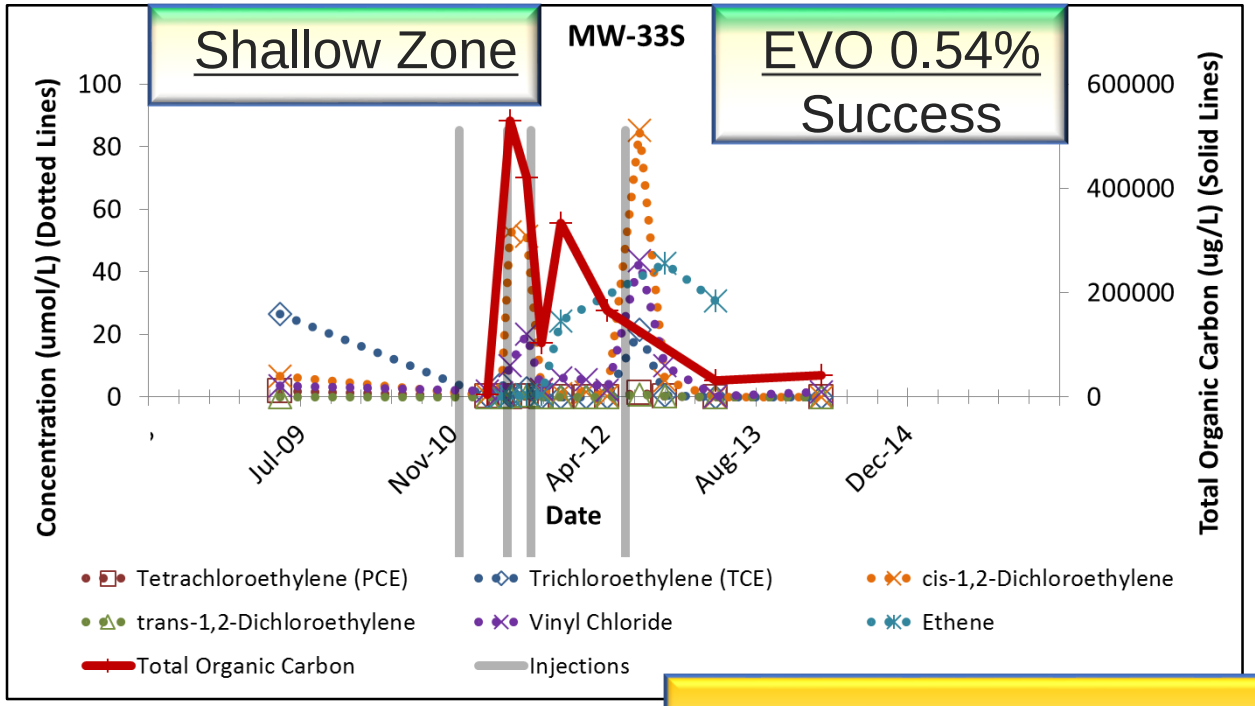
2. Certain areas recalcitrant to treatment:
   - rebound, *cis*-1,2-DCE stalling, or maintaining a low pH

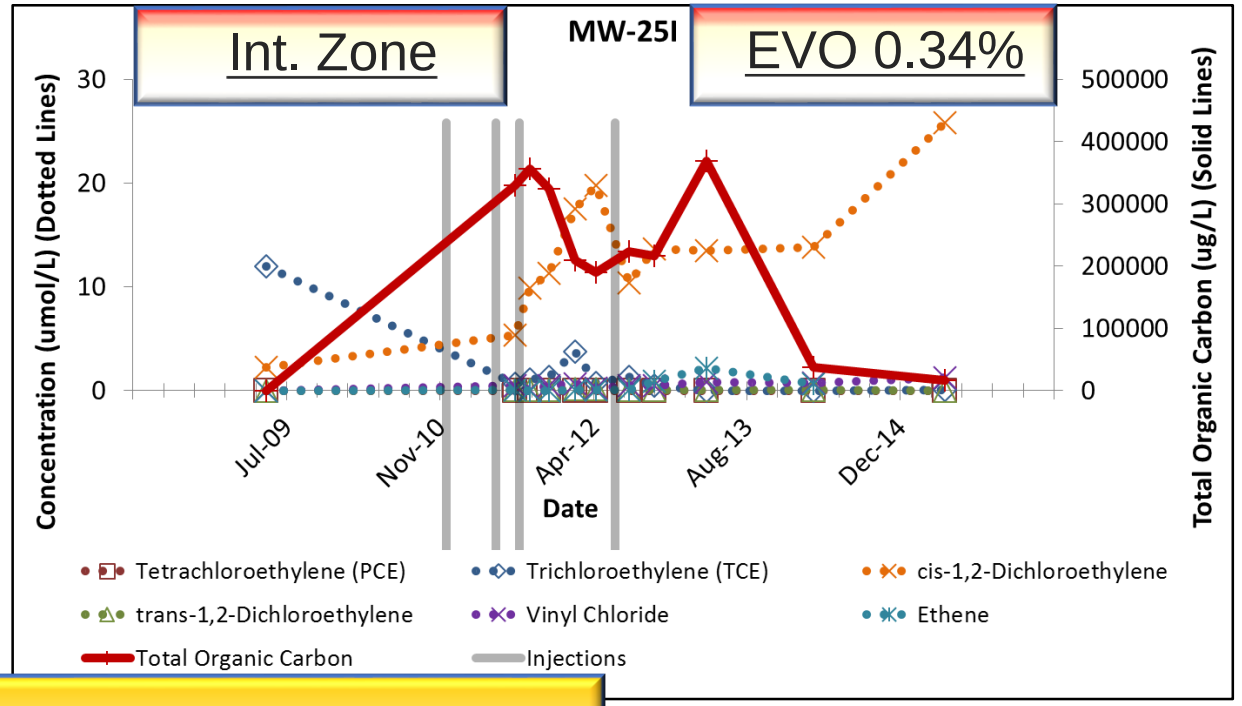
3. Polishing injections implemented
   - more pH Buffer and injections of culture (Phase IV-V)
   - polishing injections (Phase VI)





Contact and Multiple Rounds Necessary





EVO Loading Analysis:

Effective at 0.20% - 0.54% of soil mass

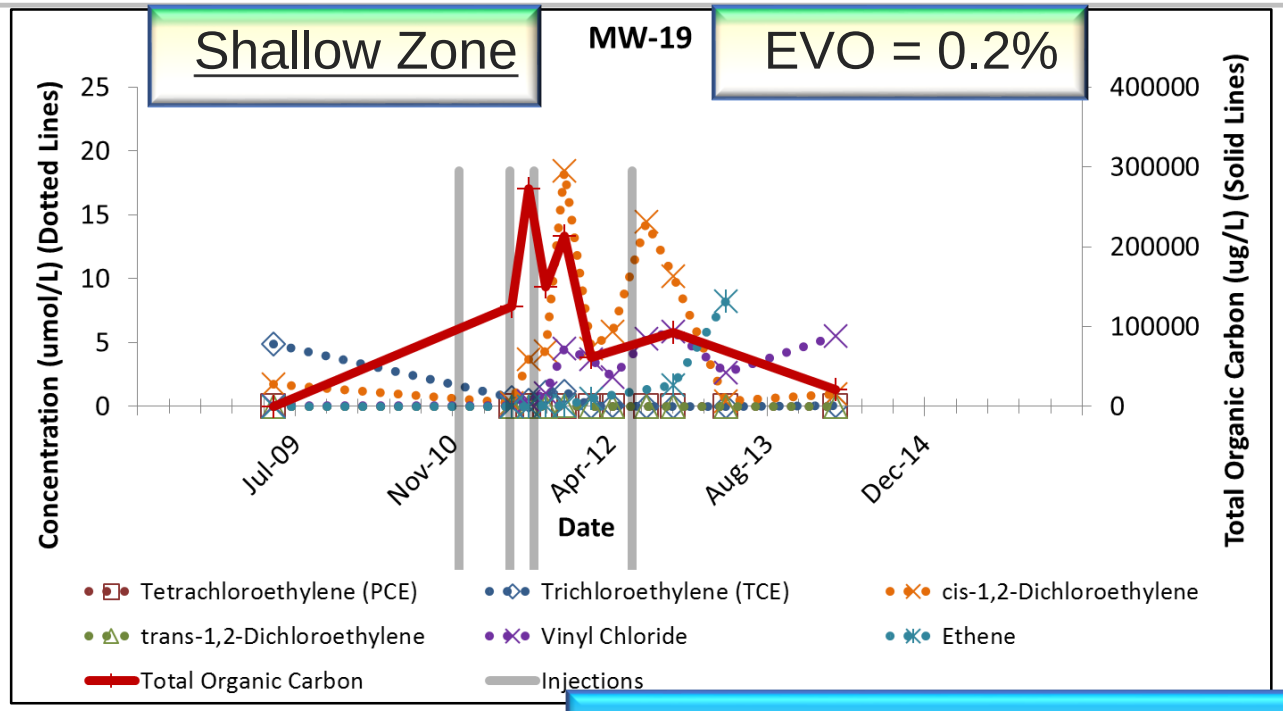
Ineffective at 0.16% - 0.34% of soil mass

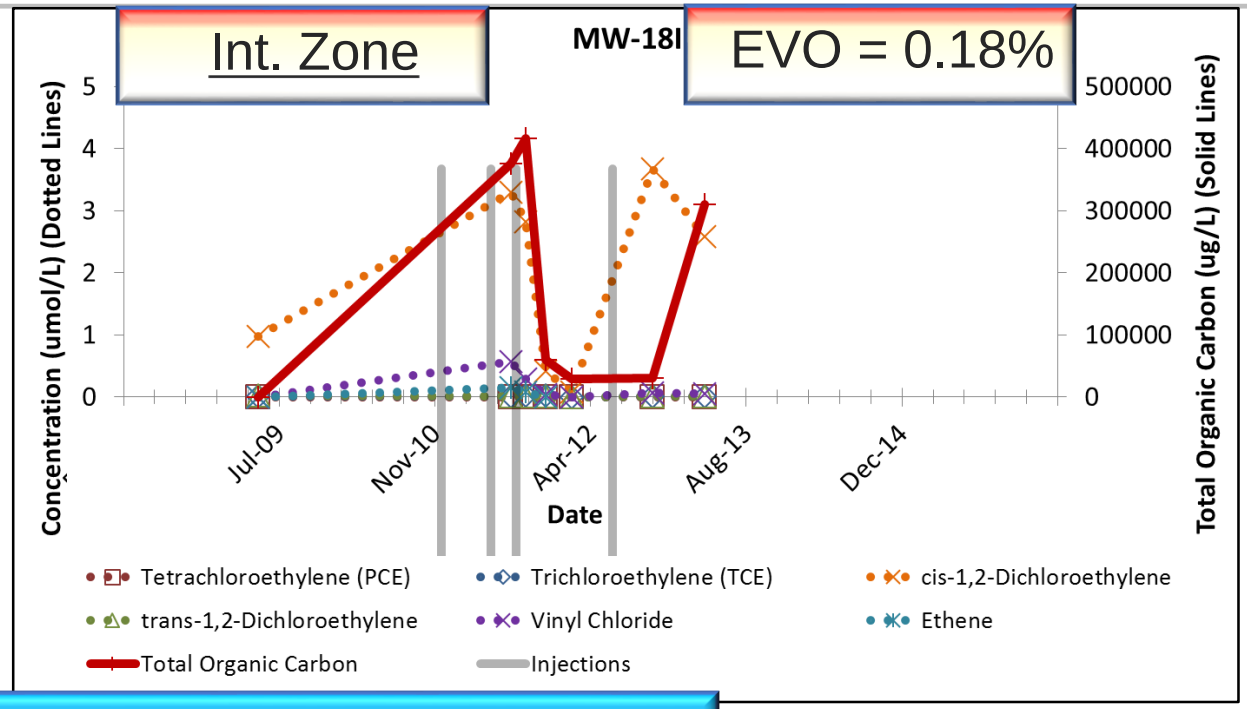
Bicarb Loading Analysis:

Effective at 1 - 2.7 lbs bicarb/ton soil

Ineffective at 0.5 - 1.9 lbs bicarb/ton soil

Back-Diffusion and Rebound





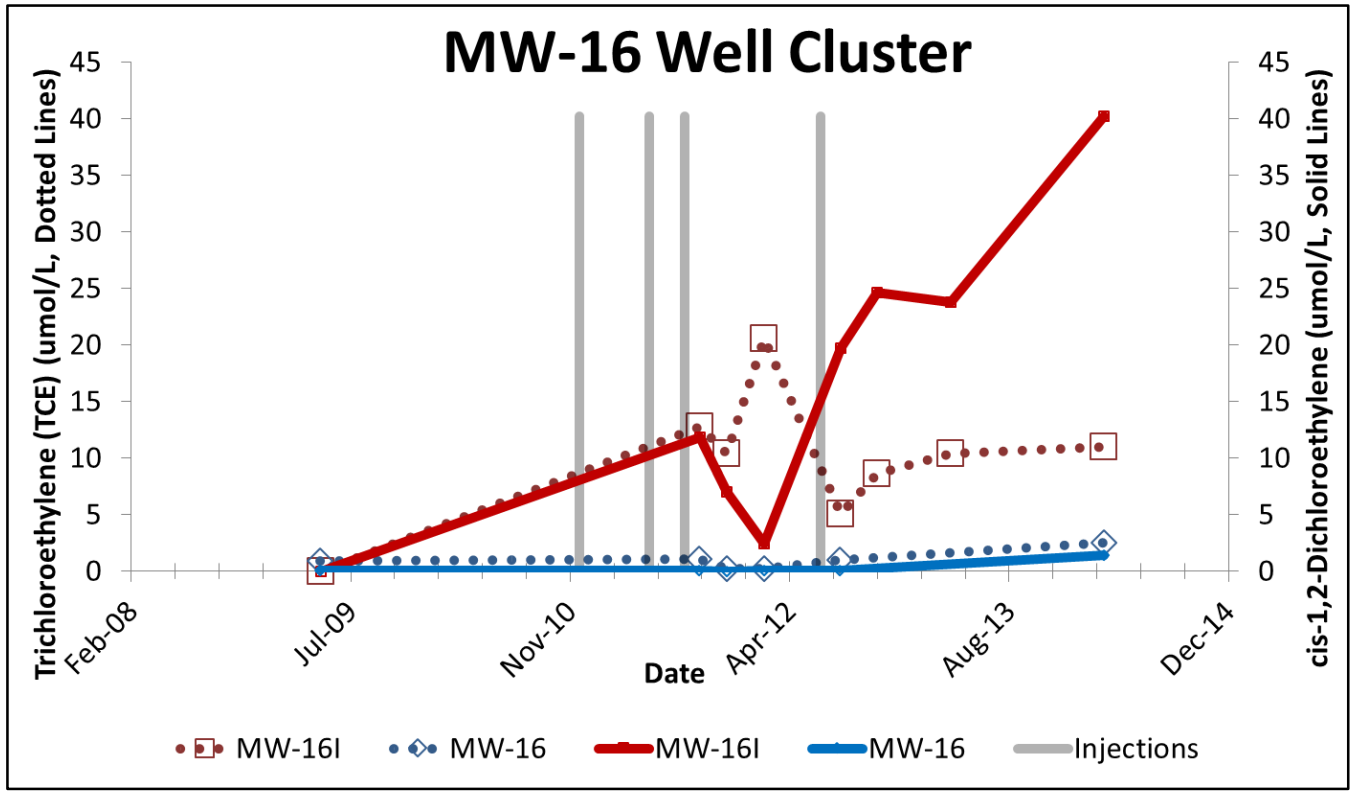
Back-Diffusion Analysis:

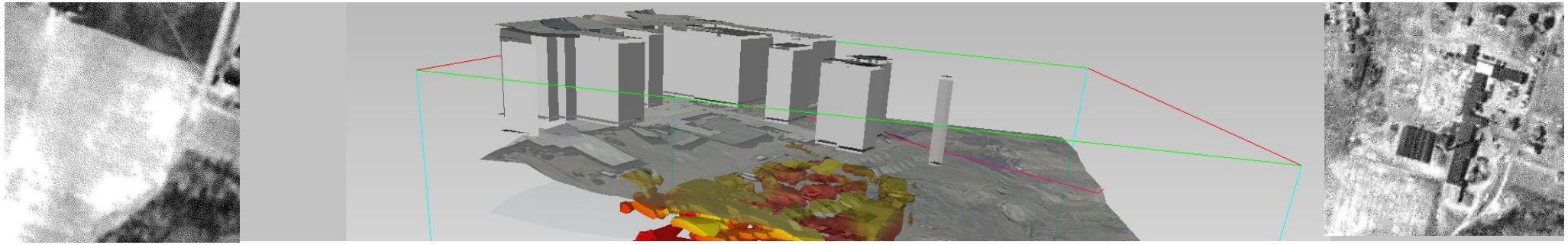
- Rebound and back diffusion near source areas was significant
- Treatment successful with multiple rounds
- Stalls or incomplete degradation due to under loading, poor distribution or buffer consumption

Intermediate Zone Response Resulted in PDI

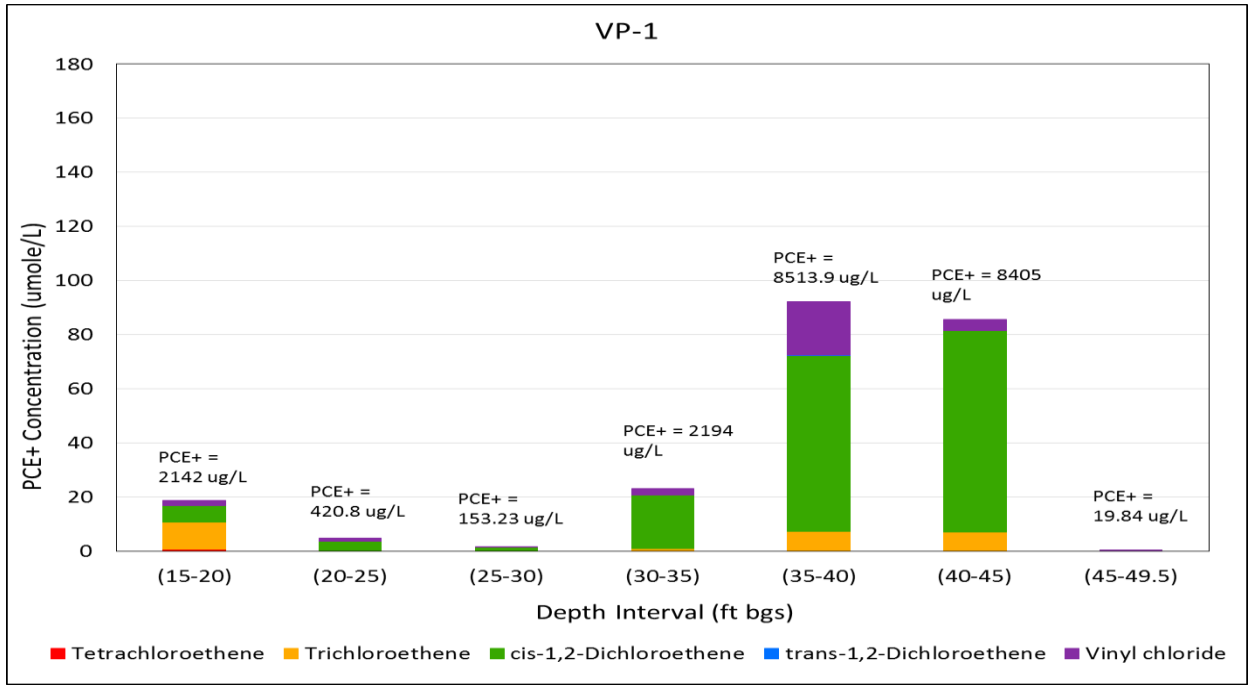
1. Rising concentrations in intermediate and shallow zone wells suggested untreated source beneath inaccessible bldgs.

2. Intermediate PDI developed to reveal a high degree of vertical discreteness and presumed vertical and lateral boundaries.





Intermediate Zone Expands



Hydropunch Vertical Profiles

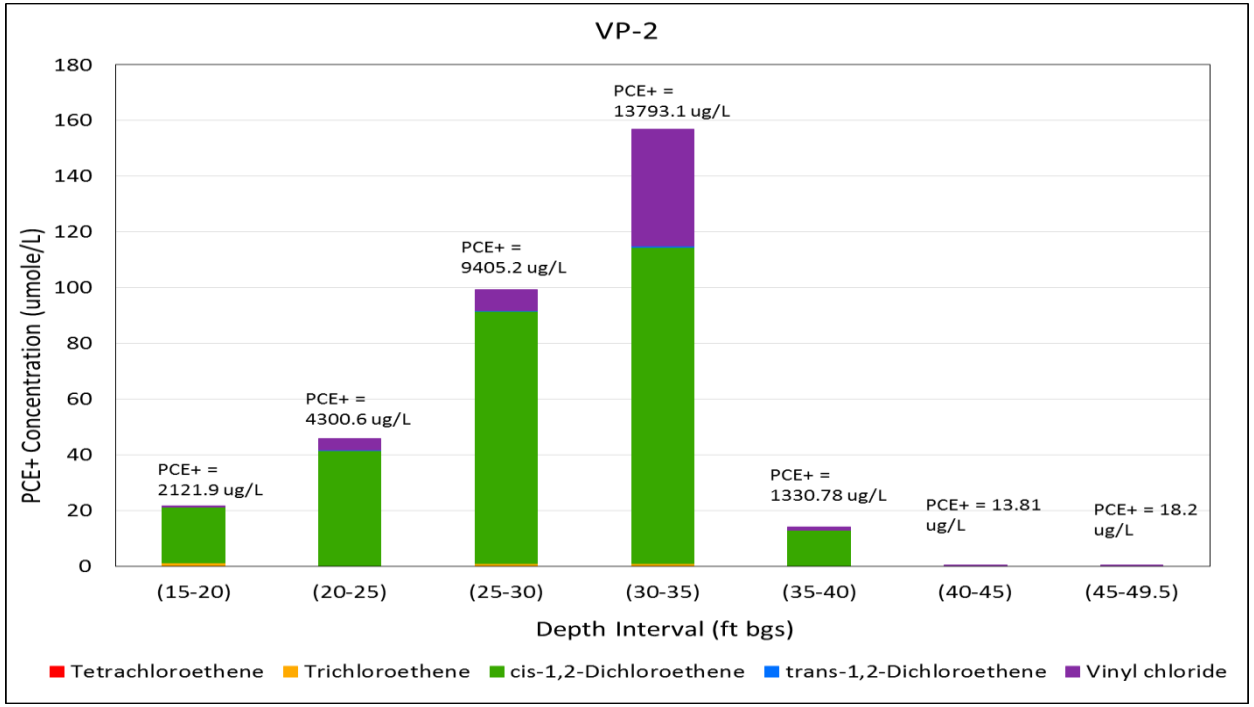
- Significant changes in 5-foot vertical intervals and among points that are 35 to 70 feet apart.
- TCE results help confirm an untreated source

The Representative Elemental Volume

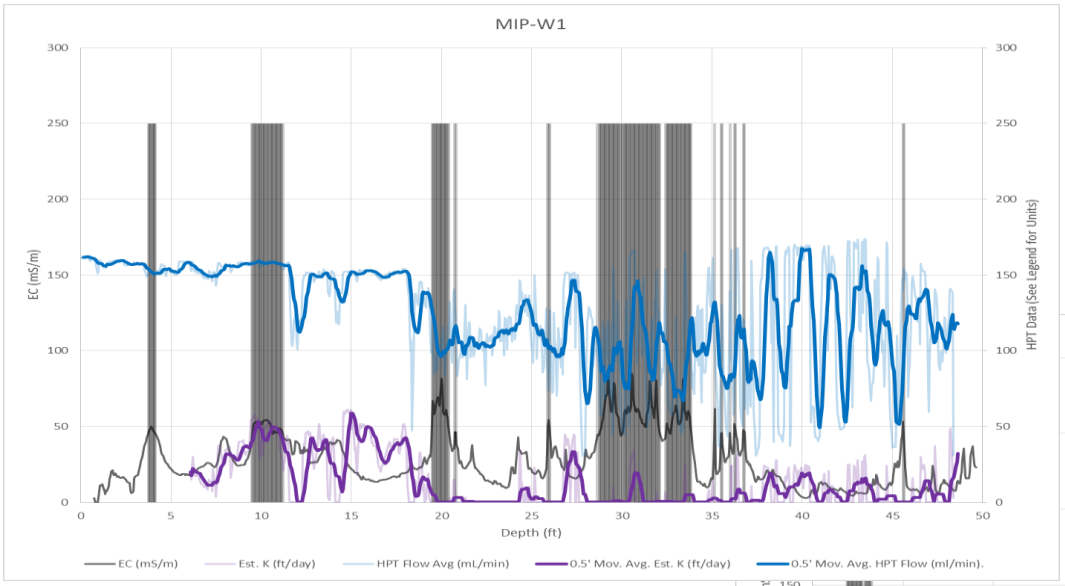
Begins to develop for the site

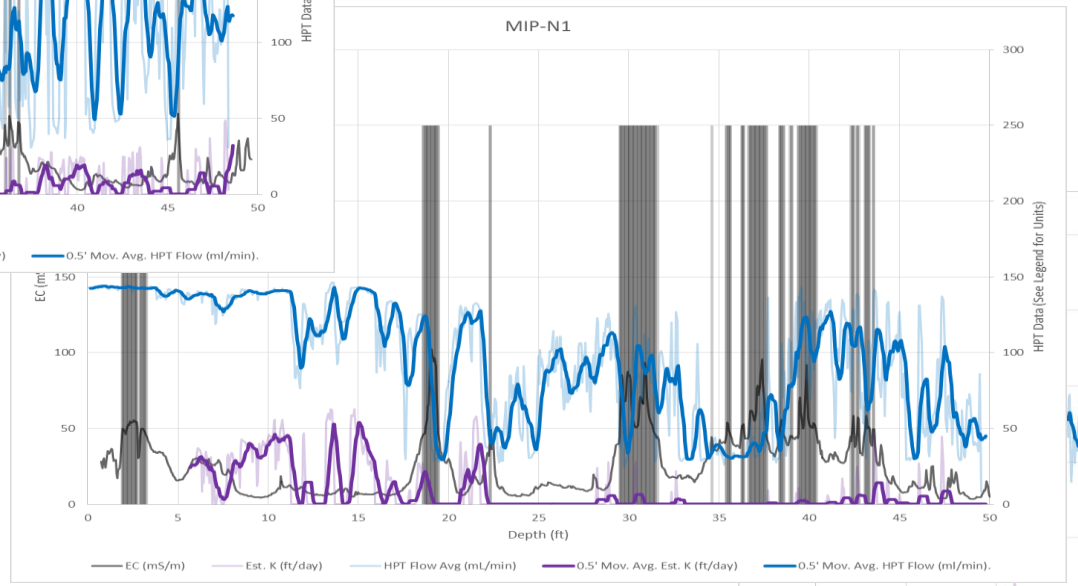
50 x 50 feet lateral

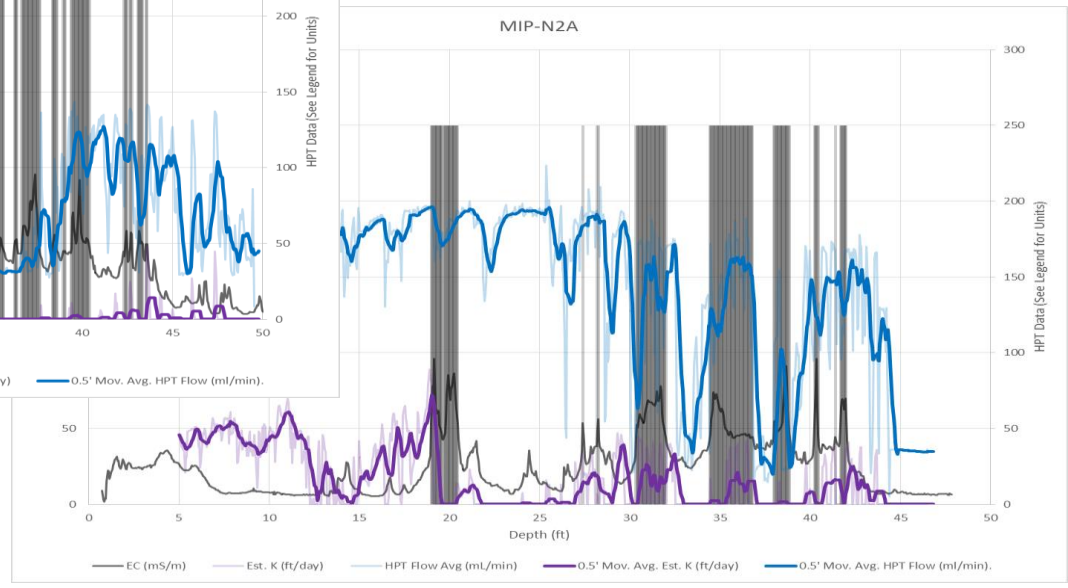
5 feet vertical



Vertical Discreteness More Prevalent







1. HPT
   - Q – blue
   - K – purple
2. EC - black
3. Shaded EC areas correlate with clay/silt in lithologic logs

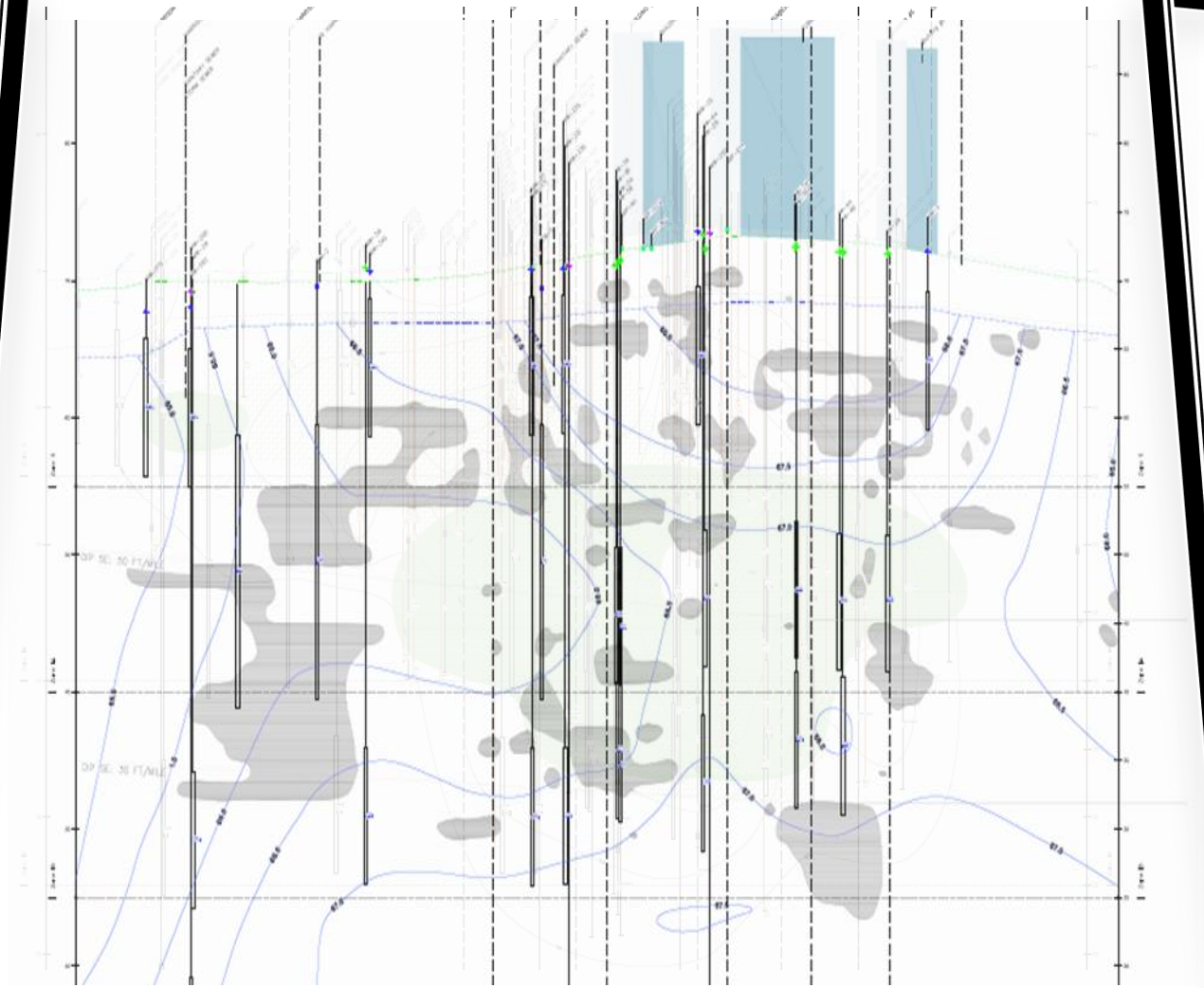
Post-IRM Mass Distribution & Visualization

DISTRIBUTION OF CONTAMINATED GW & DISSOLVED MASS

Zone S
1.5 MG | 12 Kg

Zone IA
2.0 MG | 75 Kg

Zone IB
1.3 MG | 31 Kg



DISTRIBUTION OF DISSOLVED MASS IN SAND & CLAY

Zone S
73% | 27%

Zone IA
86% | 14%

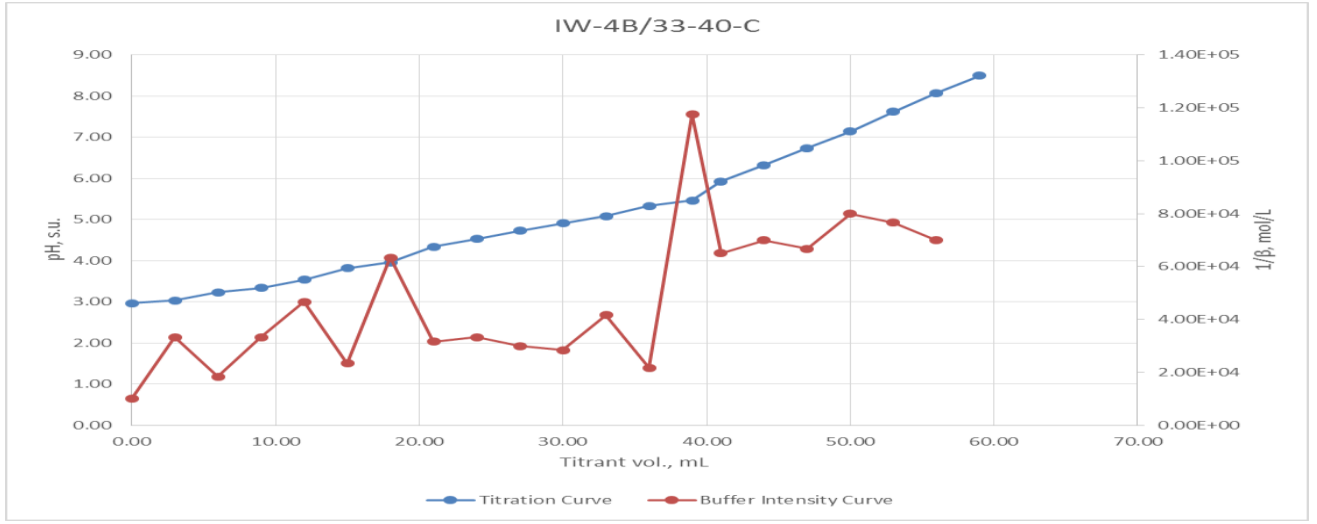
Zone IB
86% | 14%

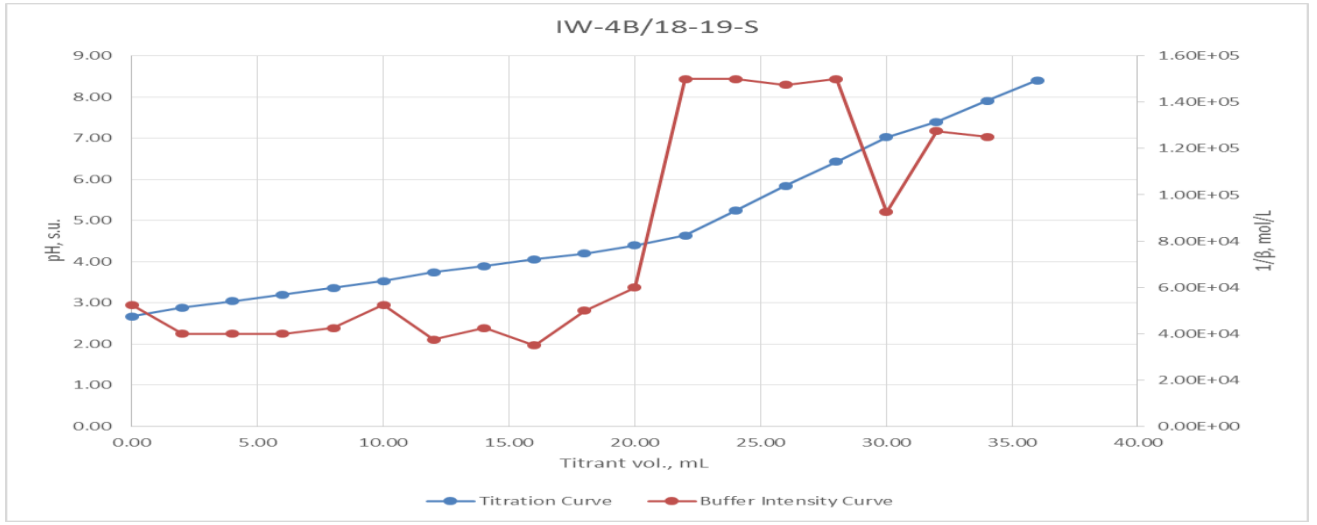
Acidity of Aquifer Matched EVO Buffer Demand

1. EVO Loading: 0.005 lb EVO/lb Soil
   - Buffer Demand: 1,448,379 OH^- Eq

2. Total Base Demand of Aquifer (***soil***, water, biodegradation products)
   - Buffer Demand: 1,294,939 OH^- Eq
   - Uses an average of the acidity results to calculate demand (not considering the max!)

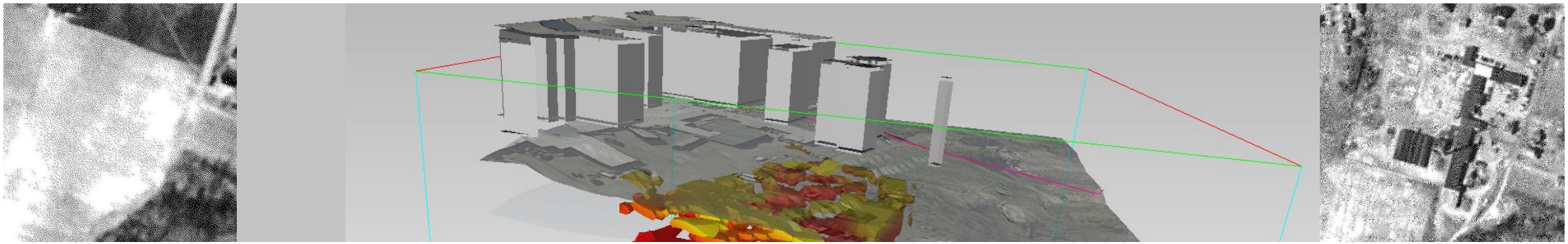
3. Iterative Acidity test showed partial rebound of demand





Lessons Learned

1. Representative elementary volume and density of samples
2. 3D models provide support for conceptual details
3. Realistic limitations that lead to decision-making, misunderstandings, successes, and failures



Acknowledgements

1. Co-authors: Dr. Nidal Rabah, Dr. Yasemin Kunukcu, and Mr. Anthony Brown

2. Various TRC Colleagues

3. Cornell University CEE: Dr. Ruth Richardson, Dr. Gretchen Heavner

4. Vendors/Subcontractors: EOS Remediation, Terra Systems, Vironex (c/k/a Cascade)

Q&A

QUESTIONS?

I'm Relieved

So good job

We nailed it

Hooray

See you later

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SUPPLEMENTAL DETAILED SLIDES

Detailed Injection Information

Injection Phase	Injection Date Range	Total Number of Injection Points	Total Volume Injected (gal)	Total Volume of Diluted EVO[1] Injected (gal)	Total Volume of Sodium Bicarbonate Solution Injected (gal)	Total Volume of Anaerobic Chase Water Injected (gal)	Total Volume of TSI DC Culture Injected (L)	Total Mass of Sodium Bicarbonate Injected (lbs)	Total Volume of Undiluted EVO Injected (gal)	Total Volume of Dilution and Chase Water Injected (gal)
Phase II	12/07/2010 - 12/09/2010	2	3,225	785	1,980	460	0	1,188	157	3,068
Phase III	03/14/2011 - 05/17/2011	192	329,787	89,385	240,402	0	0	144,241	17,877	311,910
Phase IV-V	07/19/2011 - 08/05/2011	61	74,715	345	44,178	30,192	139	23,445	69	74,646
Phase VI	05/21/2012 - 06/10/2012	71	105,366	22,926	70,010	12,430	34	35,005	4,906	100,460
All Phases (Total)	12/07/2010 - 06/10/2012	326	513,093	113,441	356,570	43,082	173	203,879	23,009	490,084

Detailed Loading Analysis

Wells	Zone	Significance of Rebound	Remediation Success	Volume 20% EOS/SRS Injected within 20' of screen (gal)	Mass of NaHCO3 Injected within 20' of Screen (lb)	Mass of EVO per Mass of Soil (%)	Mass of Bicarb to Mass of Soil (lb/ton)
MW-33S	Shallow	Rebound	Success	1581	3135	0.54%	2.7
MW-19	Shallow	Rebound	Success	595	1133	0.20%	1.0
MW-17	Shallow	Insignificant	Success	1225	2233	0.42%	1.9
MW-6	Shallow	Insignificant	Success	475	548	0.16%	0.5
MW-25I	Intermediate	Rebound	Stall at Cis	1003	2270	0.34%	1.9
MW-18I	Intermediate	Rebound	Stall at Cis	519	967	0.18%	0.8
MW-25	Shallow	Rebound	Incomplete	787	1845	0.27%	1.6
MW-16	Shallow	Increasing	Incomplete	545	1144	0.19%	1.0

Wells	Zone	Significance of Rebound	**Remediation Success**	Number of GW Sampling Events	Recent GW Sampling Date	**Max GW Concentration (µg/L)**	**Recent GW Concentration (µg/L)**	Number of Local Soil Hits within 20’ of Well	Max Local Soil Concentration within 20’ of Well (mg/kg)	Number of Local Soil Hits within 50’ of Well	Max Local Soil Concentration within 50’ of Well (mg/kg)
MW-33S	Shallow	Rebound	**Success**	14	3/18/2014	**14098**	**106**	10	216	21	803
MW-19	Shallow	Rebound	**Success**	12	3/18/2014	**2227**	**442**	1	1	5	7
MW-17	Shallow	Insignificant	**Success**	8	3/19/2014	**3018**	**49**	9	803	22	803
MW-6	Shallow	Insignificant	**Success**	6	4/3/2013	**687**	**4**	0	0	1	3
MW-25I	Intermediate	Rebound	**Stall at Cis**	11	3/19/2014	**2402**	**1392**	0	0	2	14
MW-18I	Intermediate	Rebound	**Stall at Cis**	7	4/3/2013	**363**	**257**	1	0	2	4
MW-25	Shallow	Rebound - Injections	**Incomplete**	6	7/25/2012	**79**	**79**	3	28	8	40
MW-16	Shallow	Increasing - Local GW	**Incomplete**	6	3/19/2014	**587**	**587**	2	1	8	128

Detailed Iterative Acidity Testing Data

Acidity Results Summary (mg CaCO3/kg)												
Lithology	Sand				Clay				Unspecified			
Statistic	N	Min	Mean	Max	N	Min	Mean	Max	N	Min	Mean	Max
Zone S	3	55	130	204	1	73	73	73	4	129	264	504
Zone IA	3	1357	3580	5803	3	4456	7267	12664	3	79	175	307
Zone IB	3	2682	2692	2698	3	142	4861	8559	2	184	214	243