OVERVIEW OF IN-SITU BIOREMEDIATION OF ORGANICS: CHALLENGES AND TECHNOLOGY ADVANCEMENTS

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PRESENTATION OUTLINE

- More Recent Advances
  - Alternative/Hybrid Amendments
  - Bioaugmentation

- Common Challenges
  - “DCE/VC Stall”
  - Amendment Delivery (e.g., lower permeability heterogeneous lithology)

CURRENT STATE OF BIOREMEDIATION

- Most common treatment technology for organics (especially chlorinated VOCs)
- Often selected as default “cookie cutter” technology for petroleum and chlorinated VOCs
- Design often based on default rules-of-thumb as low cost approach

ALTERNATIVE/HYBRID AMENDMENTS

- Fast and Slow Release Carbon Mixtures
- Abiotic/Biotic Hybrid Amendments
  - Carbon/ZVI
  - Titanium Citrate/Vitamin B12/Carbon
  - Iron Sulfide Generators (Chemical Reduction)
  - Sodium Dithionate
- Other
  - Bioaugmentation
  - Methane Inhibitors

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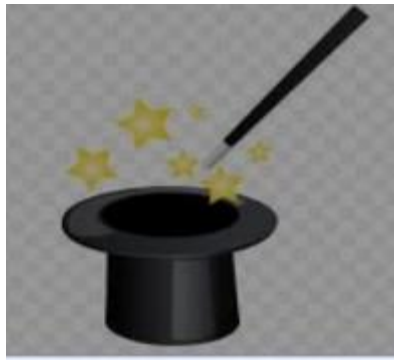

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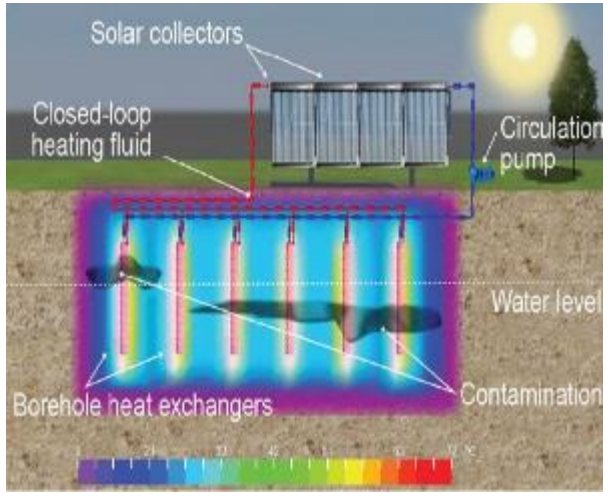
DCE/VC STALL

- Slow degradation rate more accurate description
- Indicator parameters: total ethene molarity; total organic chlorine molarity and chlorine number roughly constant
- Possible optimization actions:
  - Improve amendment delivery volume/distribution
  - Closer injection spacings & increase injection volume
  - Alternating injection locations to minimize stagnation zones
  - pH adjustment (between 6.5 & 8)
  - Bioaugmentation (including vitamin B12 & nutrients [ammonia])

Reference: Microbial Insights, Inc. webinar titled “DCE Stall: Causes and Cures” by Robert Borden, PE, PhD, EOS Remediation, LLC

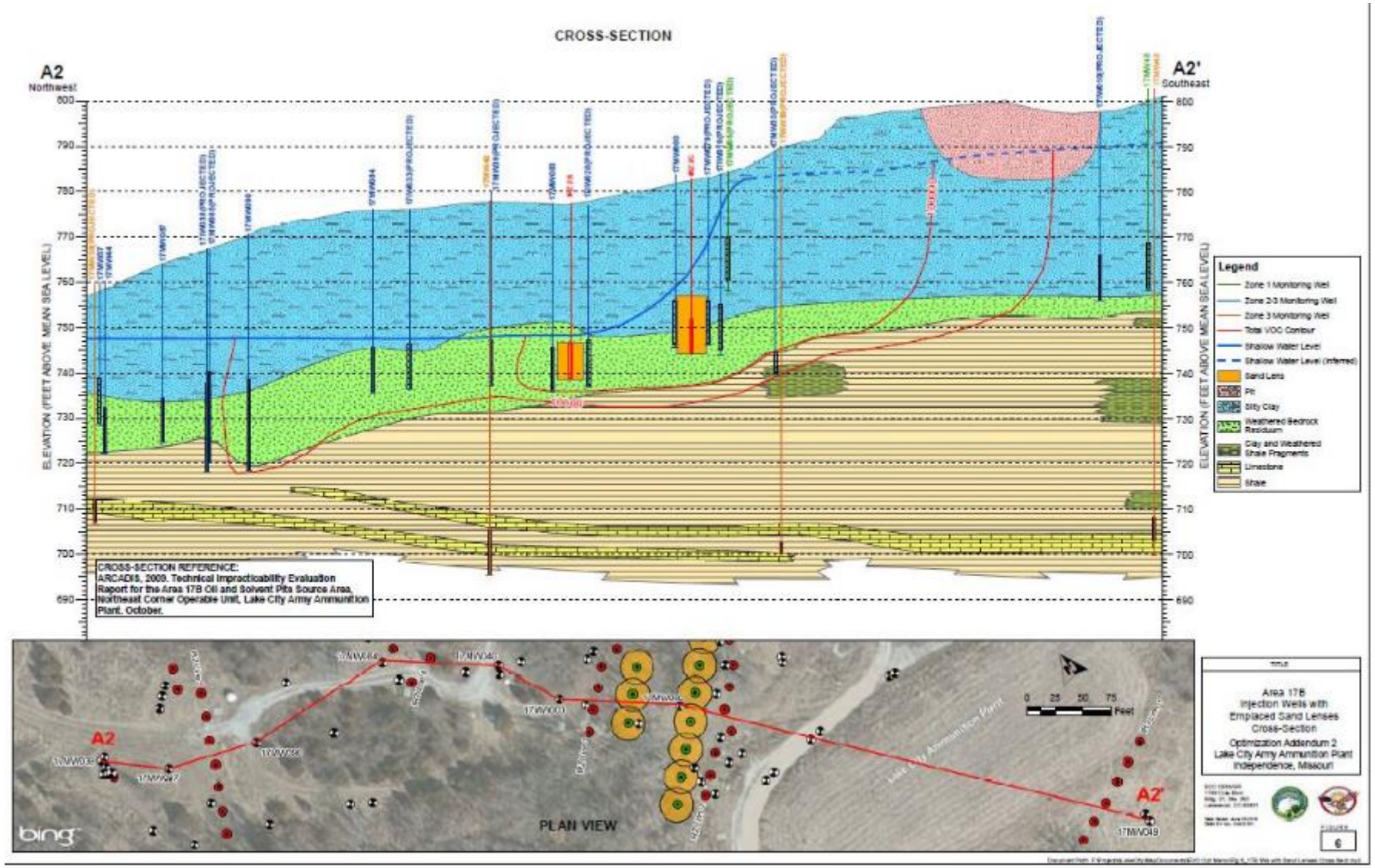
AMENDMENT DELIVERY ENHANCEMENTS

- Groundwater recirculation
- Targeted injection depth(s)
- Fracturing/high pressure jetting
- Large diameter augers
- “Grout Bomber” (ESTCP Project ER201627)
- Heat enhancements (ESTCP Projects ER200719 & 205028 [awarded June 2020])



Reference: ITRC Tech Reg titled “Optimizing Injection Strategies and In Situ Remediation Performance” available electronically at itrcweb.org

LAKE CITY AAP HYDROFRACTURING CASE STUDY



LAKE CITY AAP HYDROFRACTURING CASE STUDY

- ESTCP Project ER201430
- 2015 hydraulic fracturing: enhance delivery of ERD amendments
- 13 points with multiple stacked fractures
- Roughly 30-foot spacing
- Substantial increase in volumes delivered:
  - Line 2 (2015): Avg. 303 gal/point
  - Frac lines: Avg. 600 gal/point
- Some breakout at surface, but good success in creating stacked fractures
- NAPL in some blowback fluids

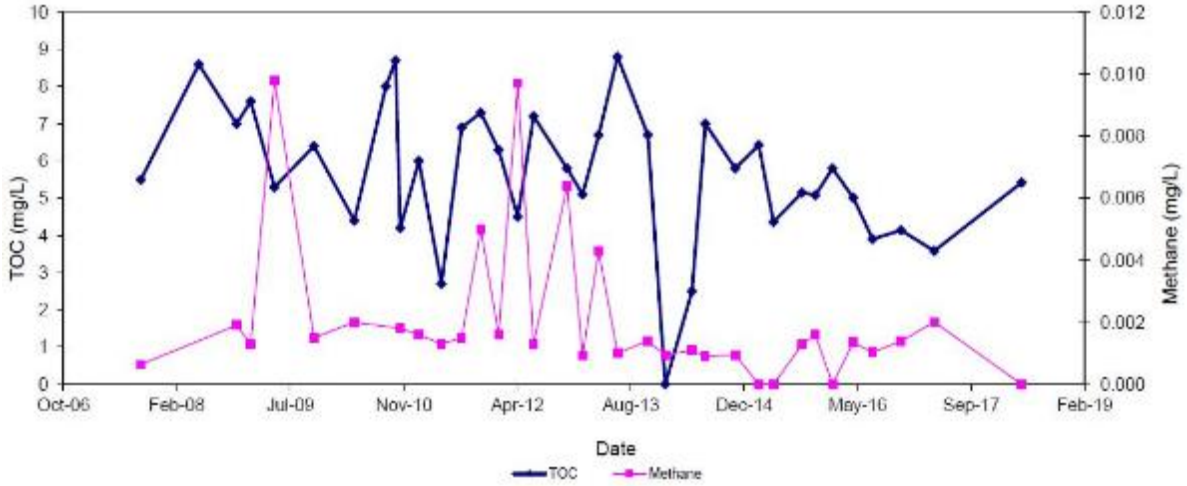
(A) Customized sand lens injection equipment.
(B) Guar-sand injection solution with rhodamine dye.
(C) DPT installation of sand lens.

LAKE CITY AAP BASELINE CONDITIONS

MW79 20 ft downgradient of injection well

Date	PCE (ug/L)	PCE (umol/L)	TCE (ug/L)	TCE (umol/L)	cis-1,2 DCE (ug/L)	cis-1,2 DCE (umol/L)	VC (ug/L)	VC (umol/L)	TCE:DCE mol ratio
9/18/07	3200	19.3	4600	35.0	7100	73.2	0	0	0.478
4/11/08									
4/24/08									
5/30/08									
11/12/08	2200	13.3	96000	731	3700	38.2	11.0	0.176	19.1
1/14/09	1100	6.63	120000	913	7800	80.5	0	0	11.3
4/28/09	6200	37.4	180000	1370	18000	186	0	0	7.37
10/19/09	1100	6.63	110000	837	11000	113	0	0	7.41
4/15/10	1400	8.62	205000	1560	33700	344	0	0	6.39
8/1/10									
10/14/10									
11/3/10	1050	6.33	84600	644	55700	575	0	0	1.12
1/25/11	1620	11.0	120000	913	56800	587	0	0	1.56
5/4/11	677	4.08	42500	323	48700	502	0	0	0.643
8/1/11	880	5.31	82100	625	59400	613	0	0	1.02
10/24/11	797	4.81	60100	457	78600	811	0	0	0.564
1/11/12	108	0.963	8670	66.2	10900	112	0	0	0.592
4/4/12	1070	6.46	78800	598	65400	675	0	0	0.886
6/13/12	2520	15.2	176000	1340	52500	542	0	0	2.47
11/7/12	1700	10.3	140000	1070	62000	640	0	0	1.65
1/15/13	2010	12.1	192000	1460	56000	601	0	0	2.43
3/27/13	2810	16.9	203000	1550	51500	531	0	0	2.92
6/18/13	1670	10.1	140000	1070	58100	599	0	0	1.79
10/29/13	2030	12.2	146000	1110	75600	780	0	0	1.42
1/14/14	2180	13.1	153000	1160	84700	874	0	0	1.33
6/12/14	3170	19.1	196000	1490	67200	693	0	0	2.15
7/9/14	2000	12.1	97600	743.0	102000	1050.0	0	0	0.708
11/18/14	168	1.0	90600	690.0	113000	1170.0	219	4	0.590
3/2/15	2310	13.9	114000	868.0	118000	1200.0	314	5	0.723
5/6/15	1340	8.1	79700	607.0	113000	1230.0	486	7	0.493
8/6/15	3100	18.7	154000	1170.0	88600	924.0	0	0	1.266
11/5/15	1320	8.0	85100	648.0	80700	832.0	358	6	0.779
1/20/16	1710	10.3	120000	913.0	81600	842.0	239	4	1.084
4/21/16	1730	10.4	90100	686.0	107000	1100.0	0	0	0.624
7/15/16	2340	14.1	107000	814.0	86800	895.0	199	3	0.909
11/17/16	1690	10.2	136000	1040.0	99800	1030.0	0	0	1.010
4/13/17	1660	10.0	124000	944.0	89900	927.0	0	0	1.018
9/8/18	4180	25.2	173000	1320.0	93200	961.0	0	0	1.374
5/22/19	2520	15.2	120000	858.0	67100	690.0	456	7	1.060

Contaminants & Degradation Products

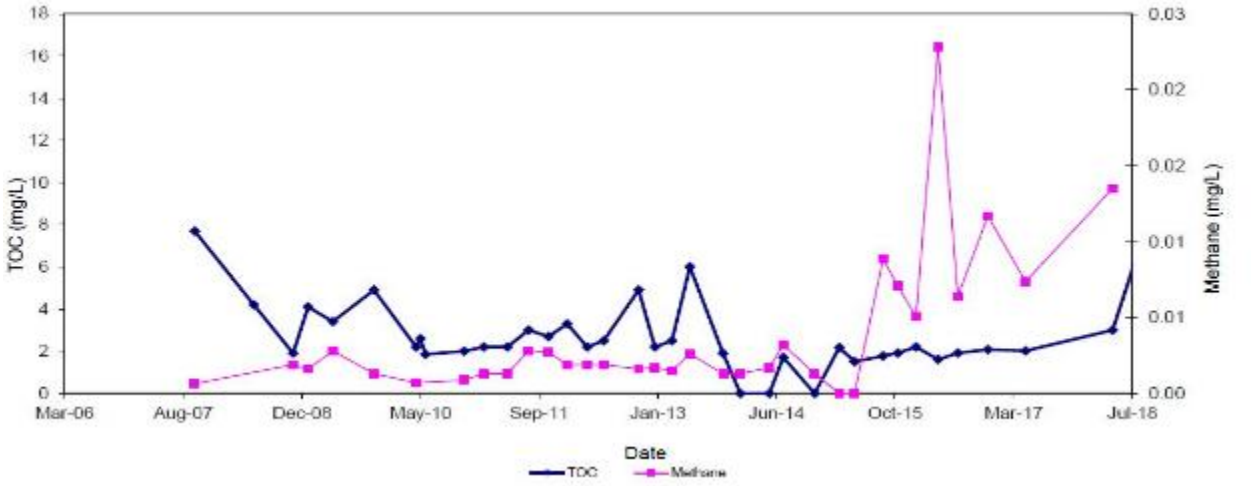


MW81 20 ft downgradient of injection well

Date	PCE (ug/L)	PCE (umol/L)	TCE (ug/L)	TCE (umol/L)	cis-1,2 DCE (ug/L)	cis-1,2 DCE (umol/L)	VC (ug/L)	VC (umol/L)	TCE:DCE mol ratio
9/24/07	5300	32.0	169000	1290	38800	402	0	0	3.03
5/30/08									
11/12/08	3000	18.1	208000	1585	19000	196	0	0	1.01
1/14/09	990	5.97	56000	426	20000	209	0	0	1.47
4/28/09	2100	12.7	82000	624	27000	279	0	0	2.24
10/19/09	1300	7.84	20000	152	5500	56.7	0	0	2.68
4/15/10	1180	7.12	2350	17.9	1430	14.8	0	0	1.21
8/3/10									
5/24/10									
11/3/10	557	3.36	25200	192	20200	208	0	0	0.923
1/25/11	1140	6.87	27400	209	20200	208	0	0	1.00
5/4/11	571	3.44	13100	99.7	16500	170	0	0	0.586
8/1/11	769	4.64	16300	124	22000	227	0	0	0.546
10/24/11	772	4.66	21500	164	26000	268	0	0	0.612
1/11/12	1190	7.18	42100	320	48100	496	0	0	0.645
4/4/12	1200	7.24	31900	243	60700	626	0	0	0.388
6/13/12	1460	8.80	52900	400	54200	559	0	0	0.716
11/7/12	1640	9.89	47100	358	49100	506	0	0	0.708
1/15/13	1960	11.8	61600	469	70300	725	0	0	0.647
3/28/13	2640	15.9	78500	597	60200	621	0	0	0.961
6/11/13	2420	14.6	38700	295	30700	317	0	0	0.931
10/29/13	2440	14.7	54400	414	43400	448	0	0	0.924
1/10/14	3210	19.4	77000	586	60000	619	0	0	0.947
5/12/14	3140	18.9	65800	499	46300	478	0	0	1.04
7/9/14	2780	16.8	49800	379	36000	371	0	0	1.02
11/18/14	3240	19.5	72500	552	52300	539	0	0	1.02
3/2/15	3090	18.6	68700	523	43100	445	0	0	1.18
5/6/15	2100	13.1	43100	328	20900	280	0	0	1.10
9/3/15	2240	13.0	39000	301	27200	281	81	1	1.07
11/4/15	2180	13.1	40800	311	56800	586	0	0	0.53
1/20/16	1860	11.2	47000	362	42400	437	0	0	0.83
4/22/16	1750	10.6	27100	206	18500	191	0	0	1.08
7/14/16	1760	10.6	32300	246	25100	259	0	0	0.95
11/18/16	2280	13.7	61200	990	39600	408	0	0	0.96
4/25/17	2690	16.2	62000	624	50500	503	173	3	1.07
4/27/18	1780	10.7	34700	264	24600	254	0	0	1.04
5/22/19	1260	7.6	24300	185	22100	228	0	0	0.81

Results below reporting limits are presented as zero

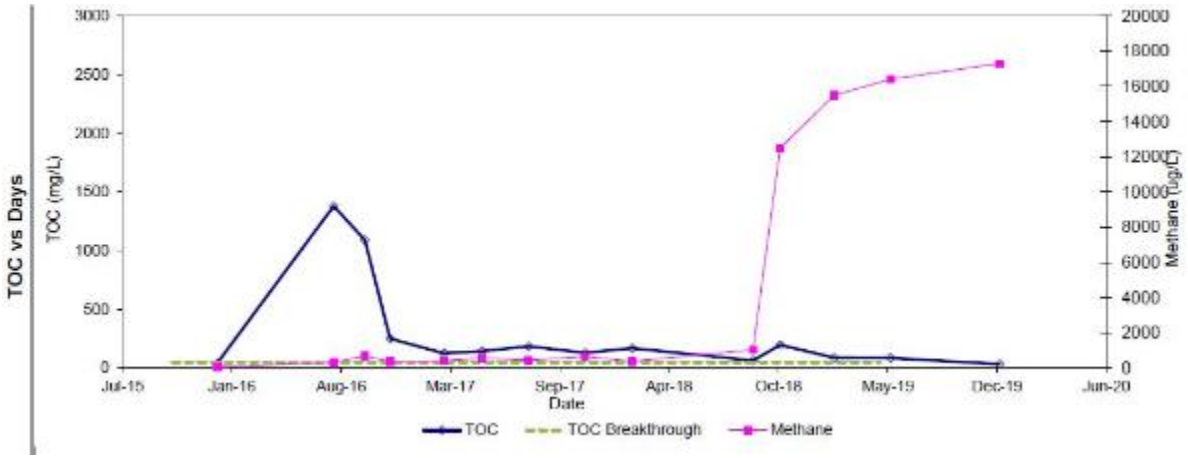
Contaminants & Degradation Products



LAKE CITY AAP FRACTURING TREND RESULTS

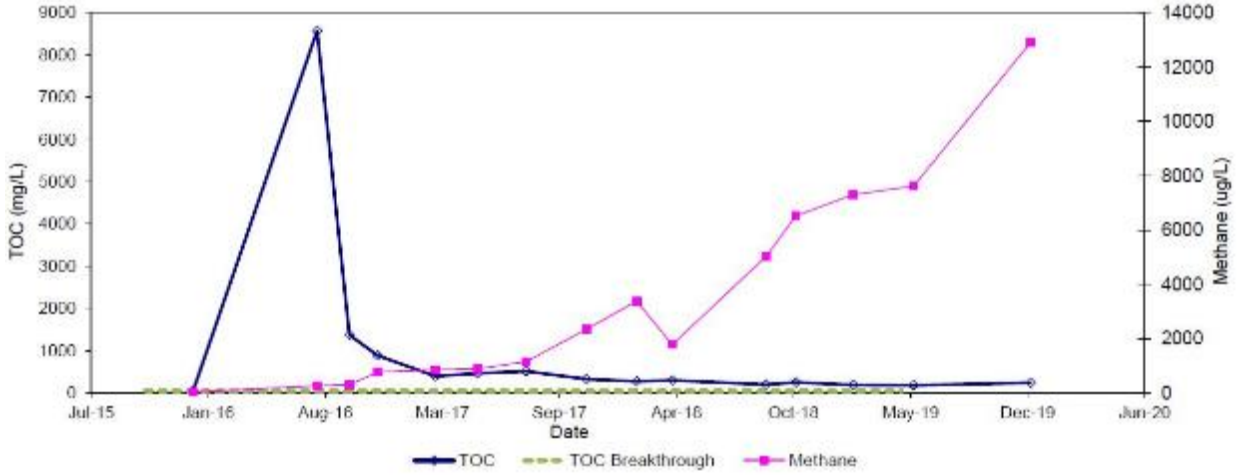
17MW129 20 ft downgradient of injection well

Date	PCE (ug/L)	PCE (umol/L)	TCE (ug/L)	TCE (umol/L)	cis-1,2 DCE (ug/L)	cis-1,2 DCE (umol/L)	VC (ug/L)	VC (umol/L)	TCE:DCE mol ratio
1/4/2016	366	2	20200	154.000	56500.00	583.0000	563	9	0.3
8/4/2016	0	0	931	7.09	82400	850	8590	137	0.008
9/30/2016	0	0	1370	10.40	66600	687	5710	91	0.015
11/15/2016	0	0	0	0.00	298000	3070	13100	210	0.000
2/22/2017	0.00	0.00	0.00	0.00	278000	2870	12200	195	0.000
5/3/2017	0.00	0.00	12700	96.70	242000	2500	17800	285	0.039
7/27/2017	0.00	0.00	12800.00	97.40	290000	2990	15300	245	0.033
11/7/2017	0.00	0.00	15600.00	119.00	219000	2260	11500	184	0.053
12/8/2017									
2/1/2018	0.00	0.00	5160.00	39.30	206000	2120	26000	416	0.019
9/10/2018	308	2	23900	182	266000	2740.00	33700	539.00	0.066
10/30/2018	0	0	3100.0	23.600	60400	623.00	35100.0	562.000	0.038
2/6/2019	0.00	0.00	1810.00	13.80	5760.00	59.40	5860.00	94.10	0.232
5/20/2019	0	0	2260	17.20	4320.0	44.600	1640	26	0.386
12/6/2019	0	0	9.3	0.071	348	3.59	386.00	6.1800	0.020



17MW131 mid-point between injection wells

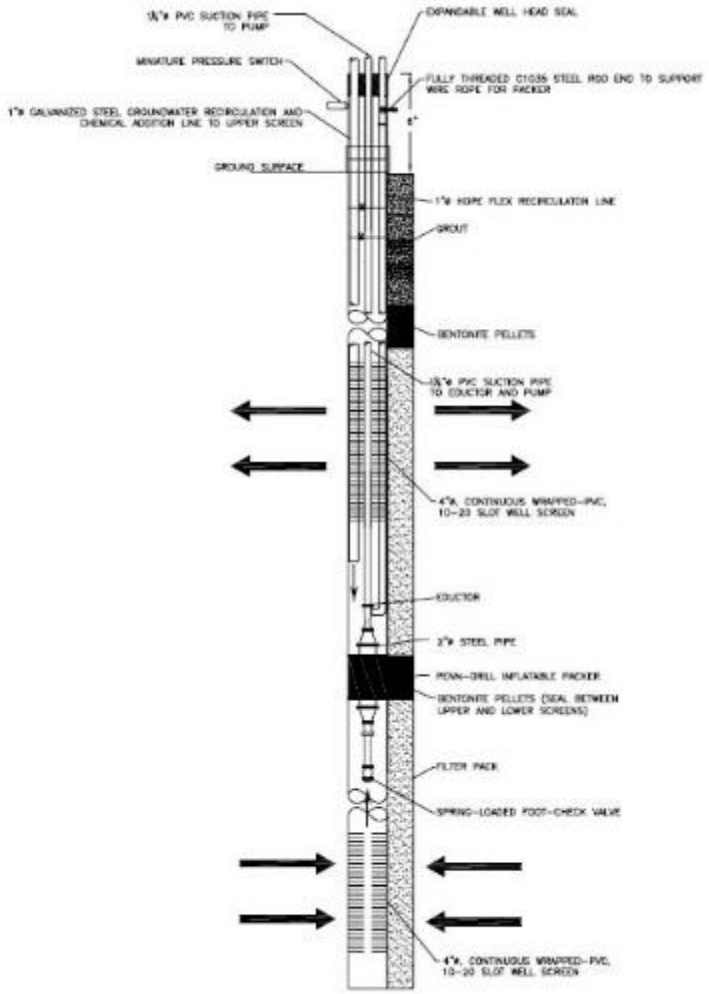
Date	PCE (ug/L)	PCE (umol/L)	TCE (ug/L)	TCE (umol/L)	cis-1,2 DCE (ug/L)	cis-1,2 DCE (umol/L)	VC (ug/L)	VC (umol/L)	TCE:DCE mol ratio
1/5/2016	394	2	21200	161.00	89400.0	922.000	446.000	7.1400	0.17
8/4/2016	0	0	363	2.760	40700	420.00	3000.00	48.0000	0.007
9/26/2016	0	0	1180	8.96	54100.0	558.000	2350	38	0
11/15/2016	0	0	332.0	2.530	120000	1240.00	3210.0	51.400	0.002
2/22/2017	0	0	0.0	0.000	141000	1450.00	8840	141.00	0.000
5/5/2017	0.00	0.00	0.00	0.00	177000.00	1830.00	11600.00	186.00	0
7/27/2017	0.00	0.00	0.00	0.00	202000.00	2080.00	14000.00	224.00	0
11/7/2017	0	0	0.0	0.0000	164000.0	1690.000	13400.0	214.00	0.000
12/8/2017									
2/1/2018	0	0	0.00	0.0000	140000.0	1440.000	51800.0	829.000	0.0000
4/3/2018	0	0	0	0	115000	1190.00	42000	672.00	0
9/10/2018	0	0	86.00	0.6550	127000.0	1310.000	65000.0	1040.000	0.0005
10/31/2018	0.00	0.00	0.00	0.00	93100.00	960.00	46900.00	750.00	0
2/6/2019	0	0	0	0.00	118000.0	1220.000	71700	1150	0
5/20/2019	0	0	233.00	1.7700	115000.0	1190.000	44500.0	712.00	0.0015
12/6/2019	0	0	0.000	0.00000	50900.0	525.000	68300.0	1090.000	0



ABERDEEN PG ALTERNATIVE AMENDMENT CASE STUDY

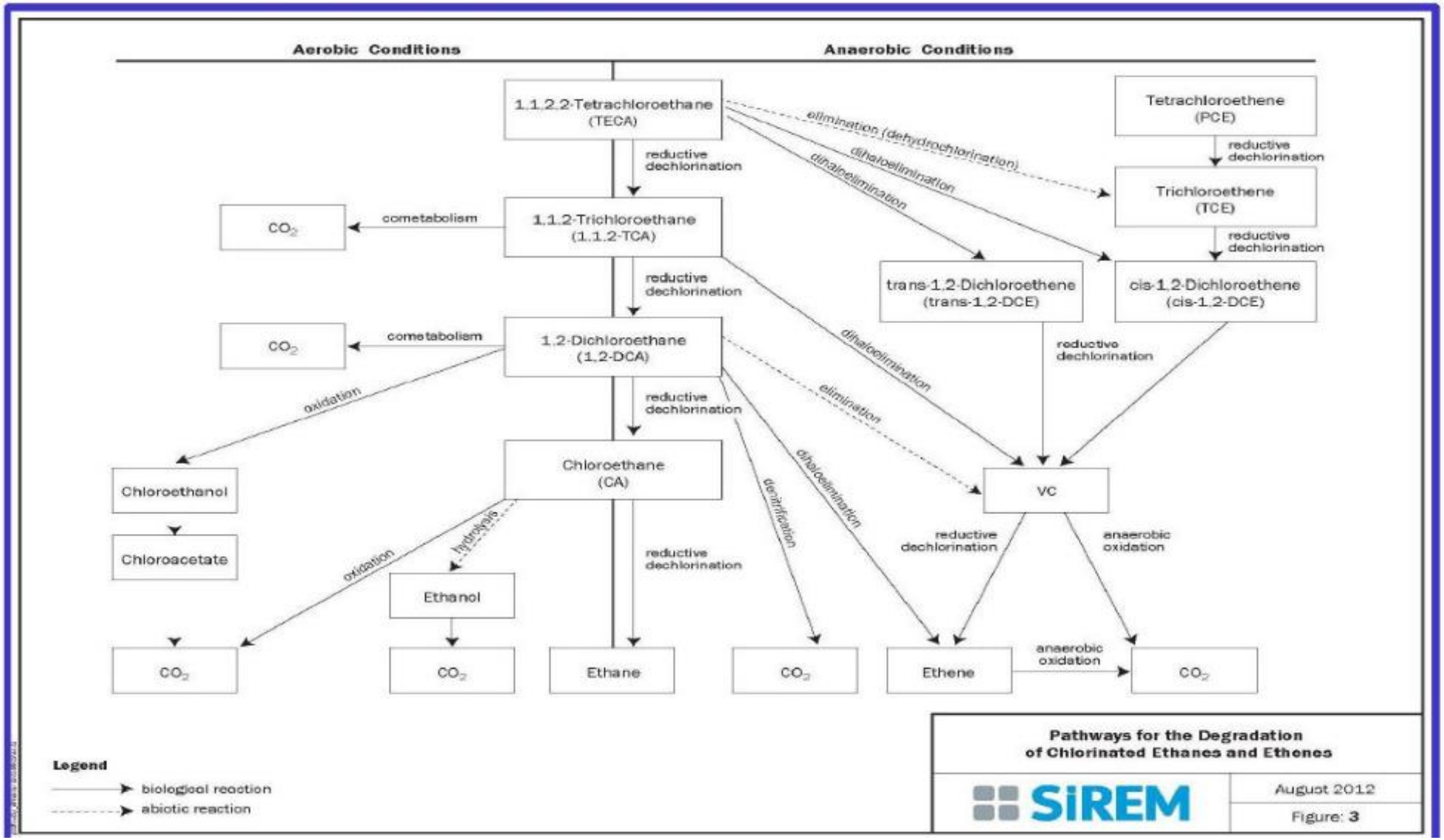
SUMMARY

- TeCA primary groundwater chemical of concern.
- Vitamin B12/titanium citrate/carbon source amendment used for abiotic/biotic degradation.
- Delivery by groundwater recirculation wells.
- TeCA & daughter products effectively degraded by both mechanisms.
- Dissolved phase degradation occurred quickly.
- Rebound in areas from silty-clay units addressed by cyclic operation until plateau levels reached.
- Microbial assay testing after shutdown showed marginal levels of DHCs, DHBs, and VCR – demonstrated biodegradation, but not sustained.

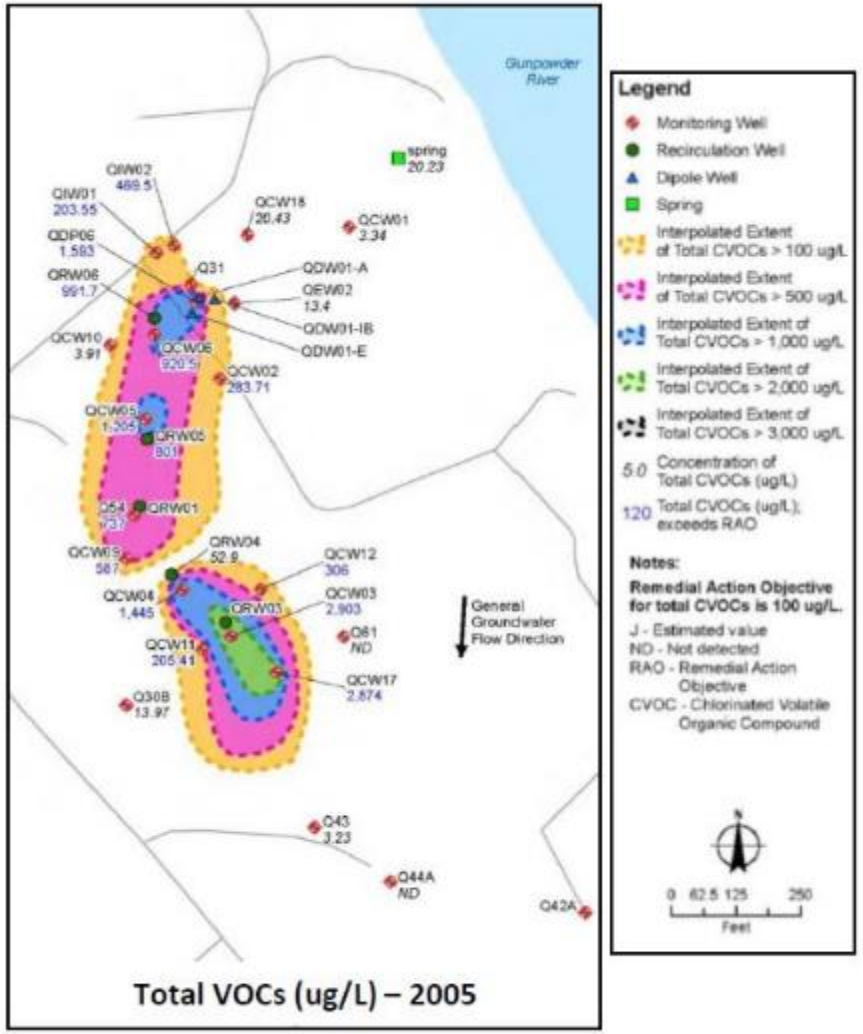


DEEP RECIRCULATION WELL CONSTRUCTION DETAIL
N.T.S.

ABERDEEN PG TECA DEGRADATION PATHWAYS



ABERDEEN PG TITANIUM CITRATE CASE STUDY



Legend

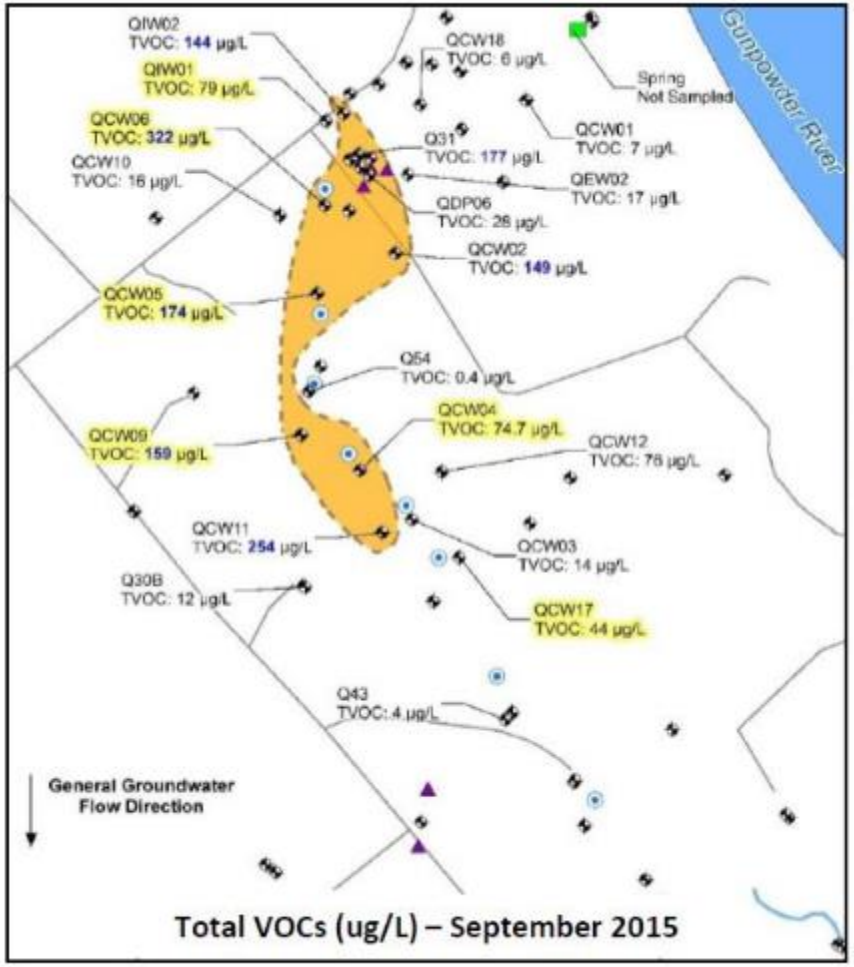
- Monitoring Well
- Recirculation Well
- Dipole Well
- Spring
- Interpolated Extent of Total CVOCs > 100 ug/L
- Interpolated Extent of Total CVOCs > 500 ug/L
- Interpolated Extent of Total CVOCs > 1,000 ug/L
- Interpolated Extent of Total CVOCs > 2,000 ug/L
- Interpolated Extent of Total CVOCs > 3,000 ug/L
- 5.0 Concentration of Total CVOCs (ug/L)
- 120 Total CVOCs (ug/L); exceeds RAO

Notes:

Remedial Action Objective for total CVOCs is 100 ug/L.

J - Estimated value
ND - Not detected
RAO - Remedial Action Objective
CVOC - Chlorinated Volatile Organic Compound

0 62.5 125 250 Feet



Well Type

- Dipole
- Monitoring
- Recirculation
- Spring

TVOC Isocontours

> 100 µg/L

Notes:

Interim Remedial Goal (IRG) for TVOC = 100 µg/L
J = Estimated Value
TVOC = Total Volatile Organic Compounds

560
Blue values indicate an exceedance of the IRG.

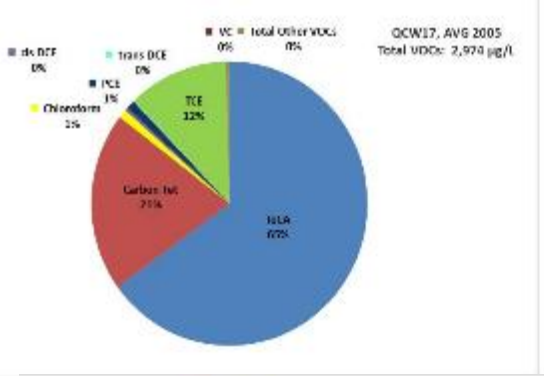
QC52
Highlighted labels indicate wells that were selected for VOC constituent pie-charts on the following slide.

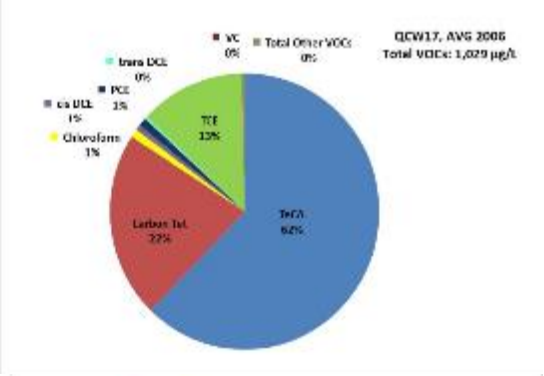
N

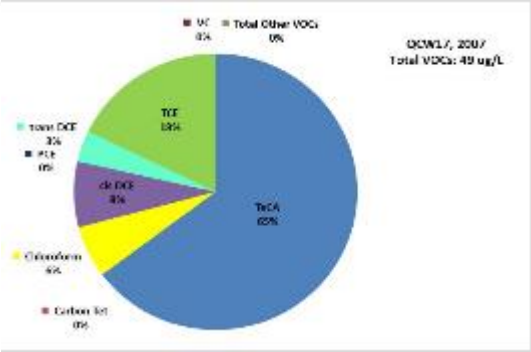
0 115 230 Feet

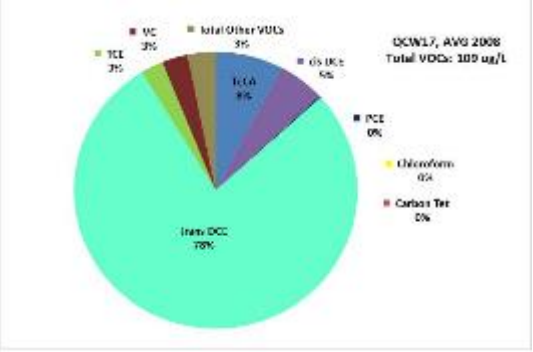
ABERDEEN PG DEGRADATION TRENDS

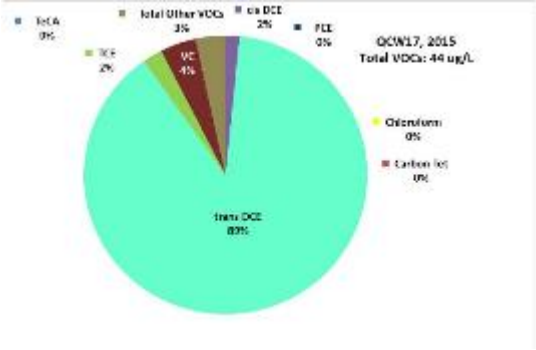
Monitoring Well QCW17 – Northern End of Plume

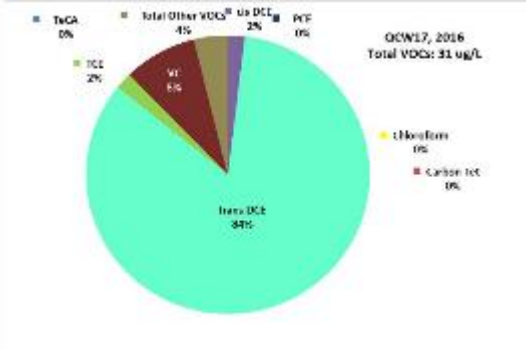




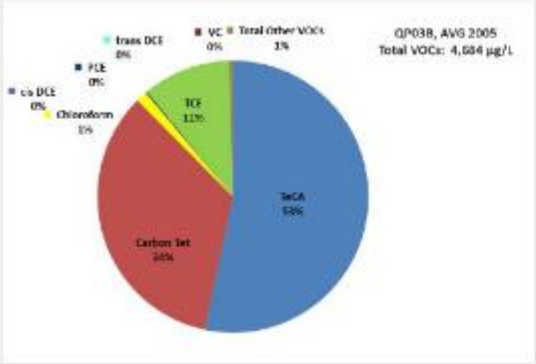


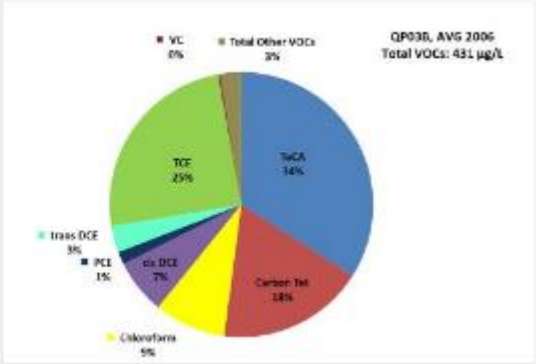


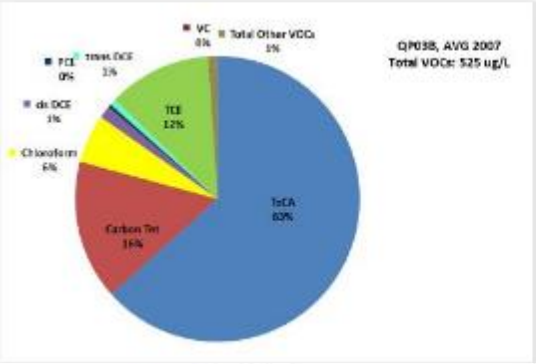


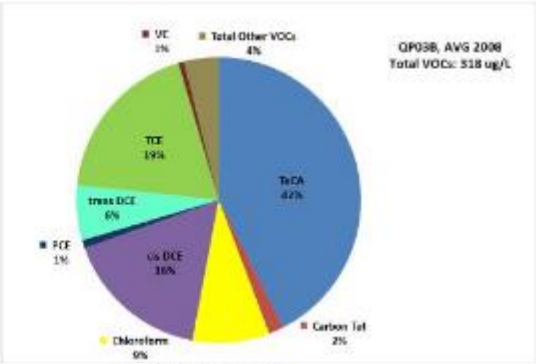


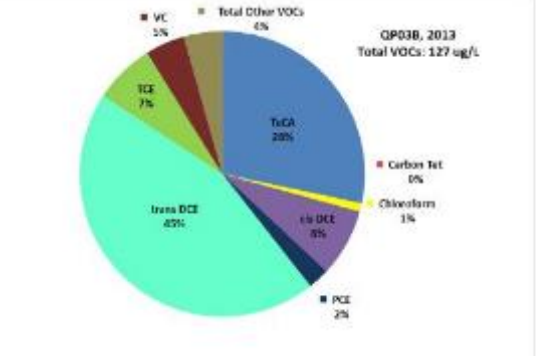
Monitoring Well QP03B – Middle of Plume

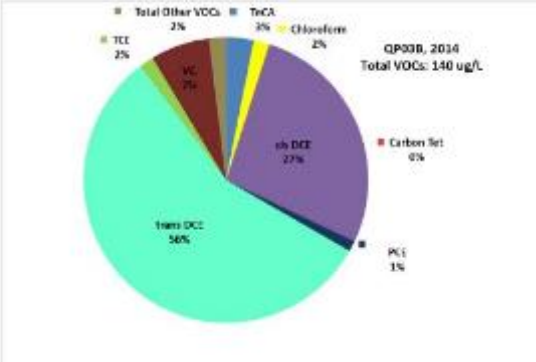












QUESTIONS ?