

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

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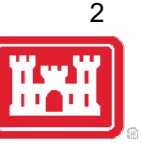


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PRESENTATION OUTLINE



➤ 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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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])

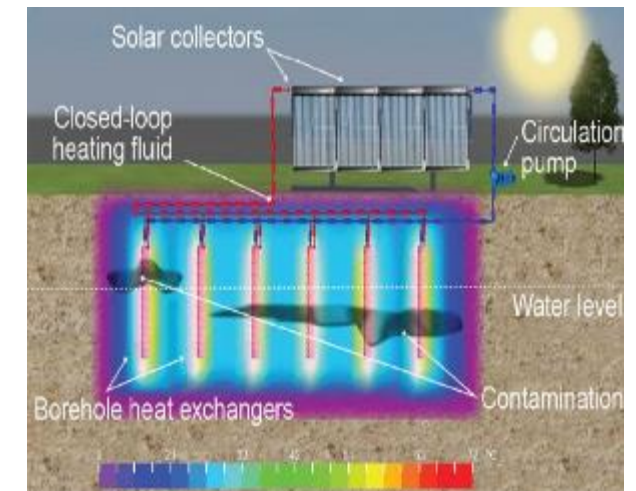
Reference: Microbial Insights, Inc. webinar titled “DCE Stall: Causes and Cures” by Robert Borden, PE, PhD, EOS Remediation, LLC

AMENDMENT DELIVERY ENHANCEMENTS

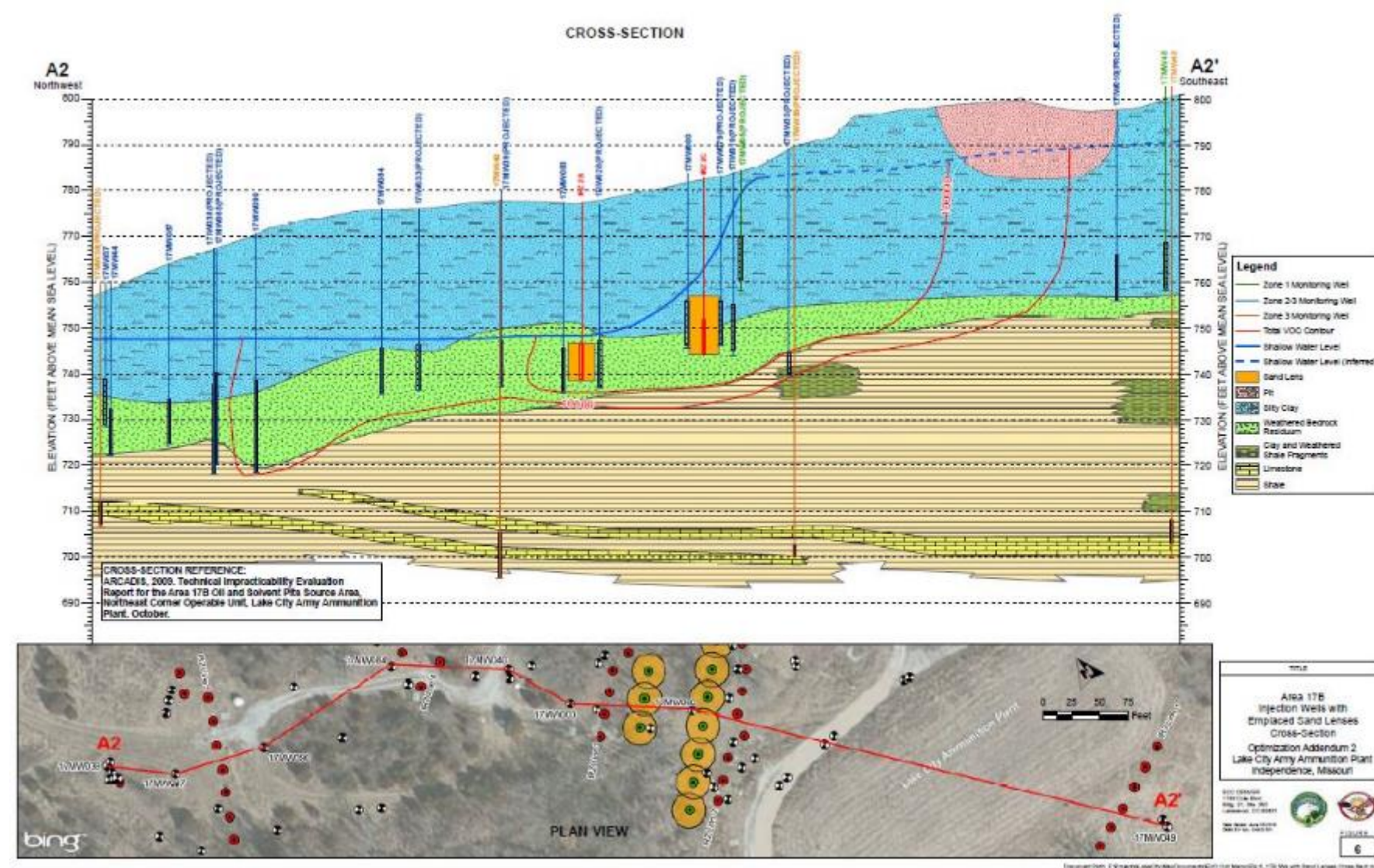


- Groundwater recirculation
- Targeted injection depth(s)
- Fracturing/high pressure jetting
- Large diameter augers
- “Grout Bomber” (ESTCP Project ER201627)
- Heat enhancements (ESTCP Projects ER200719 & 205028 [awarded June 2020])

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

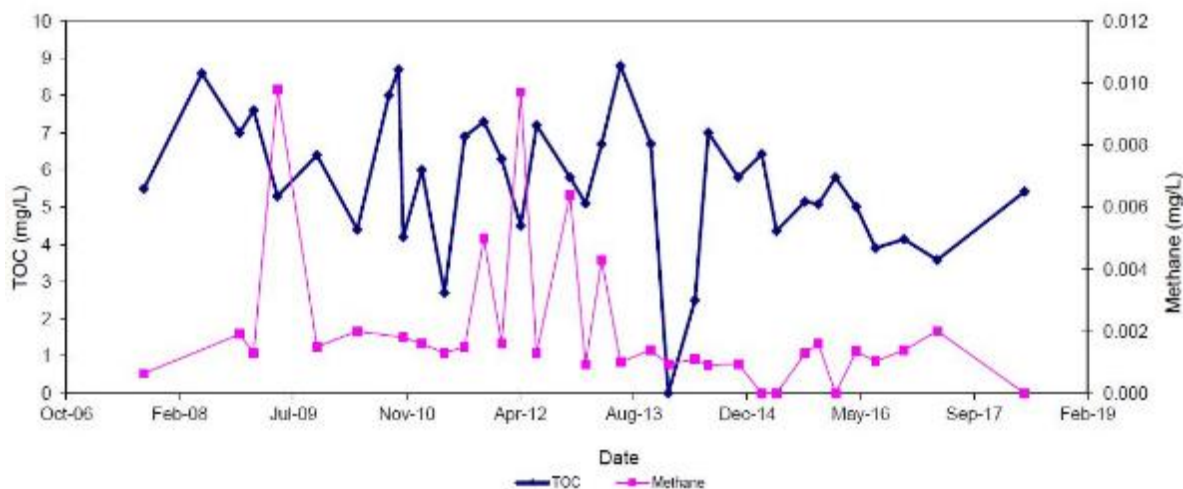
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MW79 20 ft downgradient of injection well

Contaminants & Degradation Products

Date	PCE		TCE		cis-1,2 DCE		VC		TCE:DCE mol ratio
	(ug/L)	(umol/L)	(ug/L)	(umol/L)	(ug/L)	(umol/L)	(ug/L)	(umol/L)	
5/18/07	3200	19.3	4600	35.0	2100	23.2	0	0	0.478
2/15/08									
4/24/08									
6/30/08									
11/12/08	2200	13.3	38000	231	3700	38.2	11.0	0.176	19.1
1/14/09	1100	6.63	120000	913	7800	80.6	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
3/15/10	1400	8.82	205000	1560	23700	244	0	0	6.39
8/1/10									
10/14/10									
11/29/10	1050	6.33	84800	644	55700	575	0	0	1.12
1/25/11	1620	11.0	120000	913	56900	587	0	0	1.50
5/4/11	677	4.08	42500	323	45700	462	0	0	0.613
8/3/11	880	5.31	82100	625	55400	563	0	0	1.02
10/24/11	797	4.81	60100	457	78600	811	0	0	0.564
1/11/12	108	0.663	6070	46.2	10900	112	0	0	0.582
4/4/12	1070	6.46	78600	598	65400	670	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	1450	56300	581	0	0	2.40
3/27/13	2810	16.9	203000	1550	51500	531	0	0	2.52
6/19/13	1670	10.1	140000	1070	58100	599	0	0	1.79
10/29/13	2530	12.2	146000	1110	75600	780	0	0	1.42
1/14/14	2180	13.1	153000	1160	84700	874	0	0	1.38
6/12/14	3170	19.1	156000	1190	67200	693	0	0	2.16
7/29/14	2000	12.1	97800	743.0	102000	1050.0	0	0	0.708
11/18/14	168	1.0	80600	620.0	115000	1170.0	219	4	0.580
3/2/15	2310	13.9	114000	888.0	118000	1200.0	314	5	0.723
5/8/15	1340	8.1	79700	607.0	115000	1230.0	489	7	0.493
8/6/15	3100	18.7	154000	1170.0	89600	924.0	0	0	1.266
11/6/15	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
2/21/16	1730	10.4	38100	290.0	107000	1100.0	0	0	0.624
7/15/16	2340	14.1	102700	784.0	86600	885.0	199	3	0.963
11/17/16	1690	10.2	136000	1040.0	95800	1030.0	0	0	1.010
4/13/17	1860	10.0	124000	944.0	89900	927.0	0	0	1.018
5/9/18	4180	26.2	173000	1320.0	93200	961.0	0	0	1.374
5/23/19	2520	15.2	136000	839.0	67100	690.0	456	7	1.060

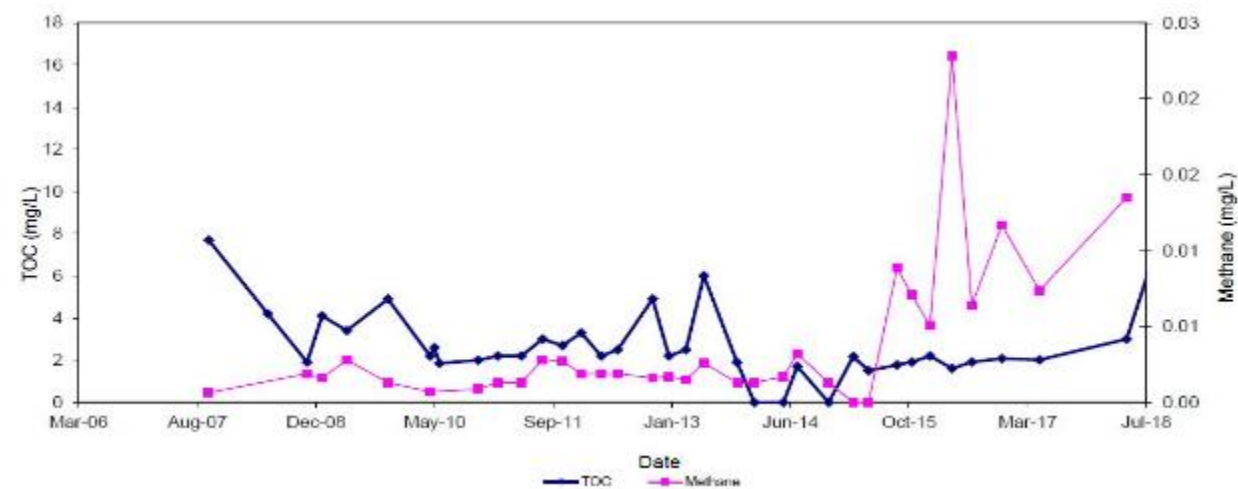


MW81 20 ft downgradient of injection well

Contaminants & Degradation Products

Date	PCE		TCE		cis-1,2 DCE		VC		TCE:DCE mol ratio
	(ug/L)	(umol/L)	(ug/L)	(umol/L)	(ug/L)	(umol/L)	(ug/L)	(umol/L)	
5/24/07	5100	32.0	160000	1220	39000	402	0	0	3.03
5/30/08									
11/12/08	29000	18.1	29300	198	19000	198	0	0	1.01
1/14/09	880	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	7.64	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
5/3/10									
5/24/10									
11/3/10									
1/25/11	557	3.36	25200	192	20200	208	0	0	0.929
5/4/11	1140	6.87	27400	209	20200	208	0	0	1.00
8/3/11	571	3.44	13100	99.7	18600	170	0	0	0.586
10/3/11	789	4.84	16200	124	22000	227	0	0	0.546
10/24/11	772	4.66	21500	164	28000	268	0	0	0.812
1/11/12	1190	7.18	42100	320	48100	458	0	0	0.645
4/4/12	1200	7.24	31800	243	60700	626	0	0	0.300
6/13/12	1460	8.80	52800	400	54200	559	0	0	0.716
11/7/12	1640	9.08	47100	350	49100	506	0	0	0.700
1/10/13	1960	11.8	61600	469	70900	725	0	0	0.647
3/20/13	2640	15.8	70500	587	60200	621	0	0	0.861
6/11/13	2420	14.6	38700	295	30700	317	0	0	0.991
10/29/13	2440	14.7	54400	414	43400	440	0	0	0.824
1/10/14	3210	19.4	77000	586	60000	619	0	0	0.947
5/12/14	3130	18.0	85800	659	35300	378	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	52000	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	320	20900	280	0	0	1.10
9/3/15	2240	13.0	39500	301	27200	281	81	1	1.07
11/4/15	2180	13.1	40800	311	58800	588	0	0	0.53
1/20/16	1850	11.2	47000	362	42400	437	0	0	0.83
4/22/16	1750	10.6	27100	208	18500	191	0	0	1.08
7/14/16	1780	10.8	32300	248	25100	259	0	0	0.95
11/18/16	2280	13.7	61200	469	39600	408	0	0	0.96
4/25/17	2680	16.2	62000	624	56500	583	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





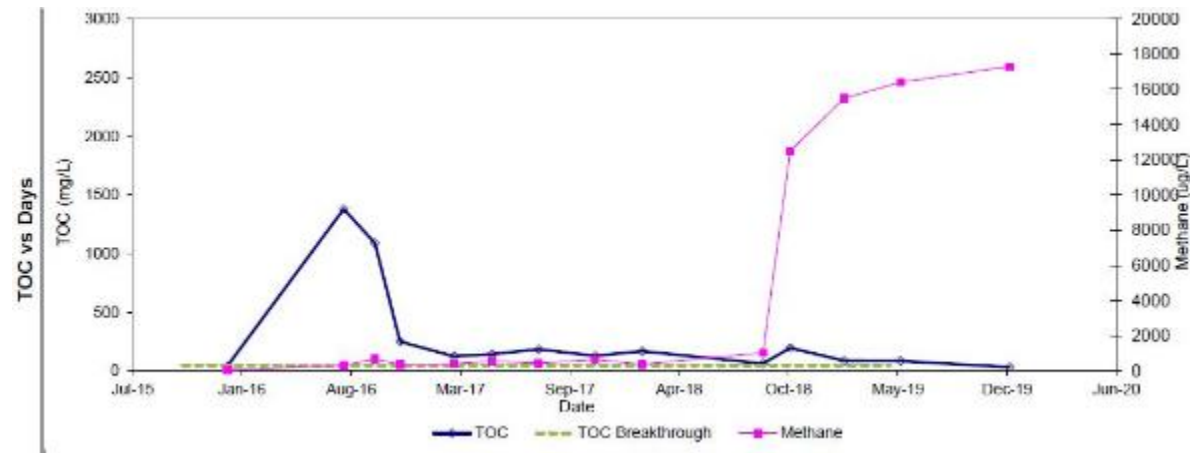
LAKE CITY AAP FRACTURING TREND RESULTS

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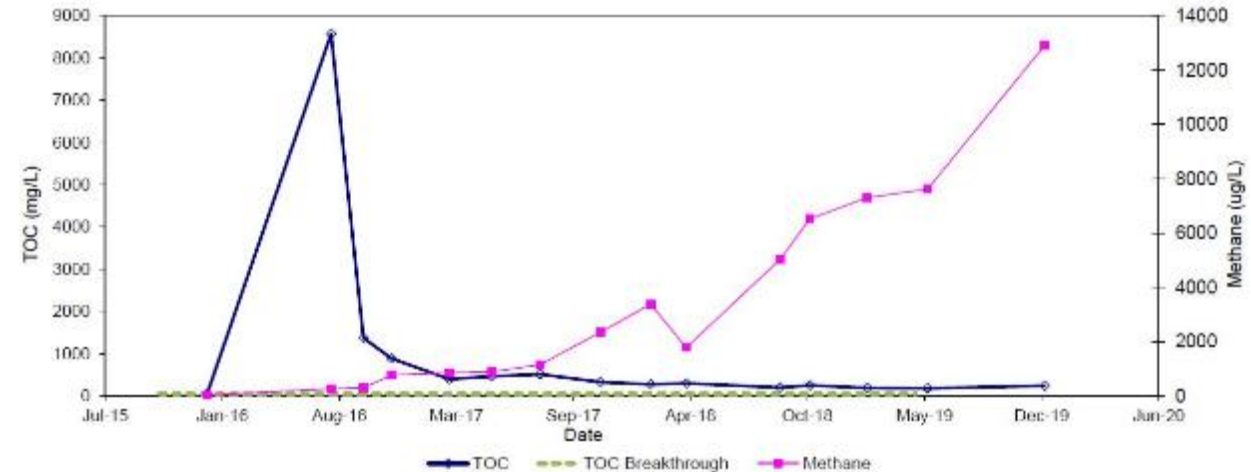
17MW129 20 ft downgradient of injection well

Date	PCE		TCE		cis-1,2 DCE		VC		TCE:DCE mol ratio
	(ug/L)	(umol/L)	(ug/L)	(umol/L)	(ug/L)	(umol/L)	(ug/L)	(umol/L)	
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	68600	687	5710	91	0.015
11/15/2016	0	0	0	0.00	296000	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	5880.00	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



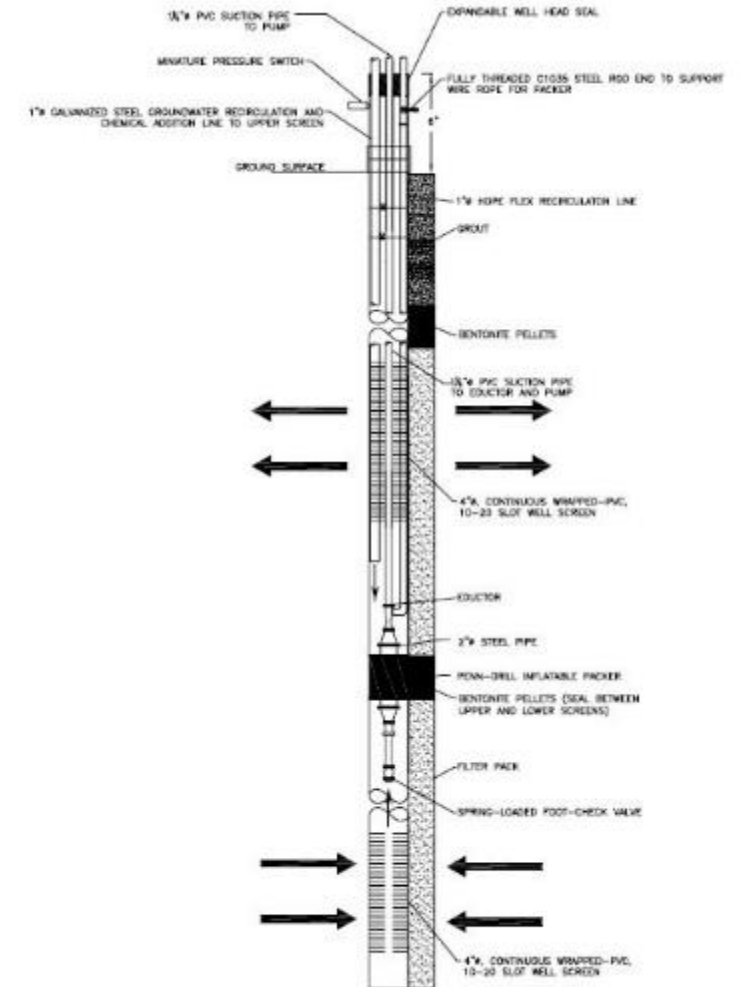
17MW131 mid-point between injection wells

Date	PCE		TCE		cis-1,2 DCE		VC		TCE:DCE mol ratio
	(ug/L)	(umol/L)	(ug/L)	(umol/L)	(ug/L)	(umol/L)	(ug/L)	(umol/L)	
1/5/2016	394	2	21200	161.00			89400.0	922.000	0.17
8/4/2016	0	0	363	2.760			40700	420.00	0.007
9/26/2016	0	0	1180	8.98			54100.0	558.000	0
11/15/2016	0	0	332.0	2.530			120000	1240.00	0.002
2/22/2017	0	0	0.0	0.000			141000	1450.00	0.000
5/5/2017	0.00	0.00	0.00	0.00			177000.00	1830.00	0
7/27/2017	0.00	0.00	0.00	0.00			202000.00	2080.00	0
11/7/2017	0	0	0.0	0.0000			164000.0	1690.000	0.000
12/8/2017									
2/1/2018	0	0	0.00	0.0000			140000.0	1440.000	0.0000
4/3/2018	0	0	0	0			115000	1190.00	0
9/10/2018	0	0	86.00	0.6550			127000.0	1310.000	0.0005
10/31/2018	0.00	0.00	0.00	0.00			93100.00	960.00	0
2/6/2019	0	0	0	0.00			118000.0	1220.000	0
5/20/2019	0	0	233.00	1.7700			115000.0	1190.000	0.0015
12/6/2019	0	0	0.000	0.00000			50900.0	525.000	0



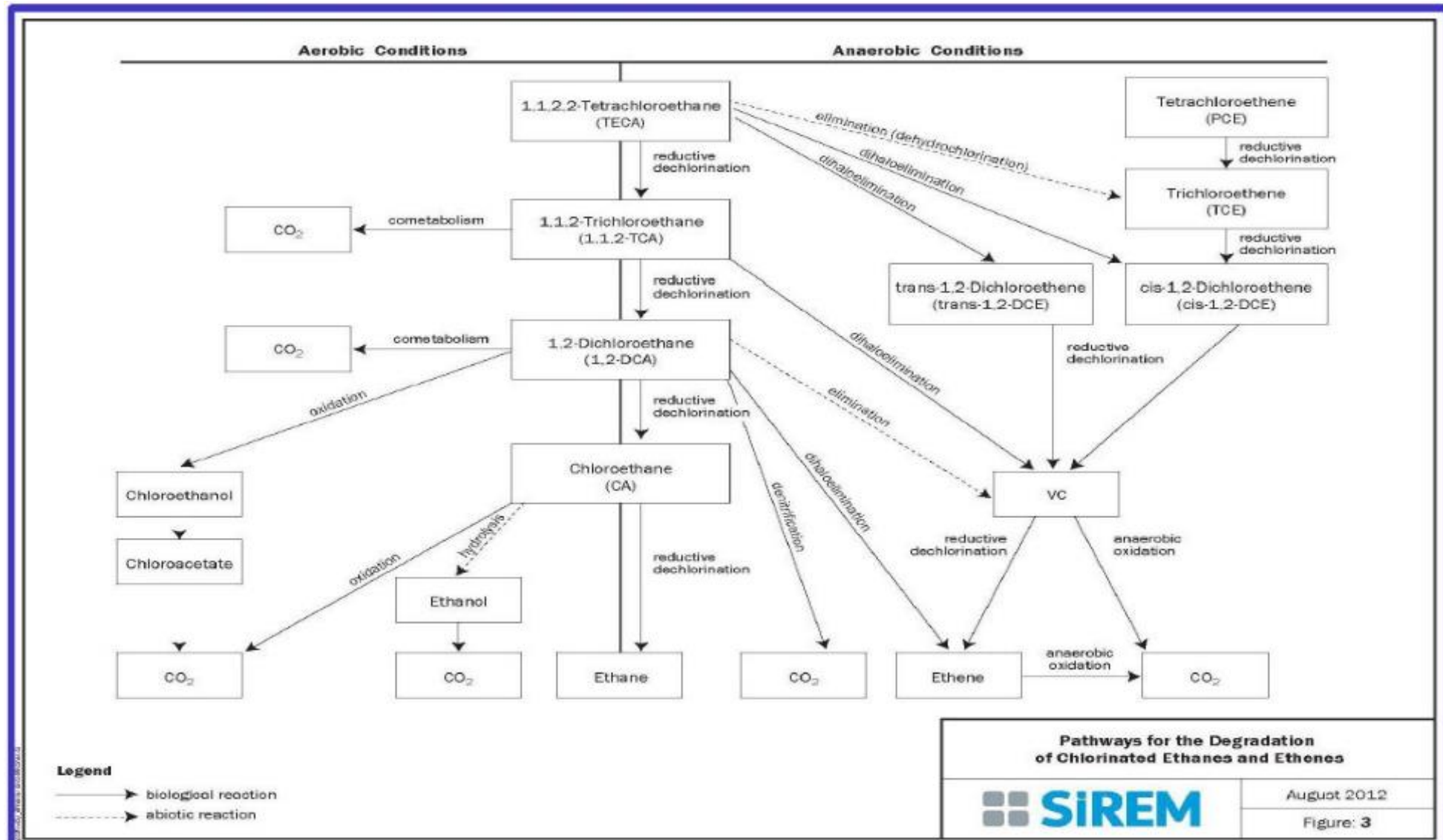
SUMMARY

- 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.

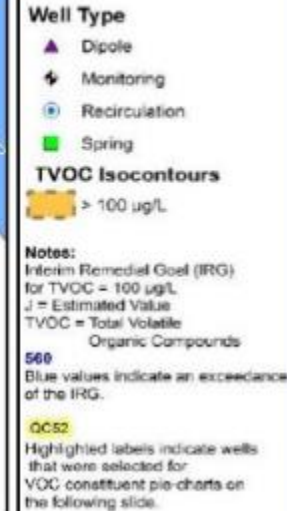
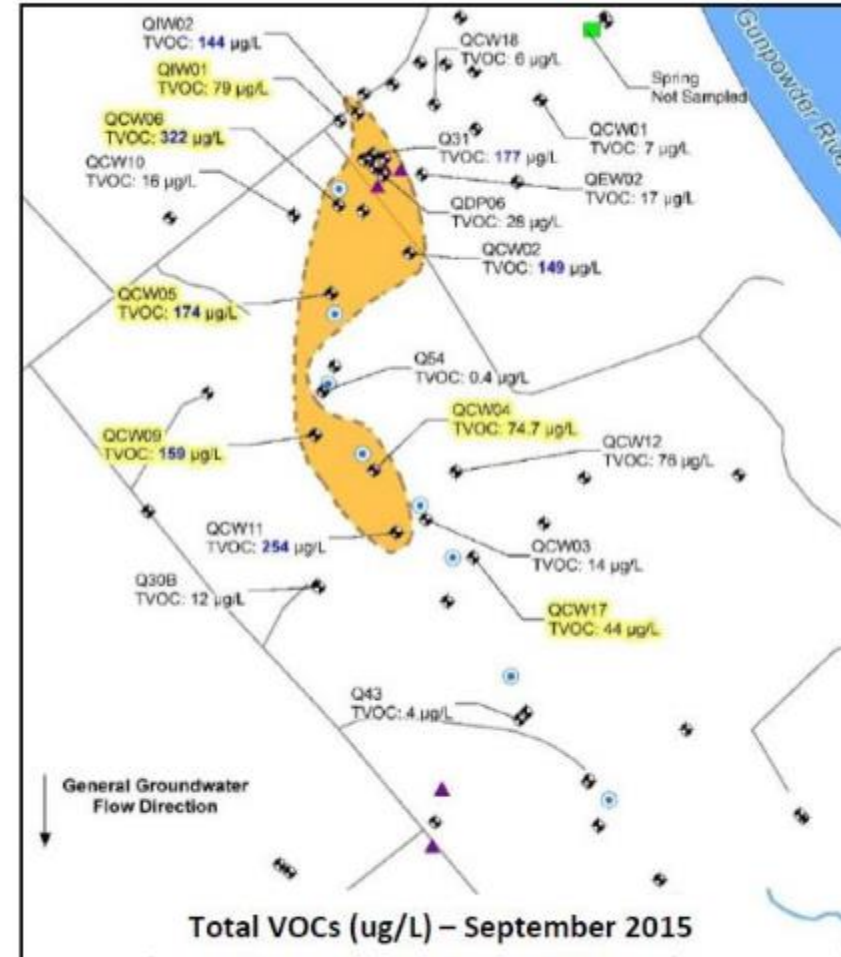
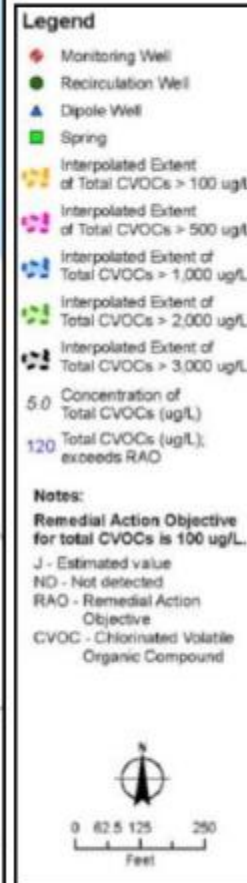
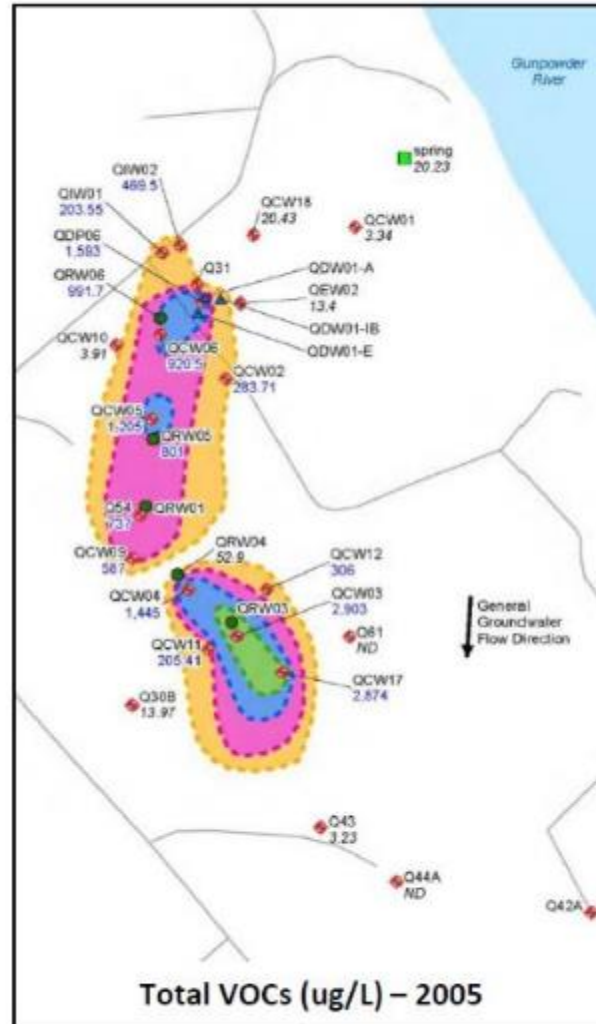


DEEP RECIRCULATION WELL CONSTRUCTION DETAIL
N.T.S.

ABERDEEN PG TECA DEGRADATION PATHWAYS



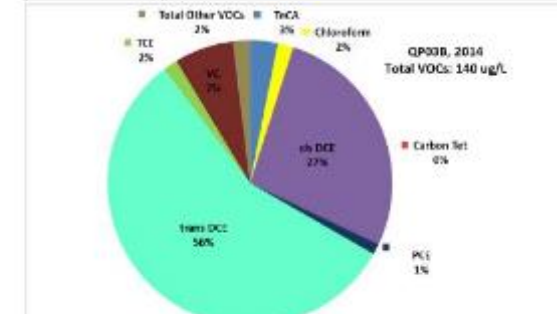
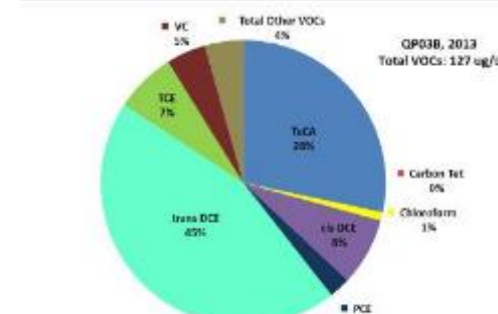
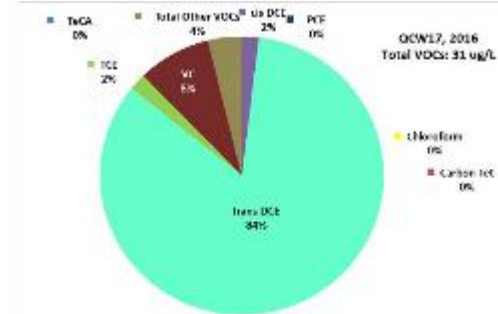
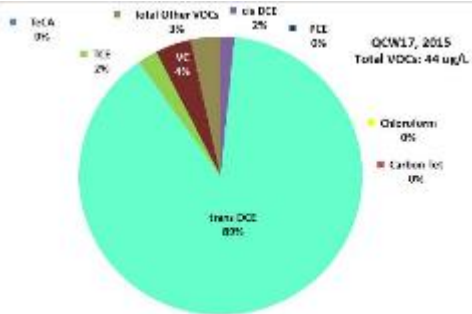
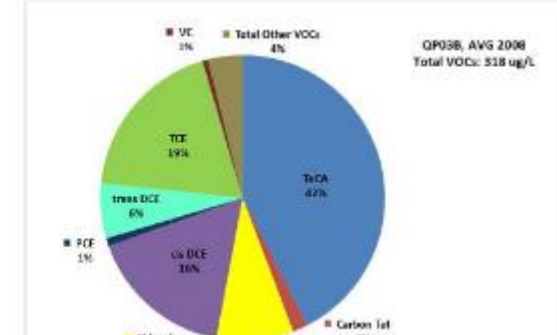
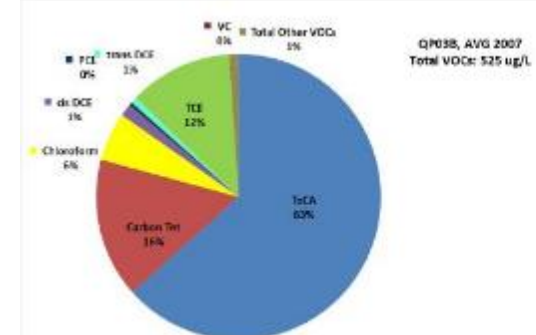
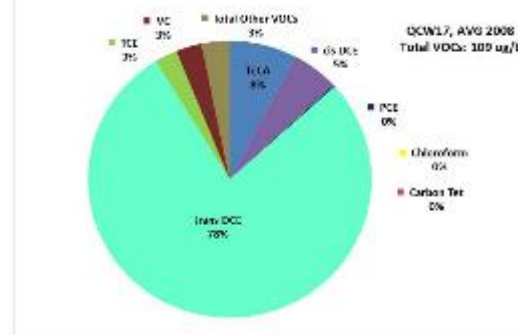
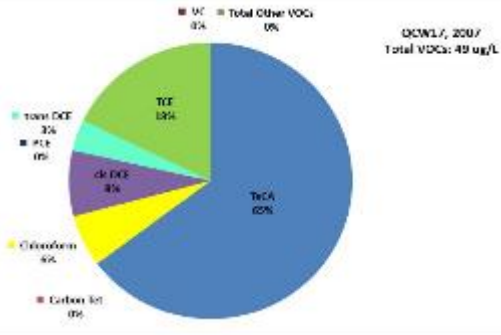
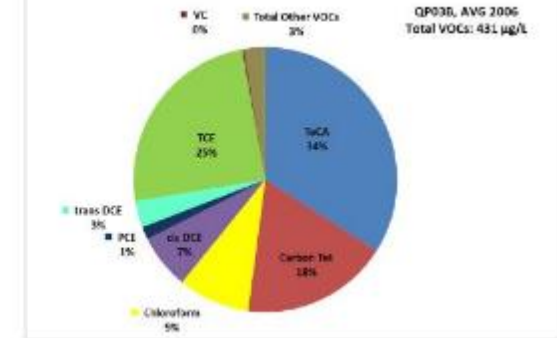
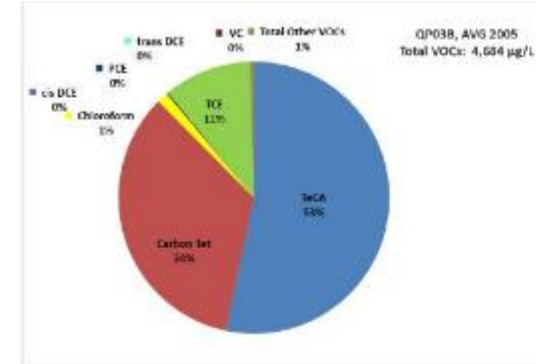
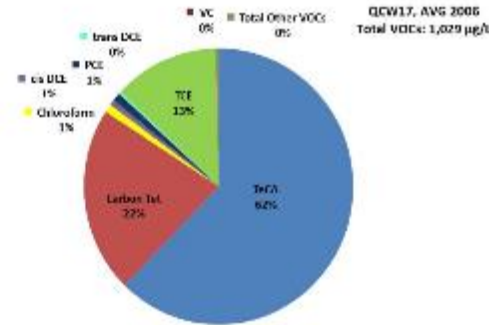
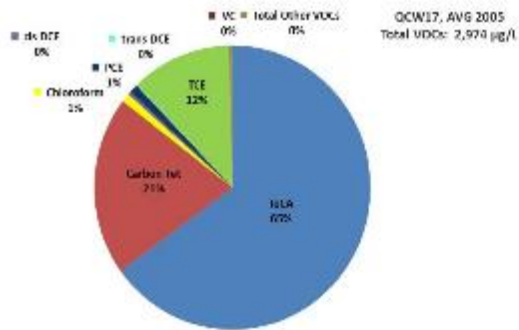
ABERDEEN PG TITANIUM CITRATE CASE STUDY



ABERDEEN PG DEGRADATION TRENDS

Monitoring Well QCW17 – Northern End of Plume

Monitoring Well QP03B – Middle of Plume





QUESTIONS ?