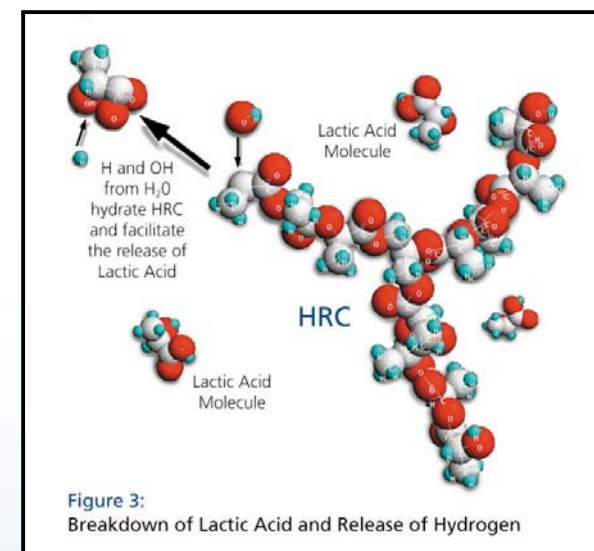


**A decade of large-scale enhanced reductive dechlorination;**  
the evolution in the usage of a high-volume controlled-  
release electron donor substrate

**Gareth Leonard**  
**Managing Director**  
**REGENESIS**

# Introduction

- Enhanced Reductive Dechlorination used for remediation of CHC's for over 2 decades
- Started with the use of soluble substrates
- Late 1990's controlled/slow release substrates came on the market
  - Overcome vinyl chloride stall
  - Avoid multiple applications
  - Low volume
    - = good for low permeability
- But chlorinated solvent plumes can be BIG!
- Wanted to create a version for large plumes



# Large Scale Enhanced Reductive Dechlorination

FIGURE 1:  
THE HRC ADVANCED™ MOLECULAR STRUCTURE

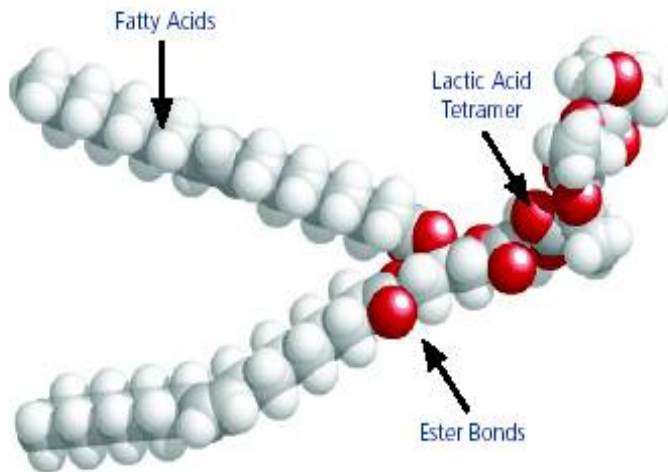
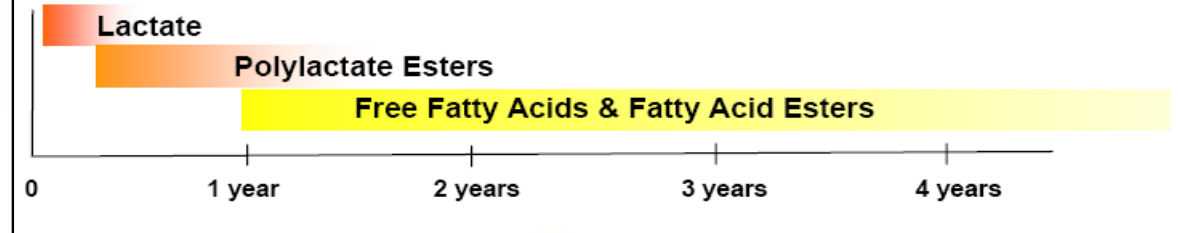
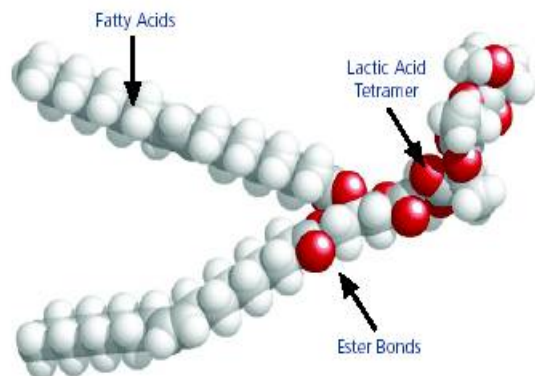


Figure 1. 3-D Microemulsion™ Release Profile



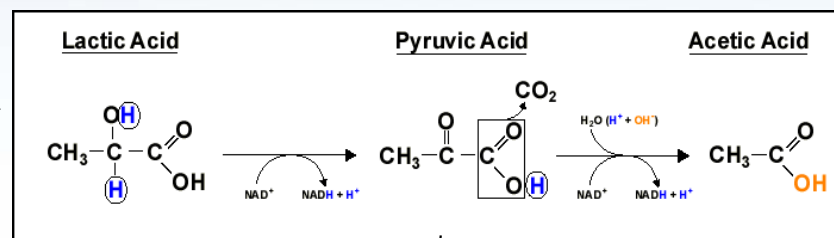
# Enhanced Reductive Dechlorination

FIGURE 1:  
THE HRC ADVANCED™ MOLECULAR STRUCTURE

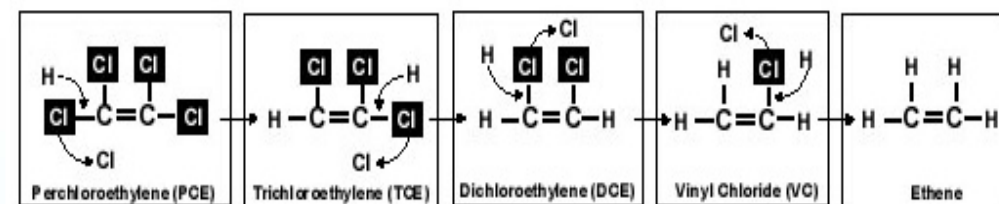


Dissolution

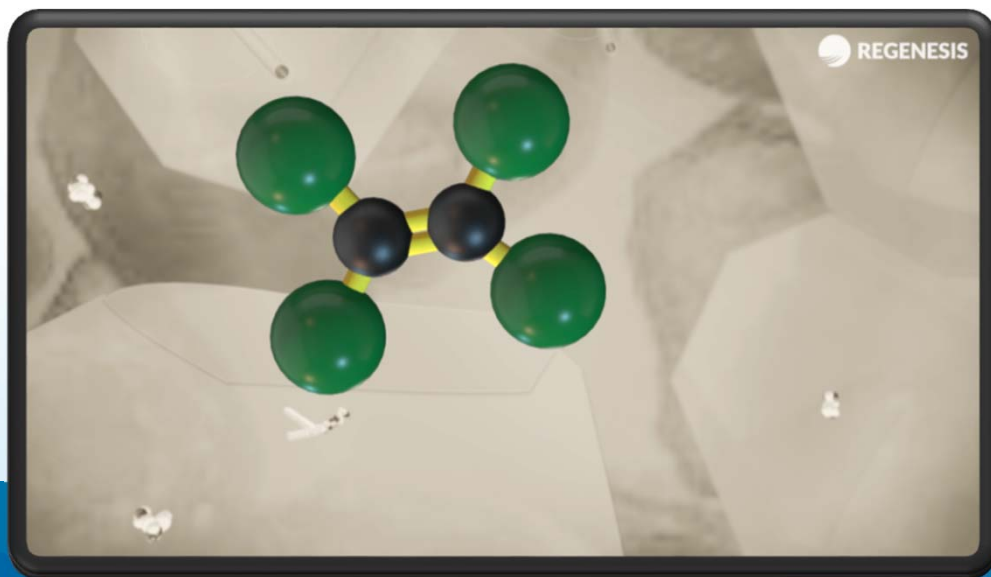
Fermentation



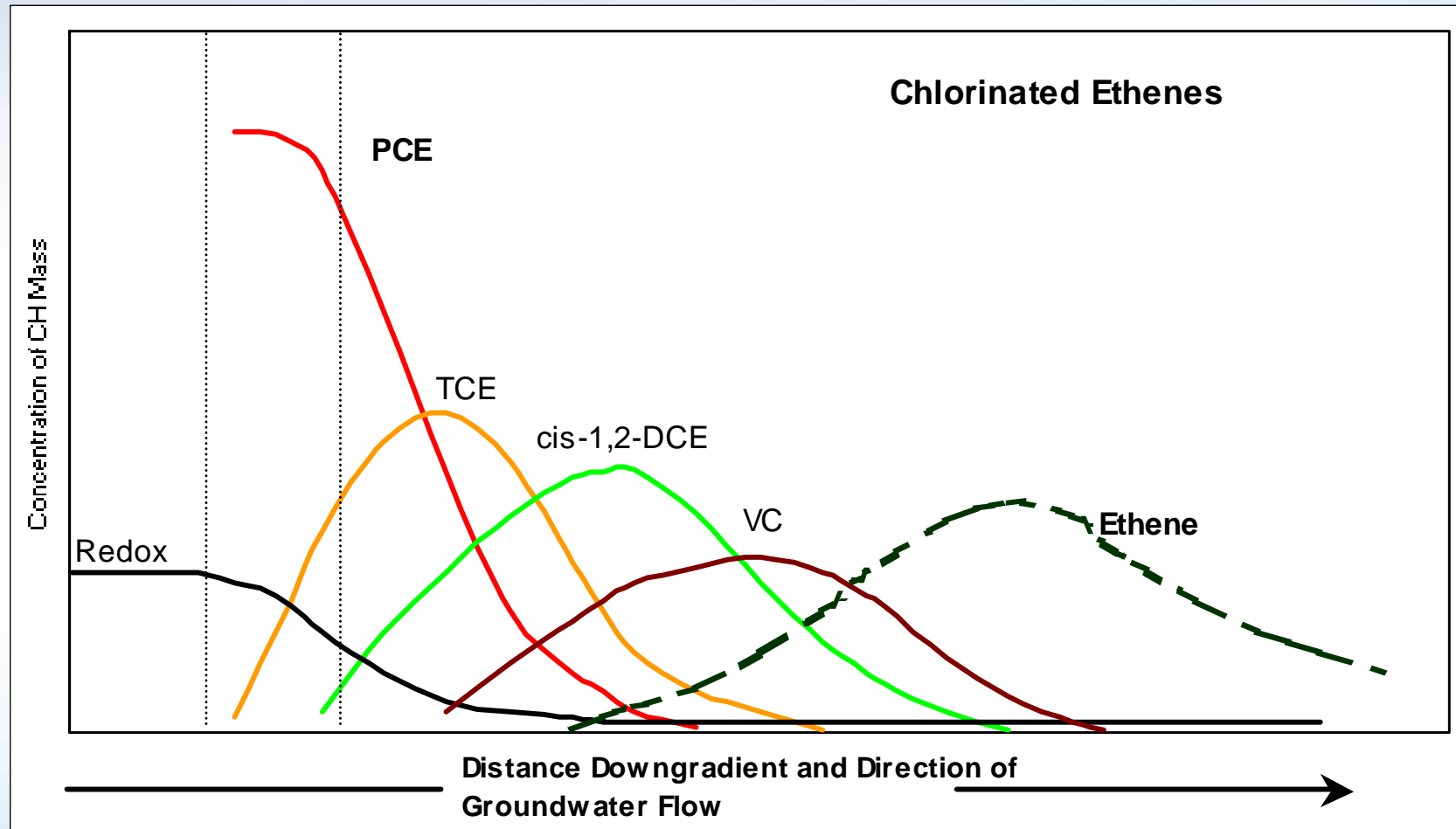
Enhanced Reductive Dechlorination



PCE → TCE → DCE → VC → Ethene

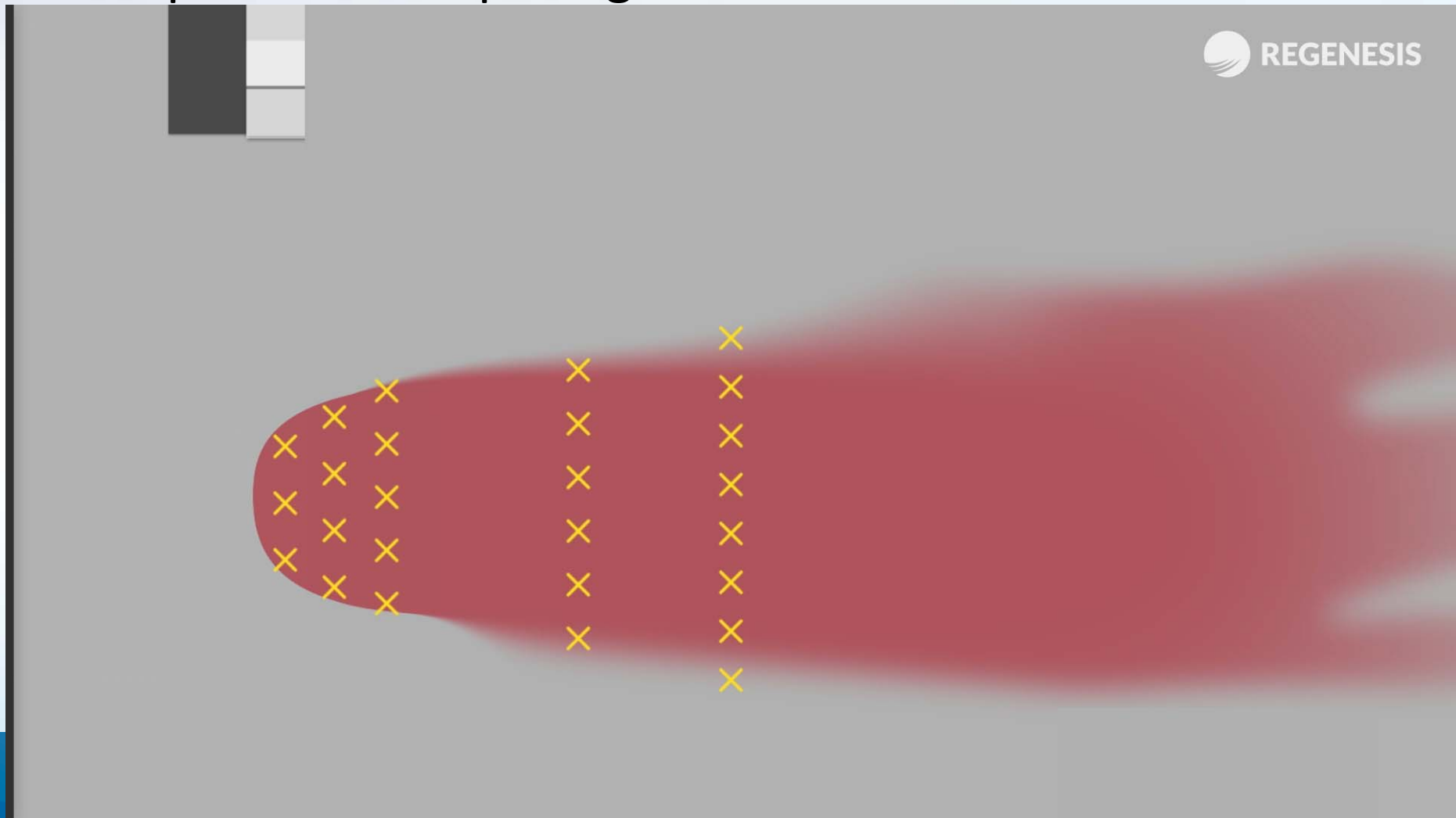


## Expected Results



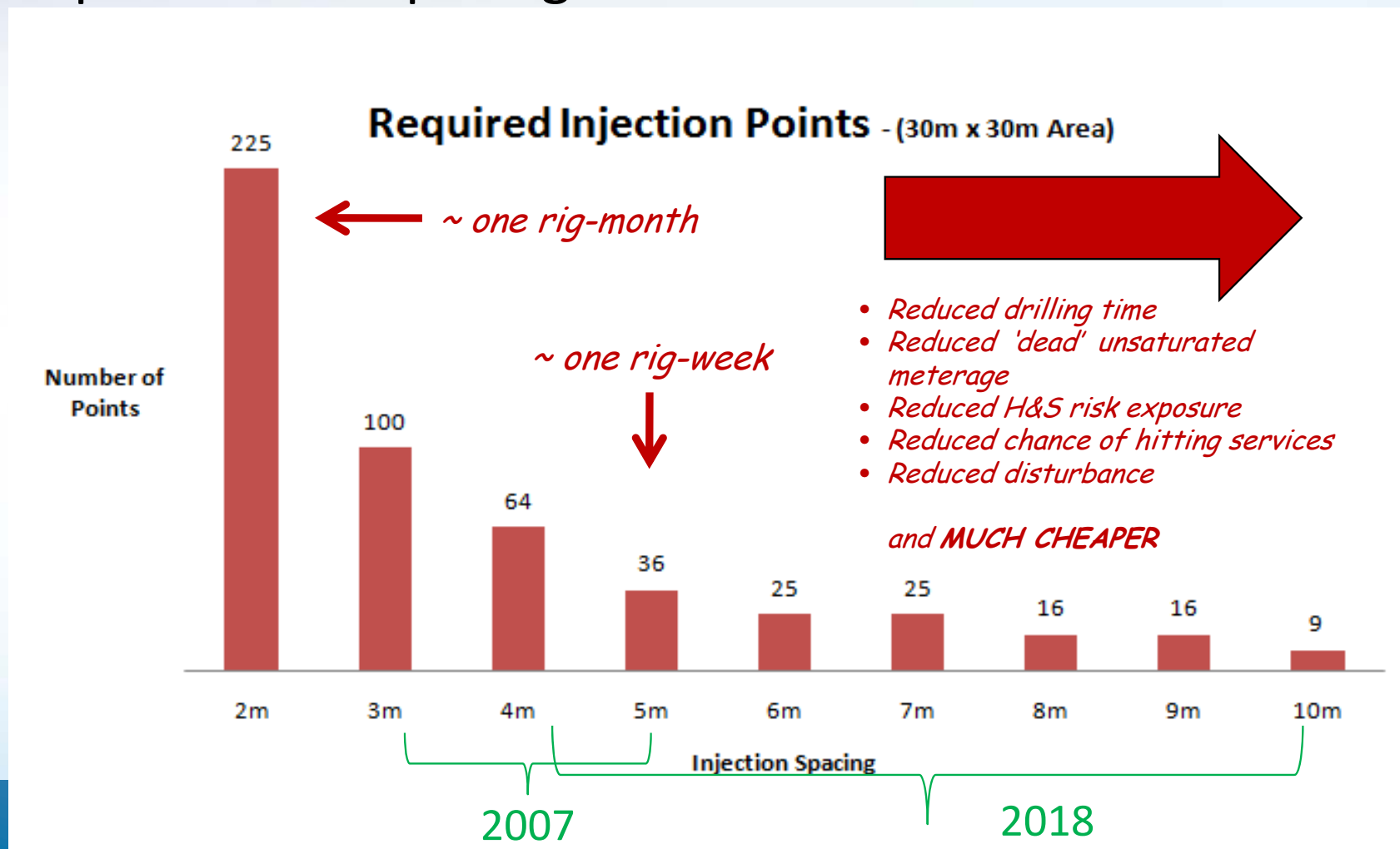
# Lessons Learned: Application Development

- The importance of spacing

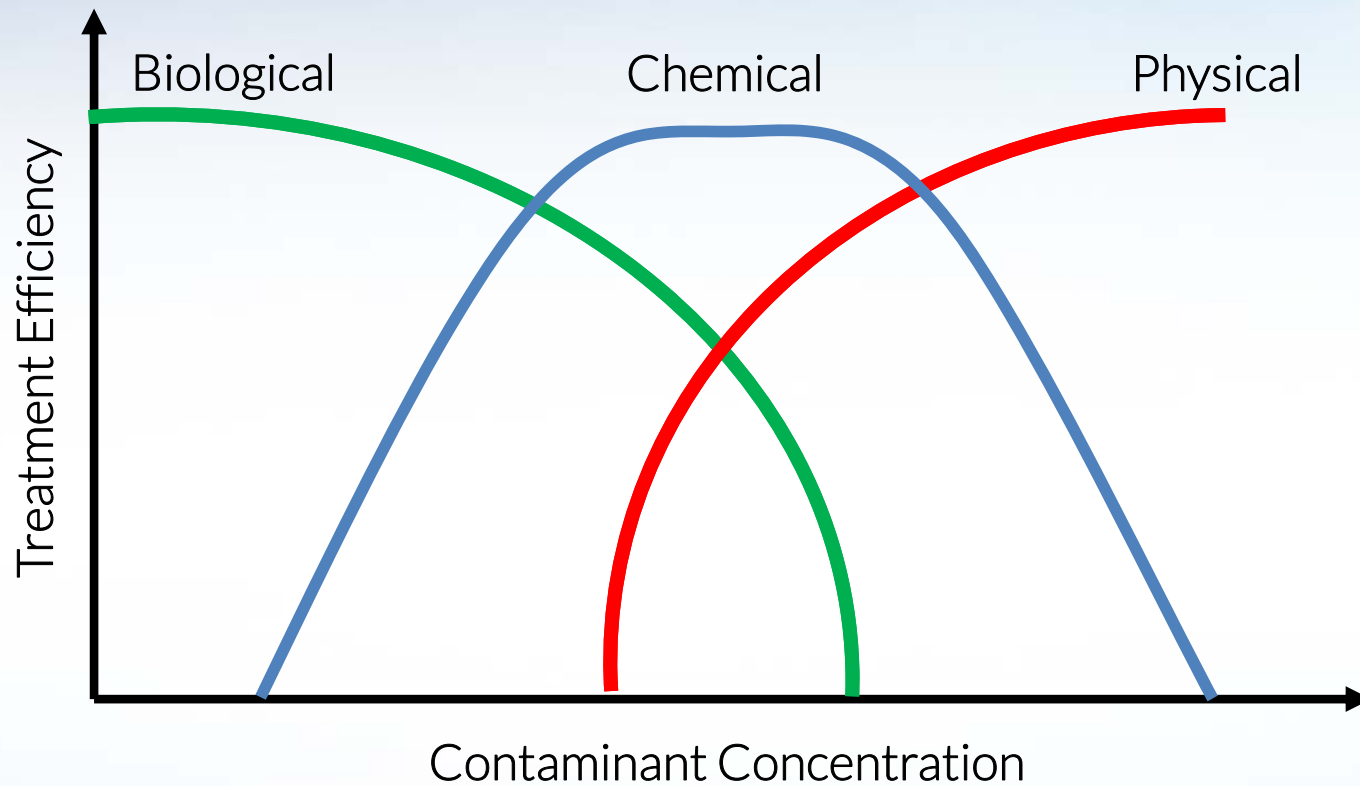


# Lessons Learned: Application Development

- The importance of spacing

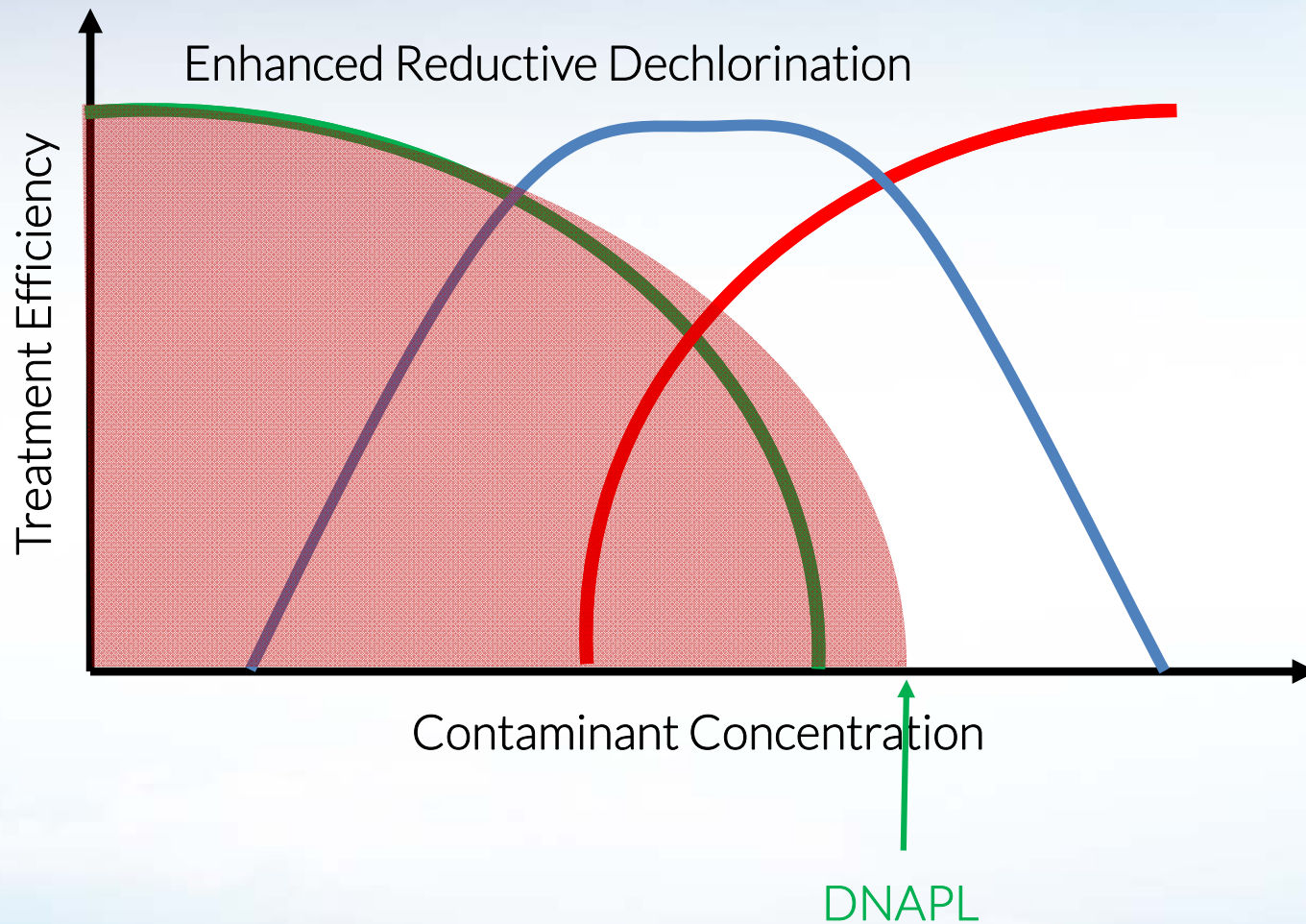


# Lessons Learned: Treatment Envelope



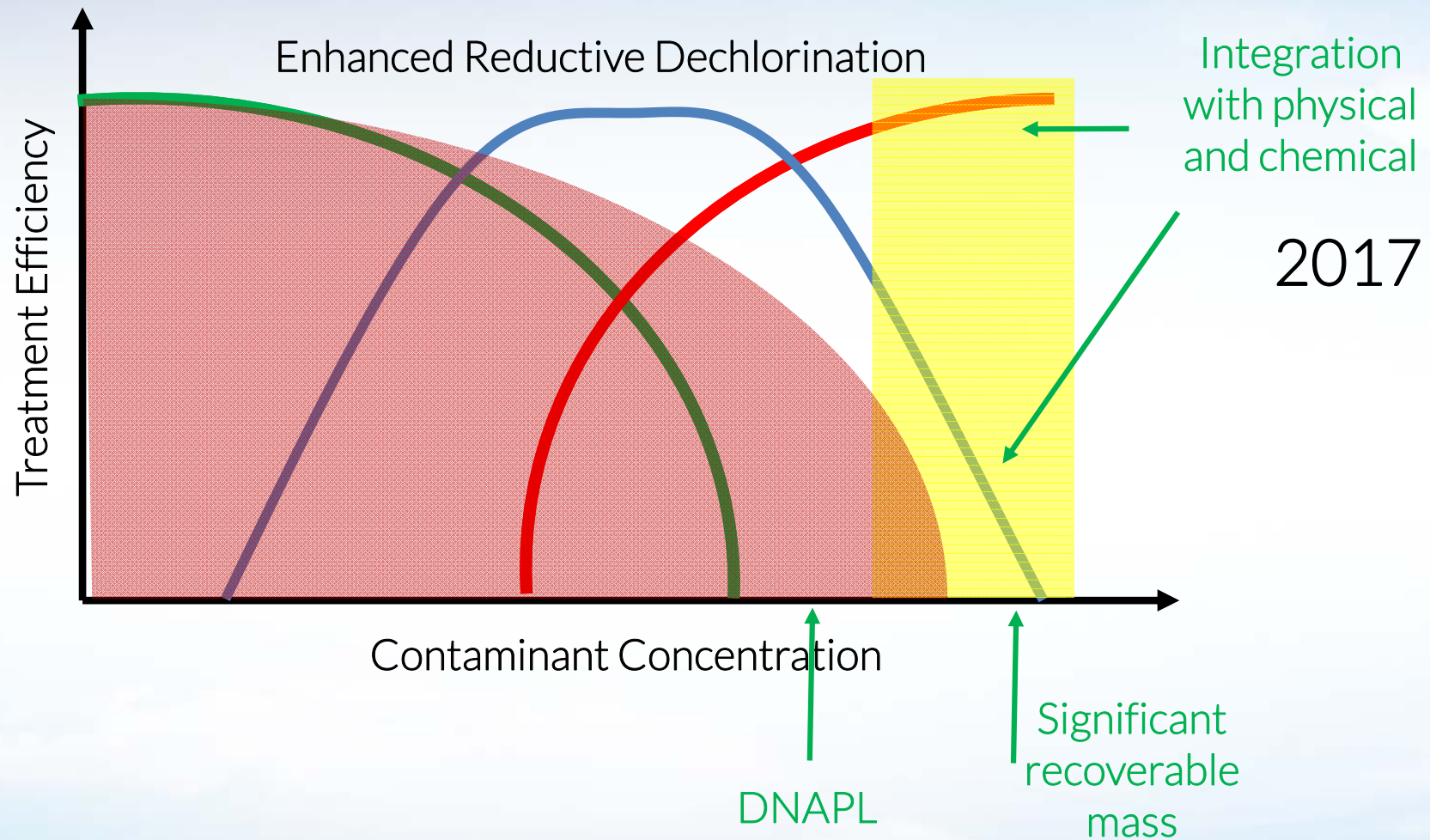


# Lessons Learned: Treatment Envelope



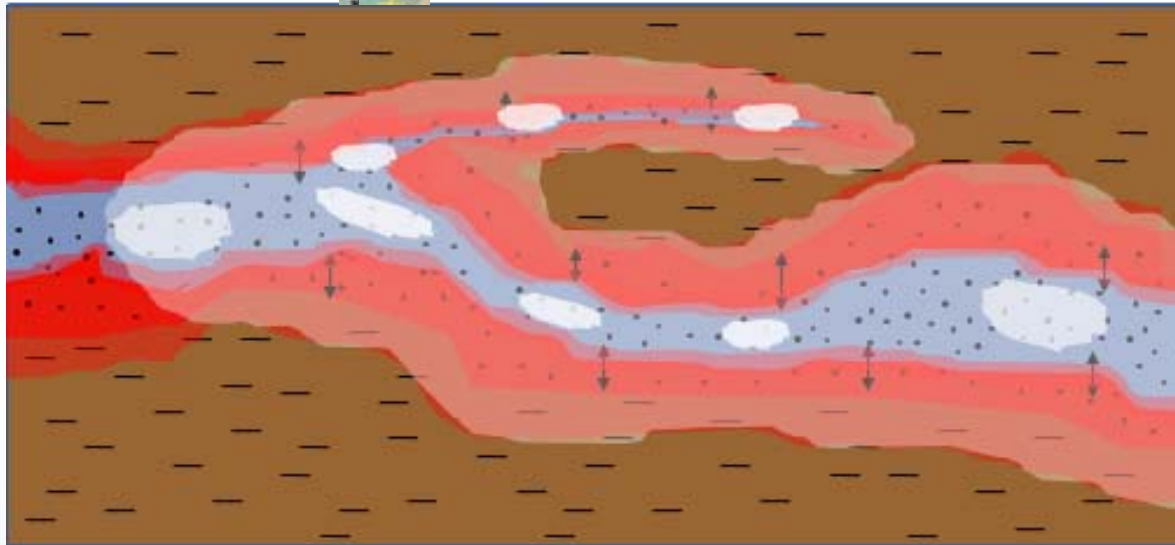
2007

# Lessons Learned: Integration Envelope



# Lessons Learned: Heterogeneous Formations

- High volume product designed to target permeable formations
- ...and that's what we use it for
- ...also able to address mass in immobile porosity
  - Crucial to avoid rebound from back diffusion





# Lessons Learned: Bedrock Treatment



## Lessons Learned: Performance

- 2017: Review of data completed on 24 sites (100 wells) in US
- Intention was to create a simple benchmark for projects
- Work in progress
  - Presently adding European data to this (6 sites, 19 wells)
  - Some sites used are still live
- Useful information emerging



W-11 ID	Site	Exp. Site	How	PCE	PCE
W-11 ID	1				
41 K1M0P01	I				
42 K1M0P02	I				
43 K1M0P03	I				
44 K1M0P04	I				
45 K1M0P05	I				
46 K1M0P06	I				
47 K1M0P07	I				
48 K1M0P08	I				
49 K1M0P09	I				
50 K1M0P10	I				
51 K1M0P11	I				
52 K1M0P12	I				
53 K1M0P13	I				
54 K1M0P14	I				
55 K1M0P15	I				
56 K1M0P16	I				
57 K1M0P17	I				
58 K1M0P18	I				
59 K1M0P19	I				
60 K1M0P20	I				
61 K1M0P21	I				
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64 K1M0P24	I				
65 K1M0P25	I				
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67 K1M0P27	I				
68 K1M0P28	I				
69 K1M0P29	I				
70 K1M0P30	I				
71 K1M0P31	I				
72 K1M0P32	I				
73 K1M0P33	I				
74 K1M0P34	I				
75 K1M0P35	I				
76 K1M0P36	I				
77 K1M0P37	I				
78 K1M0P38	I				
79 K1M0P39	I				
80 K1M0P40	I				
81 K1M0P41	I				
82 K1M0P42	I				
83 K1M0P43	I				
84 K1M0P44	I				
85 K1M0P45	I				
86 K1M0P46	I				
87 K1M0P47	I				
88 K1M0P48	I				
89 K1M0P49	I				
90 K1M0P50	I				
91 K1M0P51	I				
92 K1M0P52	I				
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95 K1M0P55	I				
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100 K1M0P60	I				
101 K1M0P61	I				
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108 K1M0P68	I				
109 K1M0P69	I				
110 K1M0P70	I				
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119 K1M0P79	I				
120 K1M0P80	I				
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122 K1M0P82	I				
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139 K1M0P99	I				</

## Nature of ERD Performance Data Reviewed

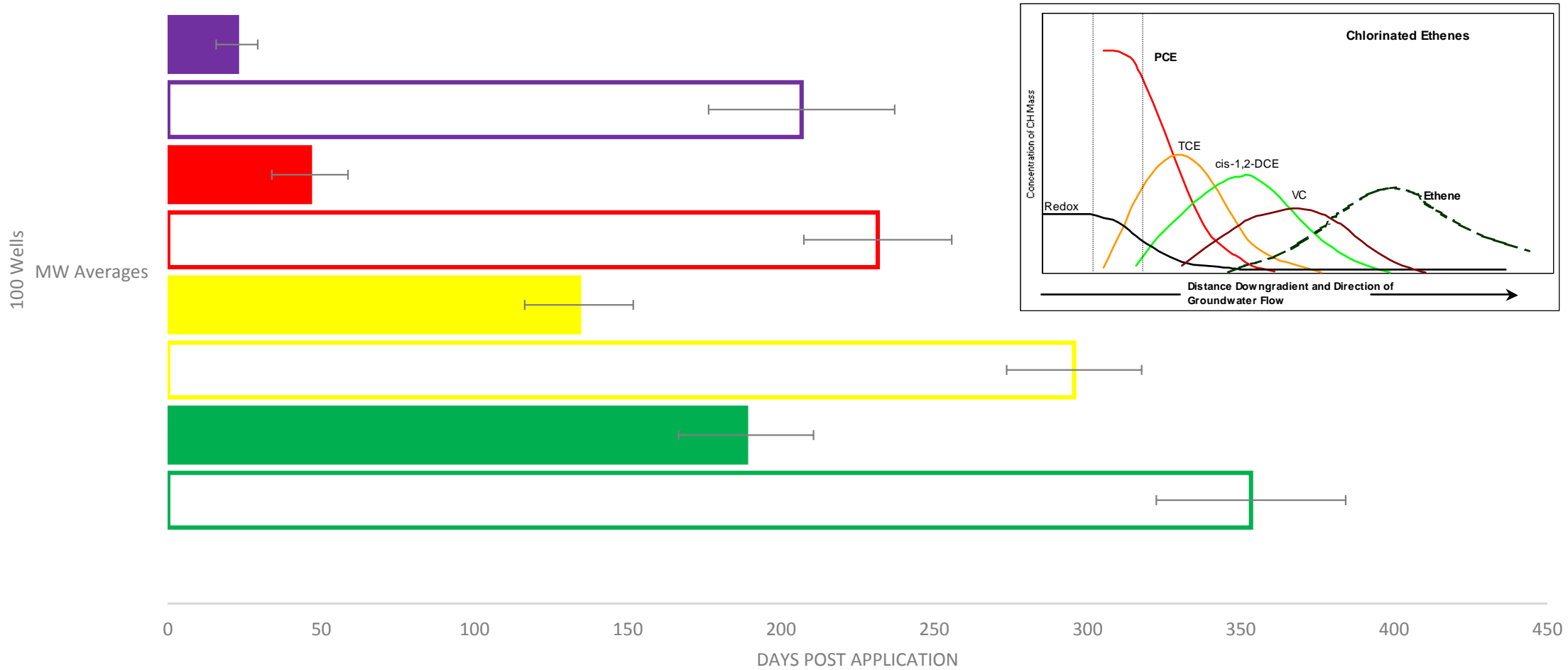
Number of Target Treatment Zones (TTZs)	24
Number of Performance Monitoring Wells (MWs) Observed)	100 (median= 4, minimum= 1, maximum= 7 per TTZ)
Site Type	Industrial or dry cleaner; one municipal landfill
Contaminant	perchloroethene (PCE), trichloroethene (TCE), cis-1,2-dichloroethene (cis-DCE) and vinyl chloride (VC)
Concentration Ranges	Tens of micrograms per litre (µg/L) to >100,000 µg/L
Soil Types	All unconsolidated, coarse-grained (sand/gravel; n=69) to fine-grained (silt/clay; n=31)
Injection Arrays	Grids ranging from 10-ft on center to 20-ft x 50-ft. Injection points within 20-ft of MWs
Reagents Applied	All MWs - Highly distributable electron donor with staged release profile and effective longevity of 3 years (or longer); 89 MWs-bioaugmentation with dehalococcoides consortium; 47 MWs - liguid dual valent iron amendment
Monitoring Period	Average= 605 days. Most wells represented by at least 1 year of data. A few with less than 1 year were included in the study.

Range	Start - End	PCEX of VOCo	TCEX of VOCo	BCEX of VOCo	VCX of VOCo
...	895	24X	16X	57X	8X
...	924	24X	3X	57X	93X
...	1497	49X	4X	73X	4X
...	362	52X	19X	28X	2X
...	4515	88X	5X	8X	8X
...	4748	39X	5X	8X	8X
...	17.8	8X	24X	23X	8X
...	46.7	8X	58X	42X	8X
...	18.2	8X	48X	48X	4X
...	28.5	8X	80X	14X	8X
...	538.2	8X	18X	8X	8X
...	18.3	8X	33X	5X	8X
...	32.3	8X	85X	45X	8X
...	5698	8X	8X	42X	49X
...	15588	8X	8X	57X	8X
...	242	188X	8X	54X	8X
...	555	59X	5X	8X	8X
...	878	54X	8X	2X	8X
...	3526	8X	37X	3X	8X
...	342	8X	58X	42X	8X
...	145	8X	48X	22X	8X
...	28.7	8X	28X	74X	8X
...	1958	8X	188X	8X	8X
...	4935	8X	55X	45X	8X
...	241	8X	8X	54X	8X
...	488	8X	8X	53X	45X
...	75.1	8X	8X	18X	18X
...	3798	45X	29X	24X	3X
...	8X	8X	8X	88X	28X
...	11828	33X	19X	43X	2X
...	1348	8X	37X	8X	5X
...	1978	8X	8X	8X	188X
...	1	747	8X	75X	21X
...	5	42878	8X	16X	2X
...	5	58958	59X	48X	2X
...	1852	8X	6X	82X	47X
...	1	7568	8X	65X	93X
...	1958	8X	8X	8X	8X
...	321	8X	24X	52X	45X
...	5184	8X	54X	44X	2X
...	54188	13X	18X	13X	3X
...	18422	47X	18X	24X	8X
...	38758	8X	62X	54X	4X
...	887	59X	16X	28X	3X
...	155	8X	88X	77X	8X
...	38	8X	27X	42X	27X
...	225	8X	59X	57X	8X
...	148	8X	35X	5X	8X
...	28888	8X	8X	83X	14X
...	1	7584	8X	52X	45X
...	54128	8X	88X	45X	1X
...	235	8X	8X	5X	8X
...	187	8X	36X	45X	49X
...	328	8X	67X	42X	8X
...	1	227	8X	49X	57X
...	483.8	88X	2X	8X	8X
...	88	5X	48X	8X	54X
...	88	58X	2X	8X	8X
...	8	5X	188X	8X	8X
...	8	235	34X	4X	8X
...	242	8X	8X	8X	8X
...	2648	57X	2X	5X	8X
...	582	188X	8X	8X	8X
...	13898	8X	65X	32X	8X
...	24818	8X	84X	4X	8X
...	2718	8X	8X	43X	5X
...	46528	8X	28X	58X	8X
...	2452.7	8X	58X	38X	2X
...	8738	8X	48X	43X	14X
...	2938	8X	25X	24X	4X
...	1885	8X	77X	23X	8X
...	256.8	8X	8X	2X	5X
...	42648	8X	59X	24X	7X
...	35165	8X	8X	45X	55X
...	11545	8X	48X	78X	12X
...	2287.2	8X	24X	8X	8X
...	3259	8X	27X	25X	1X
...	61558.36	8X	28X	28X	98X
...	37375	96X	5X	9X	8X
...	6198	59X	94X	9X	8X
...	328	73X	19X	6X	1X
...	6214.3	24X	4X	24X	3X
...	747	48X	5X	35X	8X
...	2327.4	4X	55X	4X	8X
...	1618	4X	84X	43X	8X
...	28627	69X	6X	23X	8X
...	2535	8X	82X	45X	2X

# ERD Event Analysis - Chlorinated VOCs

## Average Days to Reach Peak Concentration and 90% Reduction

■ Max PCE Reached ■ PCE - 90% reduced ■ Max TCE Reached ■ TCE - 90% reduced ■ Max cisDCE Reached ■ cDCE - 90% reduced ■ Max VC reached ■ VC - 90% reduced



# Lessons Learned

- Dechlorination Rates

Event	PCE	TCE	cis-DCE	VC
Days to reach max. conc.	22	46	134	189
Days to reach 90% reduction	207	232	296	353
Days between events	184	185	162	165

- Similar for each constituent
  - Slight faster for daughter CVOC's
- Daughter products do not build excessively
- DNAPL slows reductions
- ..but high starting concentrations may assist reaching low targets
- Geology appears to be no barrier to performance



# ...and so to the Present Day

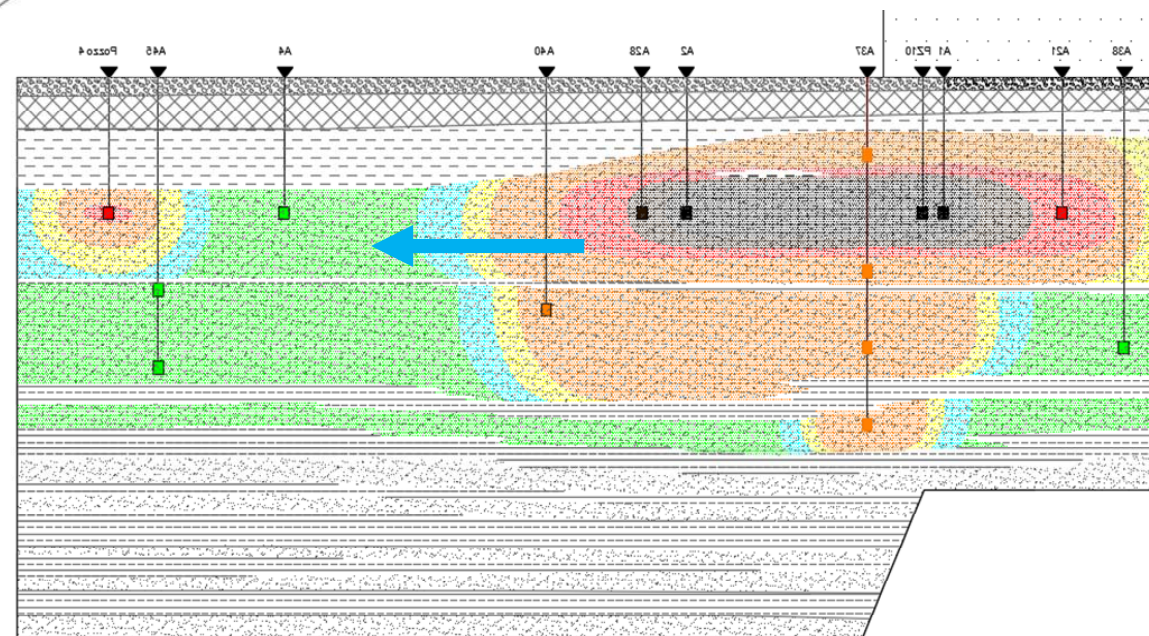


## TRICLOROETILENE

Concentrazione ( $\mu\text{g/l}$ )



Concentrazione limite D.Lgs. 152/06 pari a 1,5  $\mu\text{g/l}$

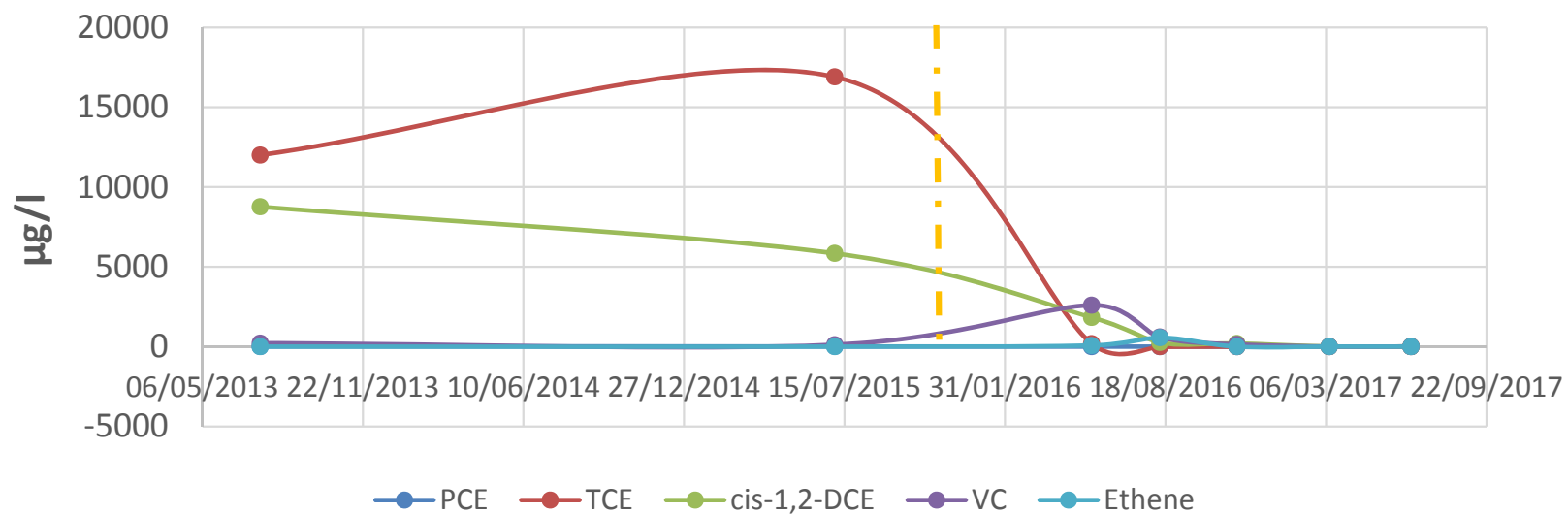




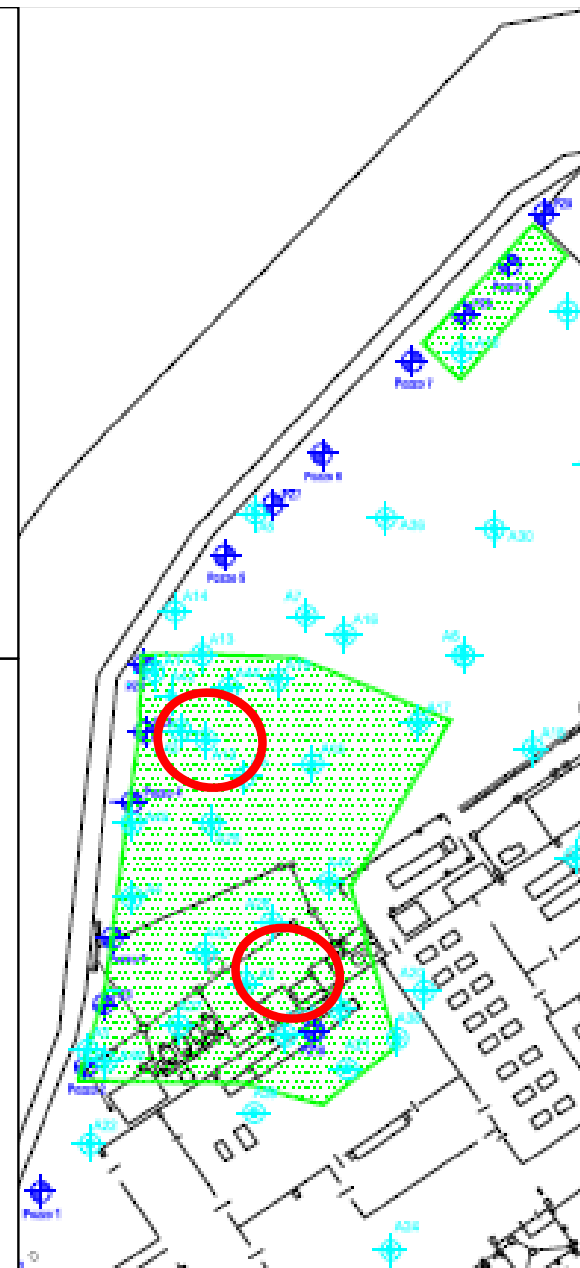
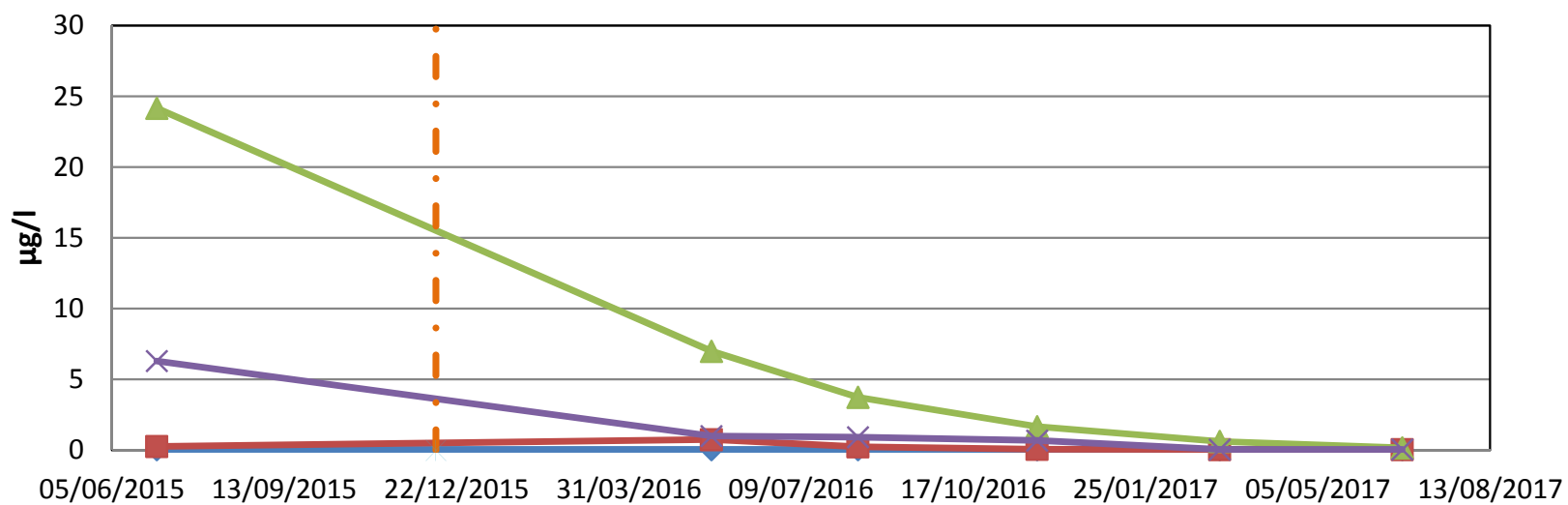
# Application



## Source



## Plume



Merci!

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