

Hydraulic Fracturing with ZVI Emplacement for Treatment of Chlorinated Solvents in a Low Permeability Aquifer

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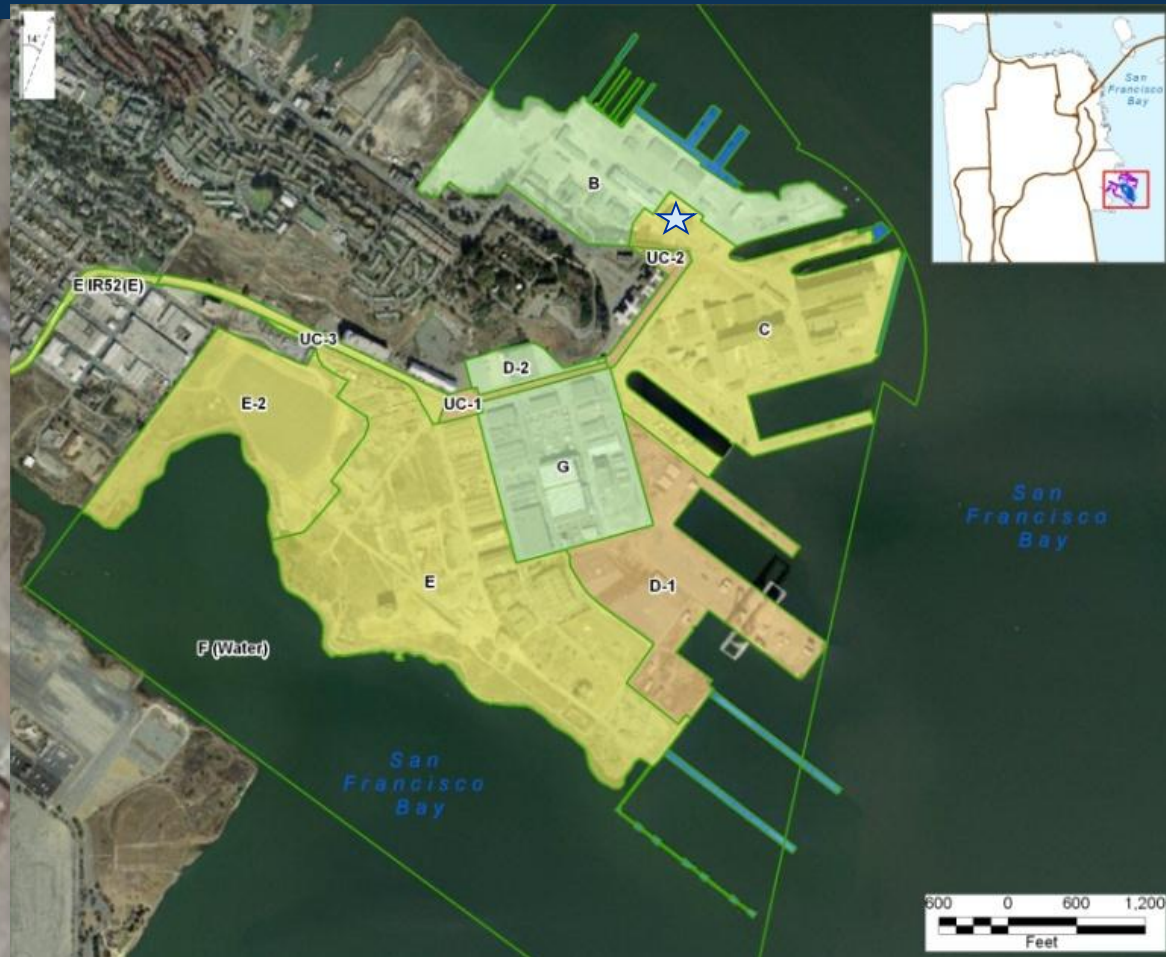
April 11, 2012



**CDM
Smith**

- Hunters Point Naval Shipyard (HPNS), Building 134
- Chlorinated benzenes and ethenes in the subsurface as dense non aqueous phase liquid (DNAPL)
- Treatability study evaluated a multi-component treatment strategy including:
 - Hydraulic fracturing
 - EHC[®] injection
 - Thermal treatment

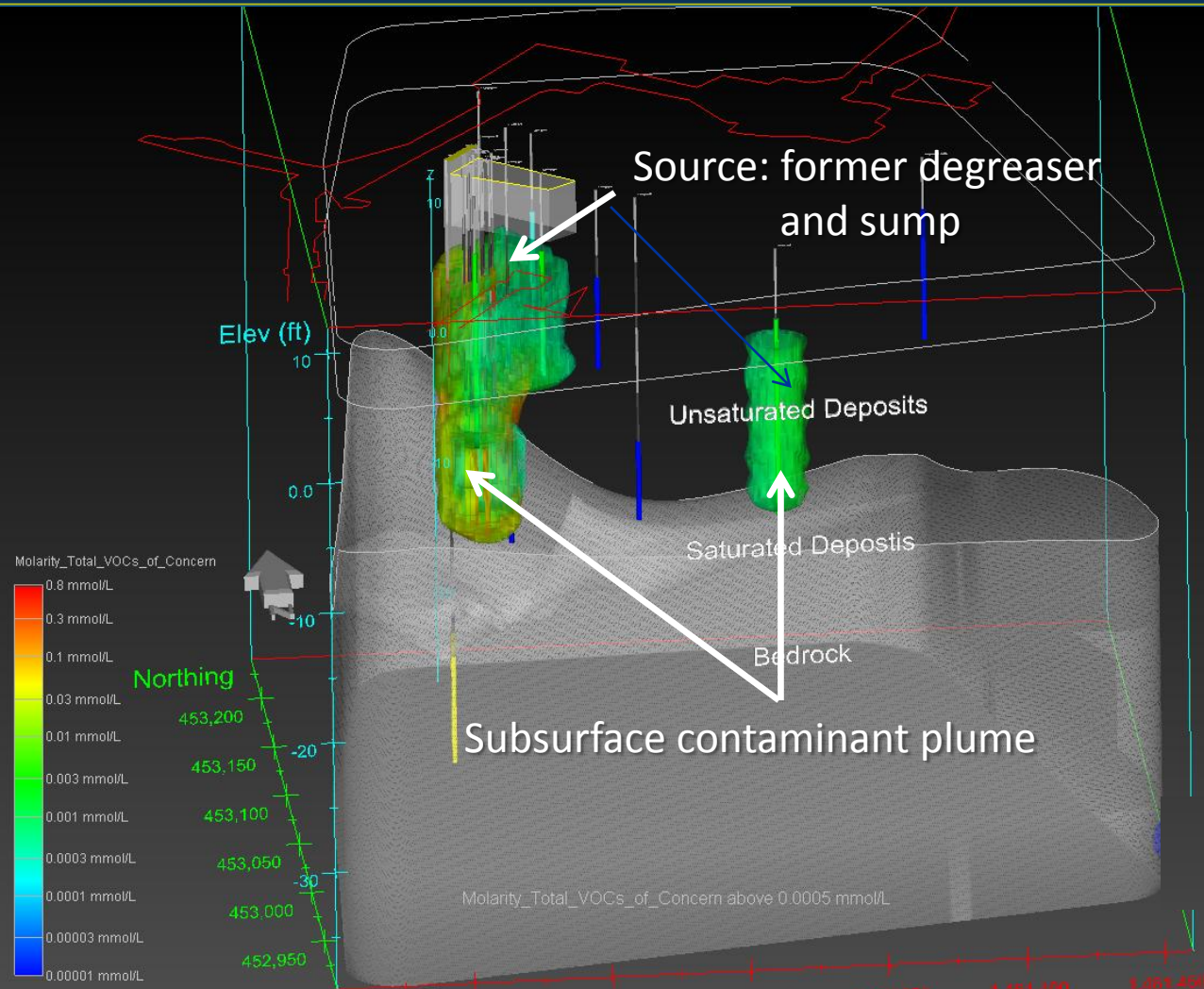
HPNS Treatability Study Area



Problem: Complex Mix of Contaminants in Groundwater and Low-Permeability Soils

Volatile Organic Contaminants (VOCs):

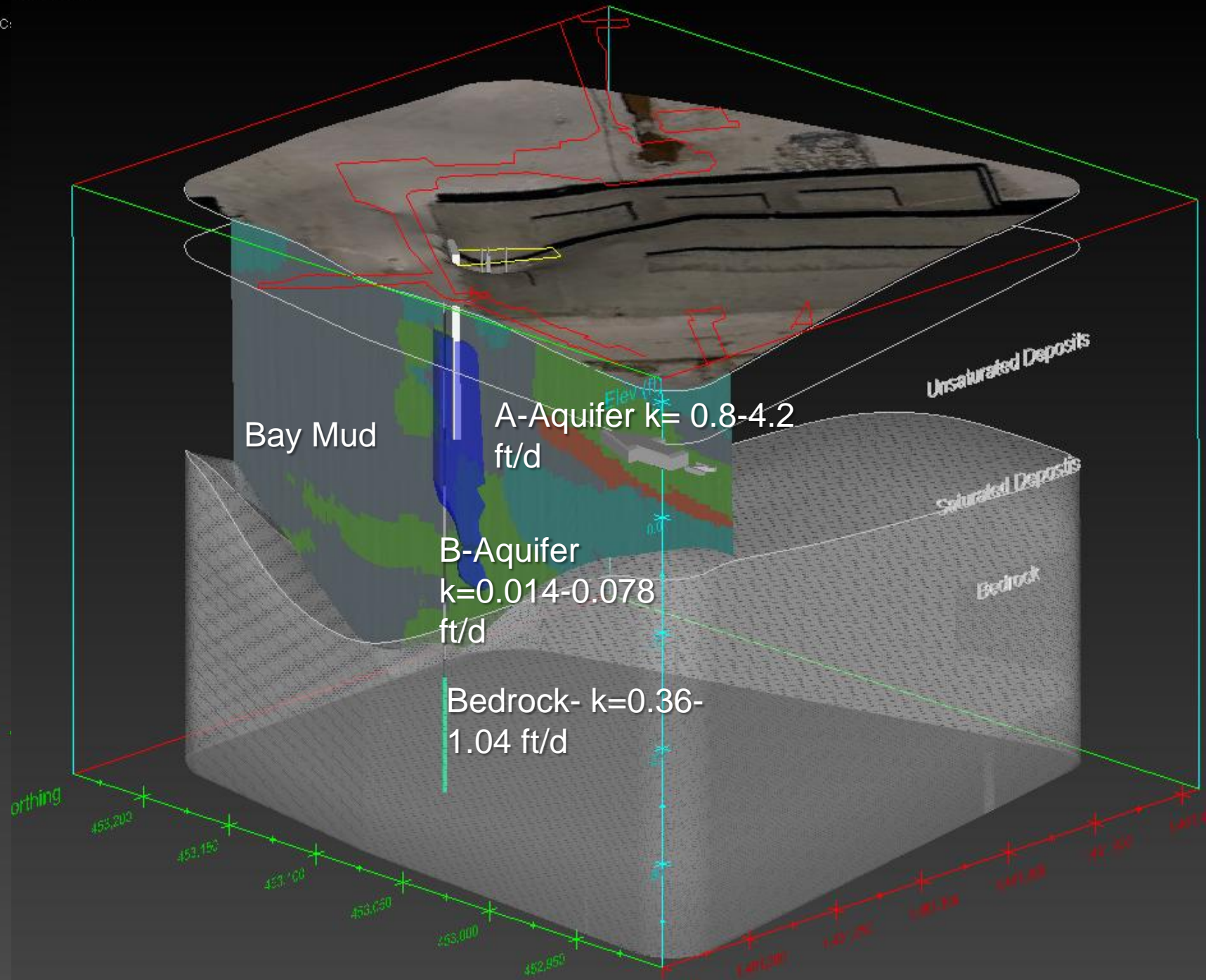
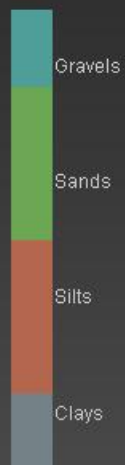
- 1,2-Dichlorobenzene (DCB)
- 1,3-DCB
- 1,4-DCB
- Chlorobenzene (CB)
- Trichloroethene (TCE)
- Tetrachloroethene (PCE)
- cis-Dichloroethene (DCE)
- Vinyl chloride (VC)



Molarity_Total_VOC:



Lithology



Treatability Study Objectives

Groundwater Technology: Hydraulic Fracturing/EHC[®]

- 80% reduction of chlorinated VOCs
- Polish remaining VOCs post-TCH to meet very stringent cleanup criteria (generally less than 5 ppb).

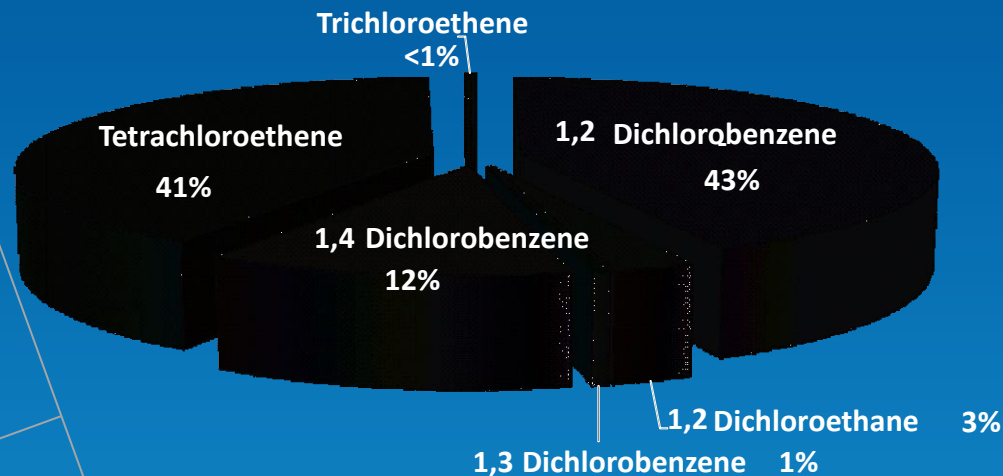
Soil/DNAPL Technology: Thermal Conduction Heating (TCH)

- 90% reduction in chlorinated VOCs
- Thermally-Enhanced Extraction of DNAPL

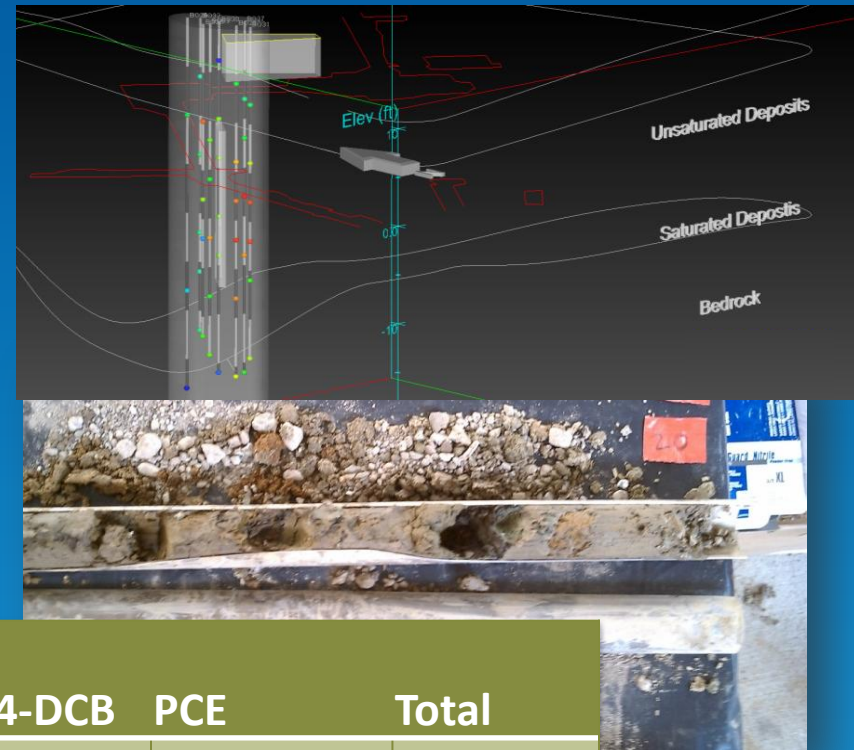
18-month Cleanup Timeframe

Pre-Remediation: DNAPL/Soil Mass Estimate

MIXTURE COMPOSITION, %

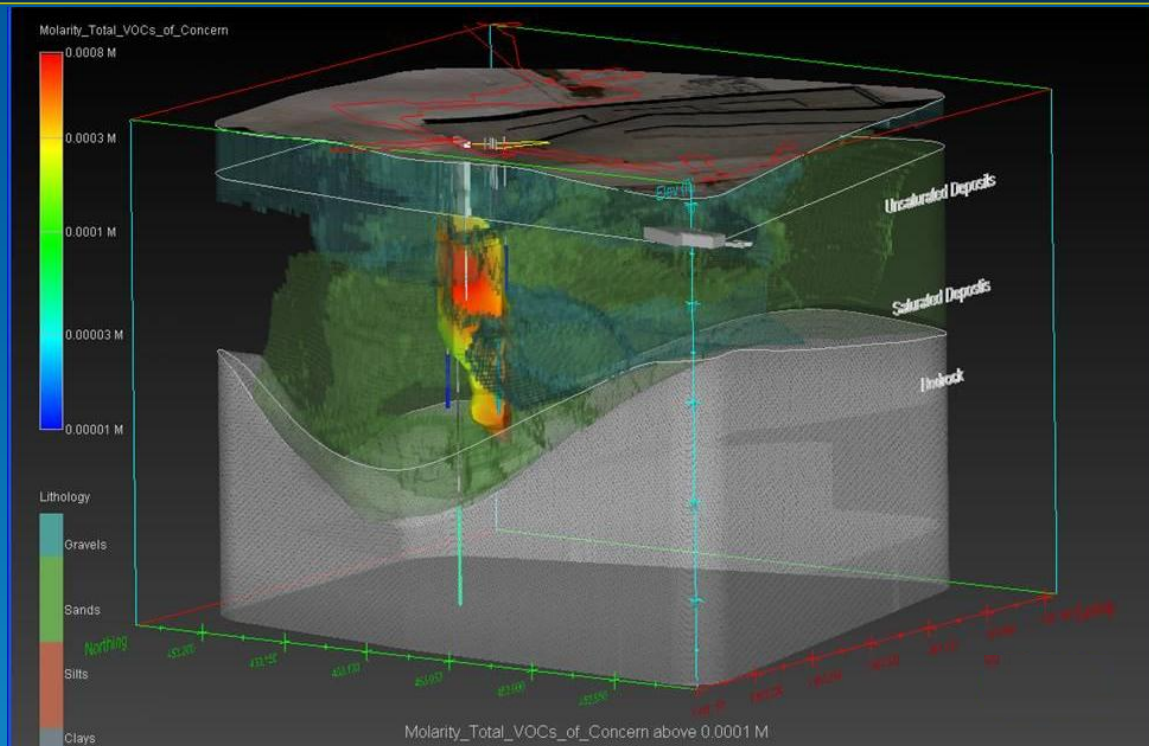


Estimate ~300 lb of VOCs present in the source area.



Total (lbs)	1,2-DCB	1,2-DCA	1,3-DCB	1,4-DCB	PCE	Total
Before Remediation:	136	2.8	2.8	48	101	291

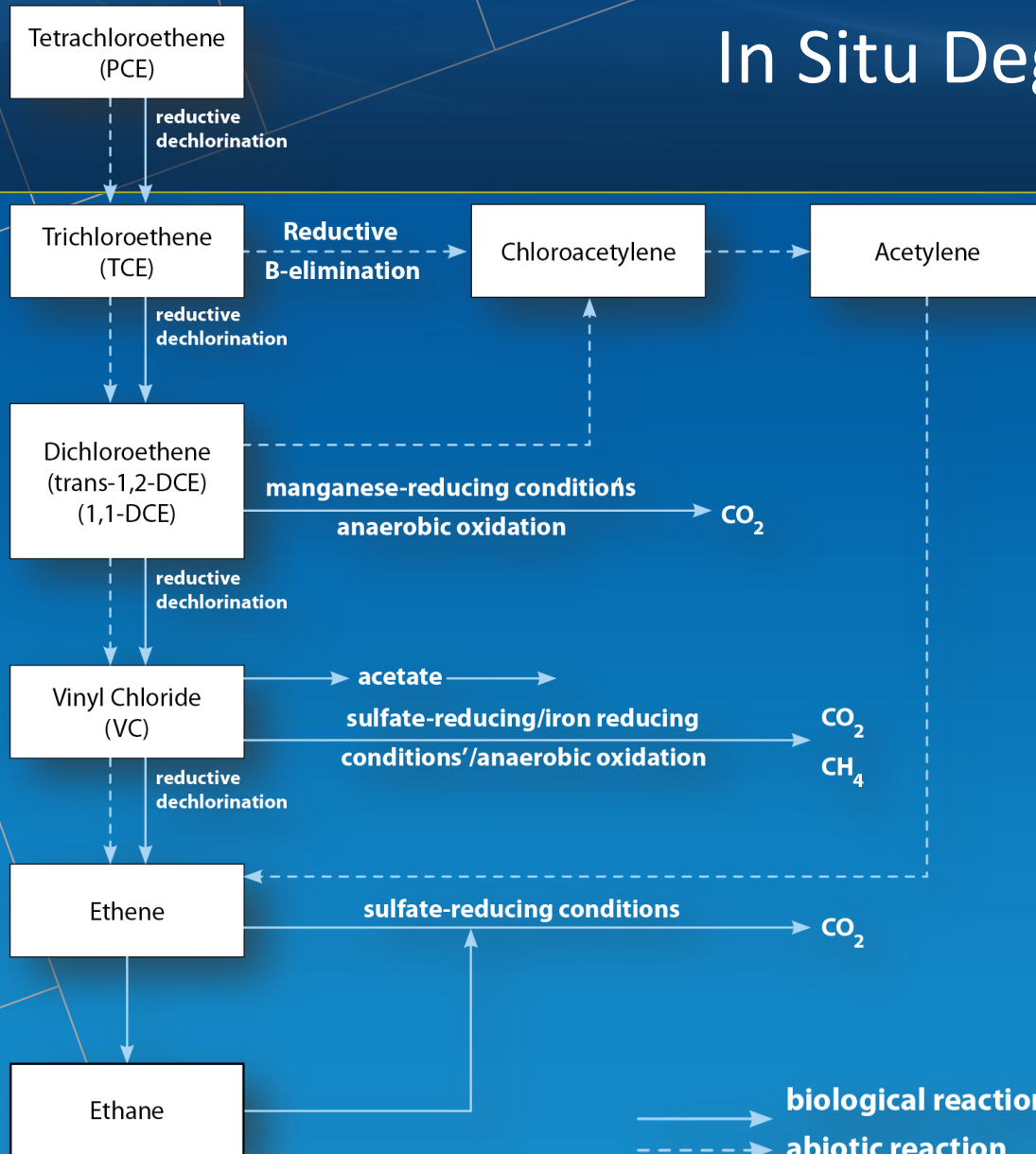
Pre-Remediation: Groundwater Contaminant Plume



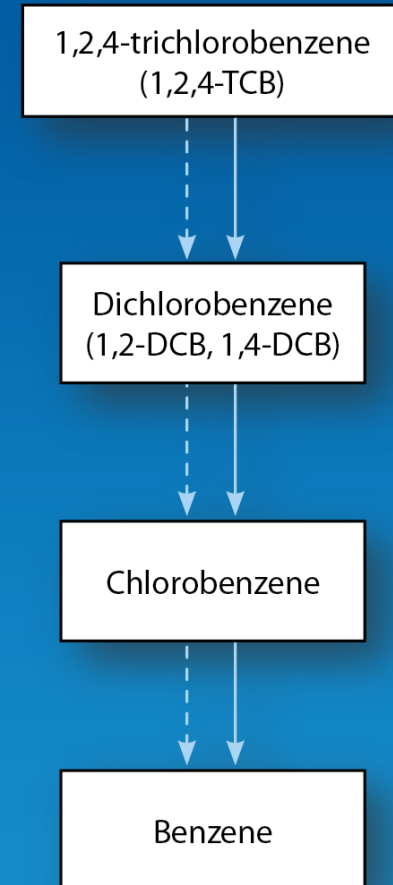
Total (lbs)	Parent Compounds					Reductive Daughter Products				
	1,2-DCB	1,2-DCA	1,3-DCB	1,4-DCB	PCE	benzene	CB	Cis-DCE	TCE	VC
Before Remediation:	4.7	0.7	0.01	1.5	0.6	0.03	0.2	2.1	0.2	0.6
Total Mass in Groundwater: 10.6 lbs										

In Situ Degradation Pathways

Chloroethene Degradation Pathway



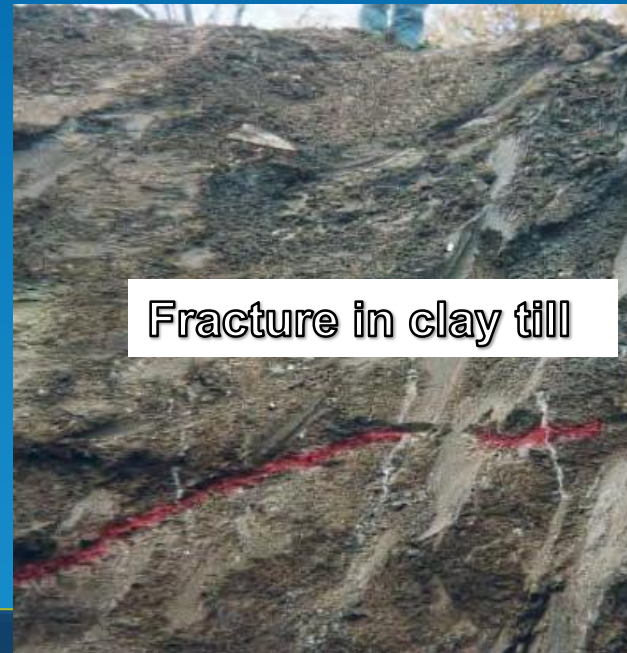
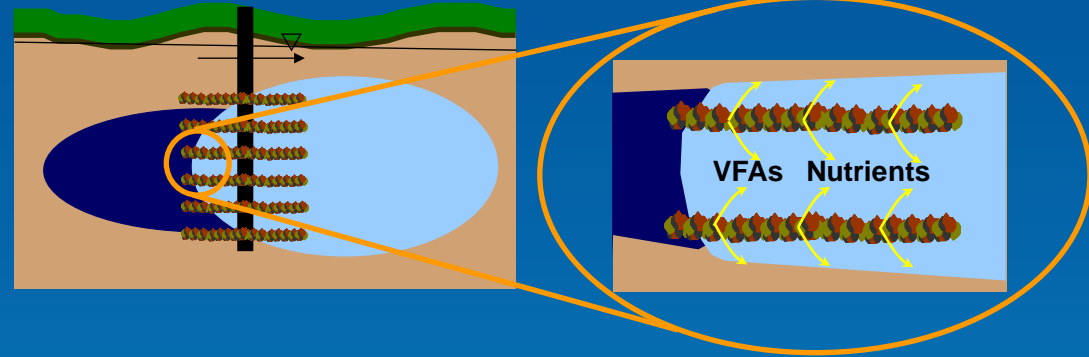
Chlorobenzene Degradation pathway



— biological reaction
- - - abiotic reaction

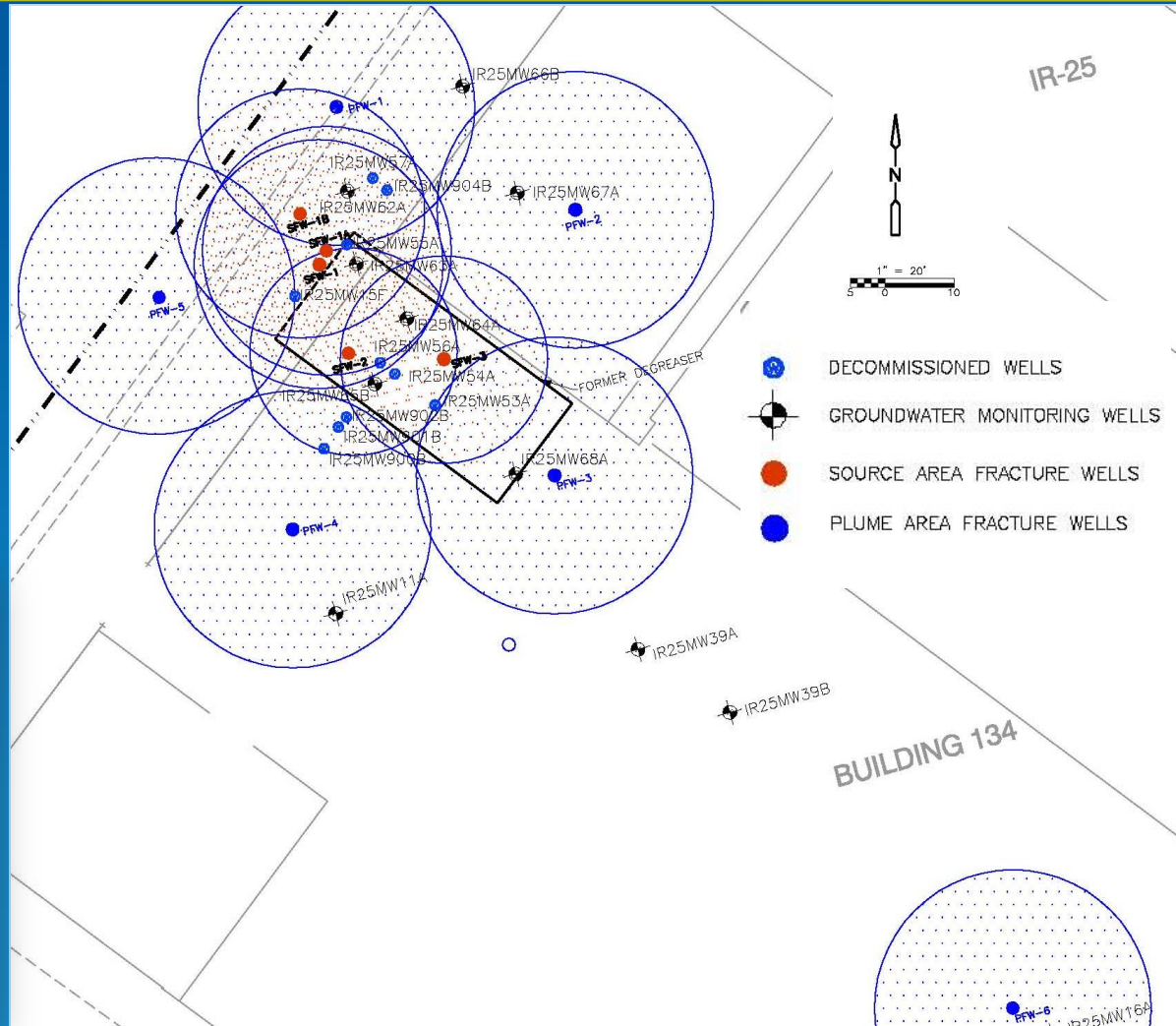
Hydraulic Fracturing

- Oil and gas industry developed in the 1940s
- At HPS: viscous fluid (guar, crosslinkers, breaker, water) carried EHC[®] and in some cases sand to create fractures containing treatment amendment



Technology 1 Implementation: Hydraulic Fracturing/EHC[®] Emplacement

- 6 source fracture wells and 6 plume fracture wells
- 15- to 20-ft radius of amendment distribution
- Emplaced 13,419 lbs in source and 17,126 lbs of amendment EHC[®] in plume



Hydraulic Fracturing and EHC™ Emplacement

Frac Boreholes	Depth interval for fractures, fracs initiated ~3 ft	Mass EHC (lb)	Target Loading % EHC Met*?	Sand (lb)
PFW1	10-43	3700	✓	1100
PFW2	10-33	3150	✓	3300
PFW3	10-33	3150	✓	3300
PFW4	10-33	3150	✓	4400
PFW5	13-43	3540	✓	0
PFW6	13-28	2300	✓	2200
SFW-1, -1A, and -1B	14-36	5801	✓	0
SFW2	13-23	1900	✓	0
SFW3	13-40	7450	✓	0

- Target EHC concentration 0.1% and 0.5% wEHC/wsoil in plume and source
- Range EHC dose for PF wells 0.09-0.11% wEHC/wsoil
- Range EHC dose for SF wells 0.36-0.63 % wEHC/wsoil

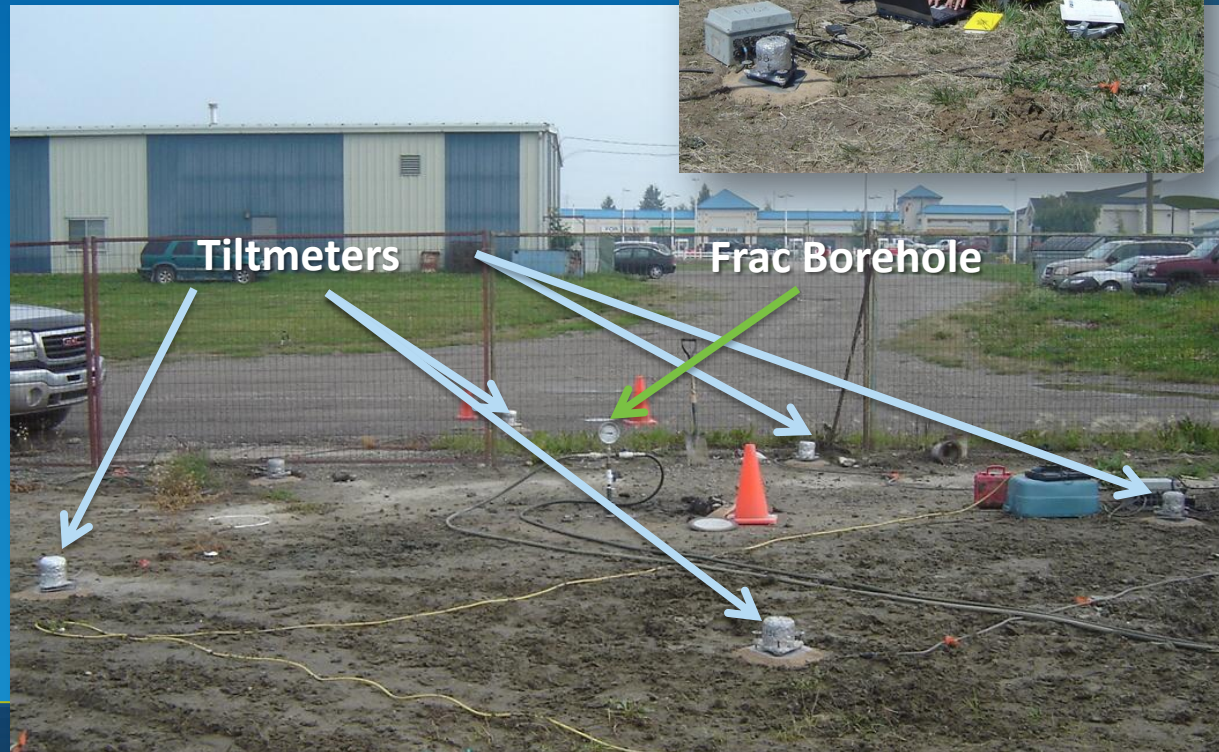


Evaluate Fracture Propagation: Tiltmeter Geophysics

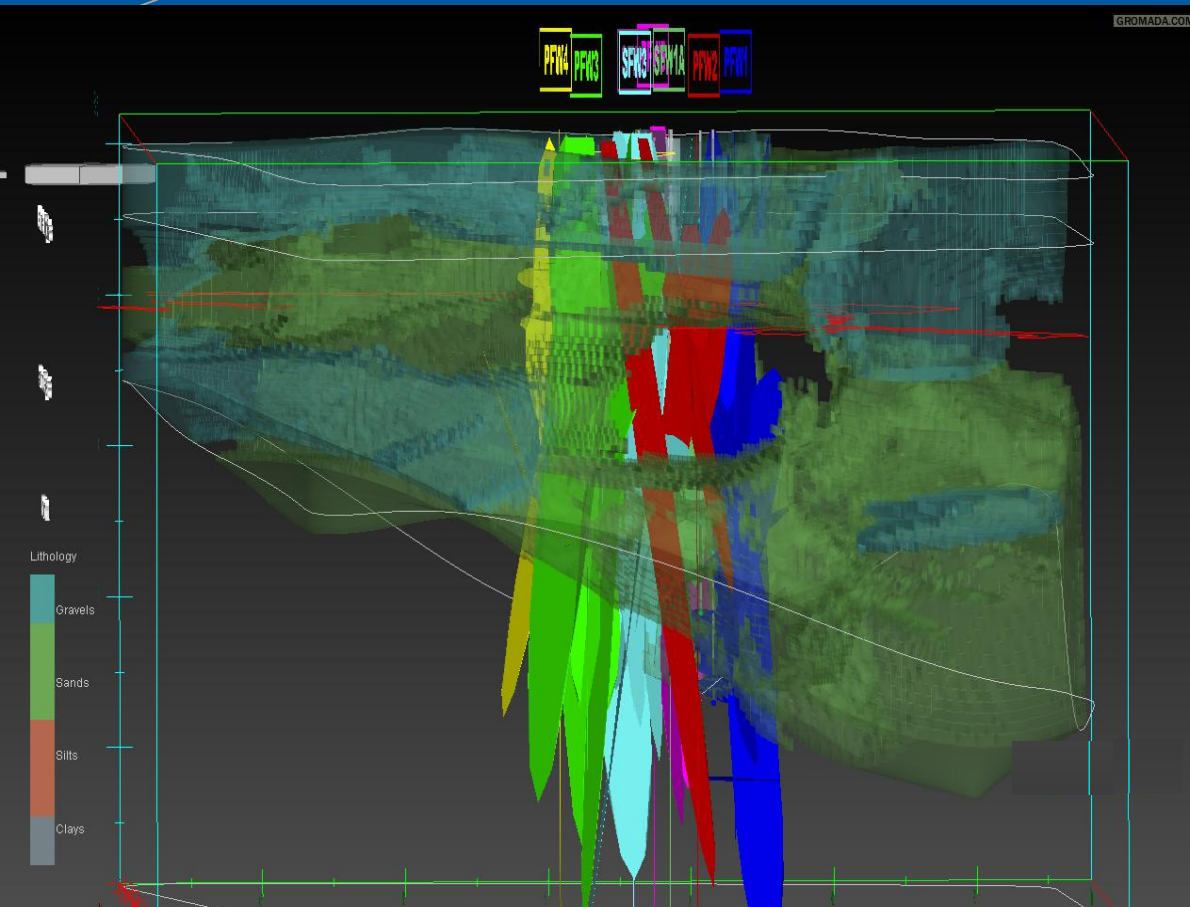
- Analyzed tiltmeter data for 60 of 87 fracs
- Modeled fracs for every borehole except PFW6 (near IR26MW16A).

Tiltmeters estimate:

- 1) Fracture extent
- 2) Fracture orientation
- 3) Fracture “center”



Results of Fracking: Amendment Distribution



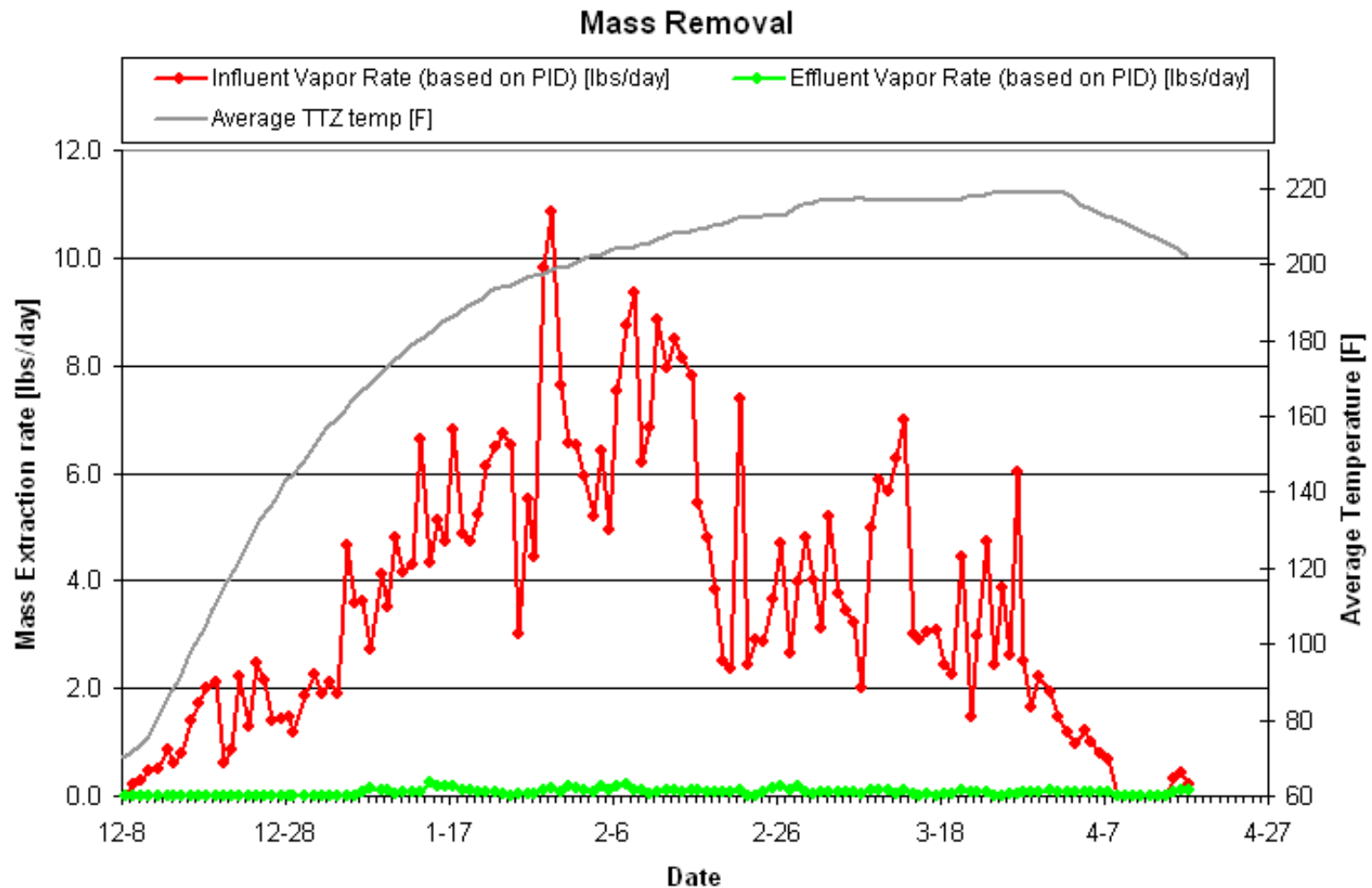
- Estimated 18 to 23-ft treatment radius
- Geochemical conditions conducive to reductive dechlorination
- Heterogeneous distribution of amendments.
- Evaluated technology for 4 months.

Technology 2 Implementation: Thermal Conduction Heating

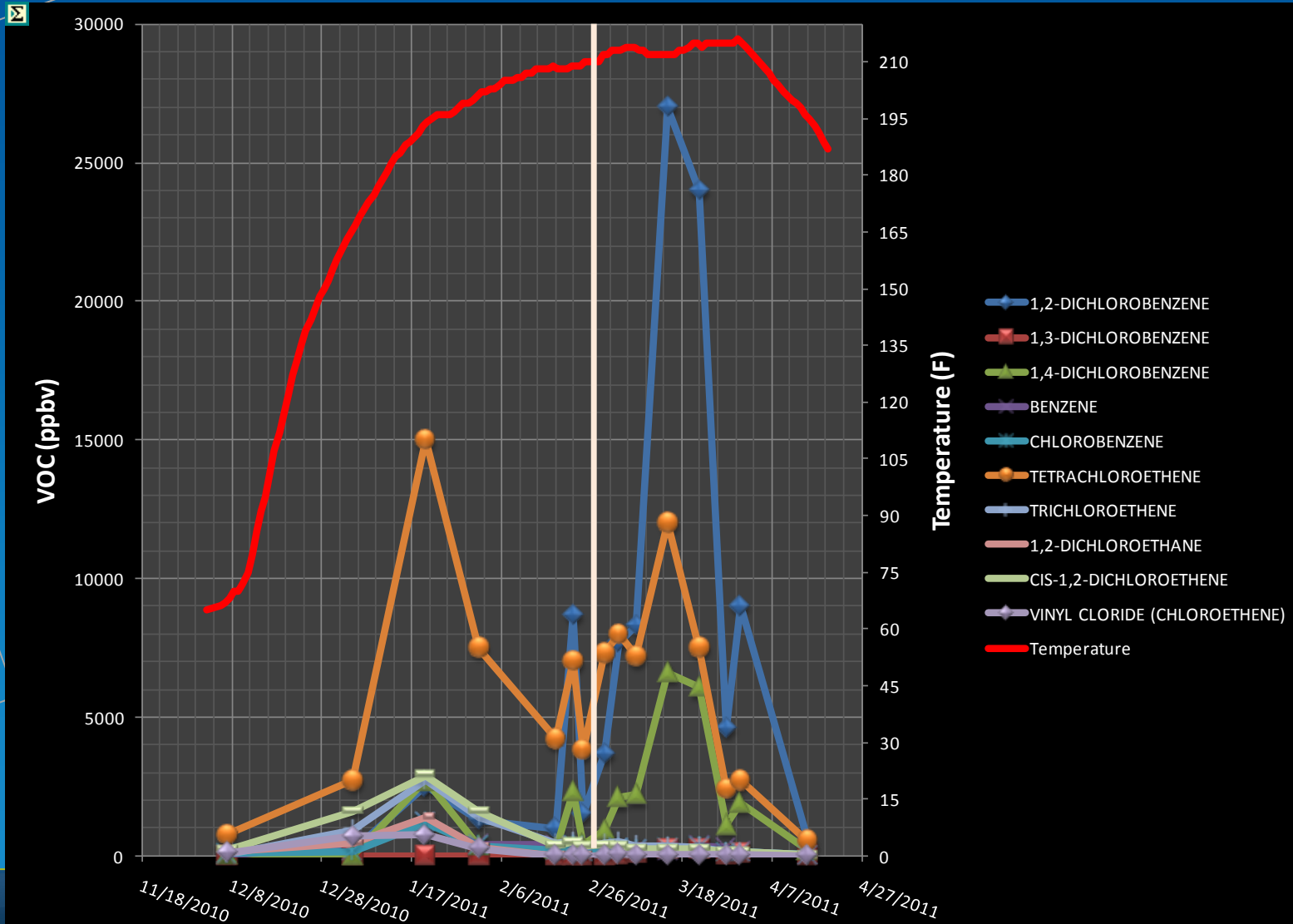


- 18 heater wells
- Soil vapor extraction system
- Above ground treatment
- 4 month operations

Contaminant Removal During TCH



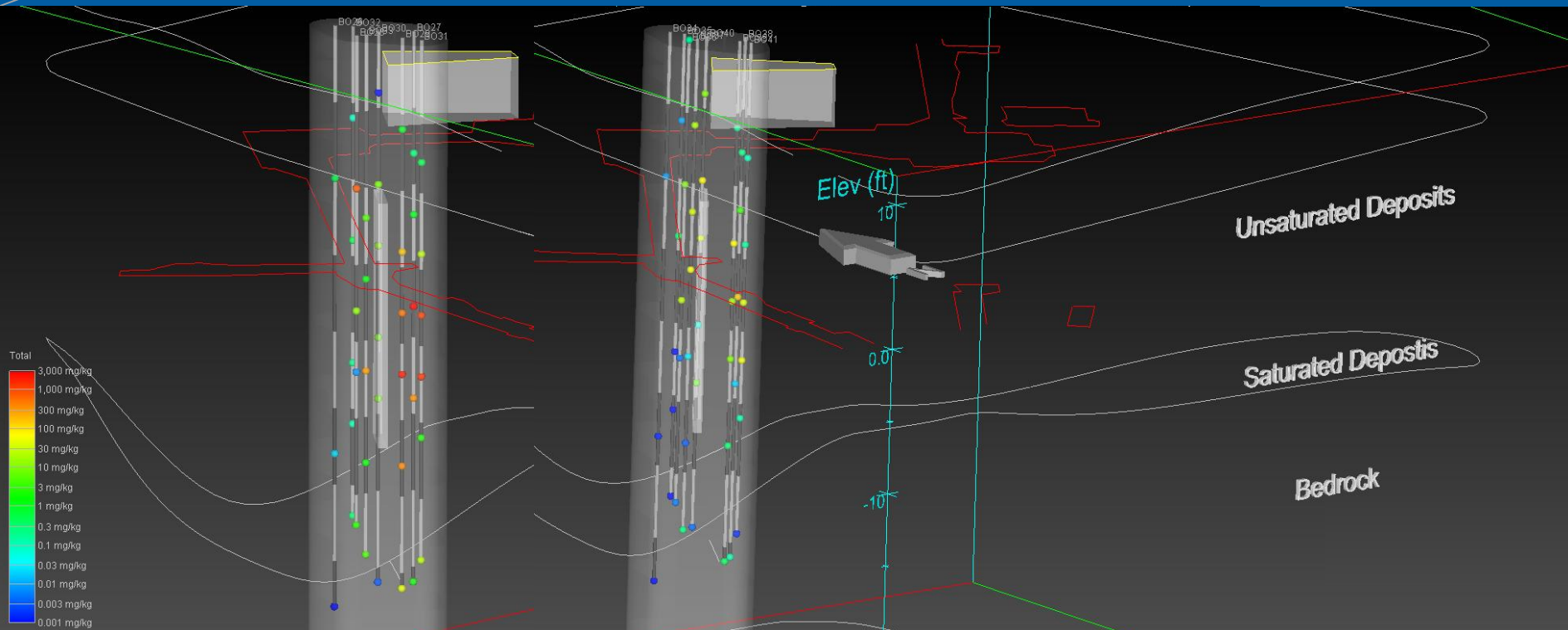
Contaminant Removal During TCH



Contaminant Mass Before and After-Treatment in Soil

Pre-TCH Soil total VOCs

Post-TCH Soil total VOCs



Total (lbs)

Before Remediation:

After Remediation:

% Reduction

12DCB

12DCA

13DCB

14DCB

PCE

Total

136

2.80

2.80

48.00

101.00

291

19.1

0.01

0.08

2.60

0.01

22

86%

99.8%

97.2%

94.6%

99.9%

92.5%

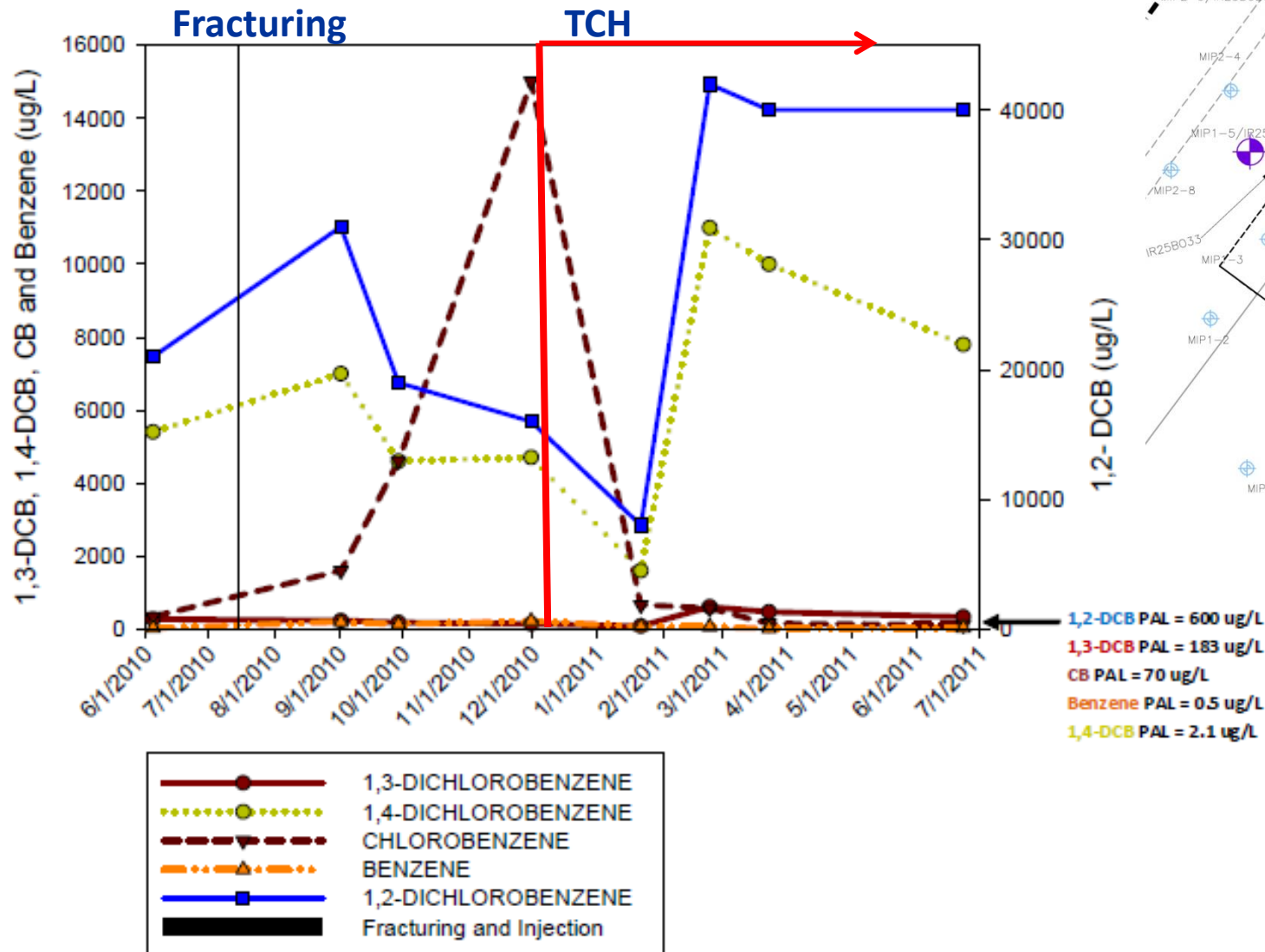
Contaminant Mass Before and After-Treatment in Groundwater

Total (lbs)	Parent Compounds					Reductive Daughter Products				
	1,2-DCB	1,2-DCA	1,3-DCB	1,4-DCB	PCE	benzene	CB	Cis-DCE	TCE	VC
Before Remediation:	4.7	0.7	0.01	1.5	0.6	0.03	0.2	2.1	0.2	0.6
After Remediation:	2.7	0.0	0.04	1.2	0.01	0.0	0.0	0.04	0.0	0.0
% Reduction	44%	100%	-300%	21%	99%	95%	96%	98%	78%	100%

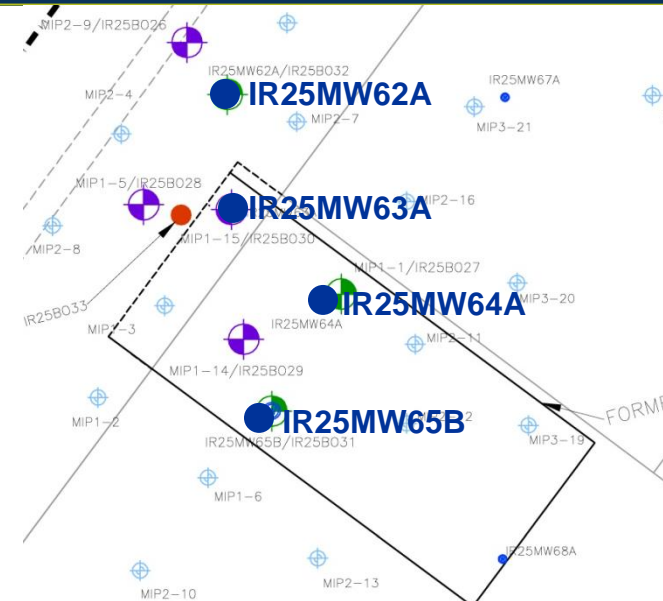
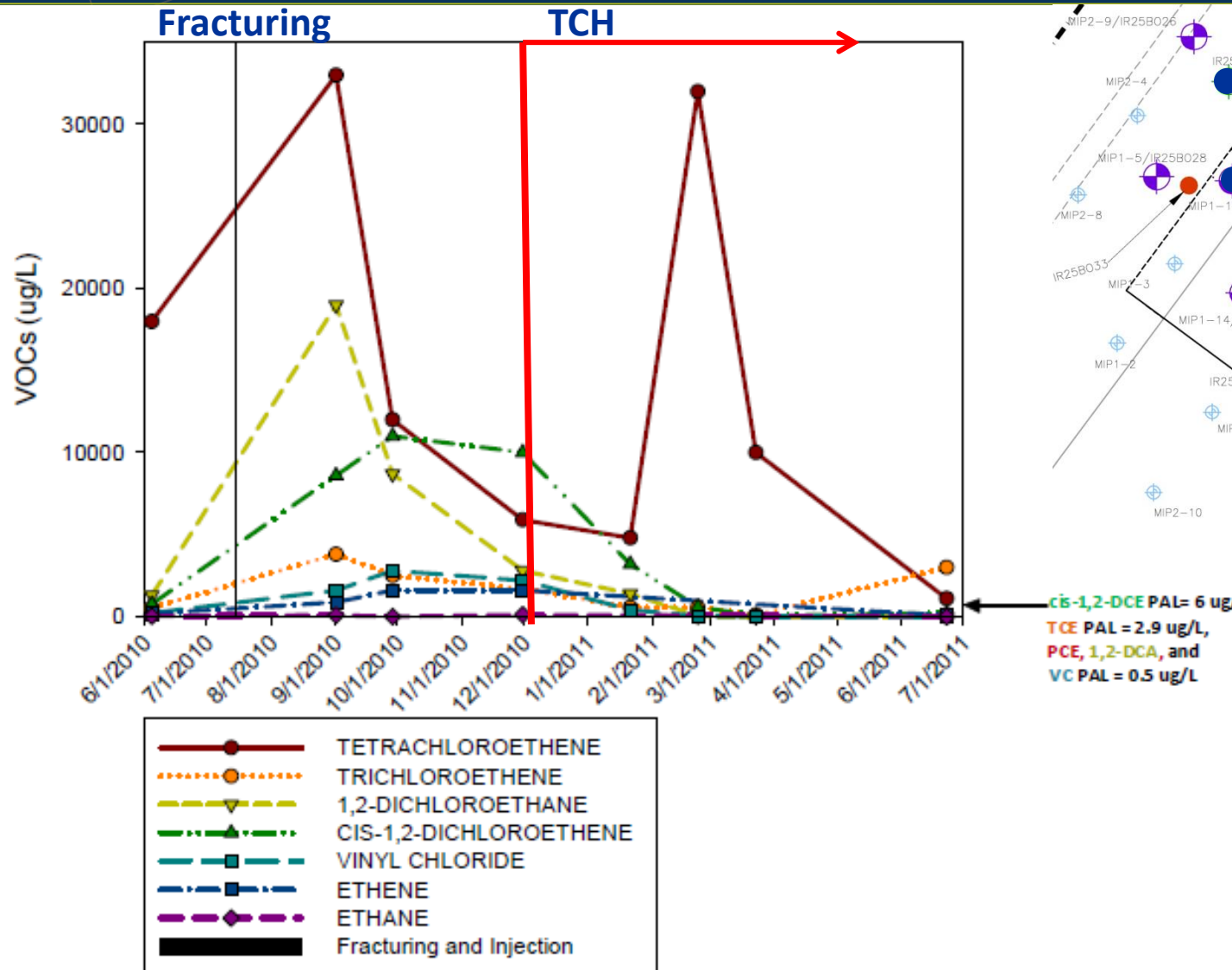
Total CoC Mass In Groundwater Pre-Treatment- 10.6 lbs

Total CoC Mass In Groundwater Post-Treatment- 4.1 lbs

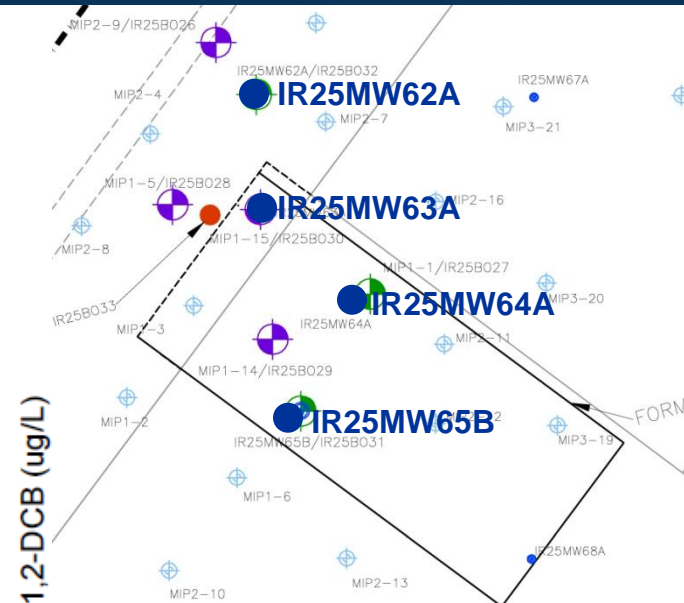
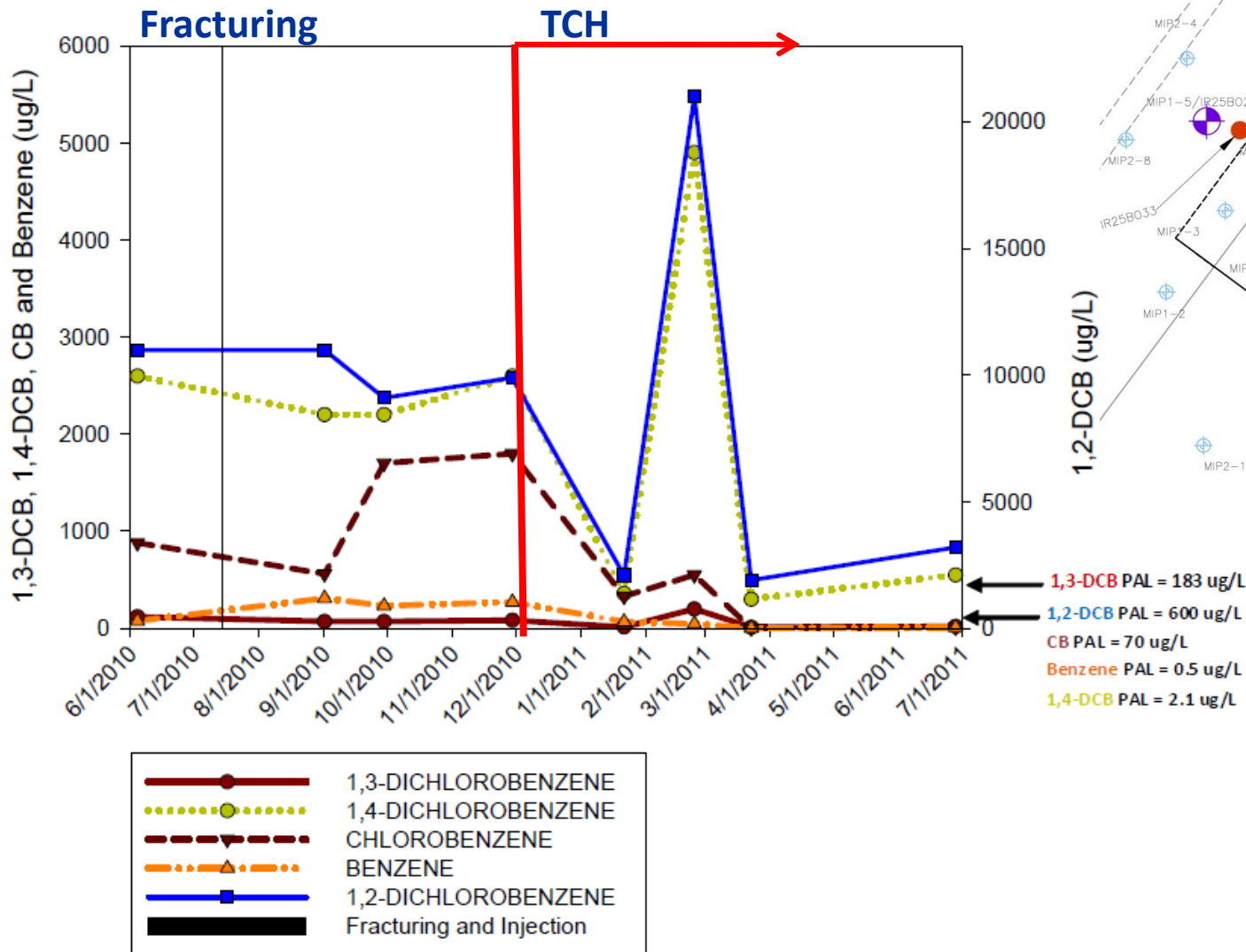
Chlorinated Benzenes: IR25MW63A



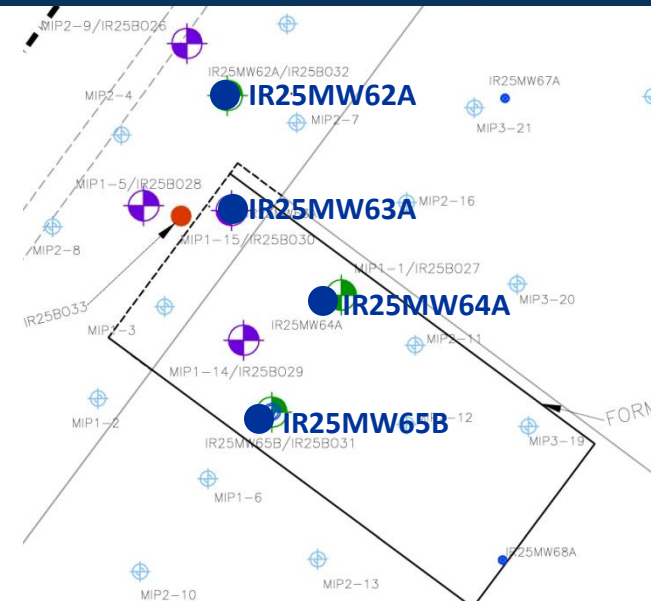
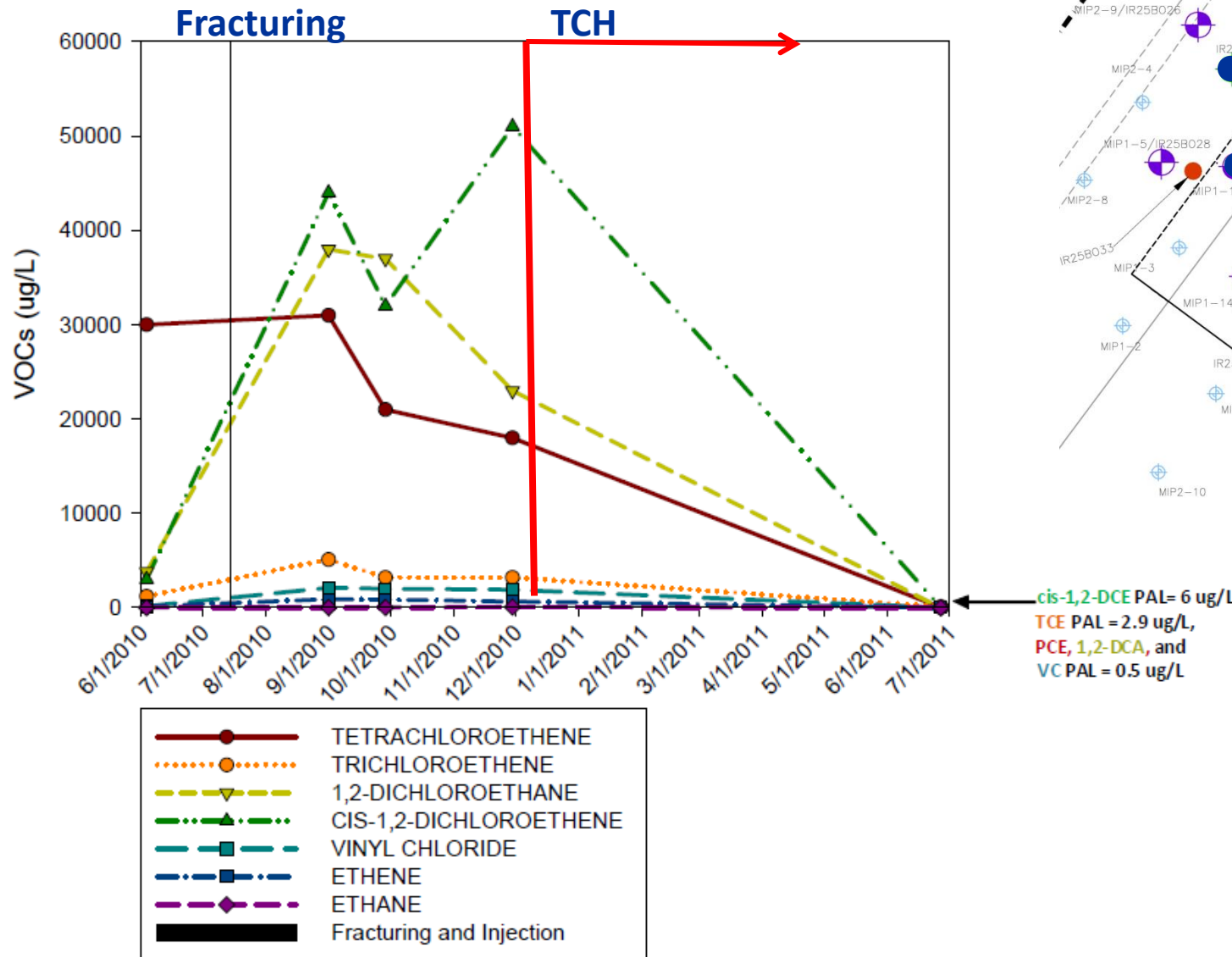
Chlorinated Ethenes: IR25MW63A



Chlorinated Benzenes: IR25MW65B



Chlorinated Ethenes: IR25MW64A



Conclusions: HPNS Treatability Study

- Fracture extents: 2.5 to 89 ft
 - Averaged 18-23 feet in the source area
 - Averaged 13-24 feet in the plume
- Treatment radius of influence > 20 ft
 - EHC[®] emplaced as discrete “sheets”
 - Diffusion of amendments created reducing conditions
- Fracturing/EHC[®]: 24-99.9% reduction in PCE and 1,2-DCA and 5-57% reduction in 1,2-, 1,3- and 1,4-DCB within four months.
- Biological degradation pathways predominated

Conclusions: Impact of Thermal Treatment

- Insignificant biological degradation at temperatures $>70^{\circ}\text{C}$.
- Removed $>90\%$ of total VOC mass in soil
 - Lowest removal for 1,2-DCB (86%)
 - Highest removal for PCE (99.9%)
- Parent compound groundwater concentrations reduced :
 - 50-93% for 1,2-DCB, 1,3-DCB, 1,4-DCB, except in IR25MW63A
 - $>94-100\%$ for PCE and 1,2-DCA
- Degradation product concentrations reduced 61-99% for chlorobenzene/benzene except IR25MW62A and IR25MW63A, which increased (due to post-TCH attenuation of DCBs).
- Post-treatment polish from emplaced carbon and EHC[®] will be evaluated over the next year.

Summary of Technology Performance

	Treatment Component	TC1	TC2	TC3	Total lbs removed
	Cost (\$) per cubic yard	\$50	\$1,950	\$28/\$32	
Groundwater	Reduction (%) of PCE and 1,2-DCA	45.0%	99.0%	95.2%	
	Reduction (%) of 1,2-DCB, 1,3-DCB and 1,4-DCB	33.9%	1.34%	45.9%	
	Reduction (%) of total PCE, TCE, 1,2-DCA, 1,2-cis-DCE, VC	33.0%	97.6%	93.2%	
	Reduction (%) of total 1,2-DCB, 1,3-DCB, 1,4-DCB, chlorobenzene, benzene	15.9%	25.5%	51.3%	
	Total DCB mass removed (lbs)	1.7	1.1	0.40	3.2
	Total PCE, 1,2-DCA mass removed (lbs)	5.25	6.36	0.09	11.7
Soil	Reduction (%) of PCE and 1,2-DCA mass	NA	99.98%	NA	
	Reduction (%) of 1,2-DCB, 1,4-DCB, 1,3-DCB mass	NA	88.3%	NA	
	Reduction (%) total VOC mass	NA	92.4%	NA	
	Total VOC mass removed (lbs)	NA	269	NA	269
	Total 1,2-DCB, 1,4-DCB, 1,3-DCB mass removed (lbs)	NA	165	NA	165
	Total PCE and 1,2-DCA mass removed (lbs)	NA	104	NA	104

The background is a solid blue color with a subtle gradient. On the left side, there are several thin, white, curved lines that intersect to form a grid-like pattern. A bright, circular light source is positioned on the right side, casting a strong, diagonal beam of light across the lower half of the image. The beam is a lighter shade of blue and has a soft, glowing effect. The overall composition is clean and modern.

THANK YOU!

Questions?