Field-Scale Demonstration of Enhanced DNAPL Dissolution Using Recirculation-Based Bioremediation

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Haley & Aldrich
2019 Battelle Bioremediation Symp.

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Outline

- Overview of Conceptual Site Model/Remedial Technology Selection
- Remedial Design and Implementation
- Performance Monitoring/Comparison with DNAPL-Enhanced Dissolution in the Literature

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Conceptual Site Model

- 175 acre manufacturing facility
- Used chlorinated solvents in several different buildings.
- Solvent-containing wastewater routed to plant's WWTP facility.
- Multiple leaks/releases from individual plants and wastewater conveyance piping.

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Conceptual Site Model

Geology/Hydrogeology

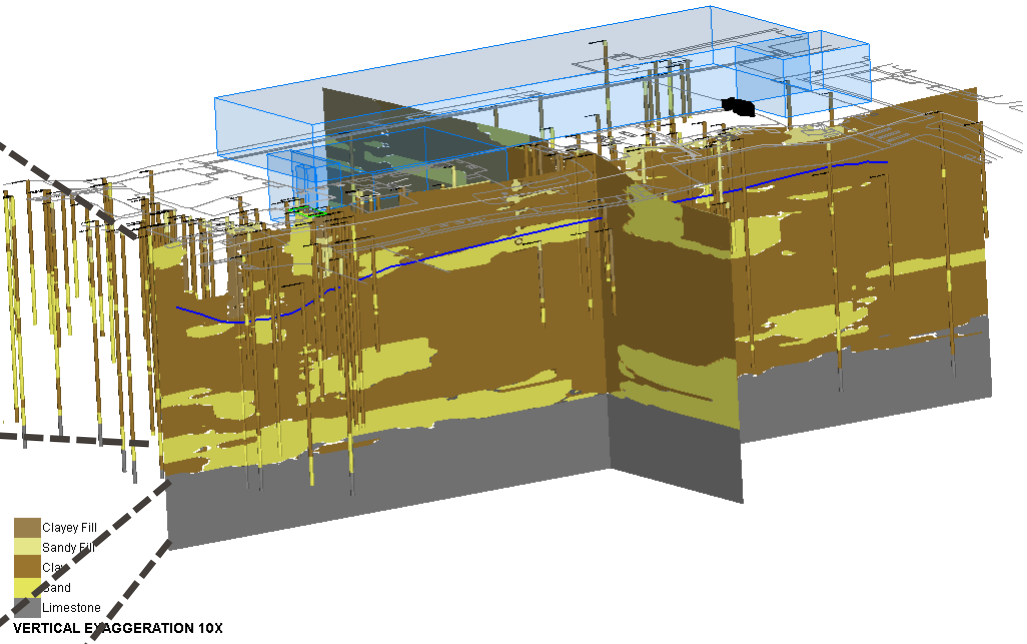
35’

- Dense/hard glacial till (direct push not feasible)
- Isolated sand zones with limited/no connectivity

5-10’

- Outwash sand – laterally contiguous across most of Site (“Top of Rock” or TOR)
- Treatment zone/focus of talk

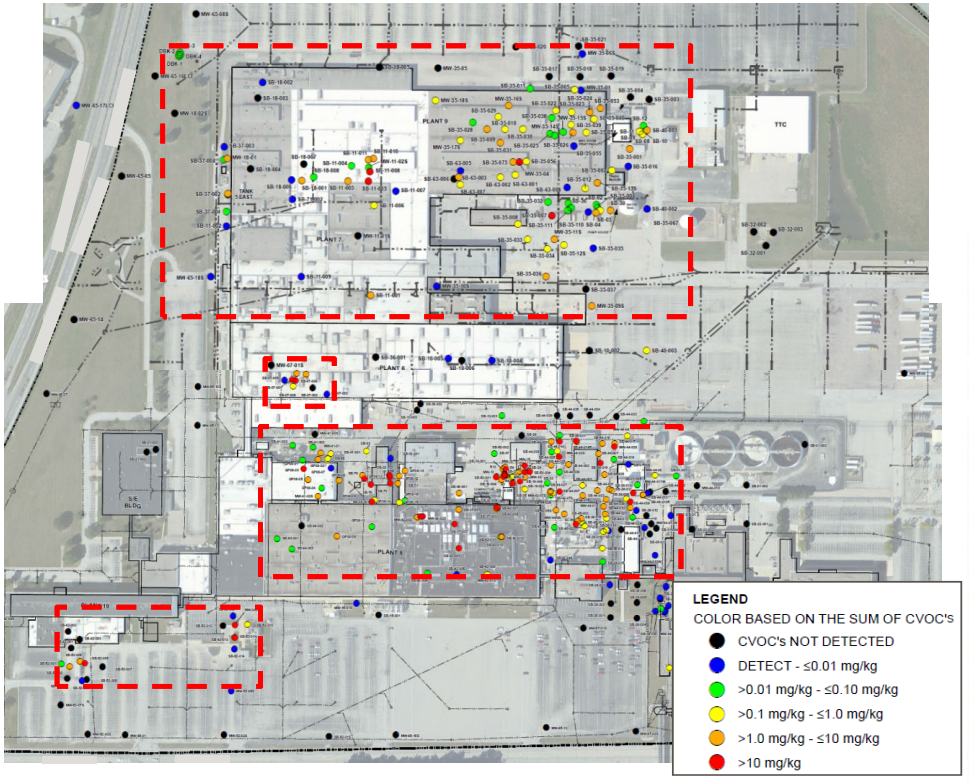
- Limestone bedrock



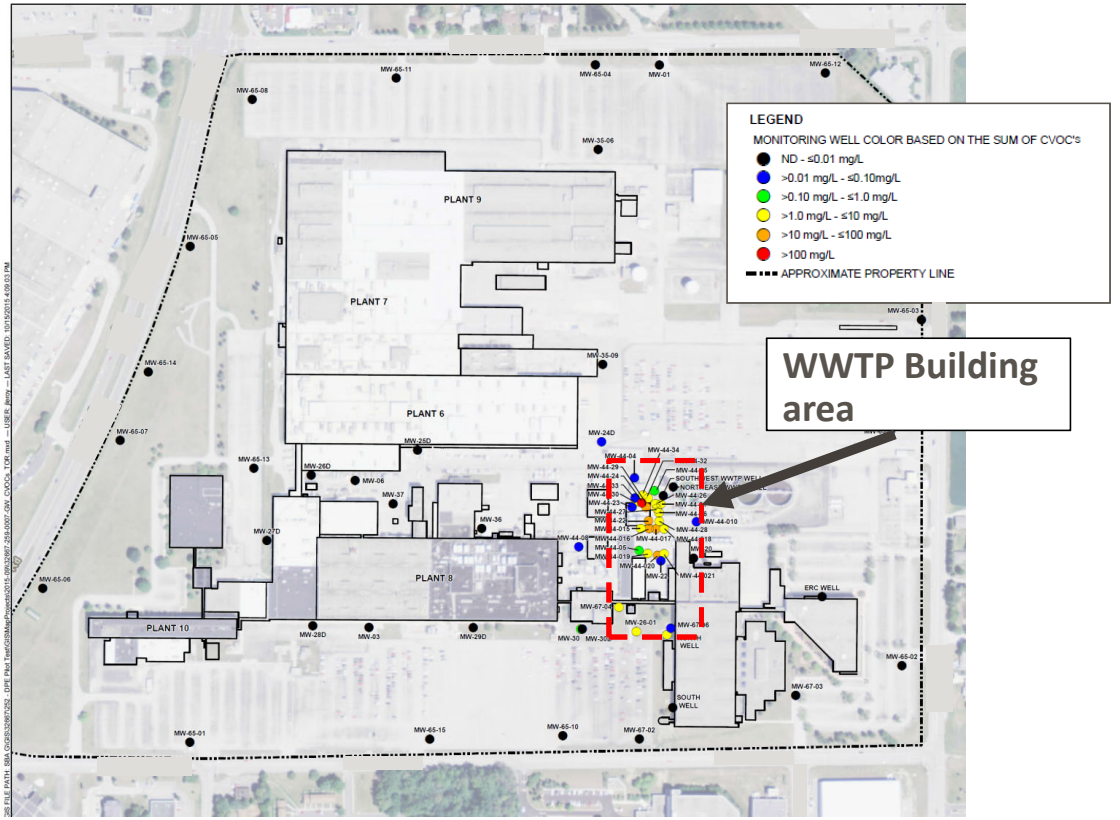
Conceptual Site Model

CVOC Distribution

CVOCs in shallow soil/till – distributed across the Site



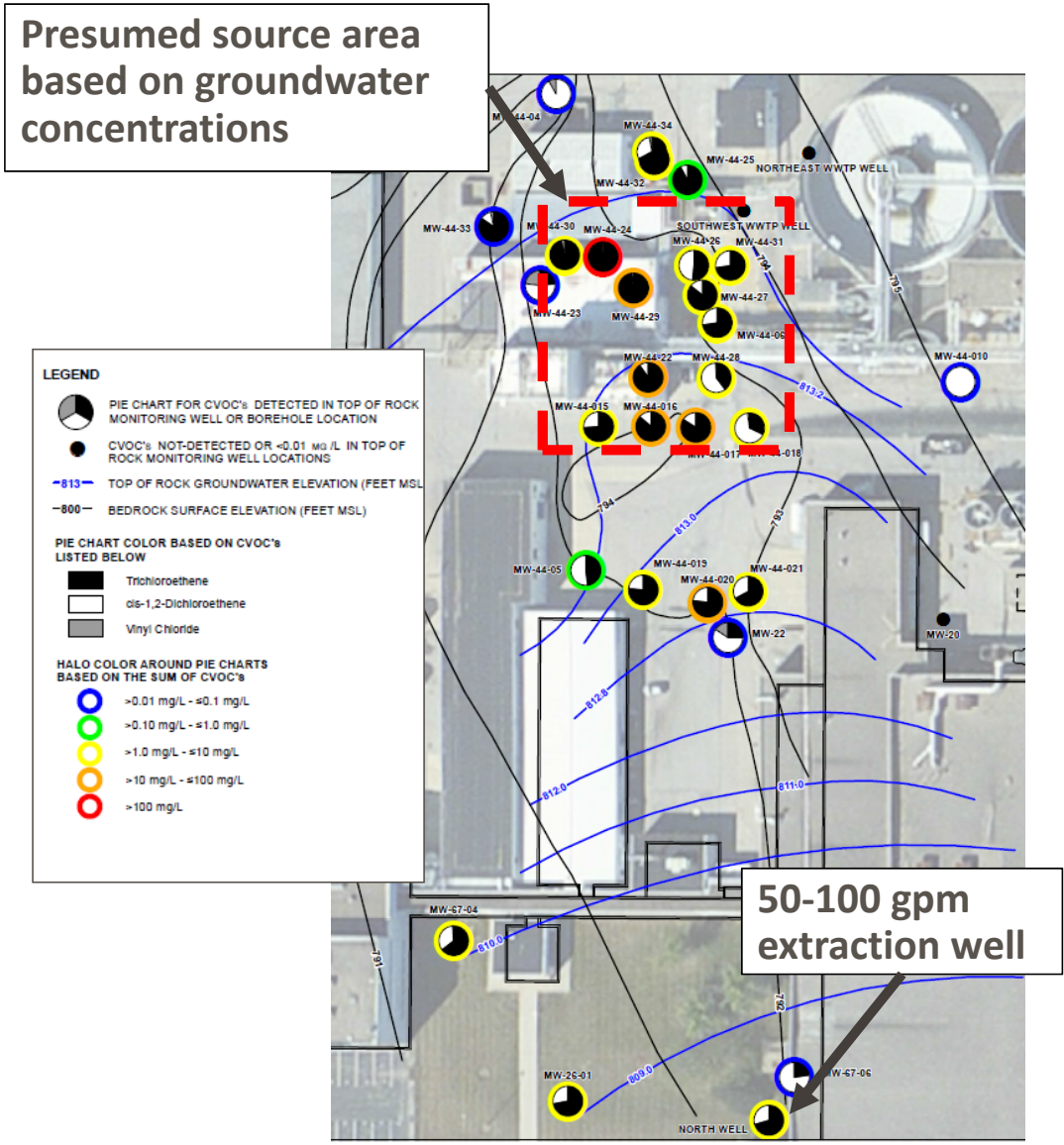
Vertical migration to TOR groundwater– limited to smaller area of Site



Conceptual Site Model

CVOC Distribution in WWTP Area

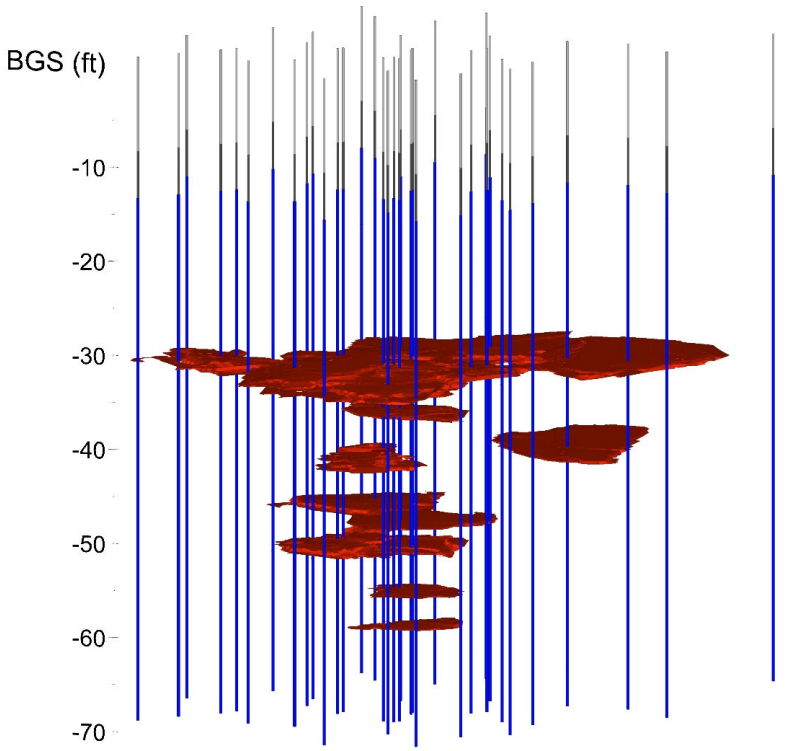
- Highest concentrations in TOR near WWTP plant building (red halos>100 mg/L; orange >10; yellow >1).
- Primarily TCE (black pies) with some cDCE (white pies).
- Groundwater flows south towards groundwater extraction well pumping at 50-100 gpm.
- Appeared to be a bedrock mound in middle of source area with groundwater flowing around the mound.



Presence of DNAPL in TOR Unit?

- CVOC mass obviously present in low permeability till based on soil sampling data but was there additional DNAPL source mass in TOR unit?
- Site was not amenable to direct push HRSC technologies like DyeLIF and needed to rely on other lines of evidence.
- Groundwater TCE concentrations exceeding 100 mg/L at one location, 10 mg/L at several others, suggest DNAPL.
- TCE concentrations at extraction well have exceeded 1 mg/L at ~100 gpm extraction well since sampling began in 2008. Maintaining this mass discharge (400 lb/yr) level for a decade with little/no decrease in concentration suggests DNAPL source.

Example DyeLIF high-resolution DNAPL characterization from site in Massachusetts

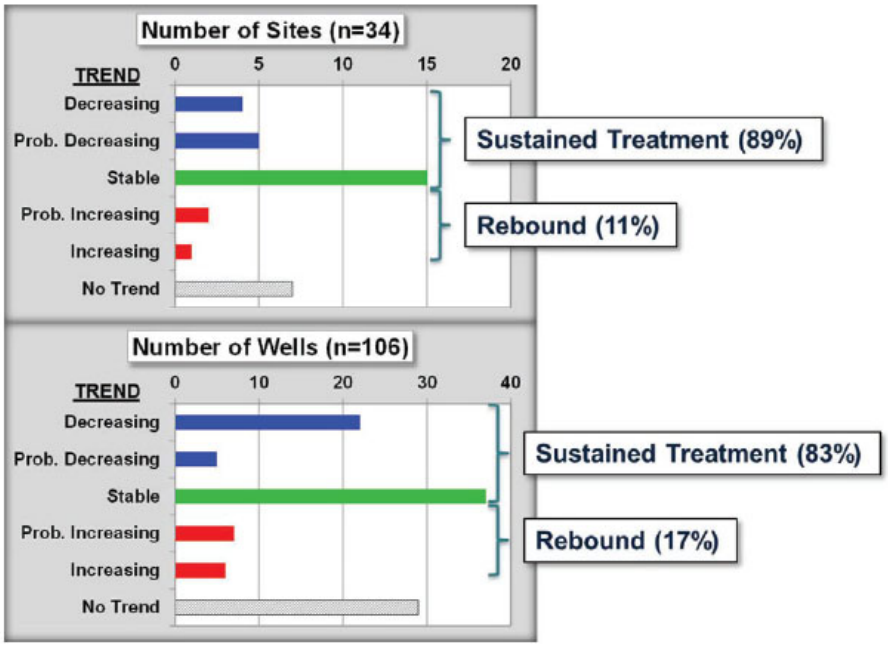


Remedy Selection

- CVOC mass in clay till difficult to access/treat due to overlying building, low permeability setting, and difficult drilling conditions. Ruled out source treatment options such as thermal/excavation.
- DNAPL mass that could be targeted in TOR groundwater unit using recirculation wells.
- Bioremediation selected due to ability to treat DNAPL mass and compatibility with MNA/potential to partially manage long-term back diffusion processes through creation of reactive mineral species, build of organic matter (carbon source).

Evaluation of Long-Term Performance and Sustained Treatment at Enhanced Anaerobic Bioremediation Sites

McGuire et al., 2016 - GWMR



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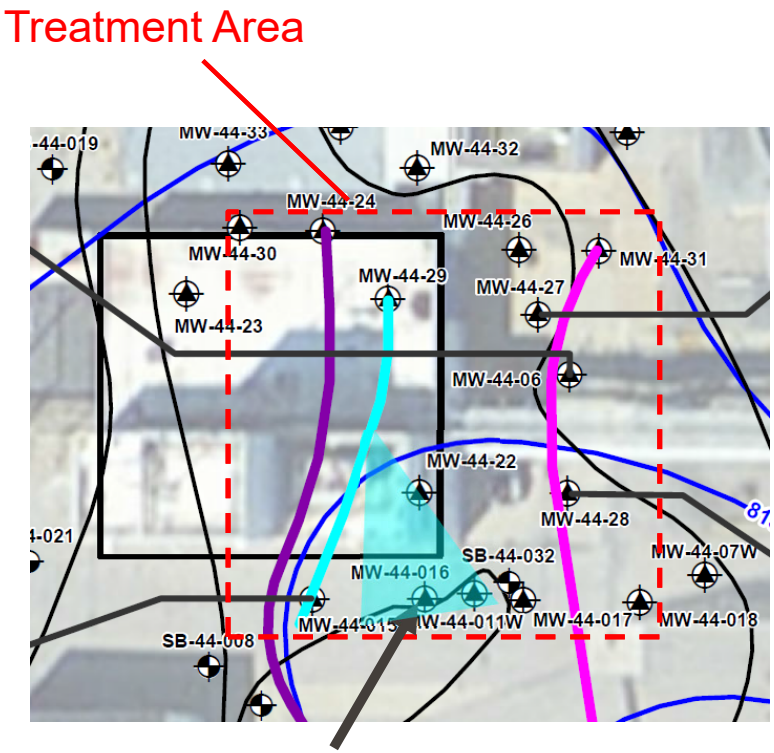
Remedial Design Investigation

Tracer Study

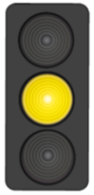
- Concern about an apparent mound in bedrock surface that indicated groundwater was flowing around center or proposed treatment.
- Released unique fluorescence tracers in different wells to better evaluate flow patterns (fluorescein, eosin, rhodamine).
- Tracer testing confirmed flow pattern inferred from bedrock contour and potentiometric lines.
- Performed a short pump test to evaluate whether pumping would pull tracer into central portion of treatment area. Testing confirmed this was the case.



Remedial Design Investigation
Additional Data Collection

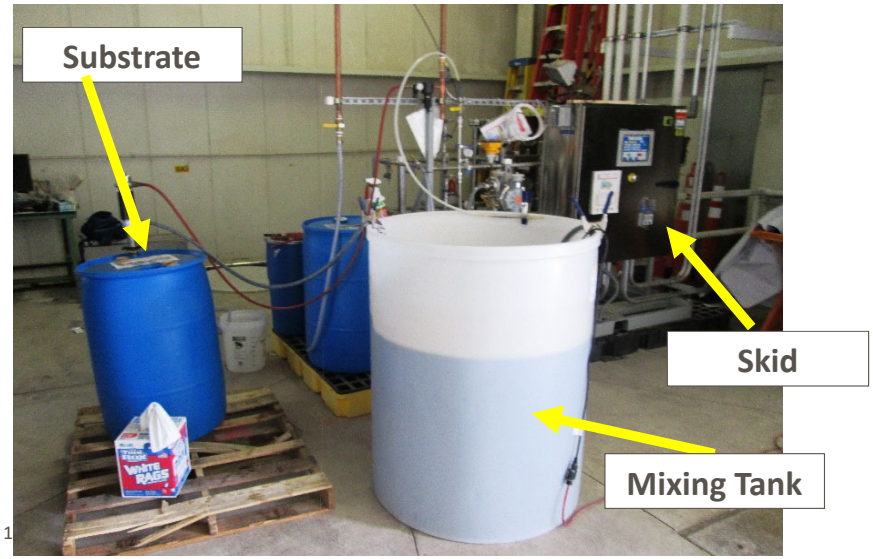
- Additional geochemistry sampling:
  - Mixed redox conditions: primarily iron/sulfate reducing with localized methanogenic zones based on dissolved methane
  - TOC ~ 1-2 mg/L
  - Adequate buffering capacity based on alkalinity data.
- Microbiological testing for Dehalococcoides (DHC) – present in the 10^1-10^2 cells/mL range

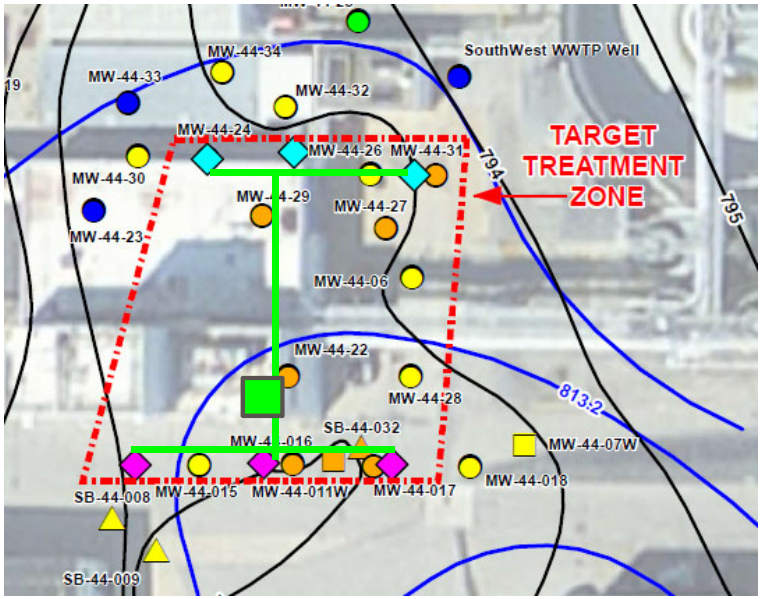
Microbial Insights Interpretation Guide – based on Lu et al. (2006)

Status	*Dehalococcoides spp.*	
	**≥ 10^4** (cells/mL)	
	**10^1 to < 10^4** (cells/mL)	**Biostimulation**
	**< 10^1** (cells/mL)	**Biostimulation + Bioaugmentation**

System Design

- 3x3 set up with three injection wells on north side of building; three extraction wells on south side.
- Designed where extracted water can be routed to any of the injection wells to allow for system optimization.





Injection well

Extraction well

Conveyance Piping

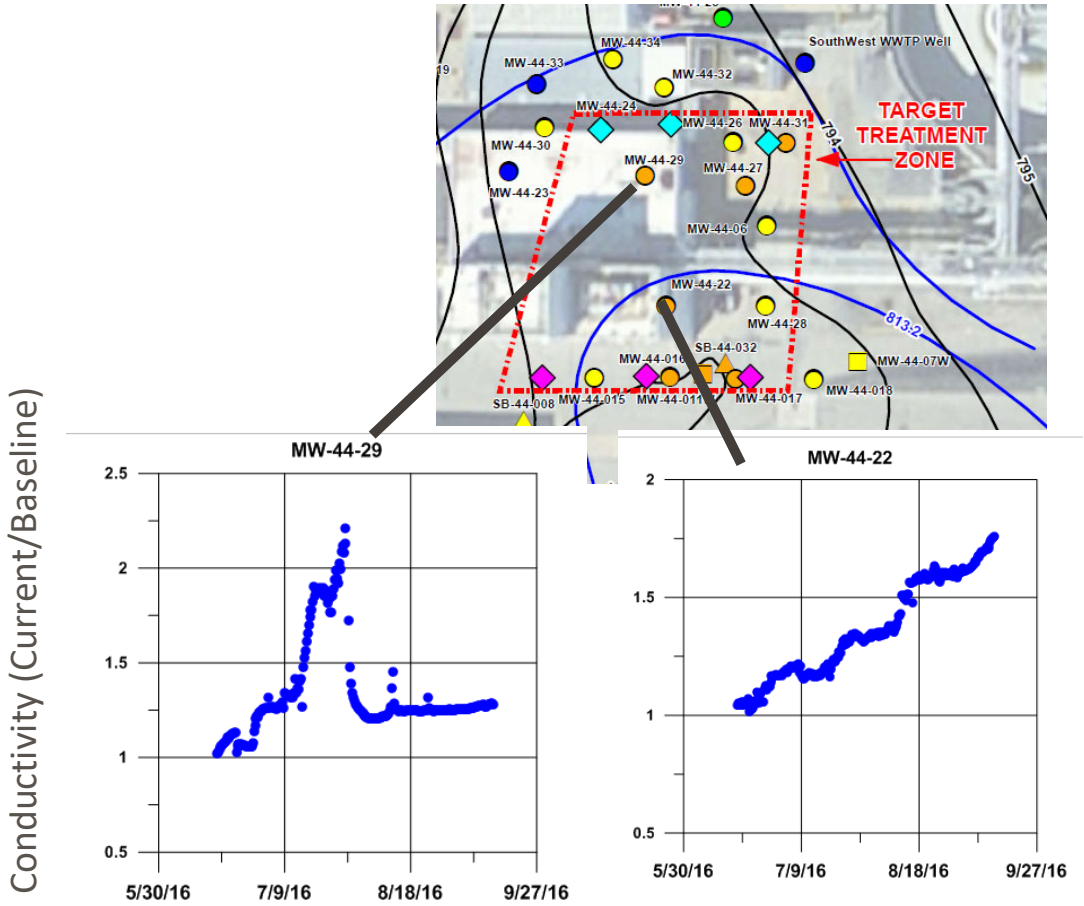
Substrate dosing skid

Recirculation Benefits

- Improved substrate distribution due to enhanced mixing.
- Helps with distributing DhC from more reduced geochemical niches.
- Enhanced mass transfer from DNAPL and lower permeability units due to increased flushing/manipulation of concentration gradients.
- Increases longevity of soluble substrates by facilitating mass transfer into low permeability zones.
- Don’t need to know source mass – can go with a more incremental substrate addition procedure.
- Can adjust flow rates/dosing to optimize distribution (adaptive management).

Startup and Optimization

- Initial period (week) of flow balancing where system where all three loops were running – additional baseline samples.
- Used down-well electrical conductivity probes to map substrate distribution in treatment area coupled with frequent TOC sampling of extraction wells.
- Started out by running just the central loop to distribute substrate in central portion of treatment zone.
- Substrate later added to eastern/western recirculation loops using pulsed additions.



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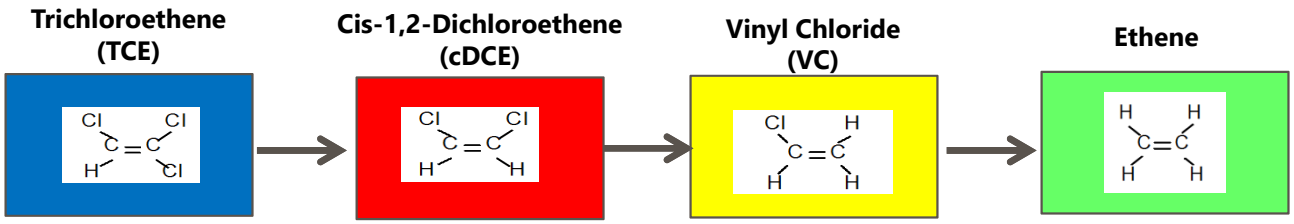
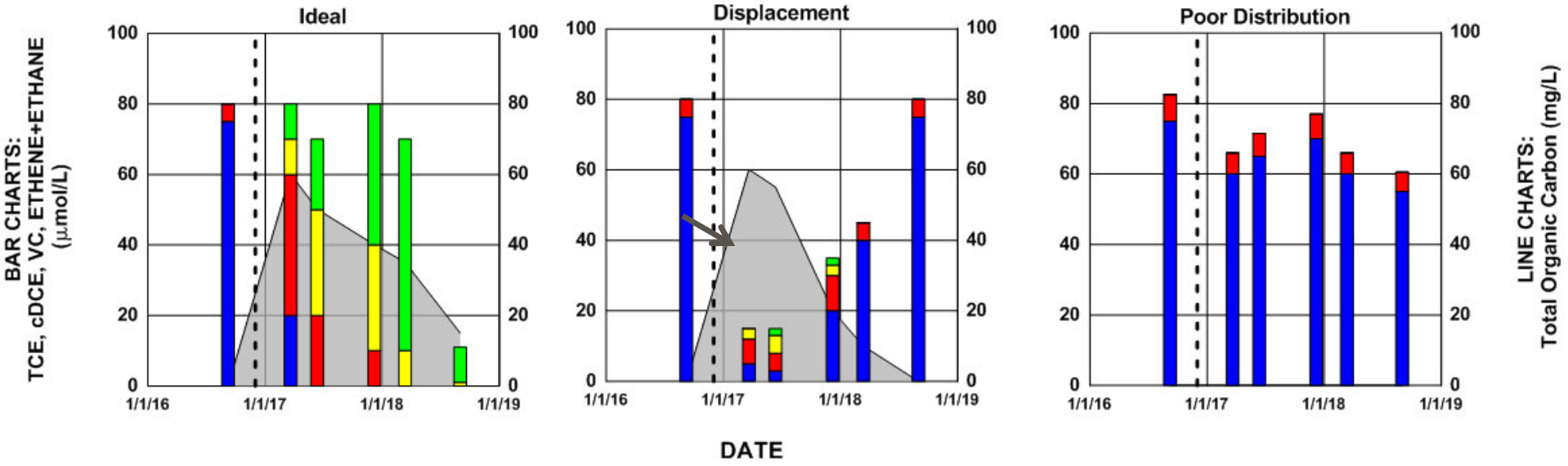
Bar Charts for Evaluating ERD Performance

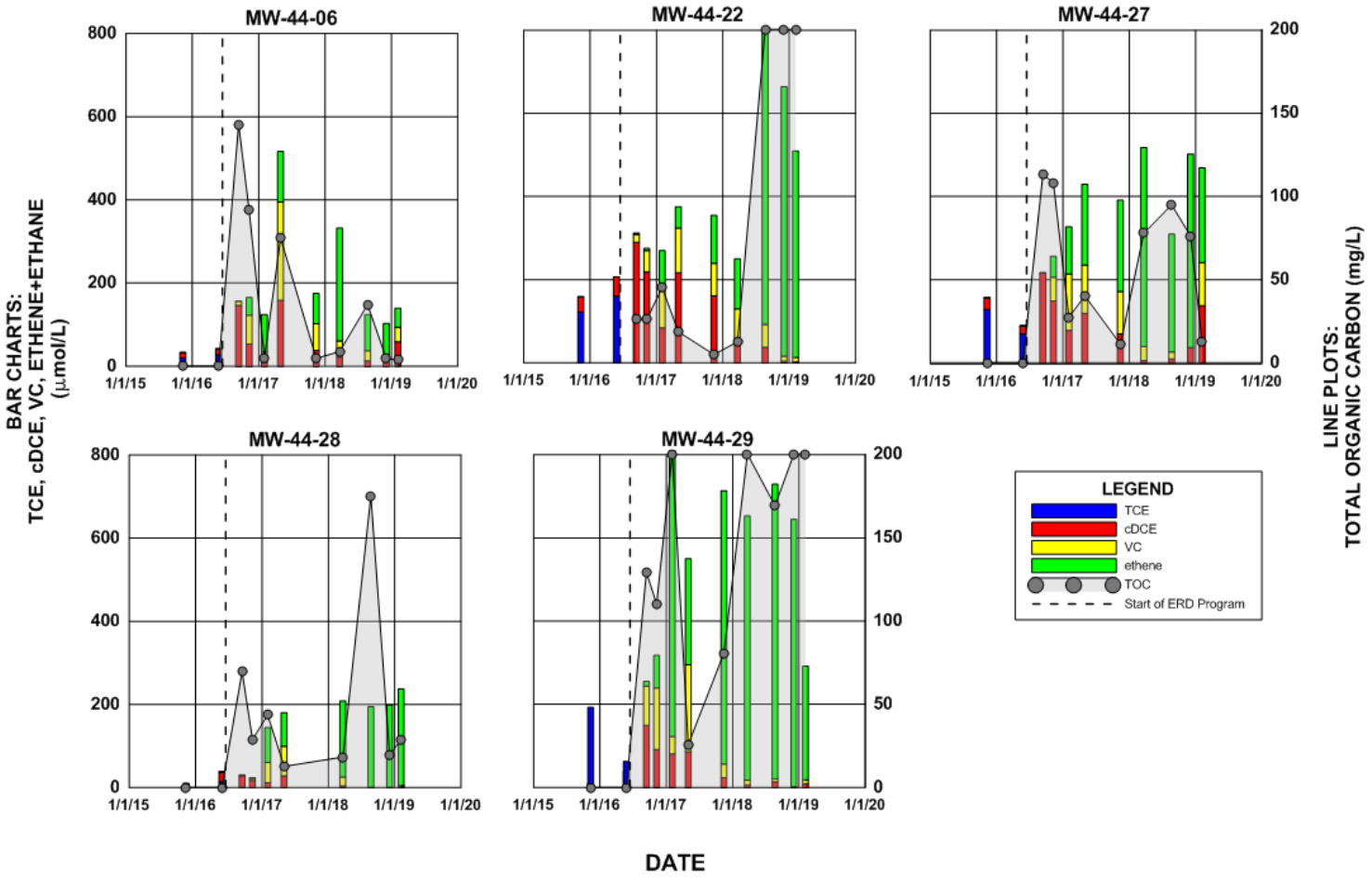


1 mole of TCE = 1 mole of cDCE = 1 mole of VC = 1 mole ethene



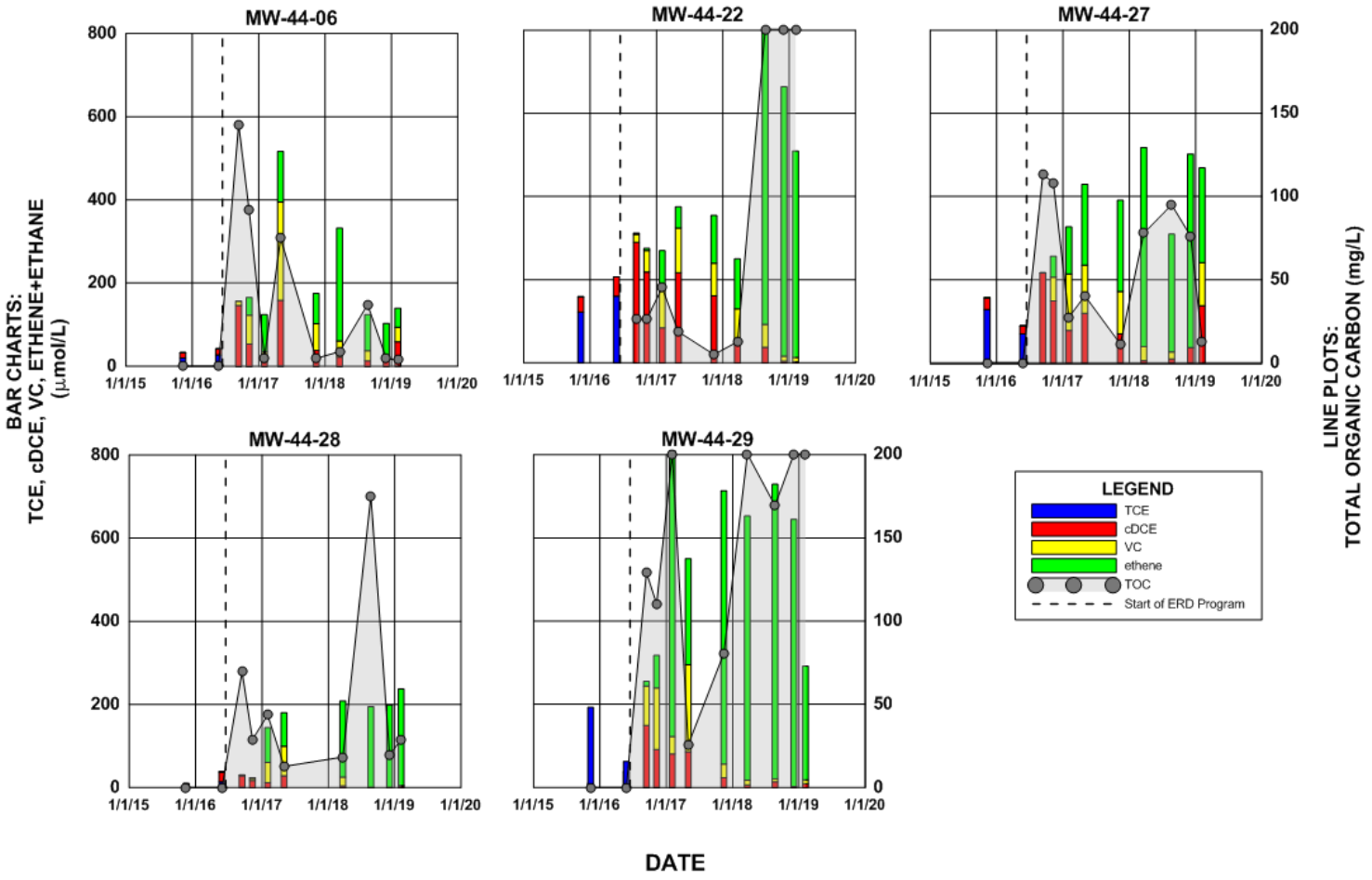
Performance Monitoring

- Substrate dosing over two year time frame
- Three application of about 1 gram per liter averaged over treatment area pore volume
- TCE rapidly degraded in first couple months on treatment.
- Period where cDCE/VC exceed initial TCE levels as source mass is worked through.

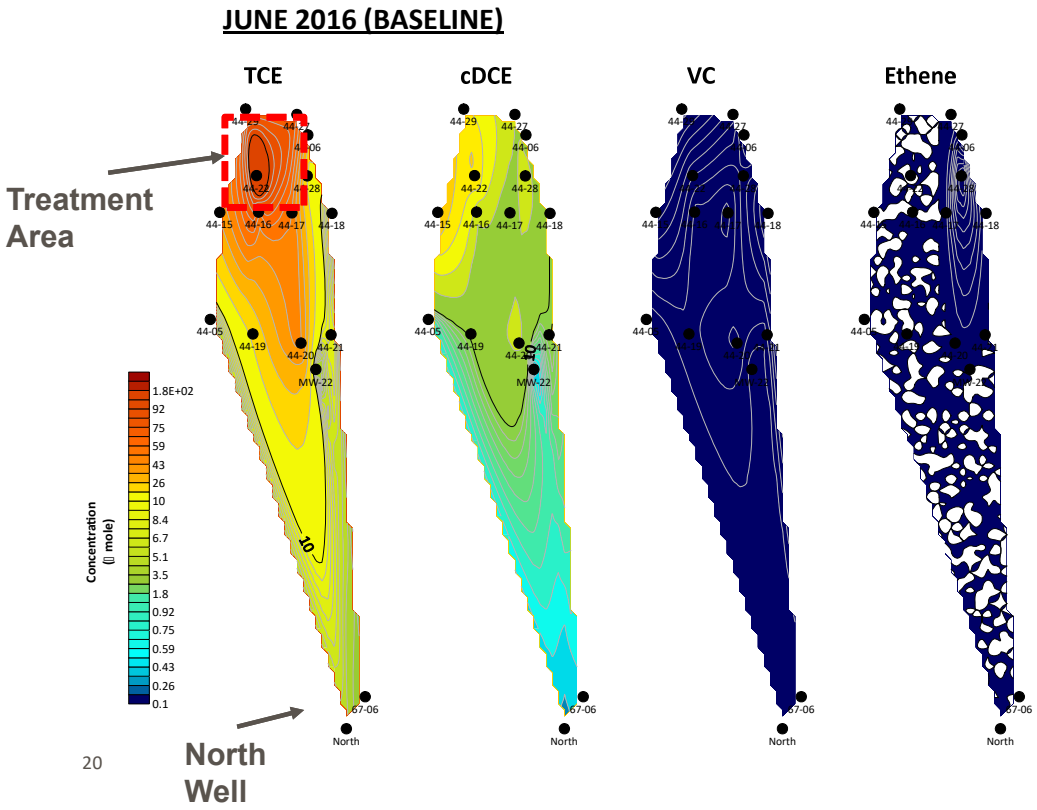


Performance Monitoring

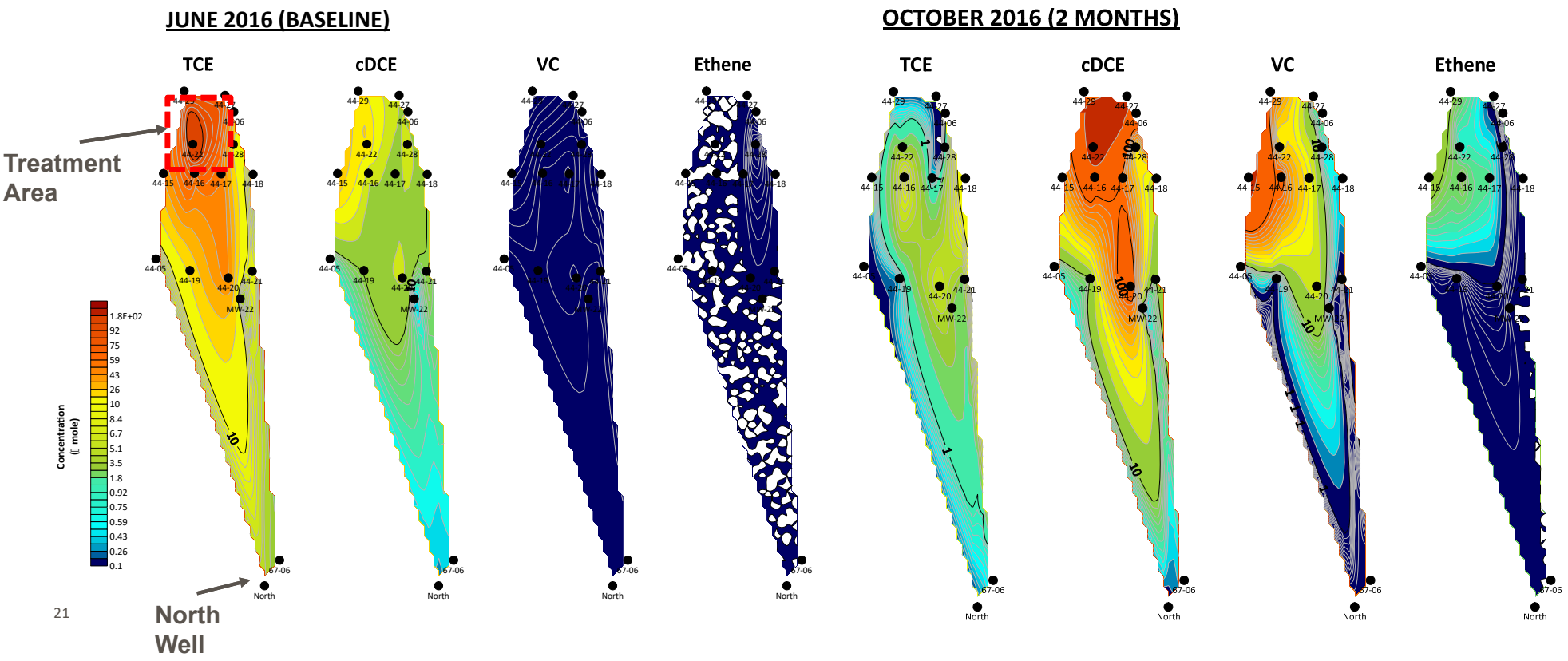
- Eventually reach condition where ethene levels are several times greater than initial TCE.
- Individual well enhancement factor up to 30 for individual wells.
- More representative spatial average enhancement factor of 5.



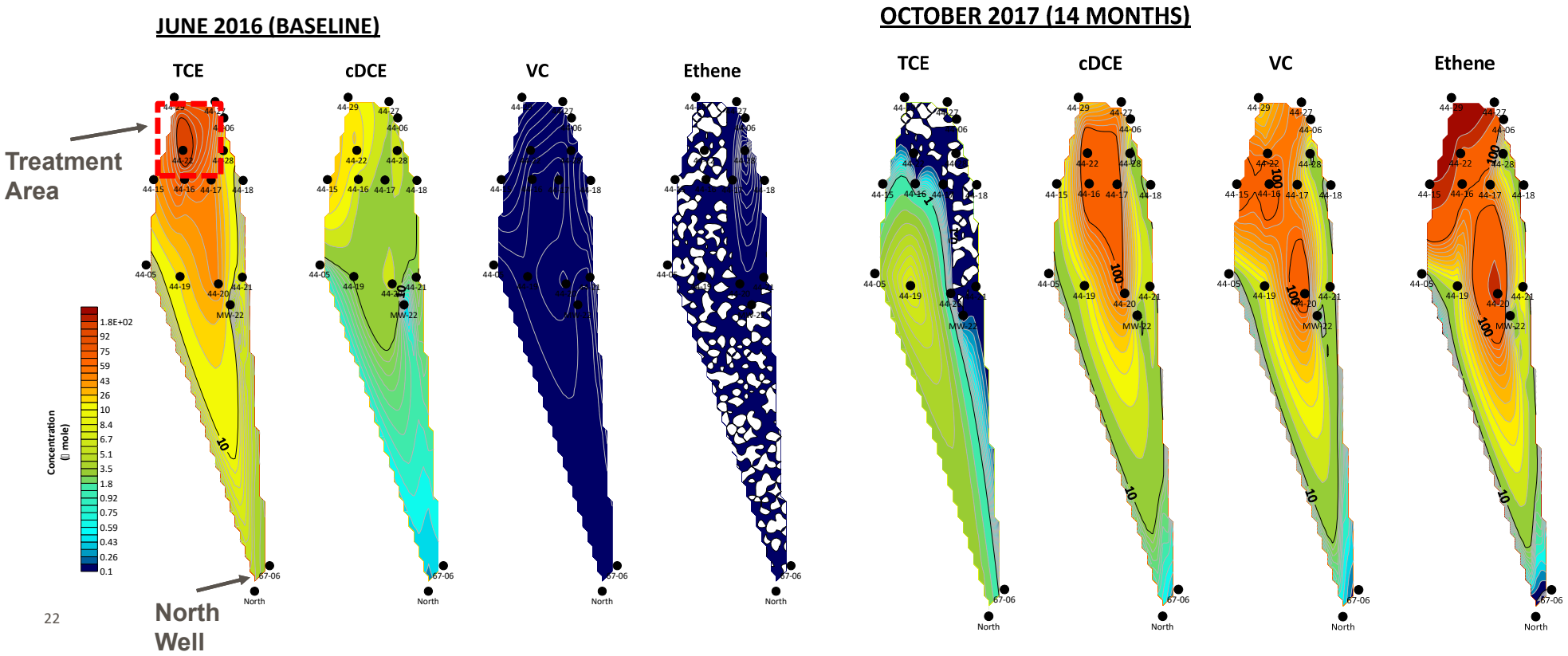
Performance Monitoring - Baseline



Performance Monitoring – 2 Months

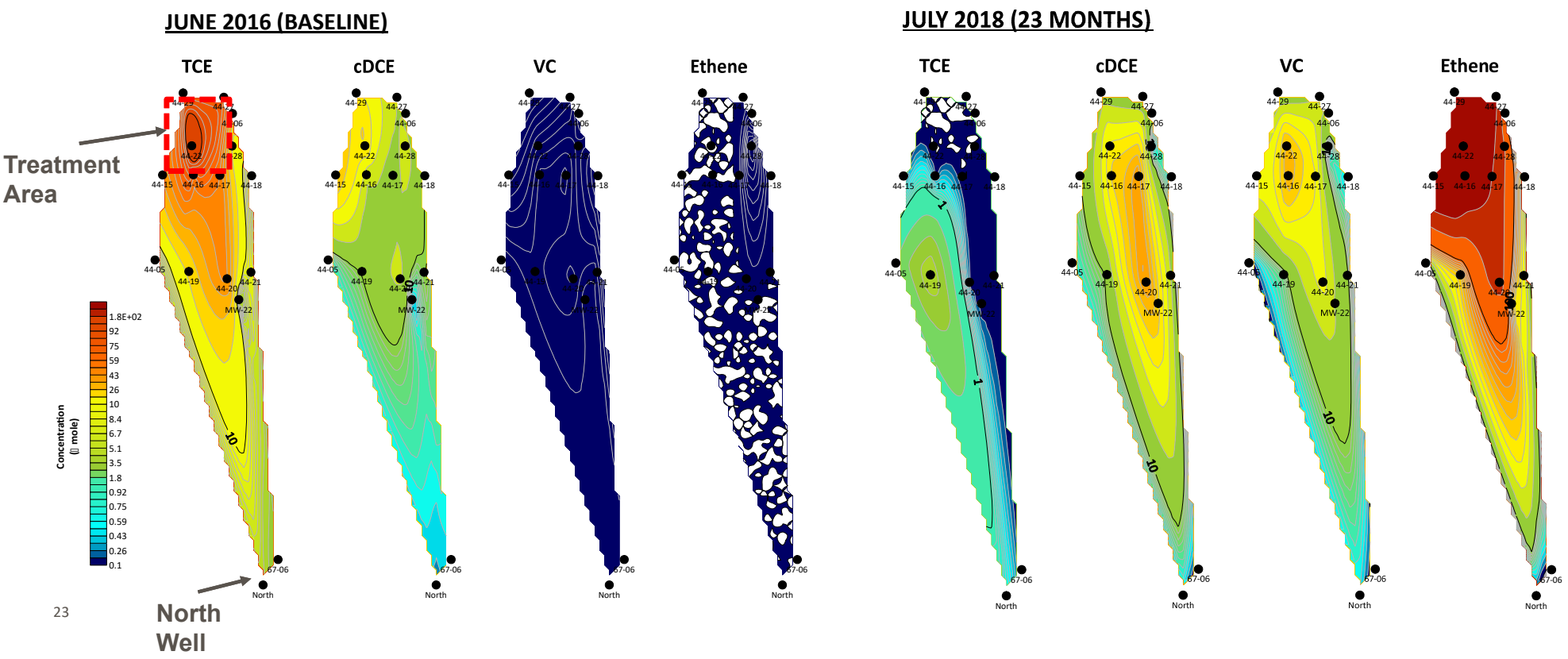


Performance Monitoring – 14 Months



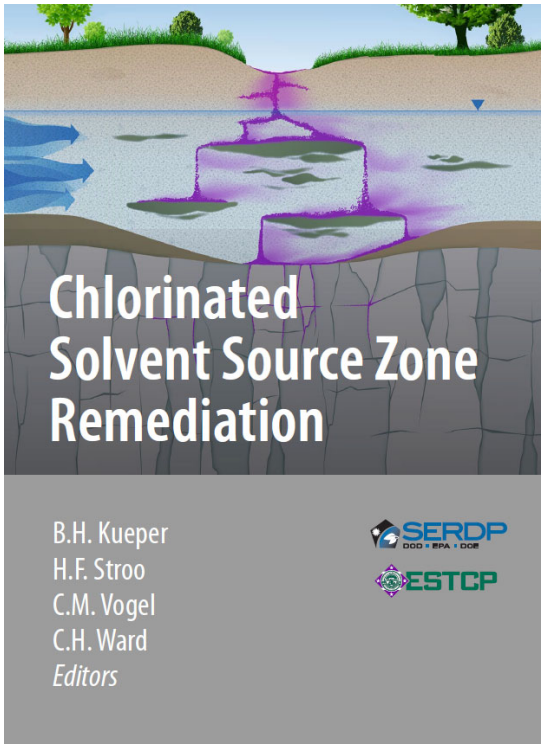
Performance Monitoring – 23 Months

**Extraction well currently ND for TCE



Enhancement Factor Comparison

- NAPL dissolution is typically modeled as the product of the concentration gradient (solubility – aqueous phase concentration near NAPL/water interface) times a mass transfer rate coefficient.
- Dissolution enhancement occurs by degrading the aqueous concentration such that the concentration gradient increases.
- Other factors to consider such as hydraulic effects of recirculation, solutes partitioning back into DNAPL, etc.
- Nice summary of enhanced dissolution research in recent SERDP/ESTCP chapter on ISB for source zone treatment (2014).



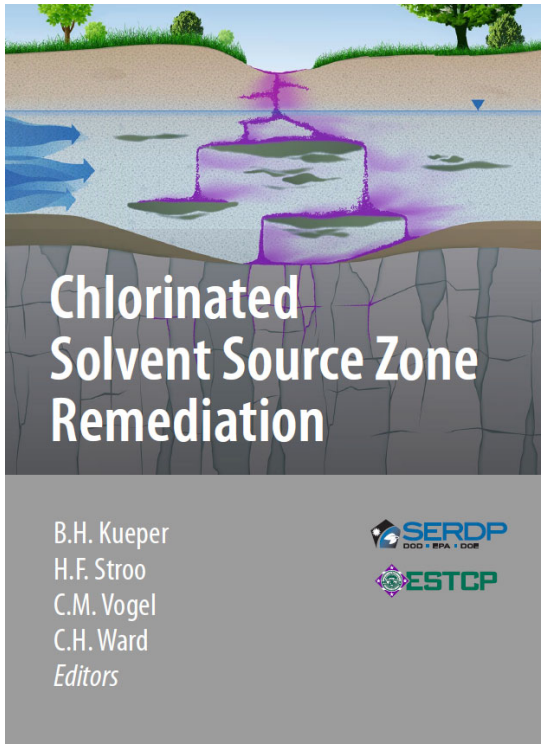
CHAPTER 12

***IN SITU* BIOREMEDIATION OF CHLORINATED ETHENE SOURCE ZONES**

Hans F. Stroo,[1] Michael R. West,[2] Bernard H. Kueper,[3] Robert C. Borden,[4] David W. Major[5] and C. Herb Ward[6]

Enhancement Factor Comparison

- Available information primarily limited to lab studies. Authors note that no peer reviewed literature on full scale remedies were available but do provide a review of three well instrumented controlled release/test cell studies.
- Reviewed 11 lab studies. Enhancement factors generally ranged from 1.5 for larger 2-D flow cells with more complex DNAPL distribution to 5 for more simple column studies.
- Field scale estimate EFs of 2-3 for Rice controlled release; 2-4 for Dover AFB controlled release; Fort Lewis test cells: 3-8.
- More recent paper (Shaefer et al., 2017) estimated EF of 5 based on chloride concentrations (limited enhancement based on molar concentrations of degradation products).



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Conclusions

- Recirculation approach allowed for an adaptive management approach and more effective and rapid treatment.
- Dissolution enhancement factors of approximately 5 were observed during treatment based on generated ethene levels.
- Nondetect levels of TCE in extraction well confirm targeted area was primary source.
- Relatively small substrate dose (~3 g/L) was required based on initial concentrations and the amount of enhanced dissolution observed.

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