

DOWNGRADIENT CHLORINATED ETHENE BULK ATTENUATION RATES AND TOTAL REMOVAL

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and Sustainable Technologies

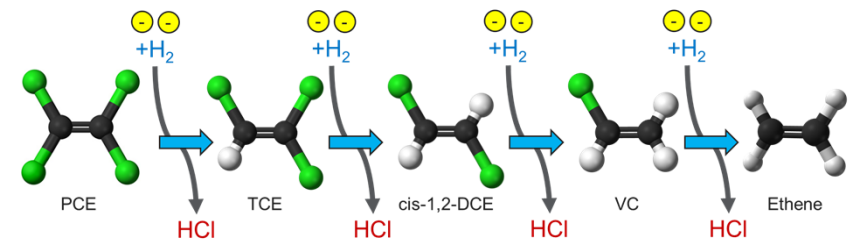
April 16, 2019 – Baltimore, Maryland

Agenda

- Introduction
- Rate and Extent of Removal Calculations
- ERD Database
- Degradation Rates
- Overall Removal
- Conclusions

Introduction

- Electron donor addition
 - Enhances CVOC reductive dechlorination
 - Most effective at reducing parent compounds; daughter products may persist
 - Injection strategies include source area injections and downgradient flux control (i.e., PRBs)
- Often achieve good degradation rates in injection areas
 - Good carbon distribution
 - Achieve optimal ERD conditions
- Increased focus on limiting concentrations downgradient



What concentration changes are we seeing downgradient of injection areas?

Downgradient CVOC Removal

- Evaluate bulk attenuation rates

- Assumed first-order kinetics

$$\ln[C(t)] = \ln[C_0] + k_1 * t$$

- PCE, TCE, cis-DCE, VC, ΣCI rates calculated
- ΣCI = measure of total organic chlorine

$$\Sigma CI = 4*[PCE] + 3*[TCE] + 2*[DCE] + 1*[VC]$$

- Trends identified using modified Mann-Kendall
- Visual Basic program allowed for multiple rates (e.g., cis ↑ then ↓)

- Calculate extent of removal (C/C₀)

- Compare with distance, geochemical conditions, etc.

- Compare with injection area wells

Rate and Extent of Chlorinated Ethene Removal at 37 ERD Sites

Jason M. Tillotson, P.E.¹; and Robert C. Borden, P.E., Ph.D.²

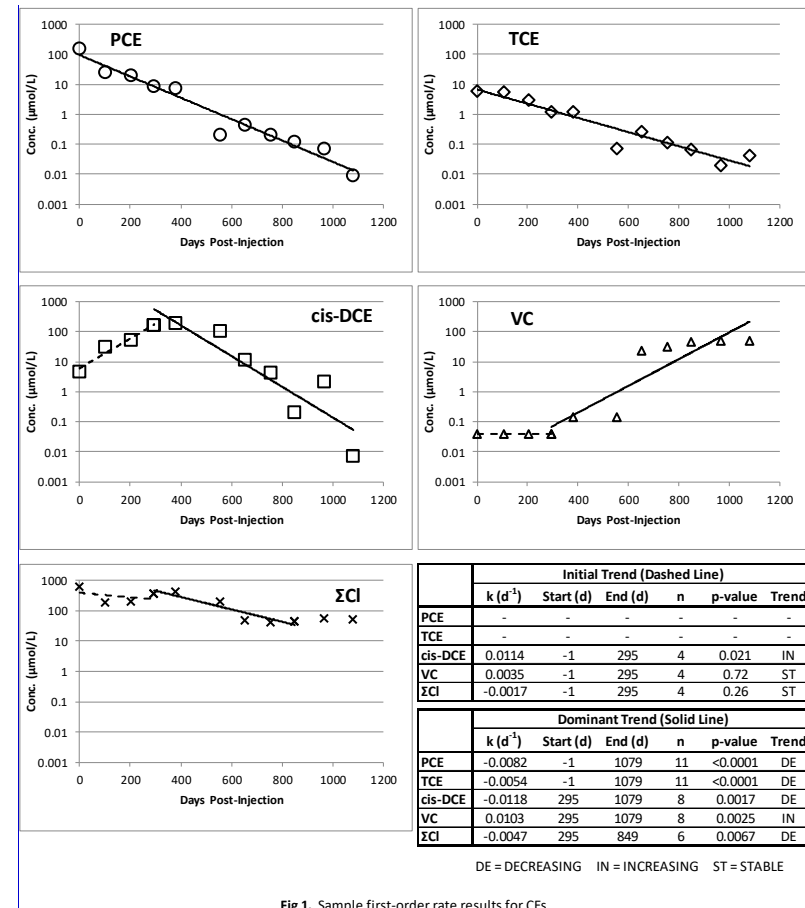
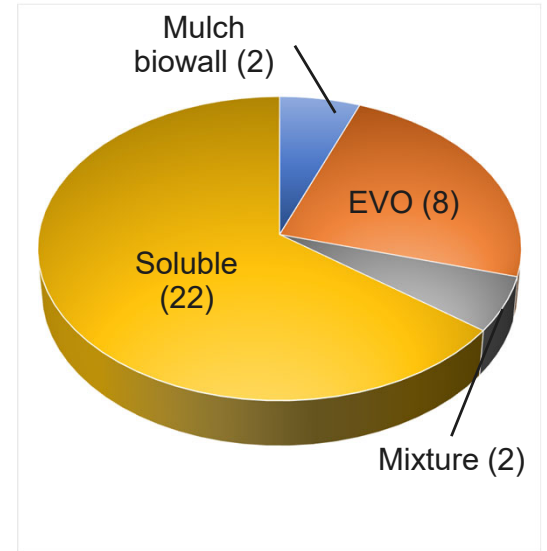
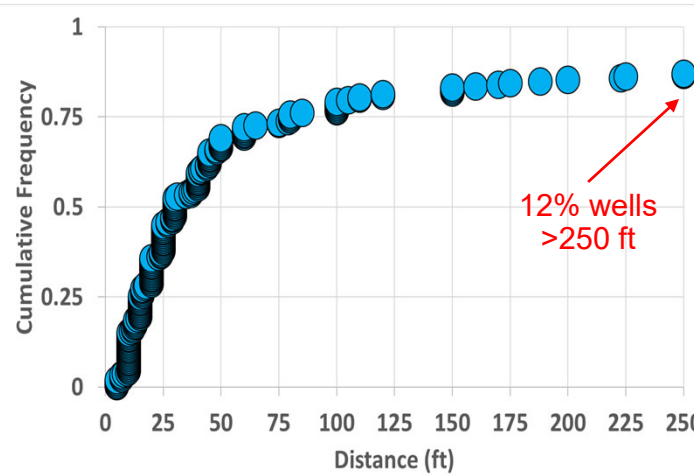
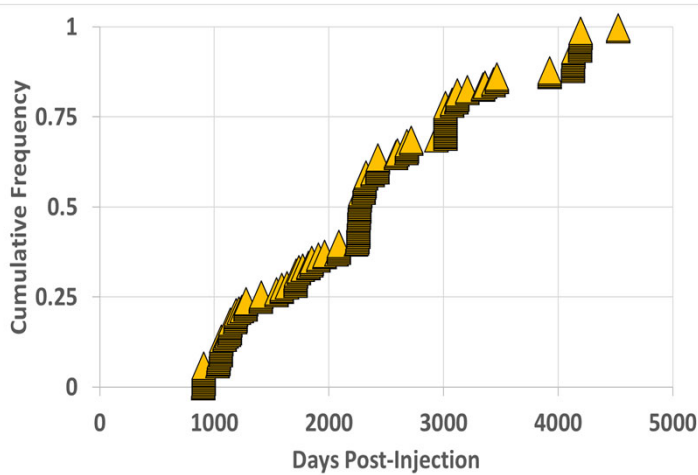


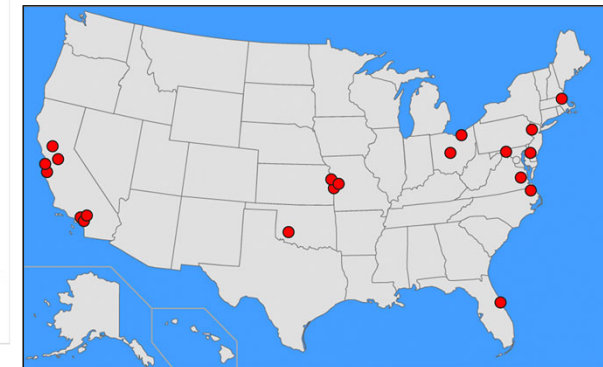
Fig 1. Sample first-order rate results for CEs.

ERD Database

- 34 ERD Sites
 - Wells with >900 days (~2.5 year) monitoring
 - 218 downgradient wells
 - Multiple substrate types



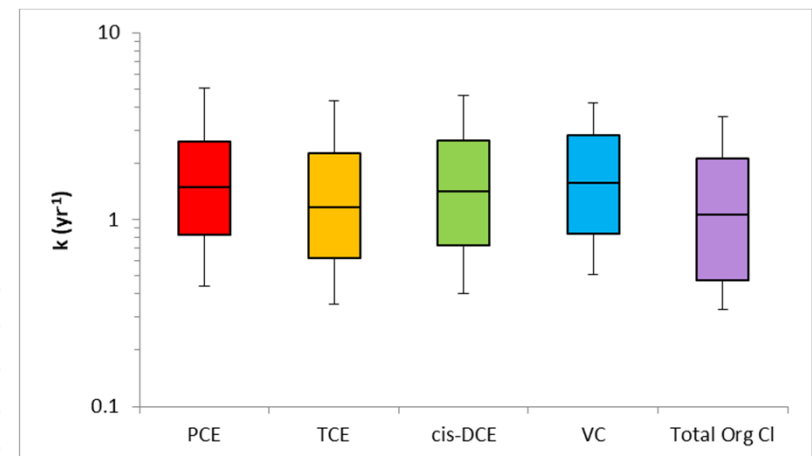
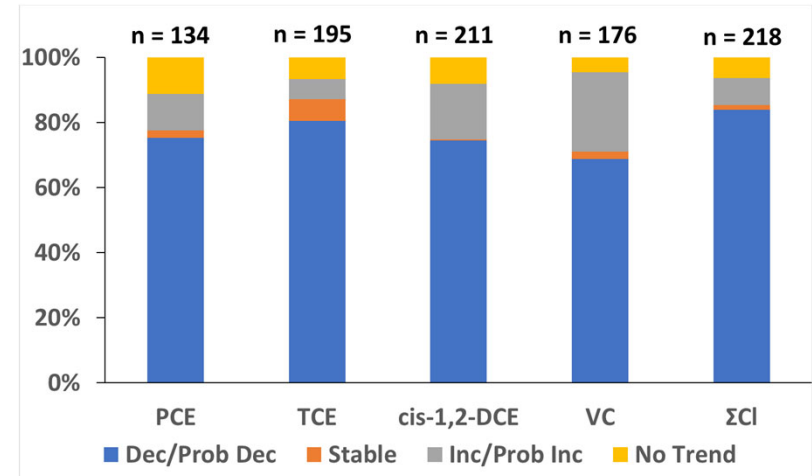
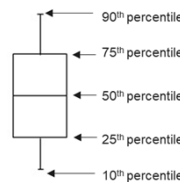
Substrates used at Sites in database



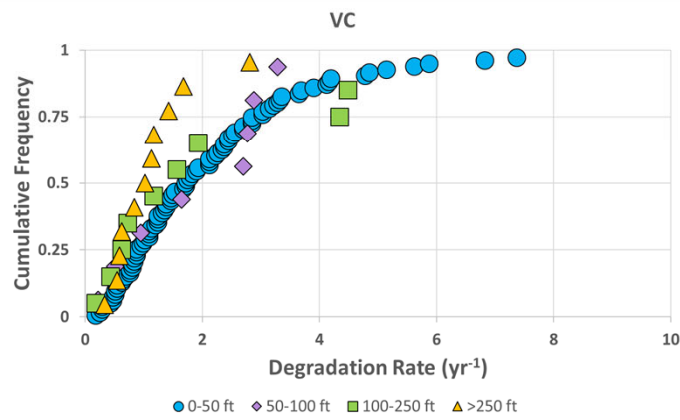
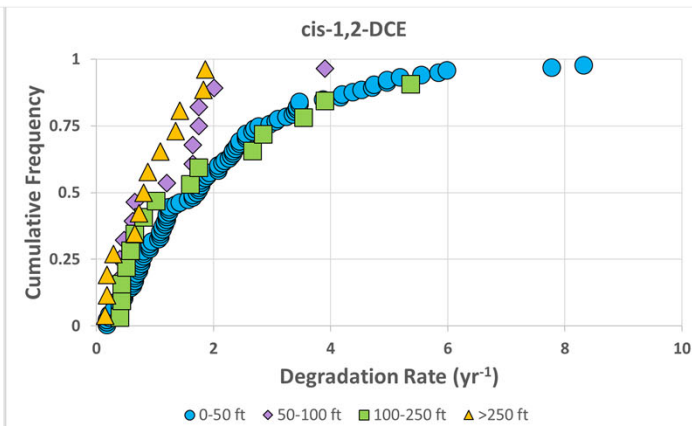
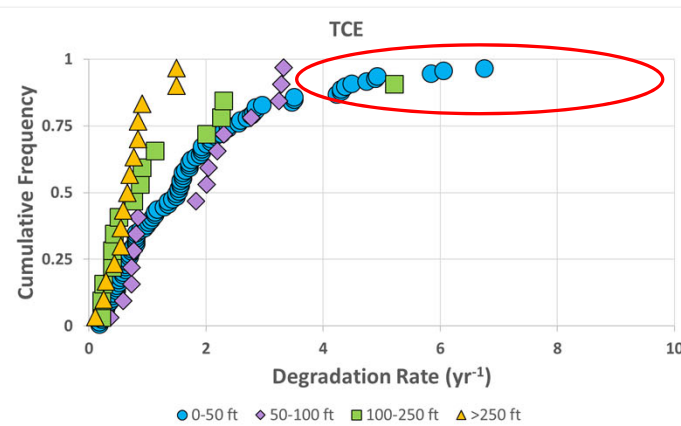
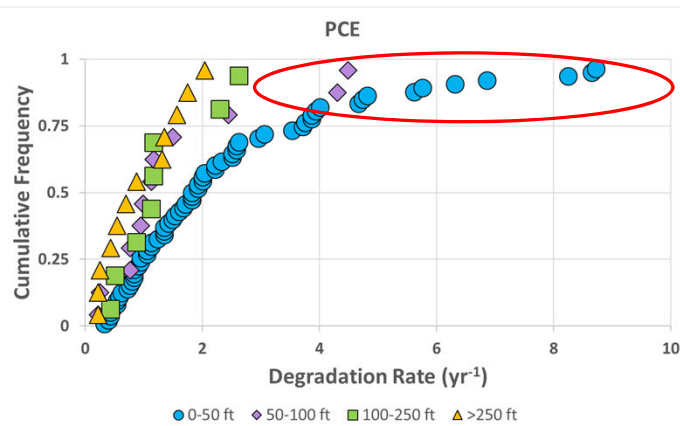
CVOC Removal Rates

- Decreasing/Probably Decreasing trends
 - Identified in at least 70% of wells
 - More likely in parent compounds (81% PCE, TCE)
 - Wells >100 ft less likely to have identified trend
- Increasing/Probably Increasing trends
 - More likely in daughter products compounds (6% TCE vs 24% VC)
 - Increasing trends in parent compounds generally small

(yr ⁻¹)	Count	Min	Median	Max
PCE	108	0.22	1.50	42.5
TCE	157	0.11	1.17	13.5
cis-1,2-DCE	157	0.15	1.42	15.7
VC	121	0.18	1.57	18.3
ΣCI	183	0.07	1.06	15.2



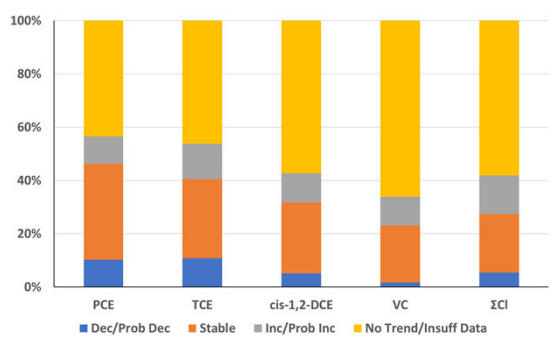
Removal Rates vs Distance



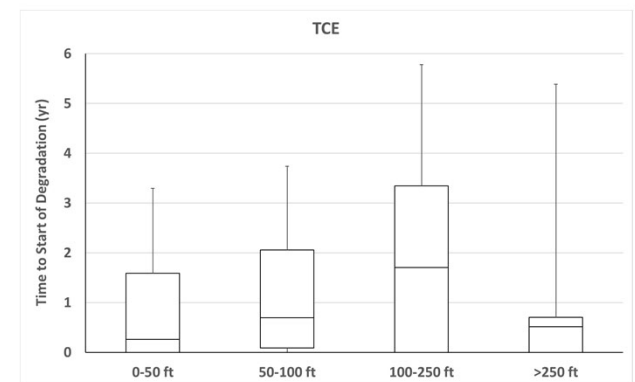
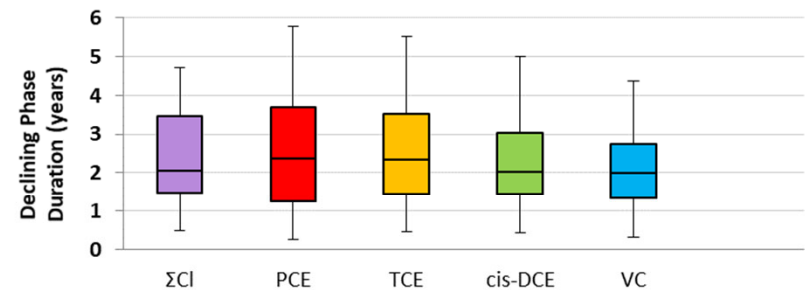
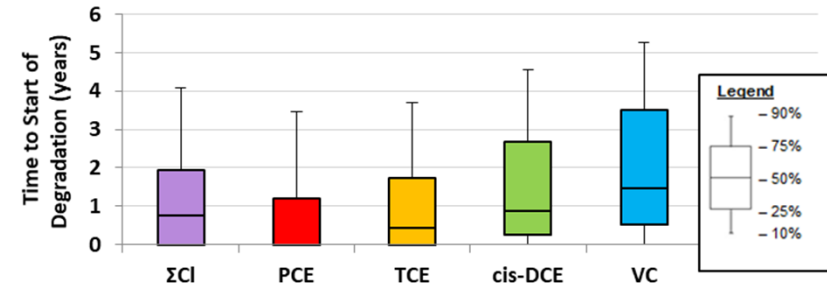
- Higher degradation rates closer to injections
 - More pronounced in parent compounds
 - PCE: 30% of wells 0-50 ft have higher rate than all wells >100 ft
 - Rates much lower at >250 ft

Degradation Phase

- Beginning of Decreasing trend
 - Generally increases with decreasing chlorination, distance downgradient
- Decreasing trend duration
 - Median ~ 2-2.5 years
 - Slightly lower durations for daughter products
- Post-Degradation Phase
 - Most wells show stable/no trend
 - Only 10-15% of wells experienced increasing trend during post-degradation phase

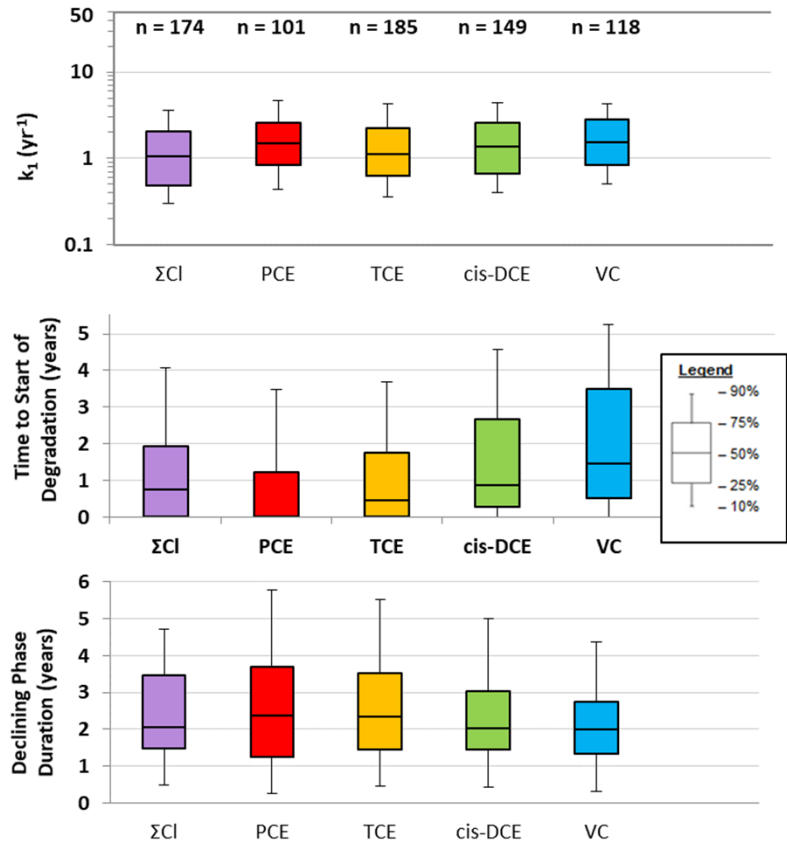


Trends in wells during post-degradation phase

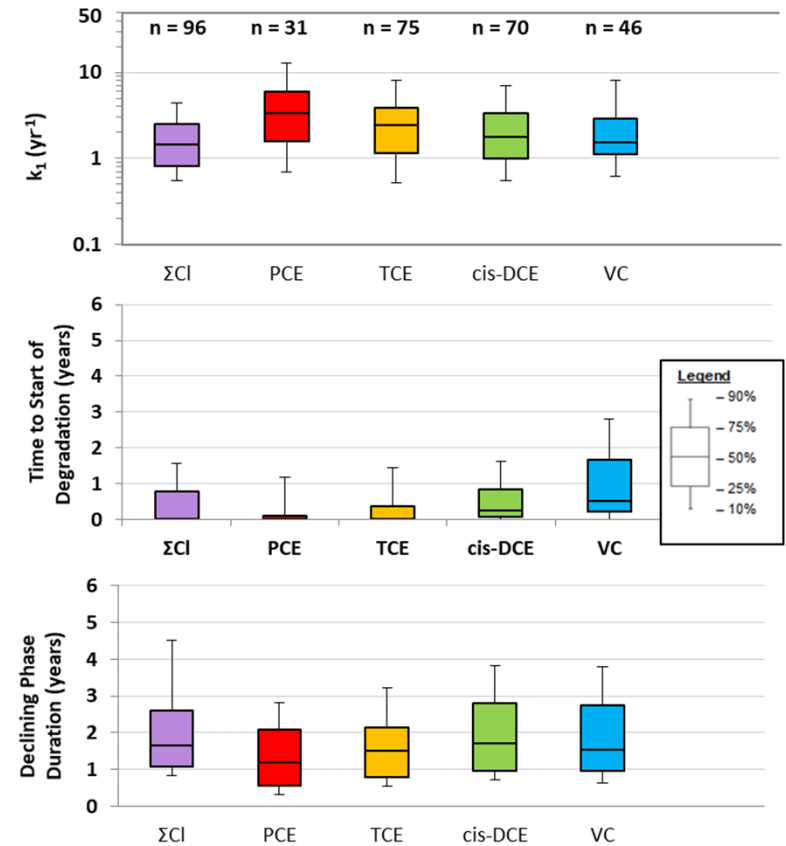


Downgradient vs Injection Area

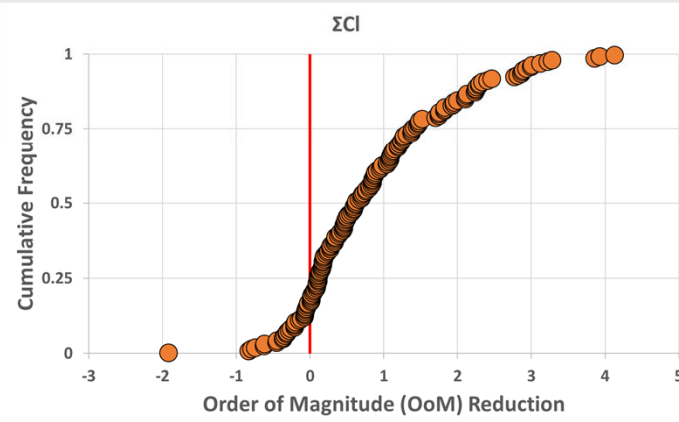
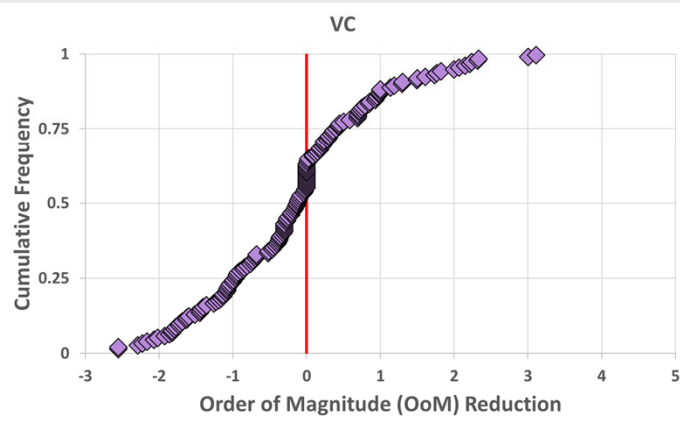
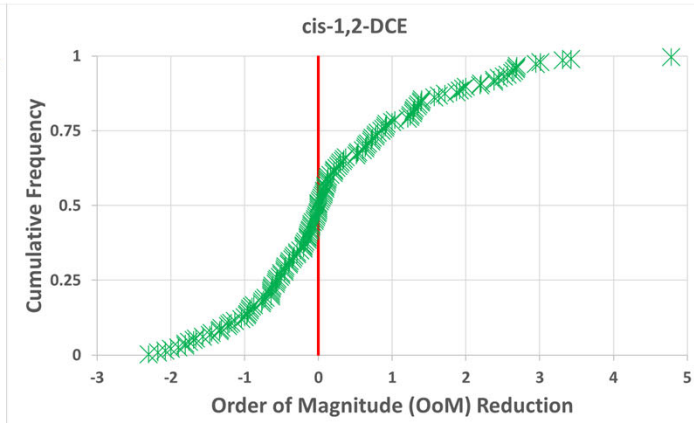
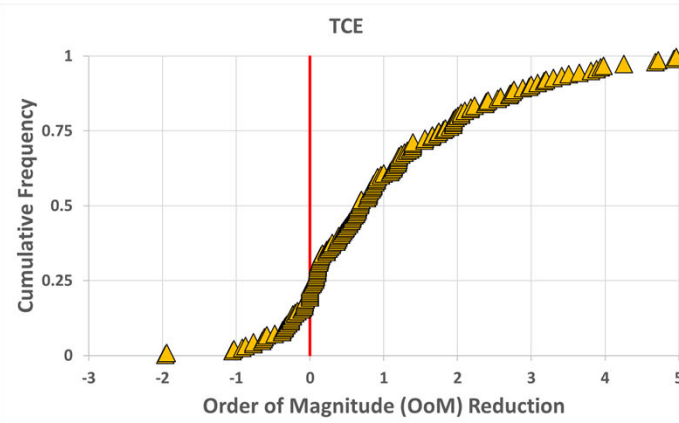
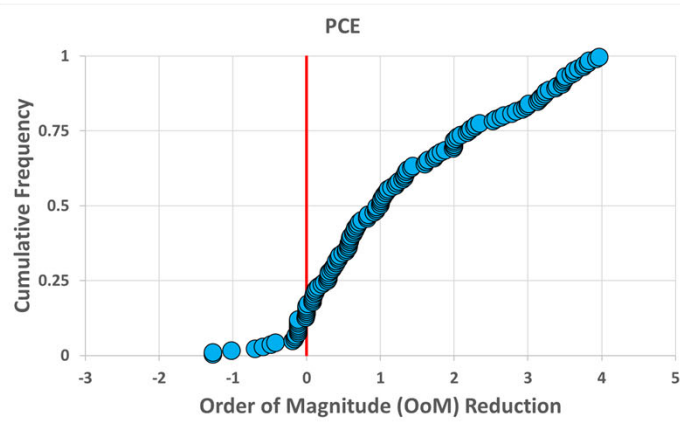
Downgradient



Injection Area

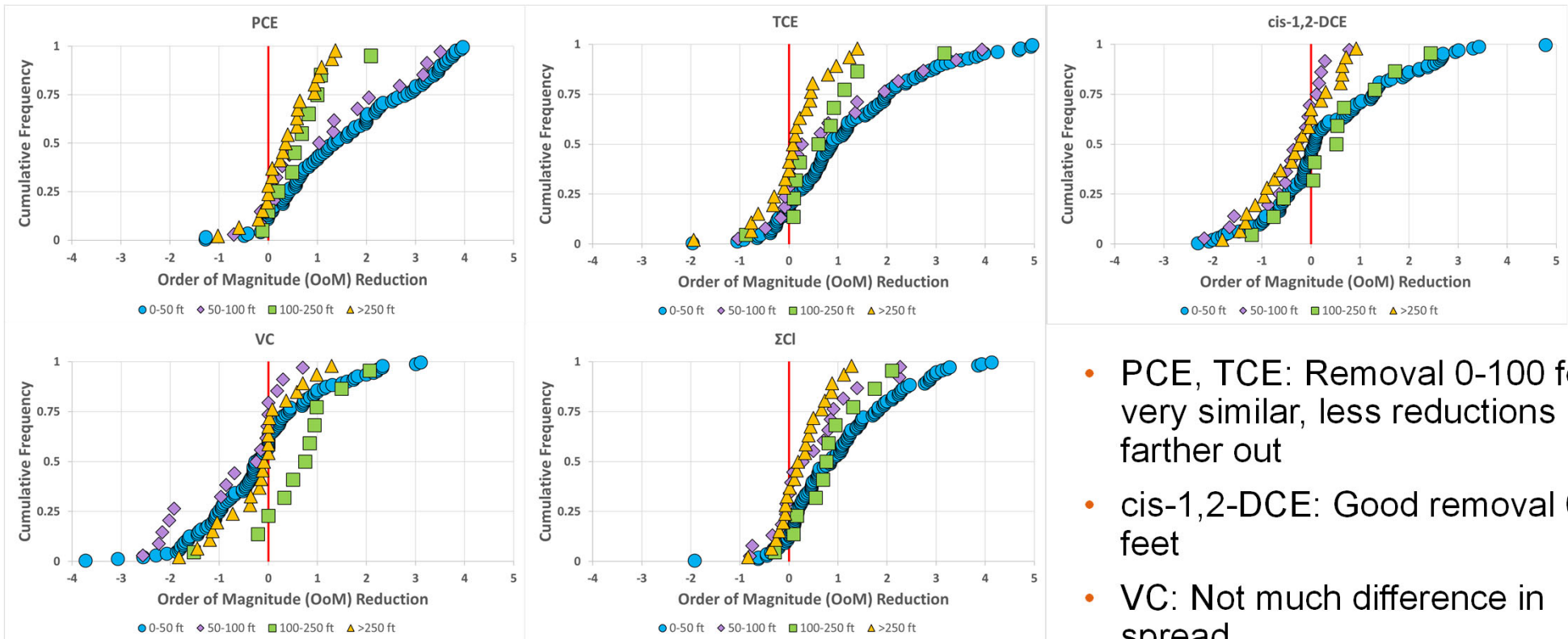


Overall Removal



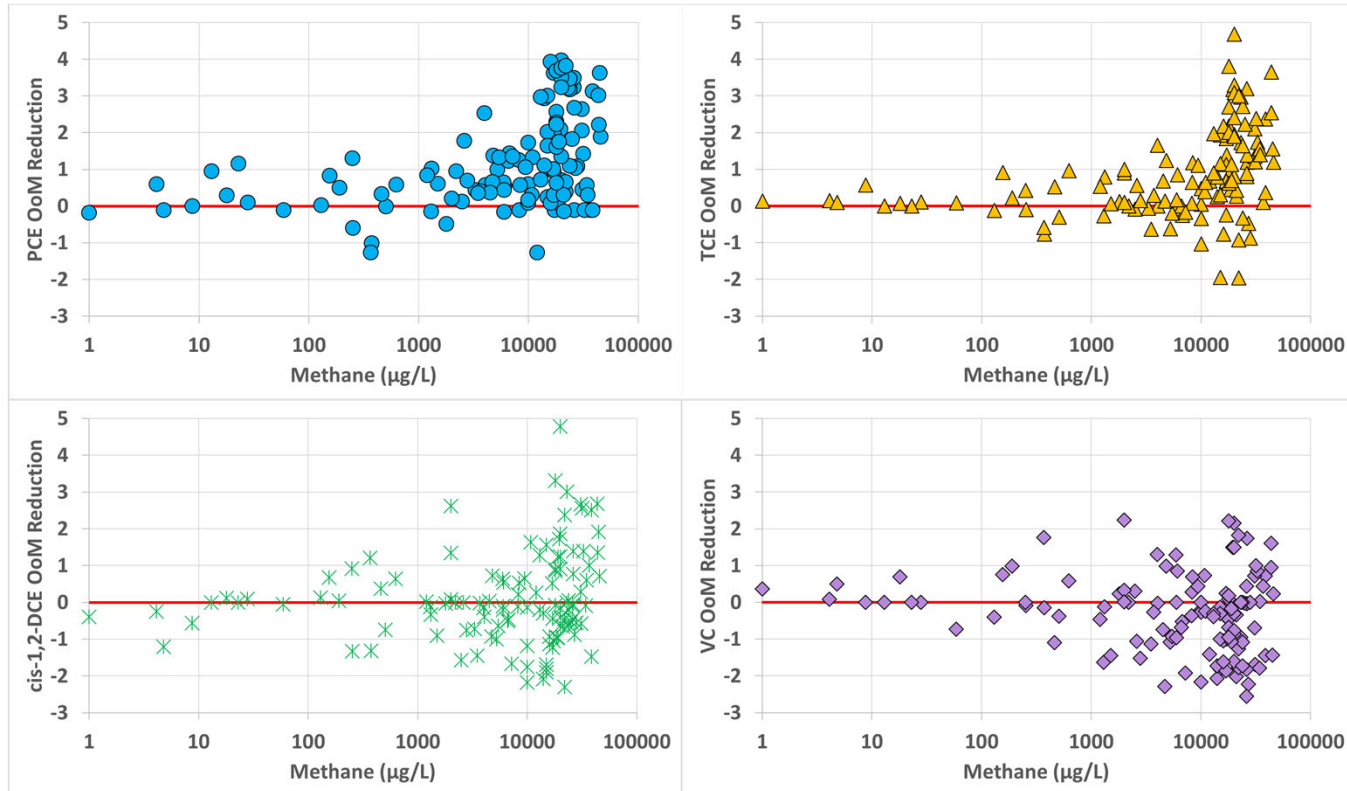
- Order of Magnitude (OoM)
 - $-\text{Log}(C_f/C_0)$
 - 90% removal = 1 OoM, 99% removal = 2 OoMs, etc.
 - Negative OoM = Concentration Increase

Overall Removal vs Distance



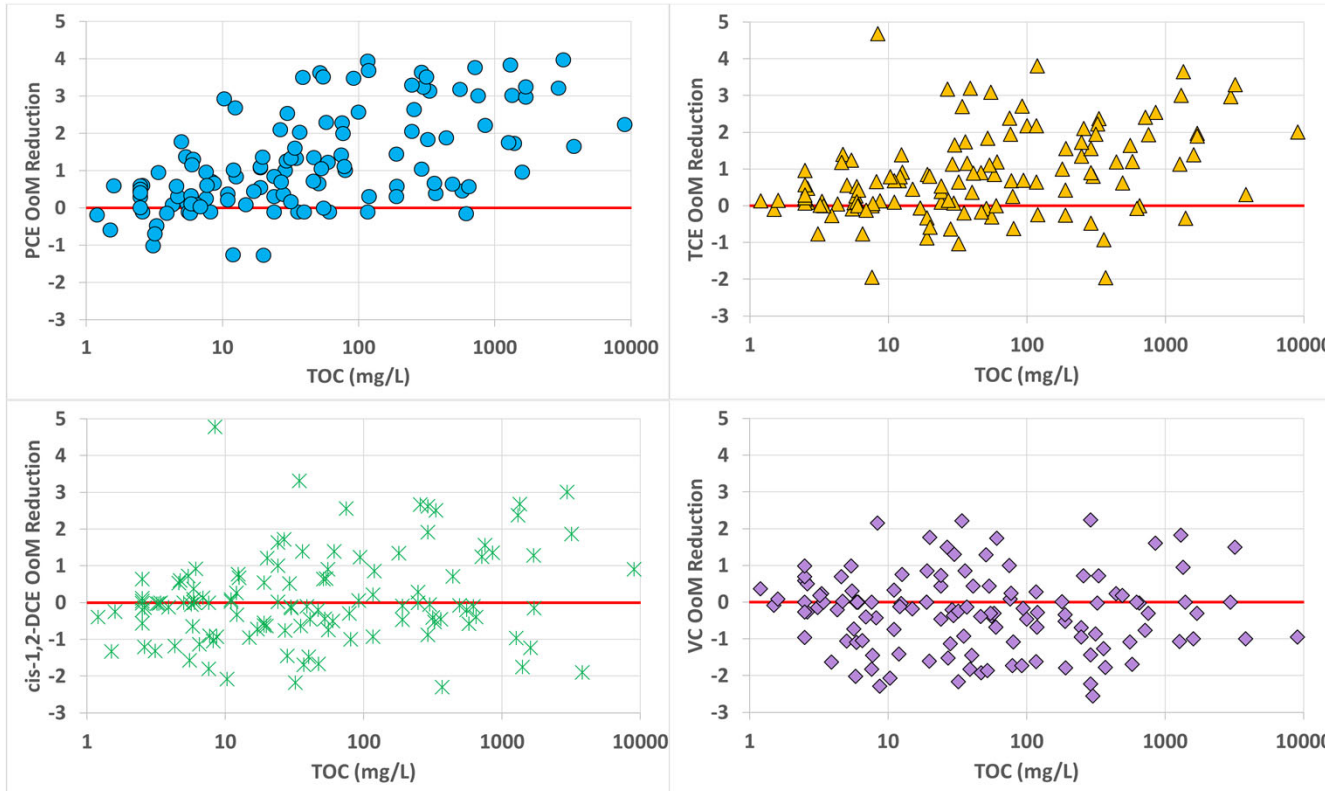
- PCE, TCE: Removal 0-100 feet very similar, less reductions farther out
- cis-1,2-DCE: Good removal 0-50 feet
- VC: Not much difference in spread
- Σ CI: Best removal 0-50 feet, decreases with distance

Overall Removal vs CH₄



- High PCE, TCE reduction = high CH₄
- Daughter products more variable
 - High CH₄ → high reduction to high production

Overall Removal vs TOC

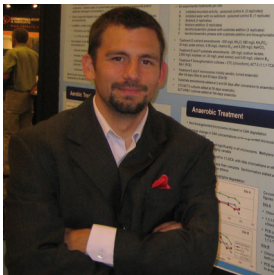


- Smaller relationship between high TOC, high reduction
 - TOC <10 mg/L → max 1-2 OoMs reduction
 - TOC >10 mg/L → max 2-4 OoMs reduction

Conclusions

- ERD positively impacts downgradient wells
 - Degradation rates identified in 70-80% of wells, more likely with parent compounds
 - Generally higher rates closer to injection area
 - Median degradation phase 2 – 2.5 years
- Compared to injection area
 - Lower PCE, TCE degradation rates (similar for daughter products)
 - Longer time to start degradation
- Overall Removal
 - 40-50% of wells experienced >1 OoM PCE, TCE removal; ~25% experienced >2 OoMs removal
 - ~Half of wells experienced cis-1,2-DCE, VC, increases
 - ΣCl – good measurement for overall removal
- Geochemical parameters
 - Higher removal = CH_4 >1 mg/L
 - Higher removal = TOC >10 mg/L

Questions?



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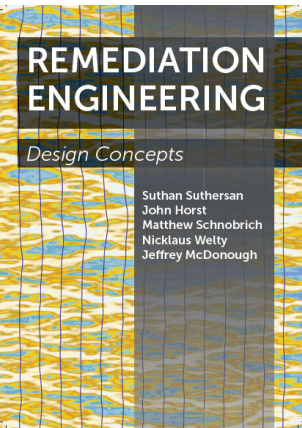
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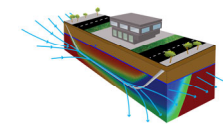


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