Enhanced Bioremediation of Chlorinated Solvents in Fractured Bedrock Aquifers

wsp

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Complex Sites

- NAPL and high aqueous concentrations
- Mixtures of contaminants
- Potentially sensitive receptors
- Complex hydrogeology

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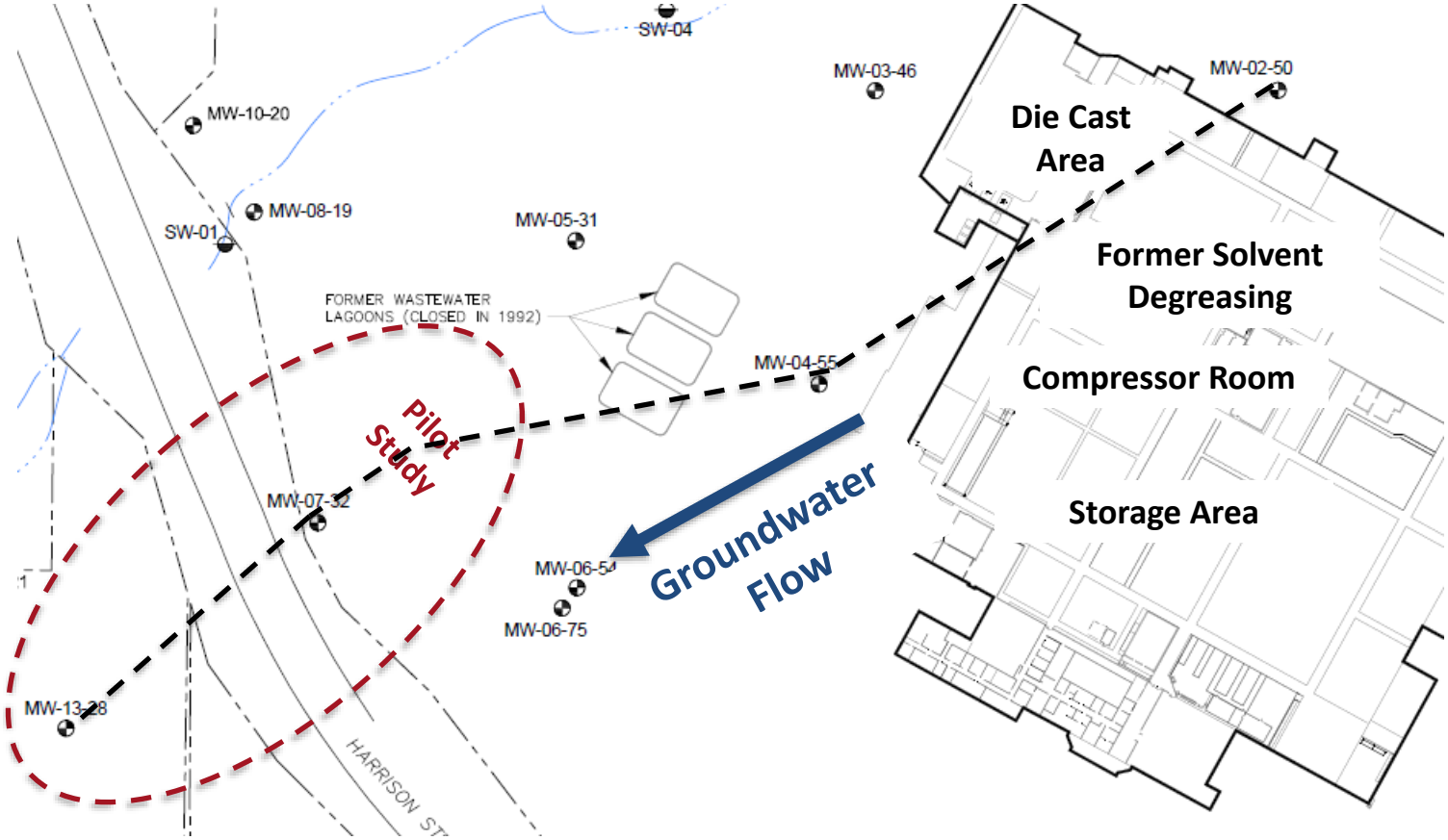
Background

- Manufacturing facility since 1961
  - Gas values
  - Metals processing – melt/re-melt, die casting, tapping
  - Solvents, degreasers, cutting oils
- Contaminants
  - TCE
  - 1,1,1-TCA
  - Some daughters

Site Layout



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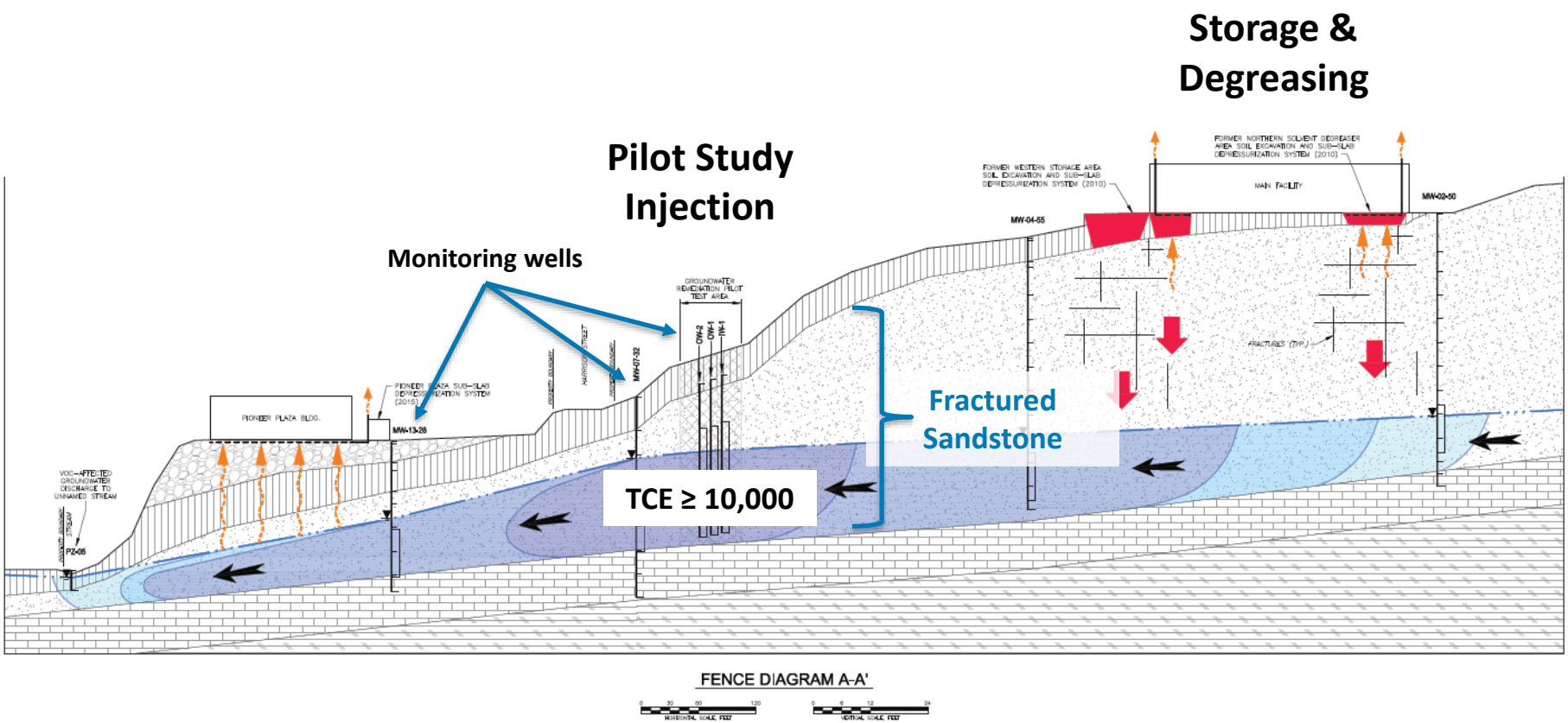
Cross Section



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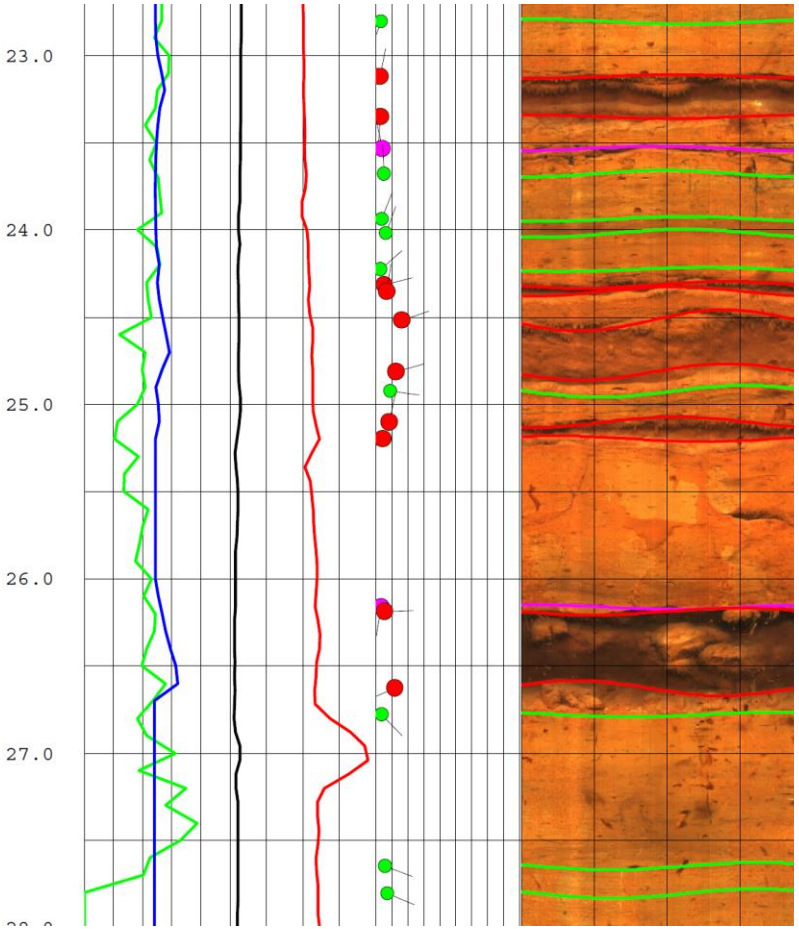
Fractures

- High flow through fractures (secondary porosity)
- Back diffusion from primary porosity of rock matrix



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Pilot Study (Combined *In Situ* Reduction)

Amendments

Electron donors
Nutrients (N+P)
Bioaugmentation
Buffer

Ferrous Iron
+ Sulfate

Biotic Reduction Dechlorination

- *Dehalococcoides*
- *Dehalobacter*
- Anaerobic conditions & sulfate reduction

Abiotic Reduction

- *In situ* FeS production
- Longer term mechanism to address back diffusion

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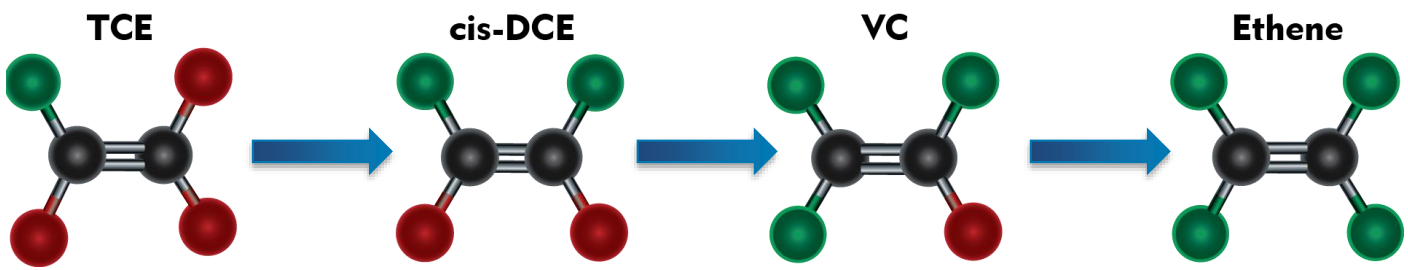
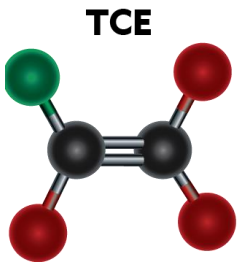
Biotic and Abiotic Degradation

Biotic Reductive Dechlorination



Abiotic



Low Product Recovery

Acetylene

Ethene

Ethane

C_2 to C_6 compounds

FeS

Fe^{2+} **S^{2-}** ← **SO_4^{2-}**

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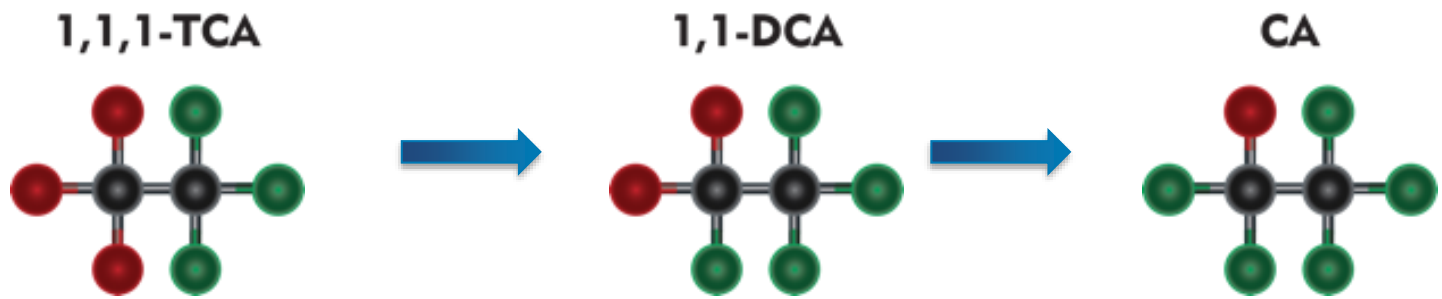
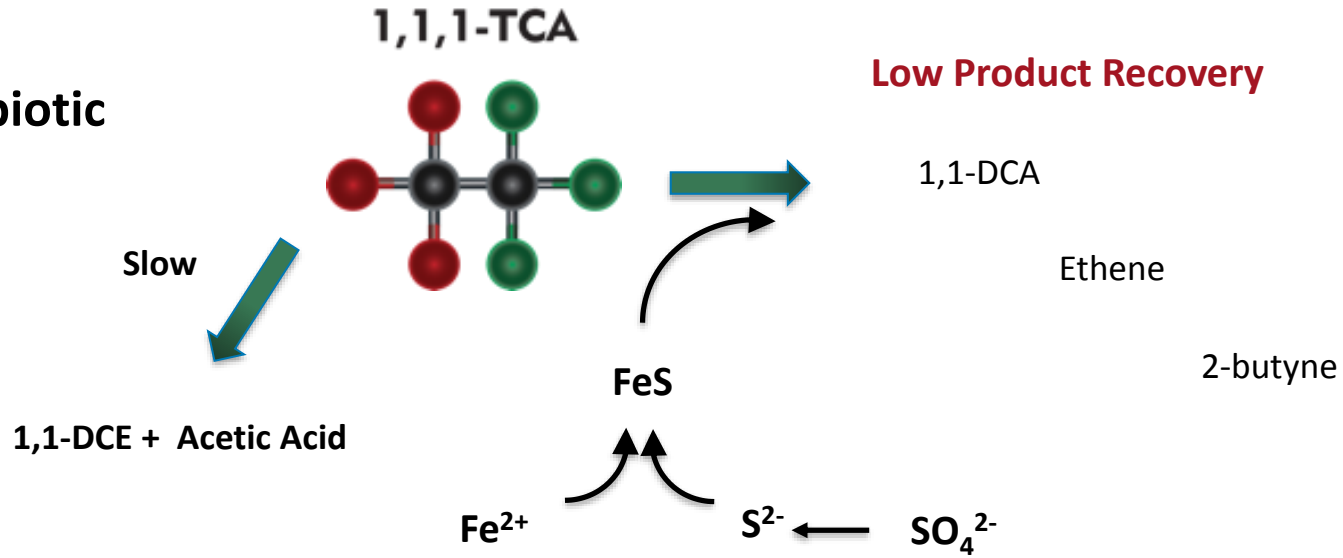
Biotic and Abiotic Degradation

Biotic Reductive Dechlorination



Abiotic



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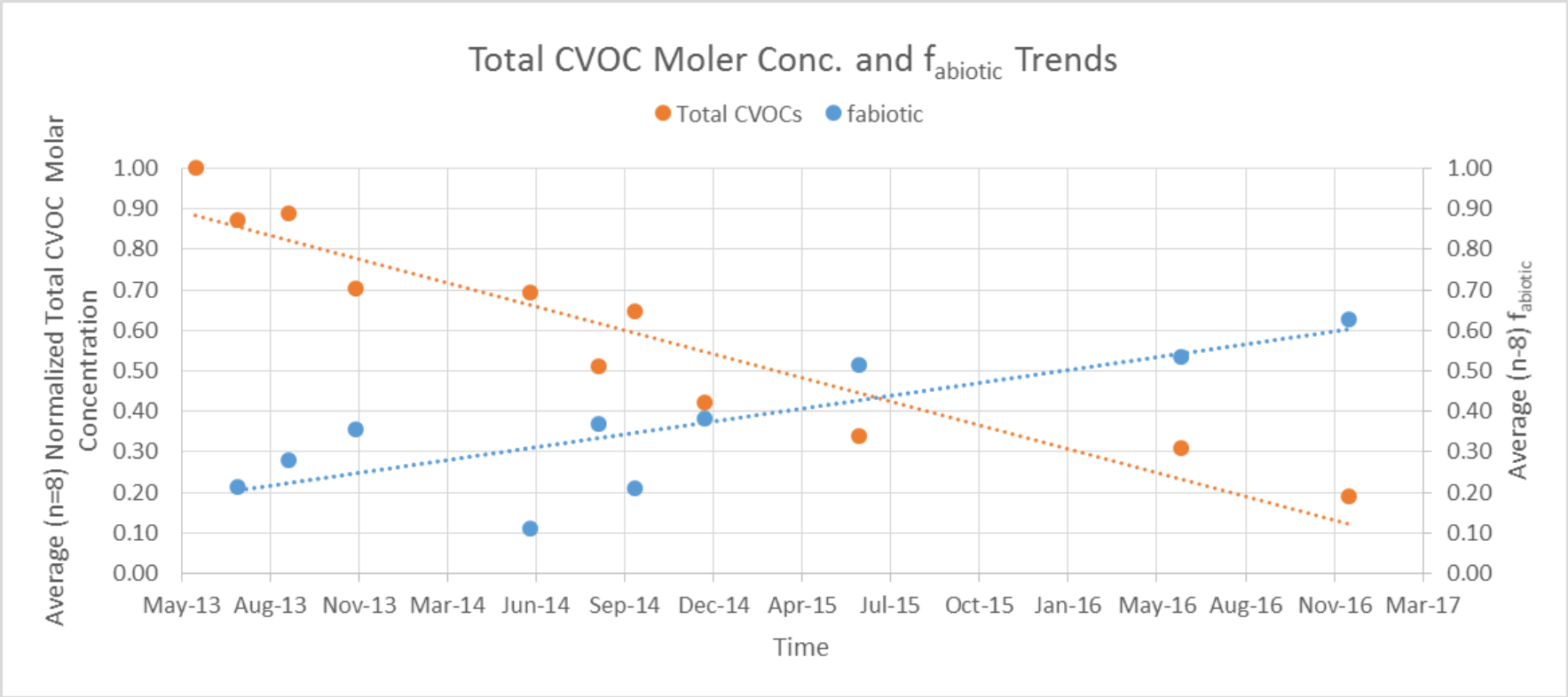
$f_{abiotic}$ over time



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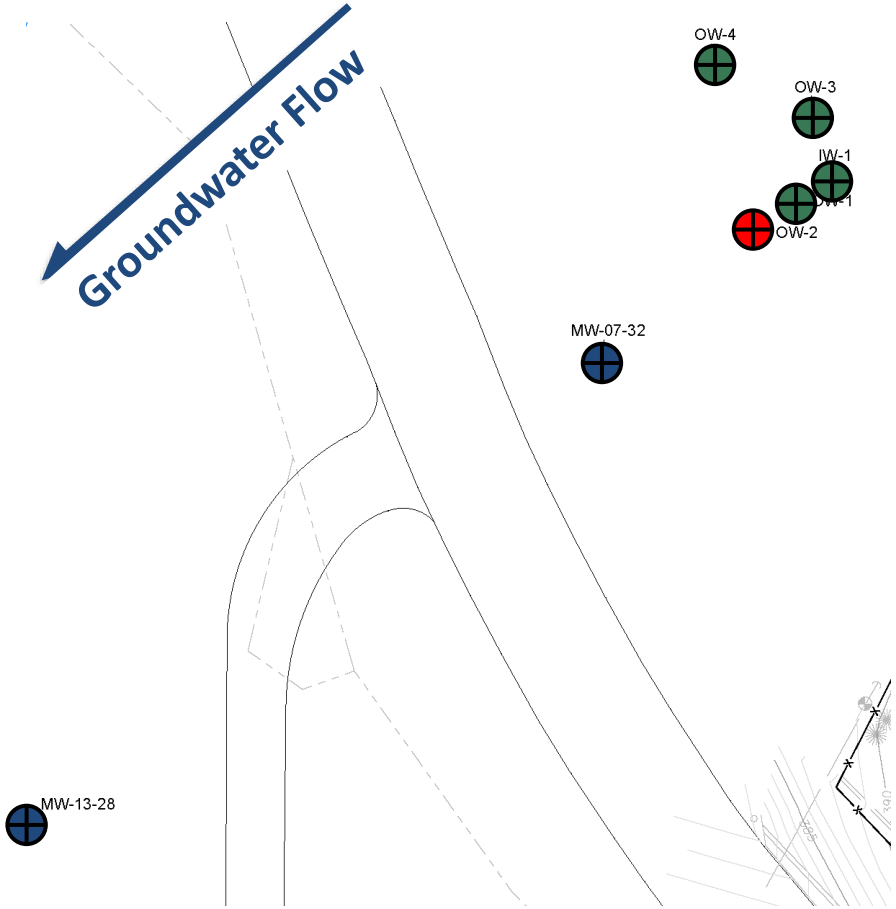
In Situ Reduction Pilot Study



Pilot Study

- Injection at OW-2 (not IW-1)
  - Electron donor
  - Nutrients
  - Fe^{2+}
  - Culture
- Groundwater monitoring
  - Four observation wells
  - Two downgradient wells

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Lines of Evidence

Chemical

- VOCs
  - Parents
  - Daughters
- Dissolved Gases
  - Ethene
  - Acetylene
- DOC
- Tracer dyes

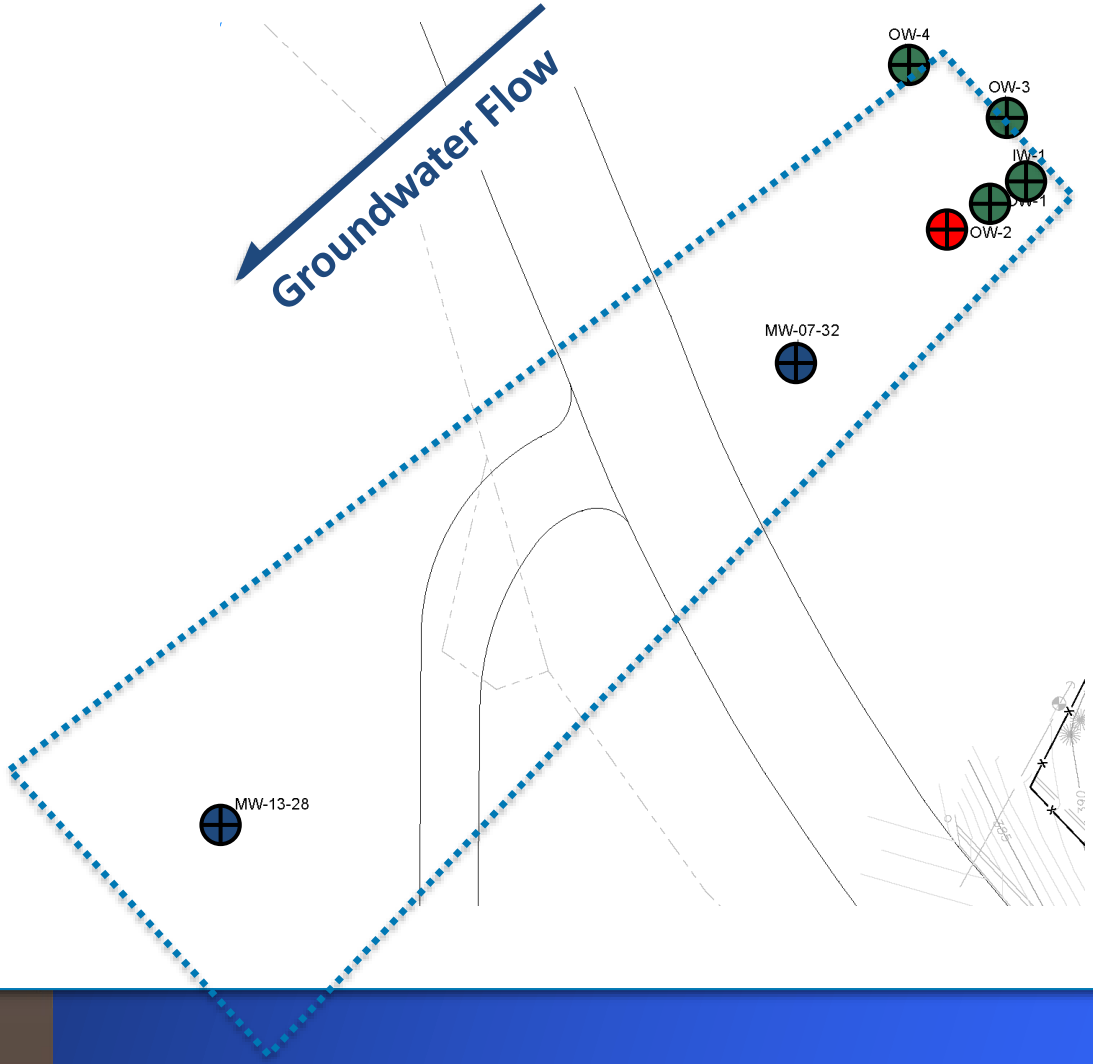
Geochemical

- Field Measurements
  - ORP, DO
  - pH
  - Etc.
- Nitrate
- Ferrous Iron
- Manganese
- Sulfate & Sulfide
- Methane
- Alkalinity

MBTs

- qPCR
  - *Dehalococcoides*
  - *tceA*
  - *bvcA* and *vcrA*
  - *Dehalobacter*
  - *Dehalogenimonas*
- Compound Specific Isotope Analysis (CSIA)

Dye Detection



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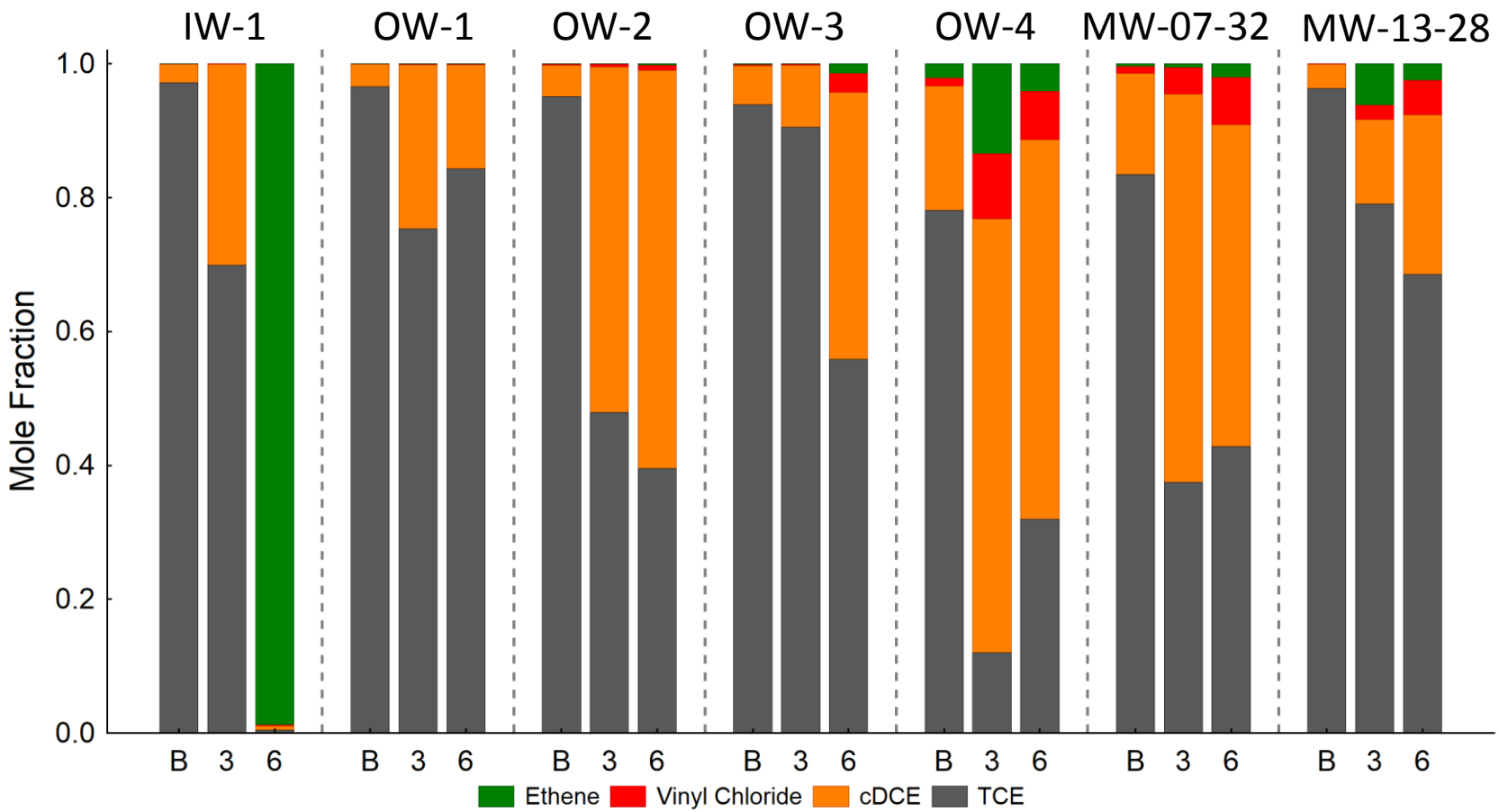
Chlorinated Ethenes - Mole Fractions



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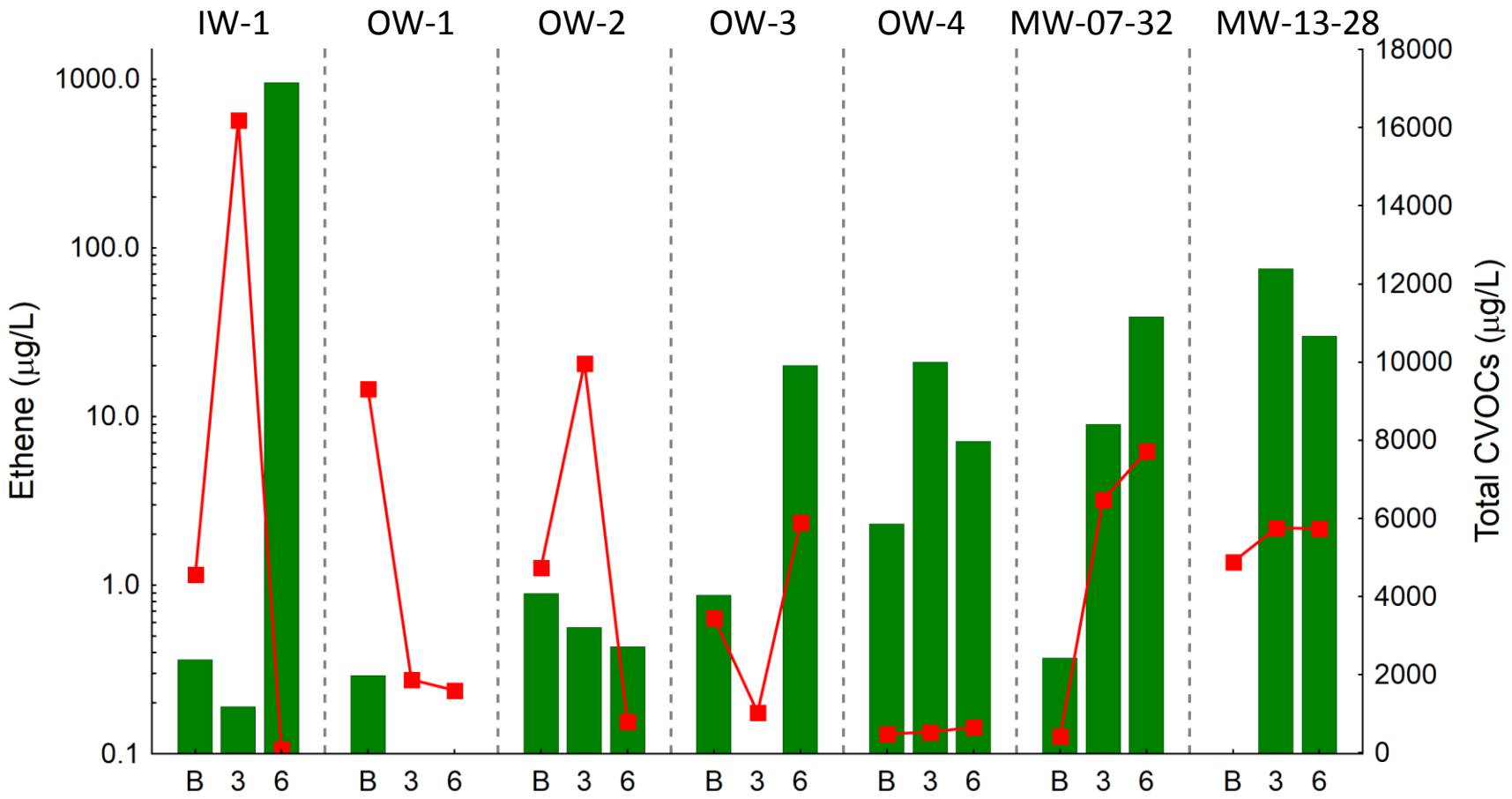
Ethene Concentrations



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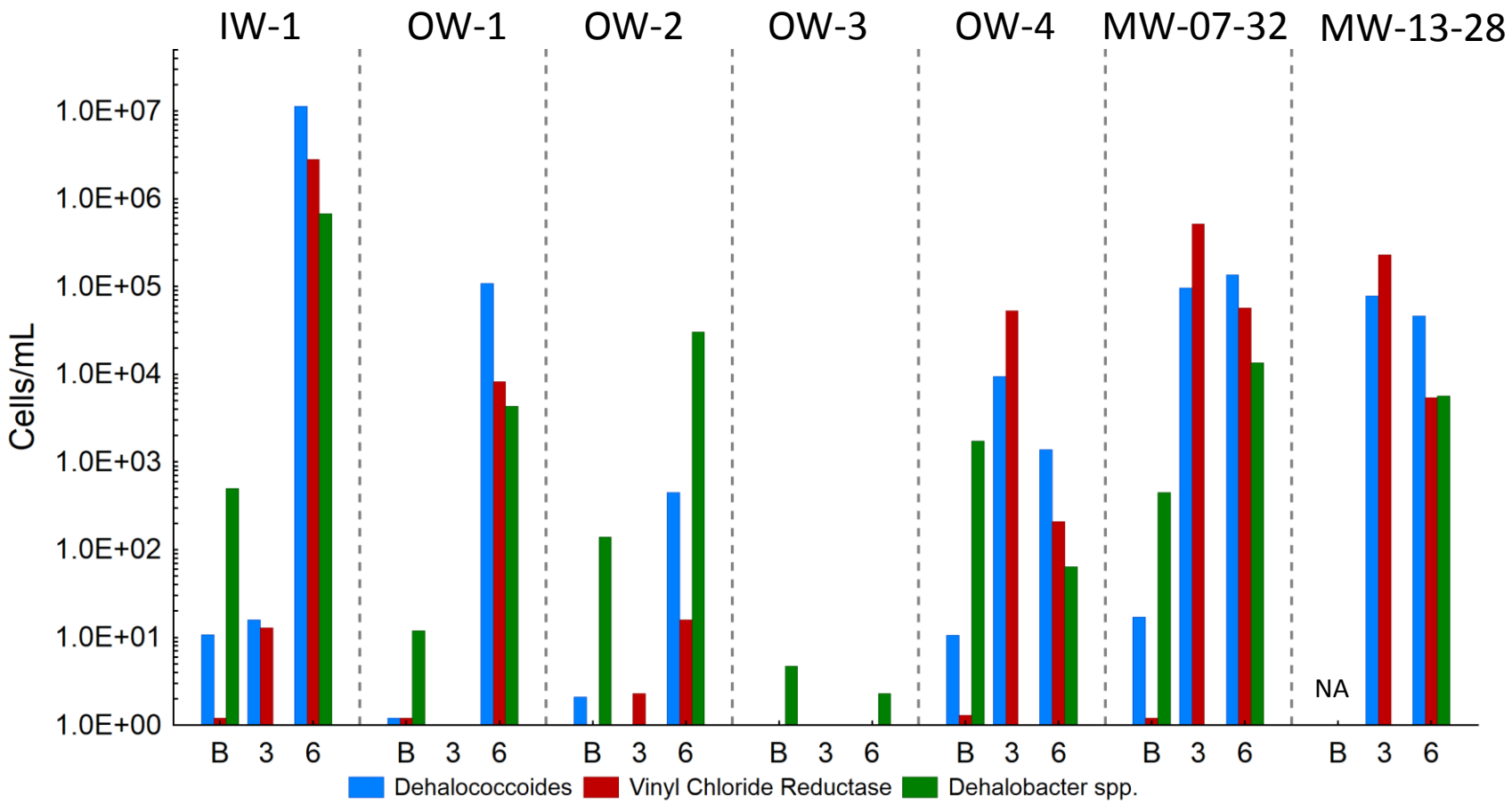
qPCR - Microbiology



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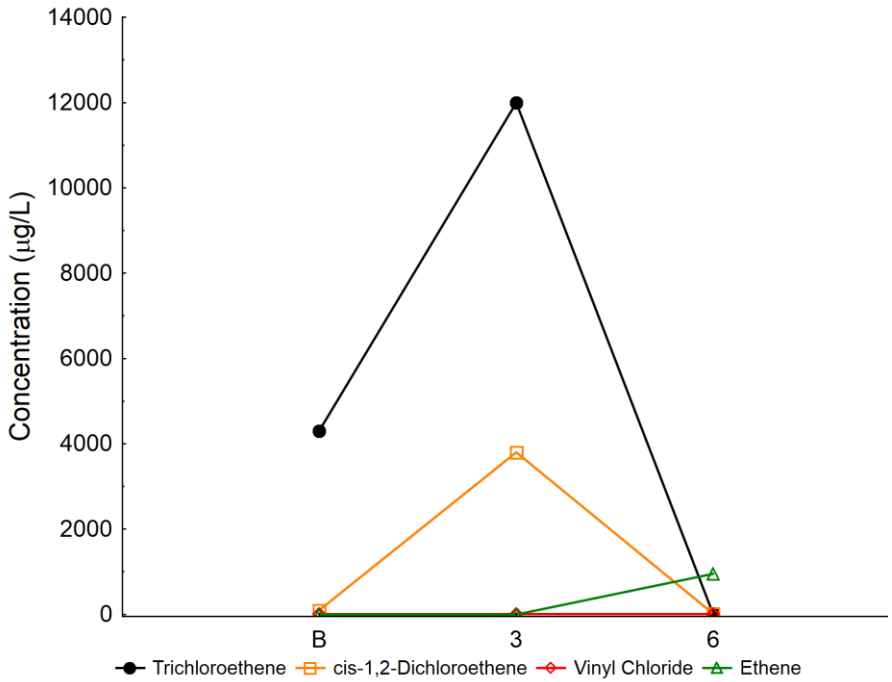
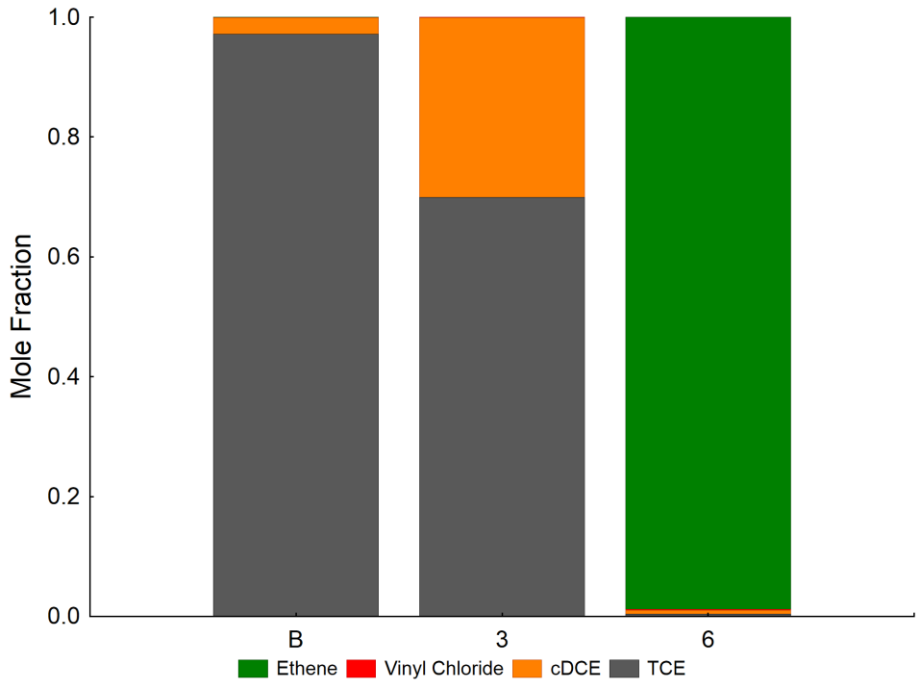
VOC Concentrations (IW-1)





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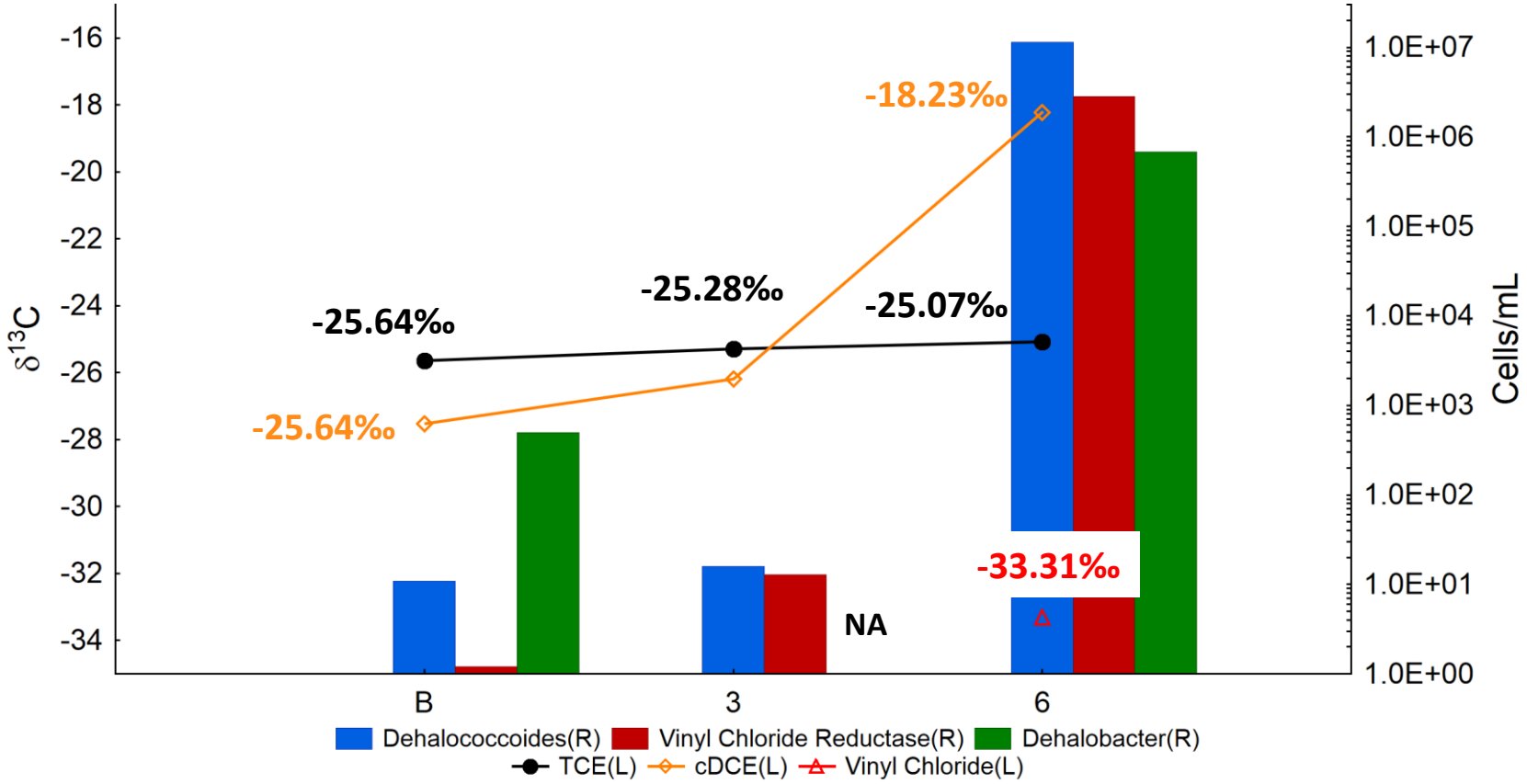
MBTs – CSIA and qPCR (IW-1)



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Weighing the Evidence

Enhanced Degradation

Contaminant concentrations varied considerably

CSIA did not confirm TCE degradation (no significant ^{13}C enrichment)

- ✓ TCE concentration decreased & ethene increased substantially
- ✓ Dissolution, back diffusion can mask isotopic enrichment
- ✓ CSIA confirmed cDCE degradation
- ✓ High concentrations of obligate halorespiring bacteria including *Dehalococcoides*

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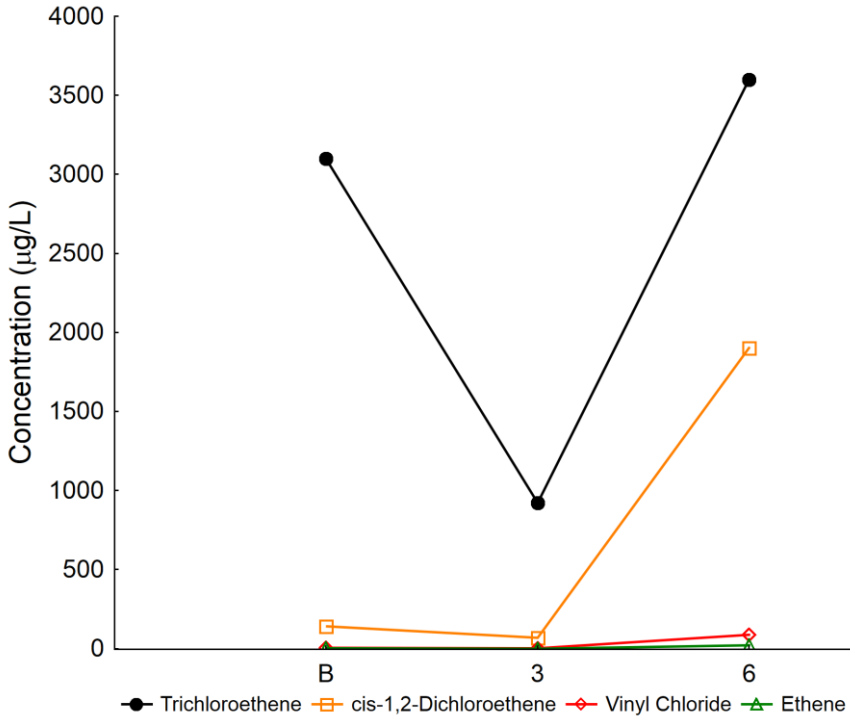
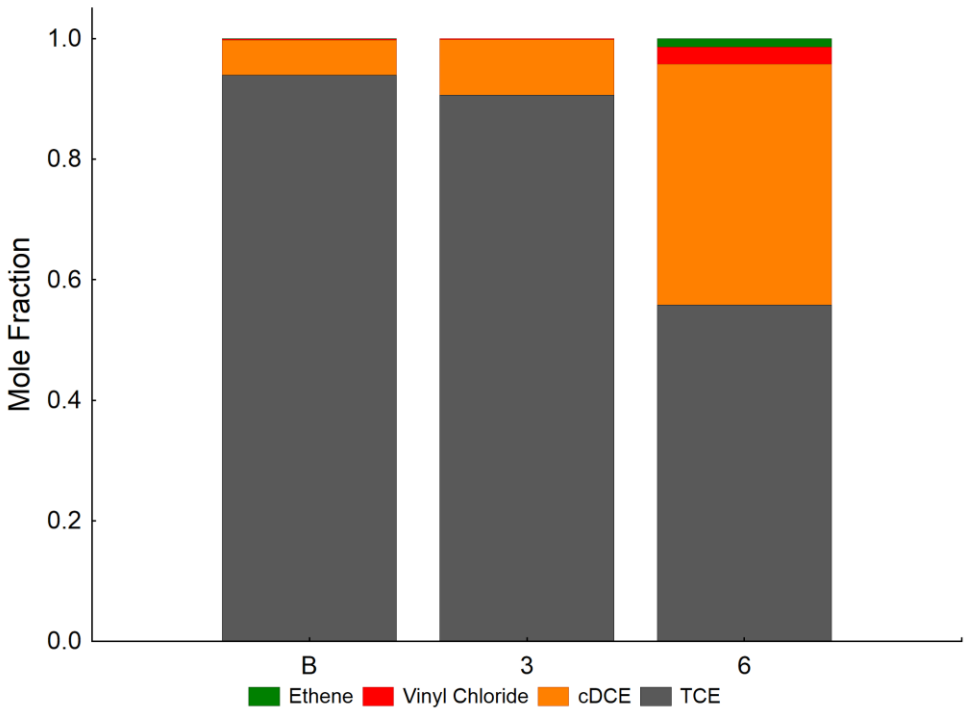
VOC Concentrations (OW-3)





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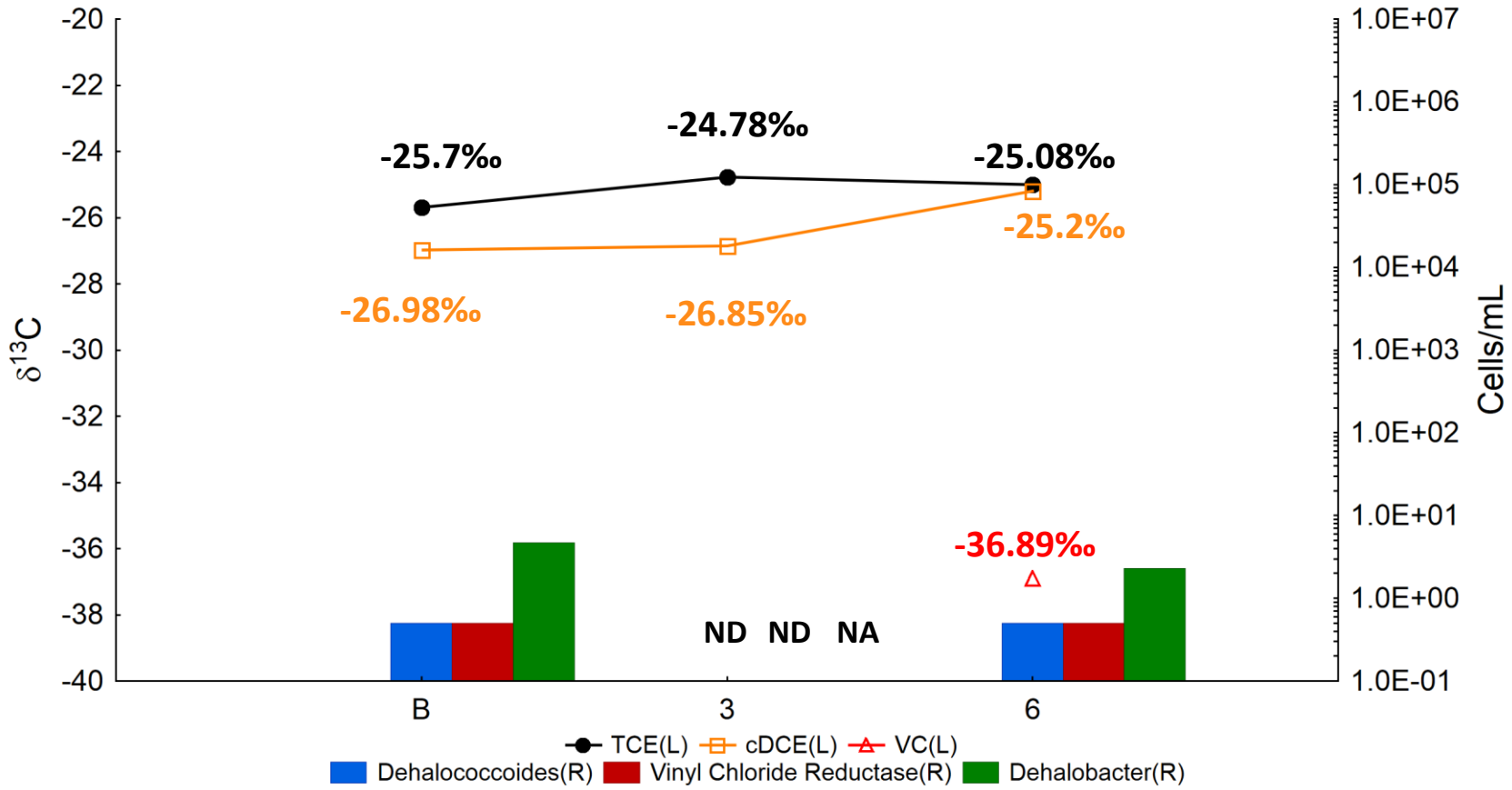
MBTs – CSIA and qPCR (OW-3)



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Weighing the Evidence

Minimal Influence at OW-3

Low concentrations of *Dehalococcoides* and *Dehalobacter*

Temporary decrease in TCE concentration

No concurrent increase in daughter product concentrations

No corresponding ^{13}C enrichment

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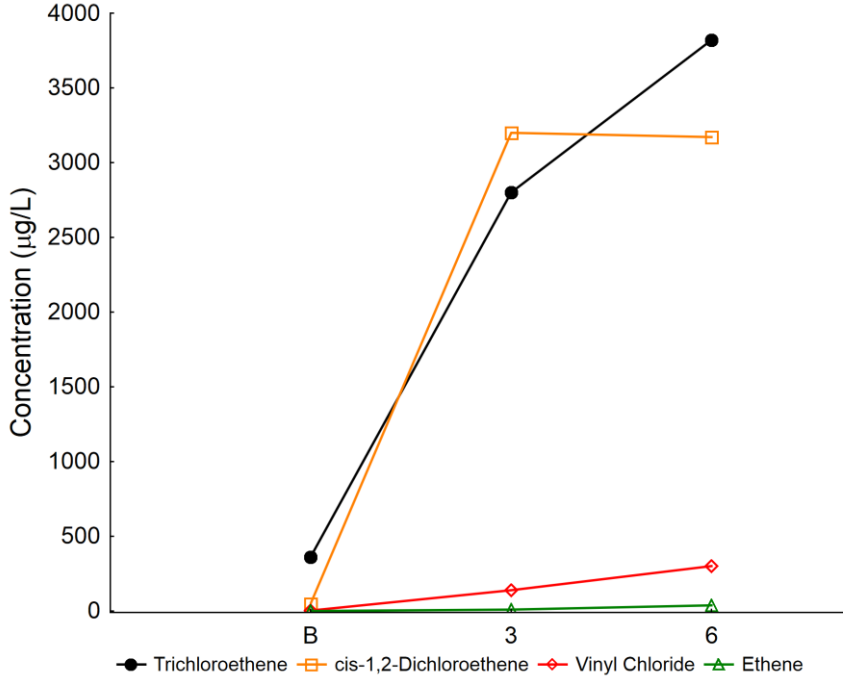
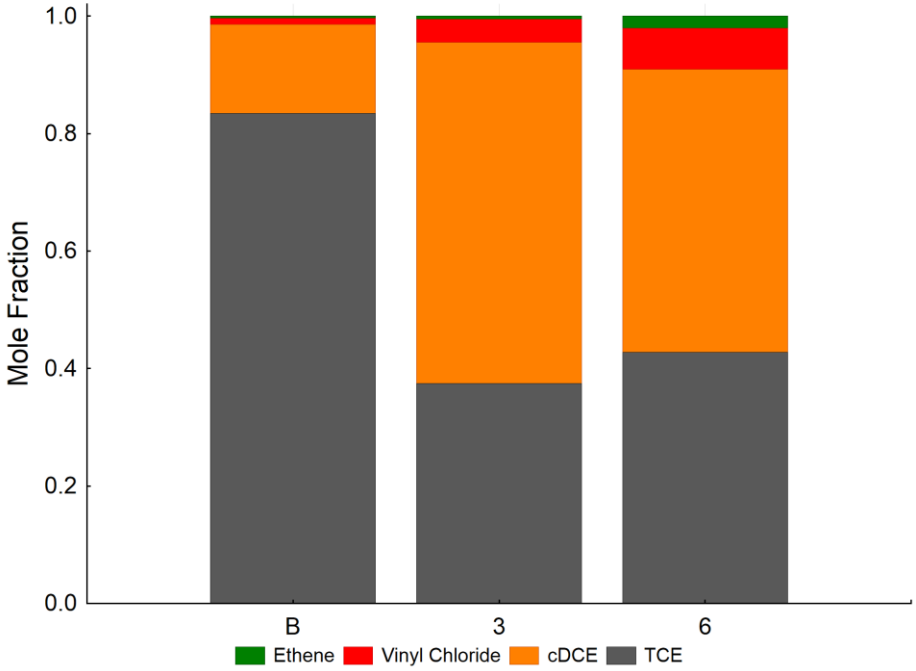
VOC Concentrations (MW-07-32)





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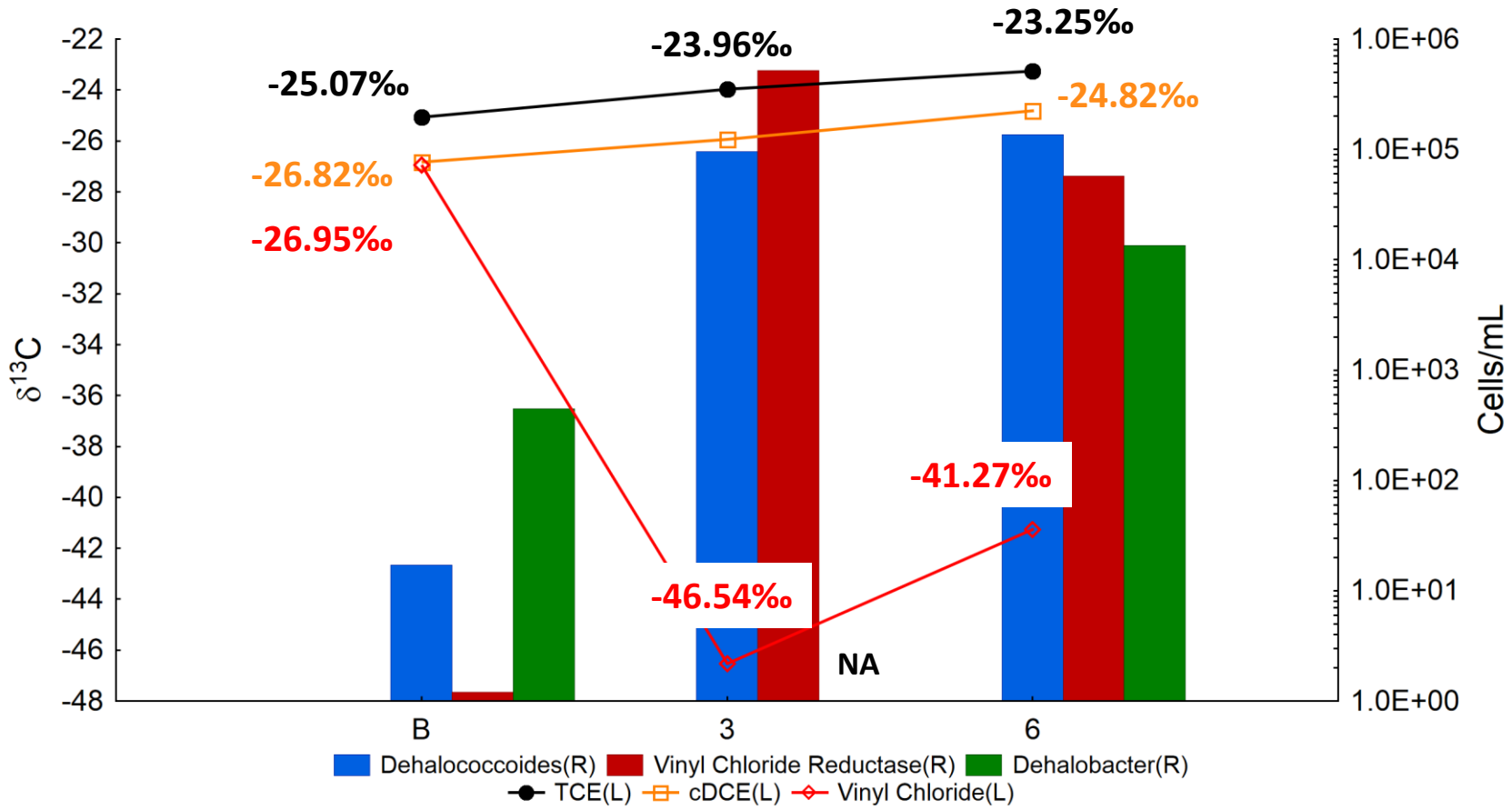
MBTs – CSIA and qPCR (MW-07-32)



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Conclusions & Lessons Learned

- Multiple lines of evidence increased confidence
  - Unclear trends in VOCs
  - CSIA added insight in contaminant degradation
  - qPCR demonstrated high probability of reductive dechlorination
- Bioremediation is feasible
  - Minimal influence perpendicular to flow (fractures)
  - Effective distribution along the flow path

Next Steps

- Additional 6 months of monitoring
  - Efficacy
  - Mechanisms
- PlumeStop® pilot study
  - Rapid reduction in contaminant concentrations
  - Continued biodegradation

Next Steps

- PlumeStop® pilot study
  - Field injection
  - Crushed sandstone *in situ* microcosm

Questions???

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