# Evaluation of Multiple Innovative Approaches for Accelerating Low VOC Concentration Plume Attenuation


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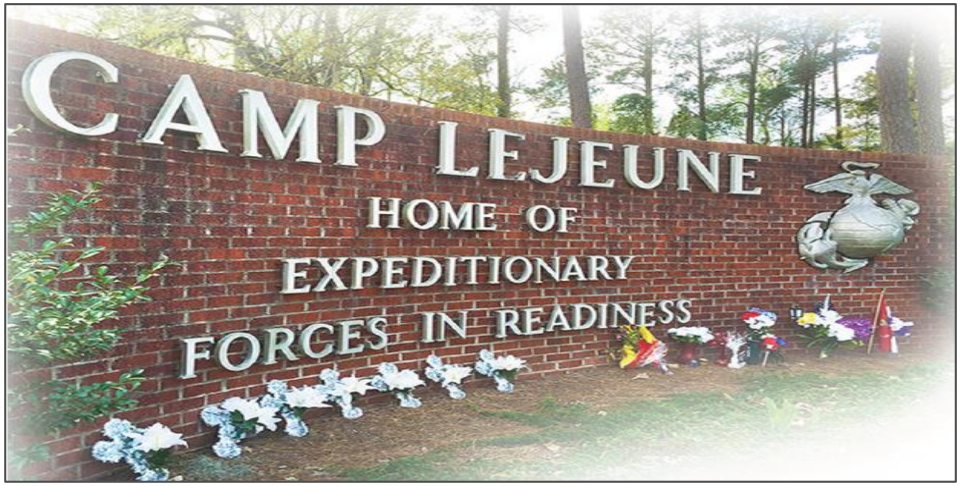
ch2m SM

Delivering Sustainable Solutions to Complex Local Challenges, Worldwide

Fourth International Symposium on Bioremediation and Sustainable Environmental Technologies

# Marine Corps Base Camp Lejeune

- Fast facts
  - More than 156,000 acres located along Atlantic Ocean near Jacksonville, North Carolina
  - Population - approximately 148,000 people (active duty, dependent, retiree, and civilian employees)
  - Placed on the CERCLA NPL in 1989
- Currently 12 CERCLA sites with RODs which include LTM in groundwater
  - Generally low strength VOCs and CVOCs
  - MCB Camp Lejeune is looking to implement pilot studies to enhance natural attenuation and reduce the time to site closure
- This presentation covers three pilot studies at three different sites

# Presentation Agenda

- Summarize the findings from three studies conducted to evaluate various bioremediation technologies to accelerate attenuation rates and reduce LTM periods at multiple low concentration VOC plumes

Solar-powered subgrade biogeochemical reactor (SBGR)

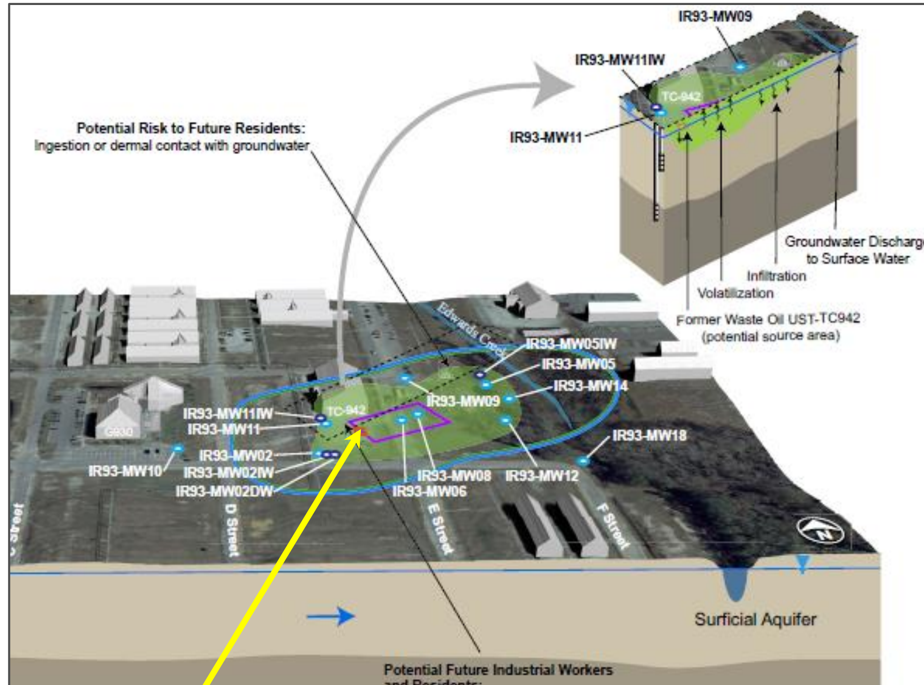
Substrate, bioaugmentation culture, and red yeast rice (RYR) injections

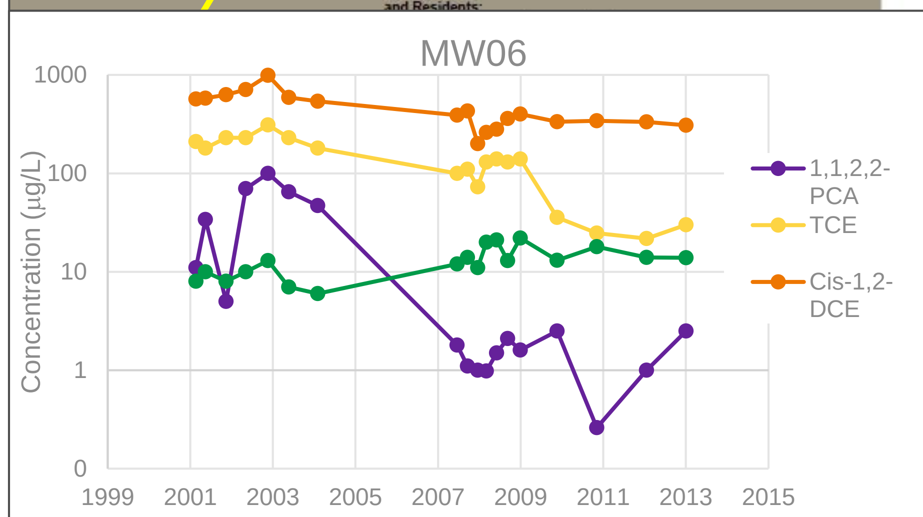
ISCO and ERD amendment bench-scale study

# Solar-Powered SBGR Pilot-Study

# Site Overview

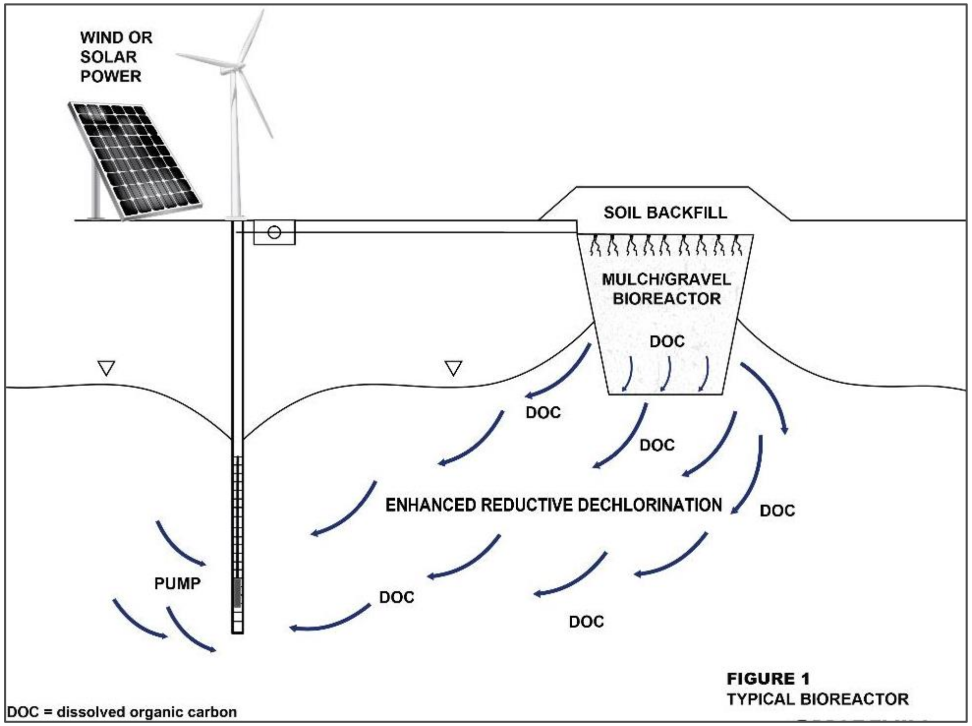
- 2.5-acre VOC plume
  - Primarily TCE, cis-1,2-DCE and VC at concentrations greater than North Carolina Groundwater Quality Standards (NCGWQS)
- Remediation approach
  - ISCO conducted from 2006 to 2008
  - MNA began in 2008
- Site water quality
  - Generally reducing conditions
  - pH lower than optimal range (6-8)
  - TOC <5 mg/L
  - VOC degradation products stable or slightly increasing
  - Insufficient population of microbes



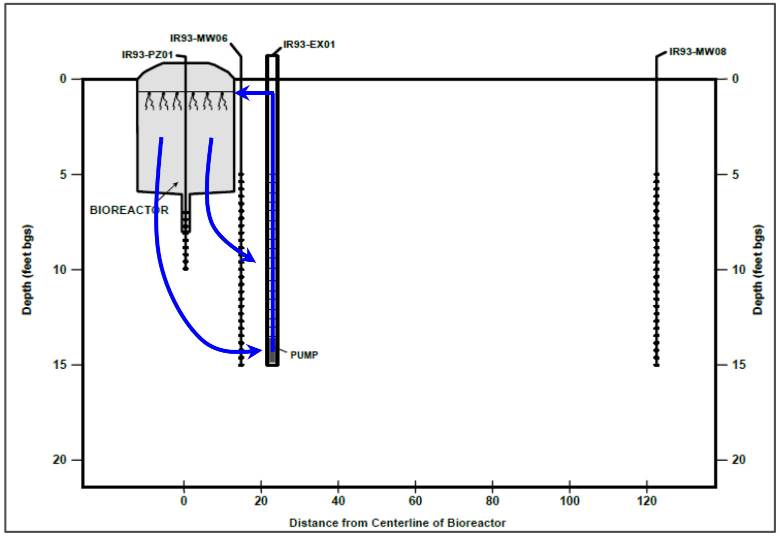
# SBGR Pilot Study

- Pilot study question:
  - Will a SBGR promote ERD and reduce COCs to cost-effectively accelerate progress toward meeting cleanup levels?
- Pilot study approach:
  - Install an SBGR consisting of mulch, vegetable oil, and gravel and a solar-powered groundwater recirculation well
  - Install one surficial piezometer within the SBGR to monitor the water level and SBGR properties
  - Conduct baseline and post-installation groundwater sampling

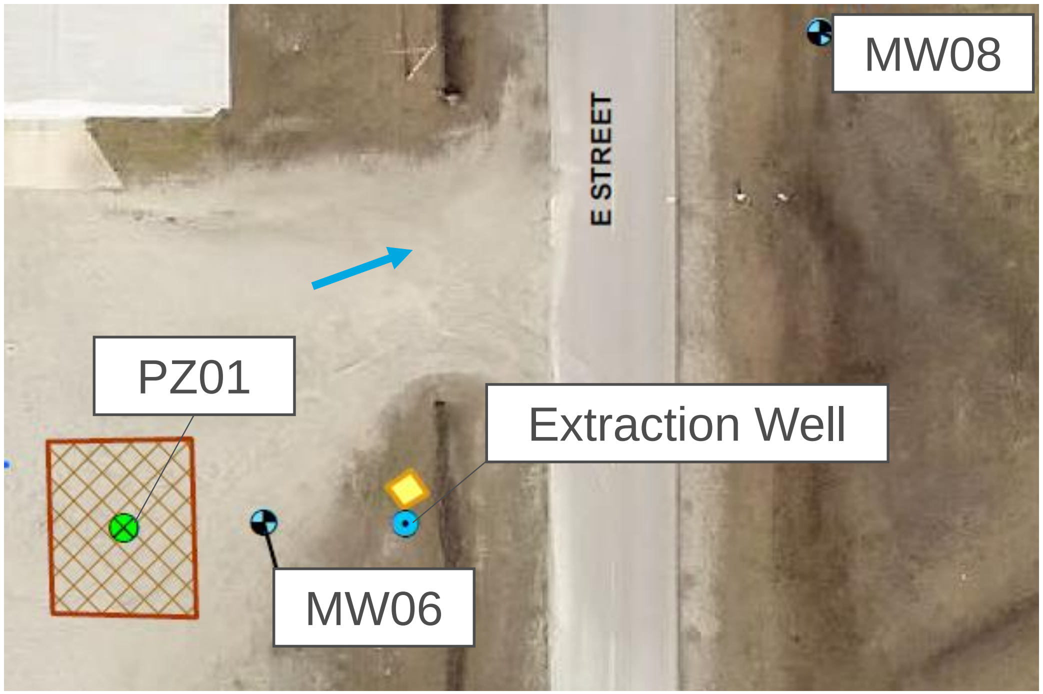


# SBGR Installation and Operation

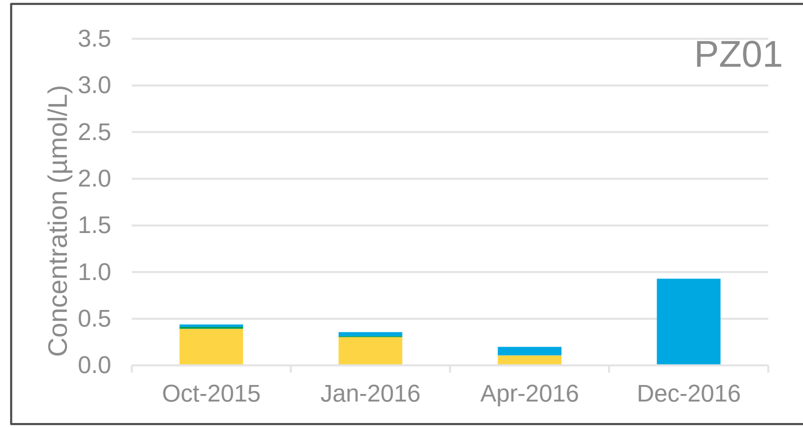
- Installation
  - Excavation: 25’ x 25’ x 6’
  - Backfill material: 60% mulch, 40% gravel, and 232 gallons soybean oil
- Operation
  - Solar-powered pump and float switch
  - Operating since July 2015; 188,000 gallons pumped to date (about 5 pore volumes)

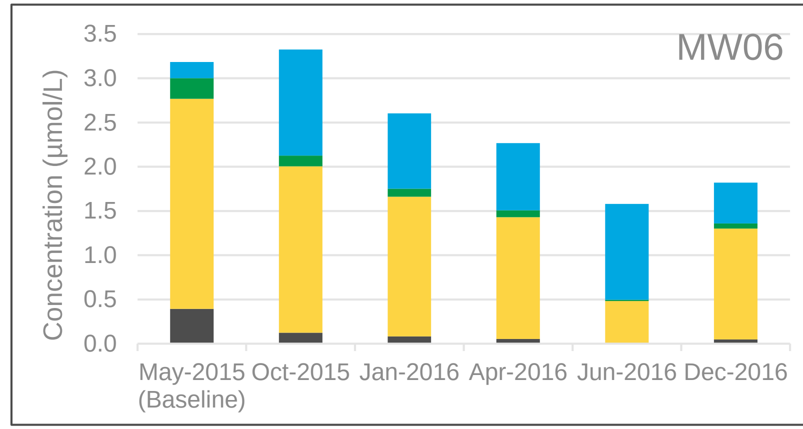


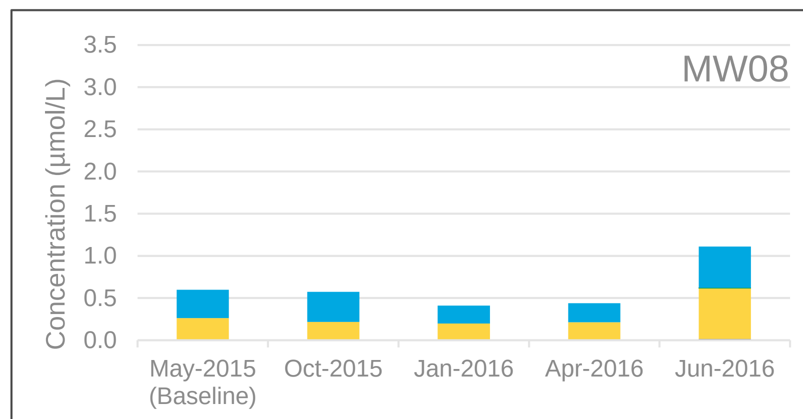
# SBGR Results




| | PZ01 | MW06 | | MW08 | |
|---|---|---|---|---|---|
| | 4/16 | 5/15 | 4/16 | 5/15 | 4/16 |
| DHC (cells/ml) | 422 | 254 | 1550 | 210 | 164 |
| VC R-Dase (cells/ml) | 1.9 U | 0.5 U | 83.2 | 0.7 | 0.5 U |




■ 1,1,2,2-PCA ■ PCE ■ TCE
■ cis-1,2-DCE ■ trans-1,2-DCE ■ VC

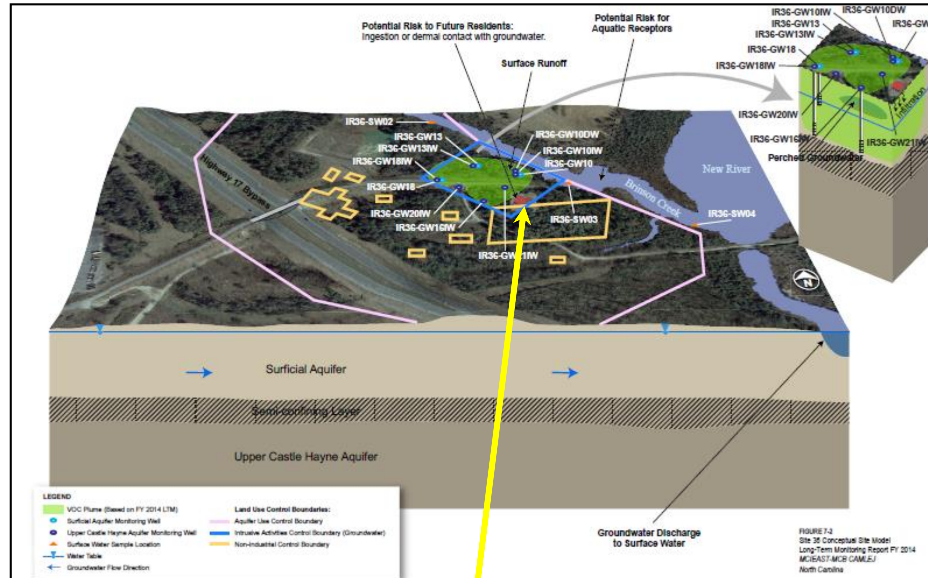
# Summary

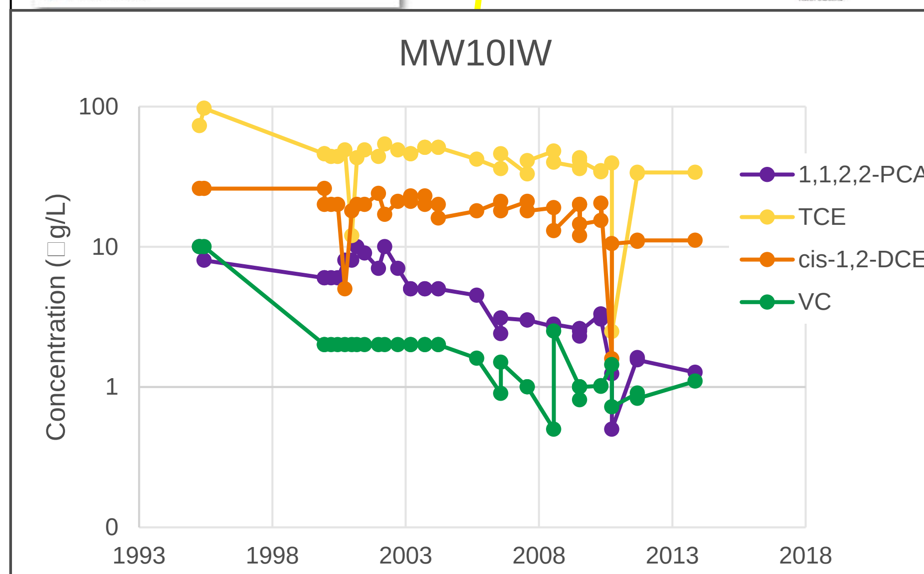
- Cost
  - Construction: ~$70,000
  - O&M: ~$5,000/year + periodic carbon substrate additions
- Findings
  - The bioreactor has established conditions within its zone of influence to facilitate reductive dechlorination
  - Estimated time to reach cleanup levels in study area decreased from 87 years to 30 years
    - Potential savings = annual monitoring and reporting cost of $45,000 x 57 years ≈ $2.5MM
- Path Forward
  - Bioaugment the bioreactor to further enhance reduction within the bioreactor, especially the persistent VC concentrations
  - Replenish the bioreactor with an injectable carbon substrate once the TOC concentration in the groundwater cannot support ERD (2 to 4 years post-installation)
  - Continue groundwater sampling to assess bioreactor performance
  - Evaluate application in other areas of site to accelerate site closure

# EVO, Bioaugmentation Culture, and RYR Injections

# Site Overview

- 3-acre VOC plume
  - Primarily TCE, cis-1,2-DCE, and 1,1,2,2-PCA at concentrations greater than NCGWQS
- Remediation approach
  - MNA began in late 1990s
- Site water quality
  - VOC concentrations stable
  - Low DO, negative oxidation reduction potential (ORP)
  - TOC <5 mg/L



# Substrate, Bioaugmentation Culture, and RYR Injections Pilot Study

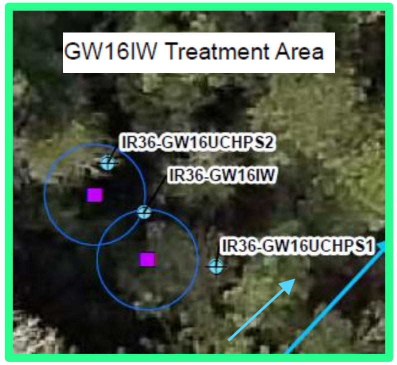
- Pilot study questions:
  - Will injections of bio-augmented EVO improve aquifer conditions for NA and reduce COCs to accelerate progress toward meeting cleanup levels?
  - Will red yeast rice extract inhibit methane generation during ERD?
- Pilot study approach:
  - Complete one round of ERD injections with bioaugmentation via DPT in two treatment areas
  - Inject red yeast rice extract with EVO injections in one treatment area
  - Conduct baseline and post-injection groundwater sampling

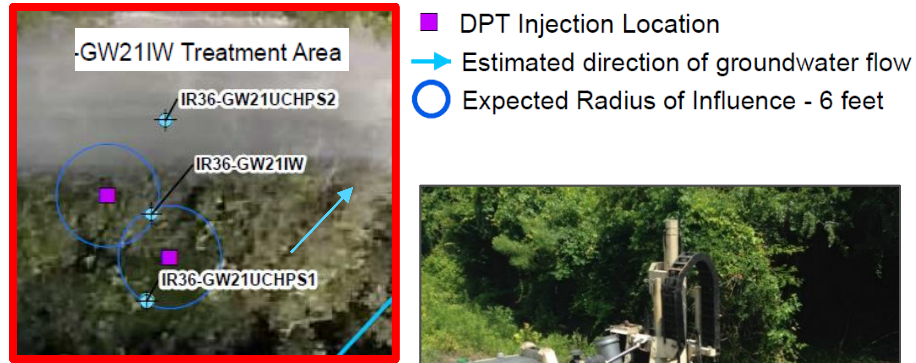


Added to de-oxygenate the dilution water

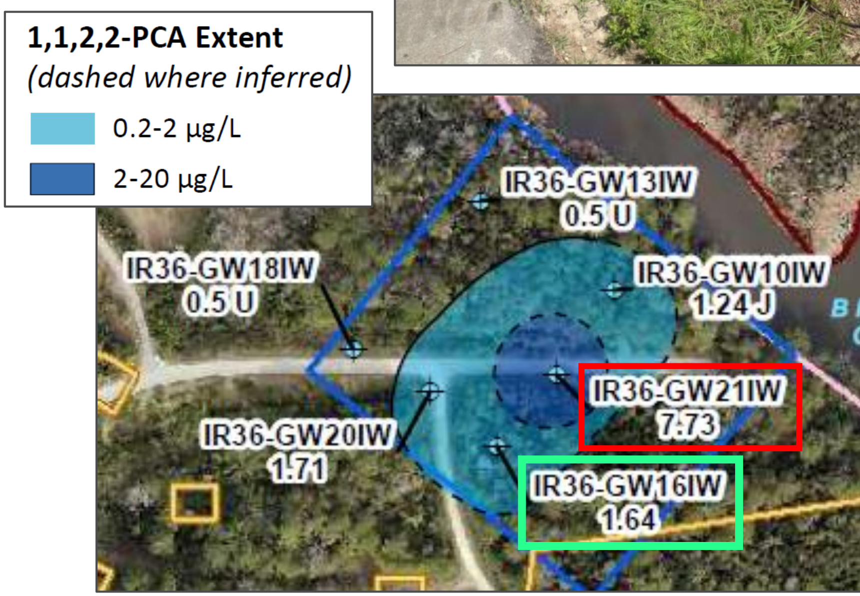
Bioaugmenting the amendment

# Injections



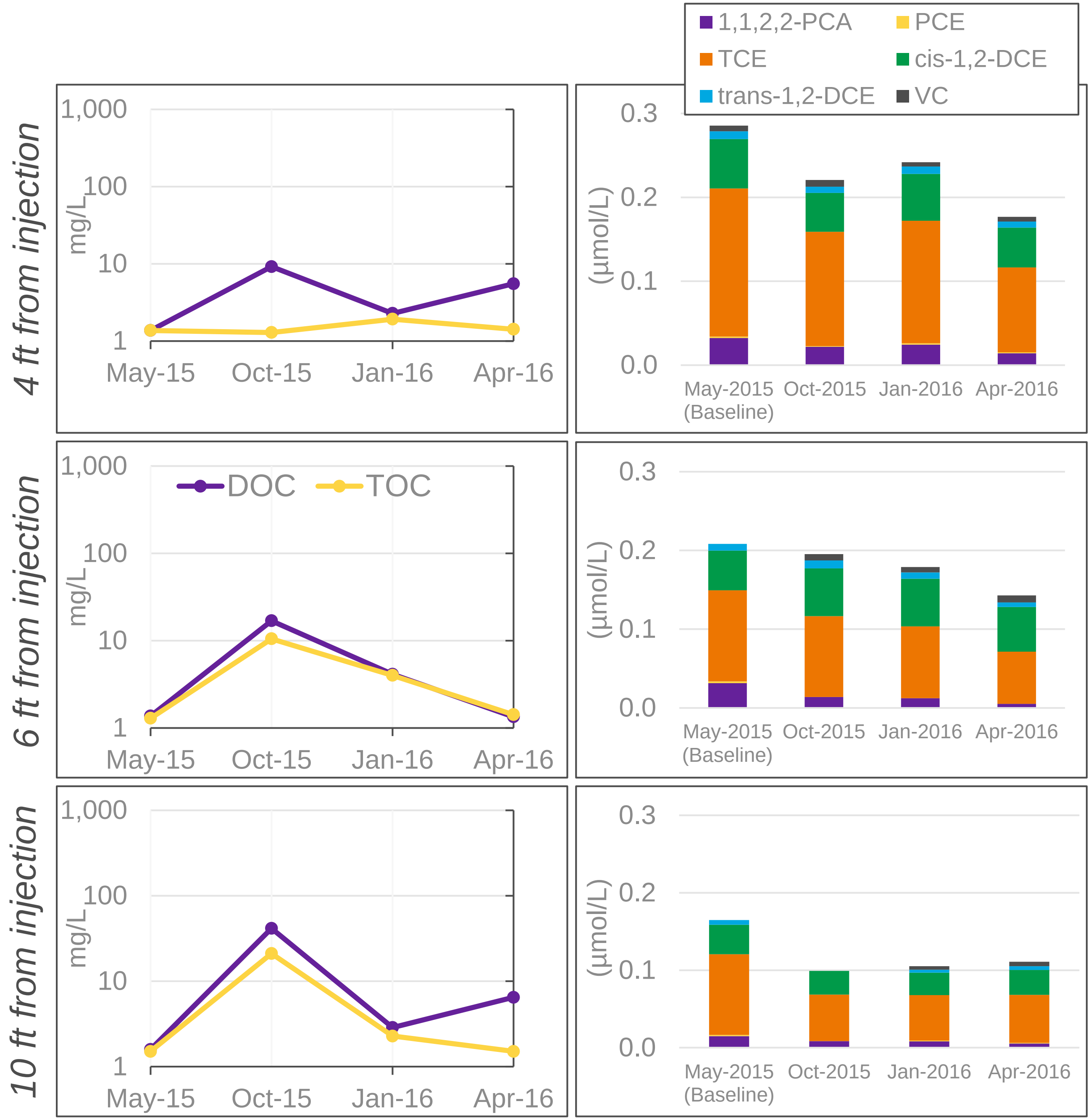




- Design
  - Target 30 to 40 feet bgs in two areas
  - Expected ROI of 6 feet
- GW16IW treatment area
  - 27.5 gal EVO, 818 gal water, 1L of TSI-DC, and 5 lbs RYR (per vendor specifications) per location
- GW21IW treatment area
  - 27.5 gal EVO, 818 gal water, and 1L of TSI-DC per location
- Average injection flowrate: 2.7 gpm



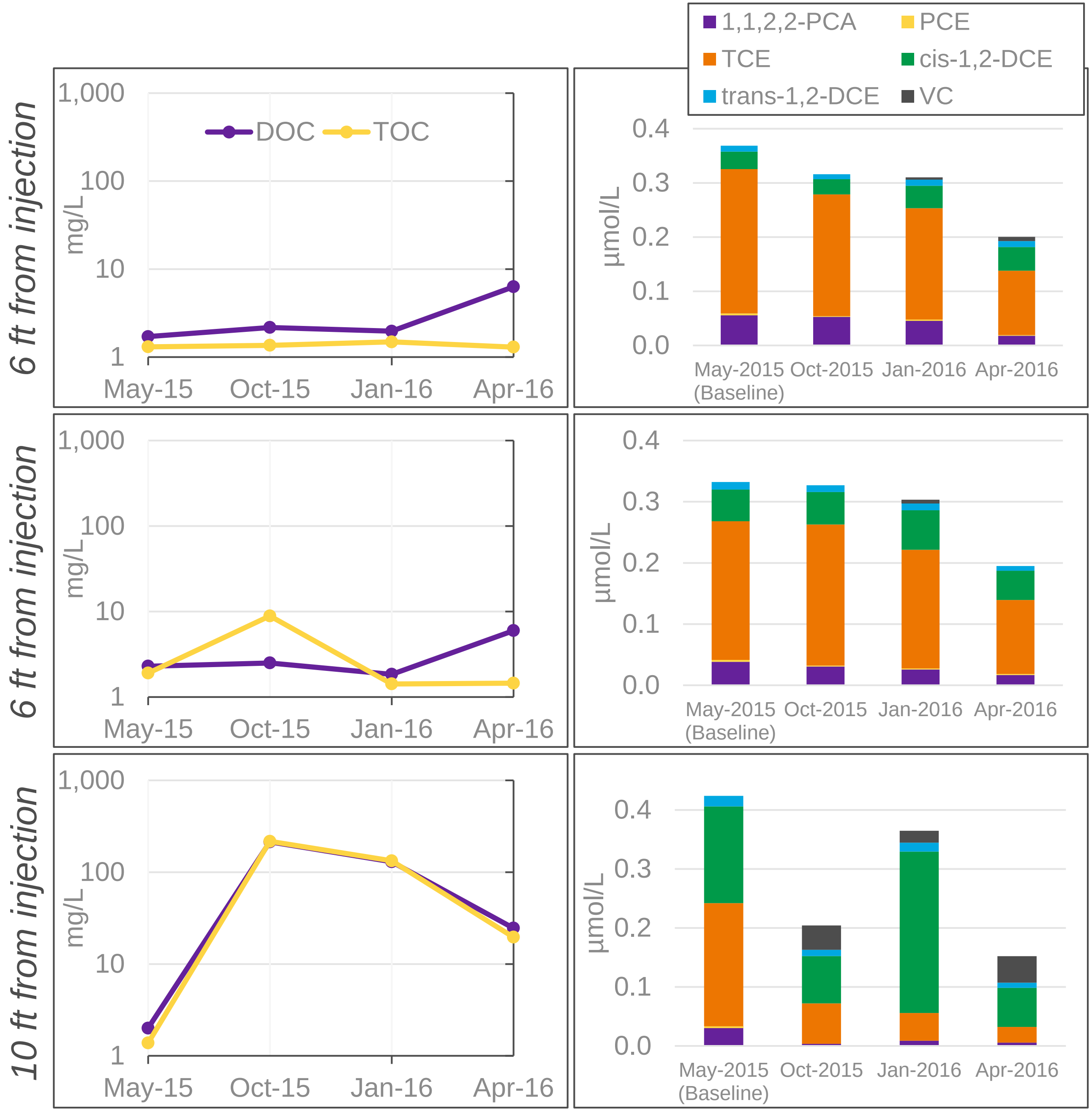
# Results: MW16IW

- Injections conducted July 2015
- WQPs indicate substrate reached MW16IW (6 ft) and MW16IWUCHPS1 (10 ft)
- Total VOCs decreased up to 40%
  - 1,1,2,2-PCA and TCE concentrations decreased up to 84%
- No COCs decreased to below cleanup levels after nine months



# Results: MW21IW

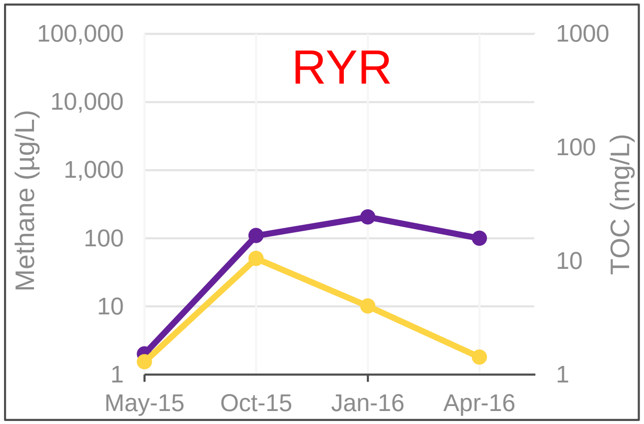
- Injections conducted July 2015
- WQPs indicate substrate reached MW21IWUCHPS2 (10 ft)
  - Less obvious at 6 ft from injection points
- Total VOCs decreased up to 60%
  - 1,1,2,2-PCA and TCE decreased 82% and 87%, respectively
- COCs remain at concentrations exceeding cleanup levels after nine months



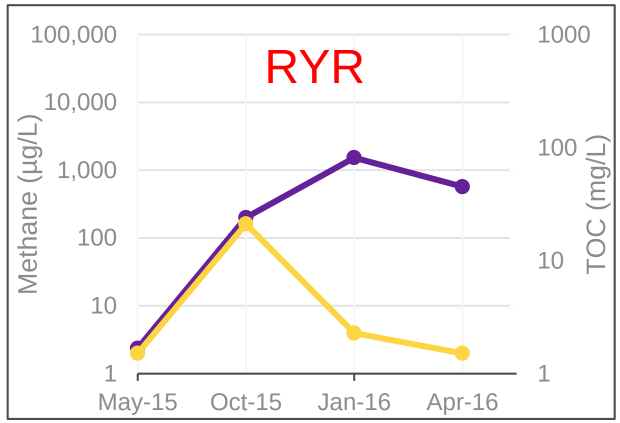
# Results: Methane

CH4 TOC

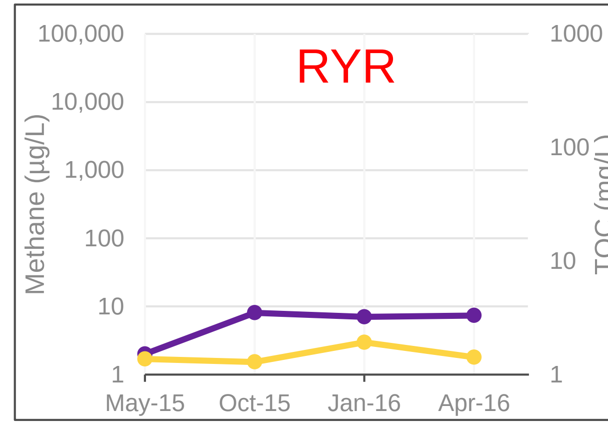
6 ft from injection



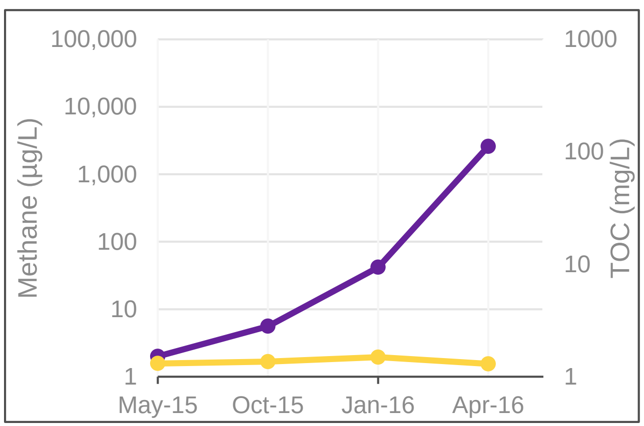

10 ft from injection



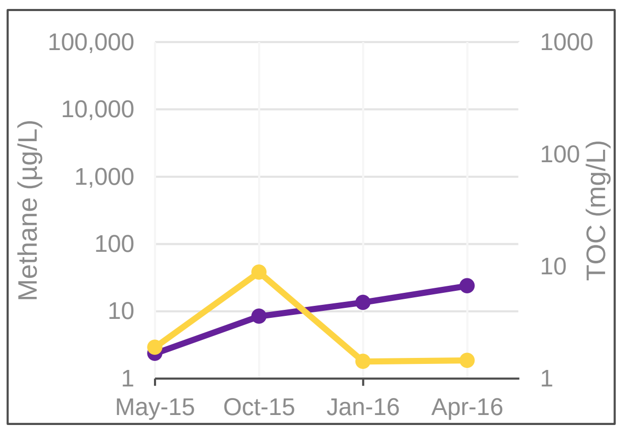

4 ft from injection



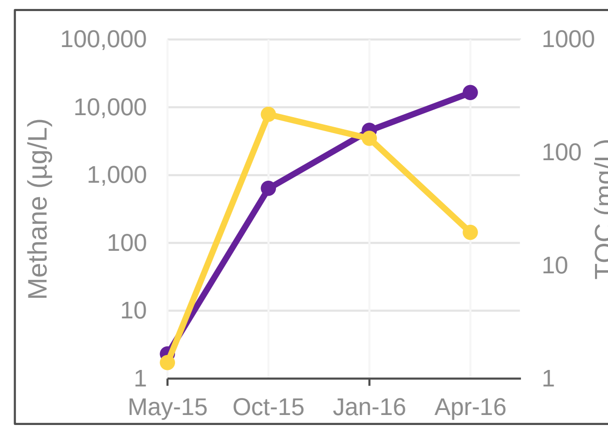

6 ft from injection




6 ft from injection




10 ft from injection



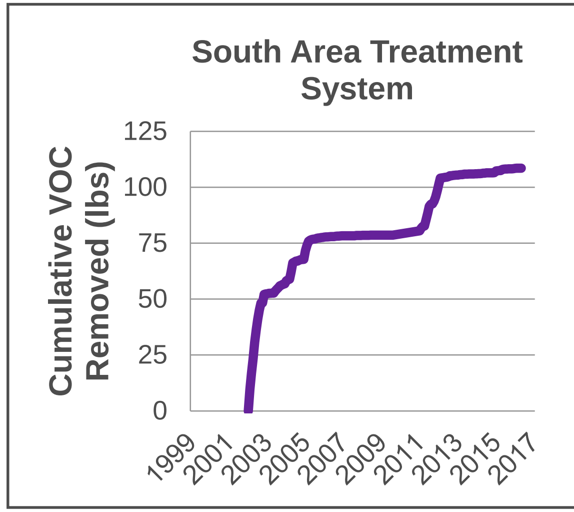
# Summary

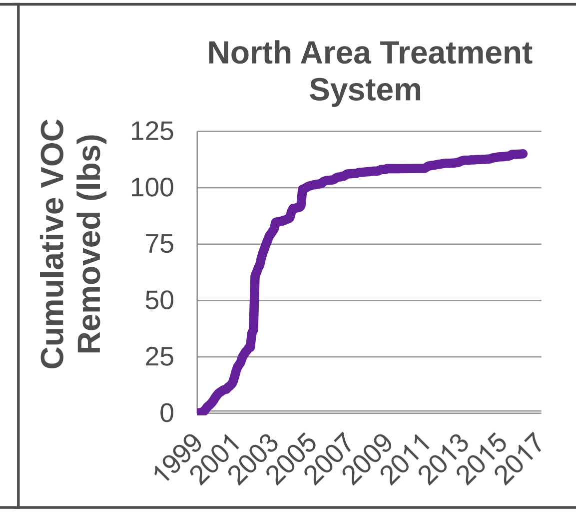
- Cost
  - Construction: $32,000
  - O&M: None
- Findings
  - Despite evidence of inconsistent substrate delivery, stimulated biodegradation and reduced COC concentrations by up to 80 percent
  - Estimated time to reach cleanup levels in study area decreased by 23 years as a result of the pilot study
    - Potential savings = annual monitoring and reporting cost of $20,000 x 23 years ≈ $700,000
  - RYR does not appear to have completely suppressed methane generation where the substrate was distributed, but may have mitigated maximum methane production to some degree
- Path Forward
  - No additional injections; rely on NA to address residual VOC impacts

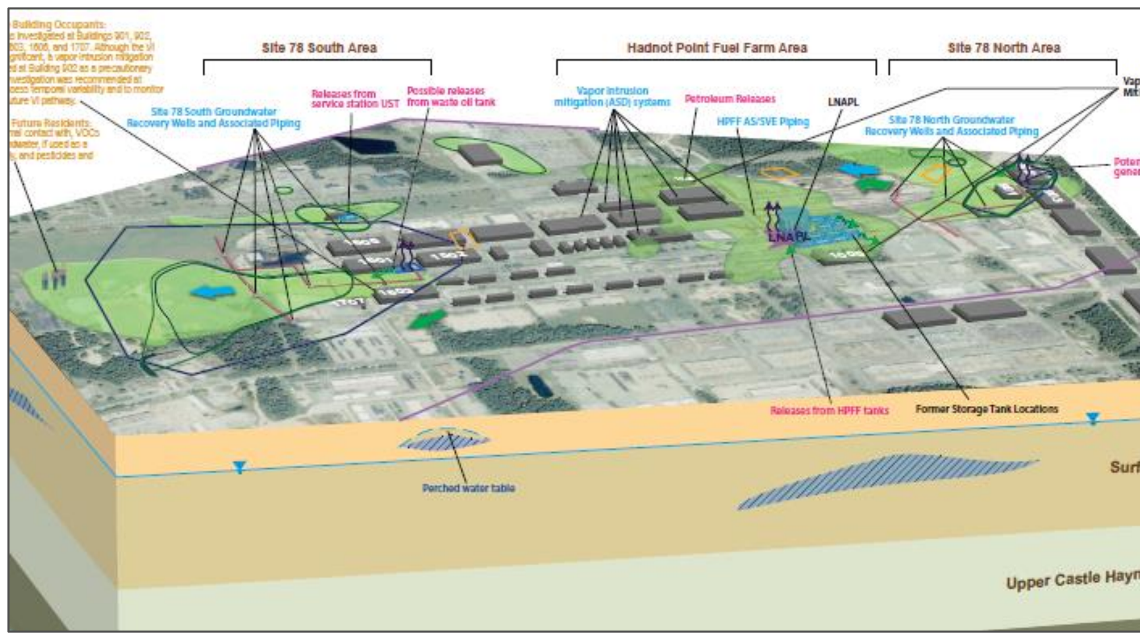
# ISCO and ERD Amendment Bench-Scale Study

# Site Overview

- Isolated VOC plumes covering over 50 acres
  - Primarily TCE, VC, and benzene at concentrations greater than NCGWQS
- Remediation strategy
  - Groundwater extraction and treatment
  - Ongoing for 20 years and has reached asymptotic conditions



# ISCO and ERD Amendment Bench-Scale Study

- Bench-scale study question:
  - What in-situ treatment is most appropriate to both CVOCs and petroleum-hydrocarbons, to accelerate progress toward meeting cleanup levels, and reduce the time to achieve site closure?
- Approach:

**Persulfate**
- Base- and Iron-activated persulfate
- **Objective:** aggressively address mixed-plume

**Sulfate**
- Epsom salt
- **Objective:** Couple sulfate reduction with benzene oxidation and CVOC reduction

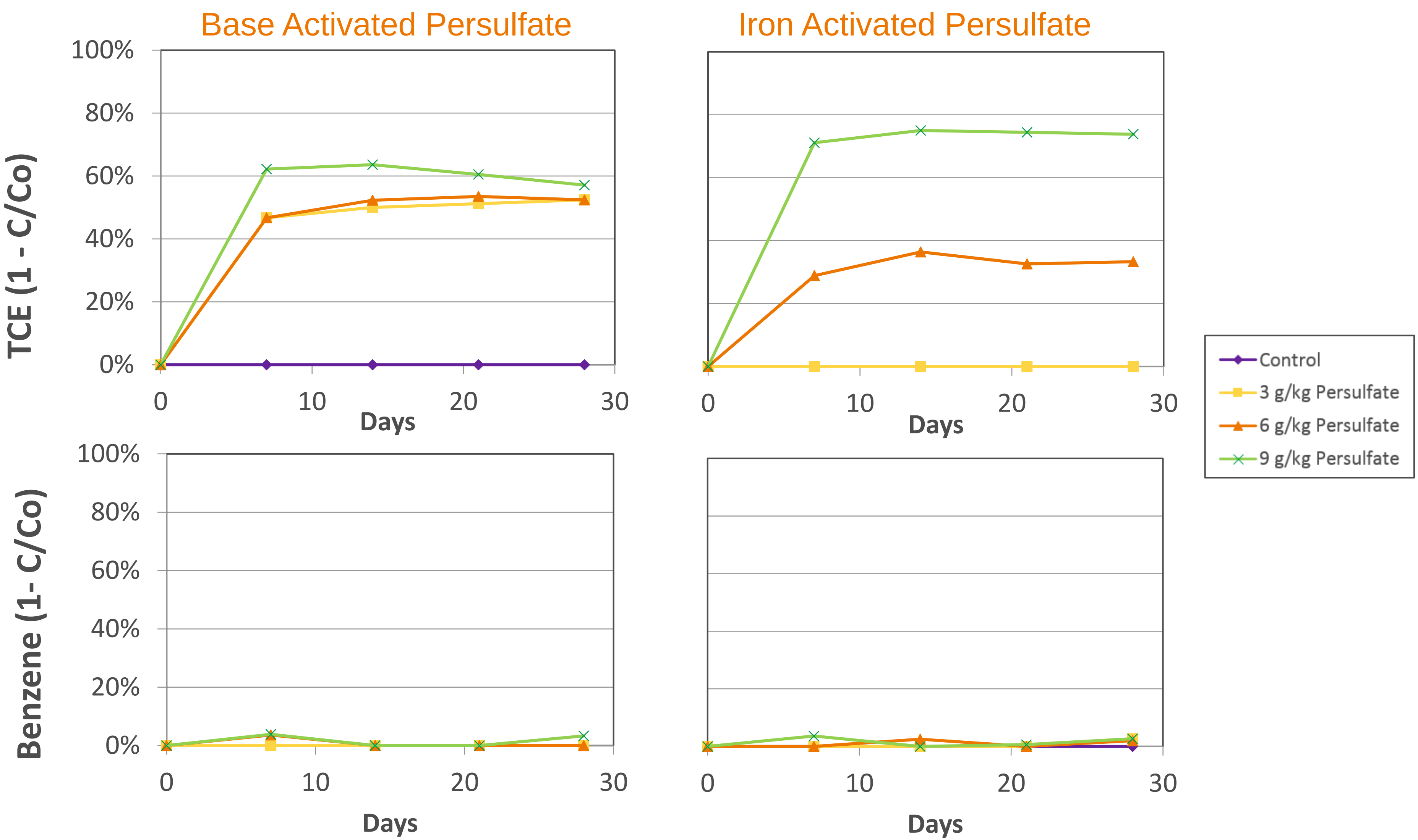
**Sulfate + Lactate**
- Epsom salt + lactate
- **Objective**: boost sulfate-only process

**Biostim.**
- EHC-L
- **Objective:** stimulate ERD with commercial substrate

**Biostim. + Bioaug.**
- EHC-L + bioaug.
- **Objective**: boost biostimulation only process

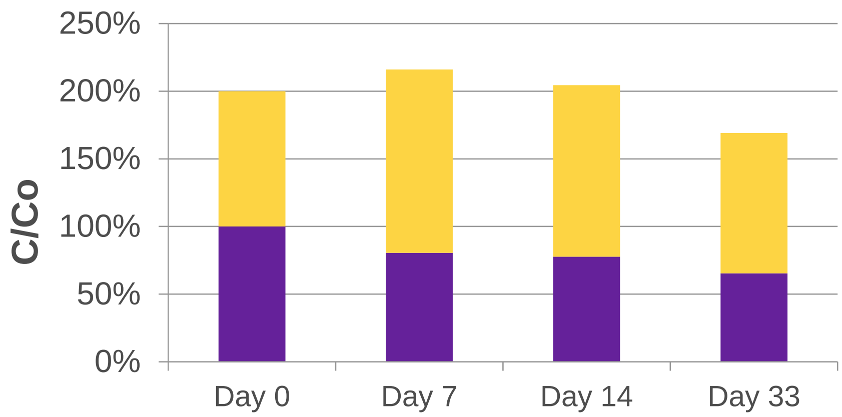
**Field-Scale Study**

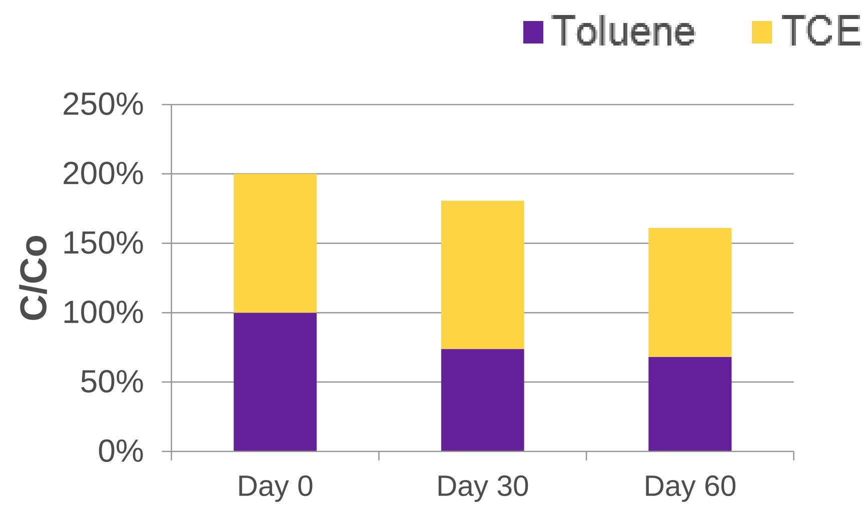
# Persulfate Results

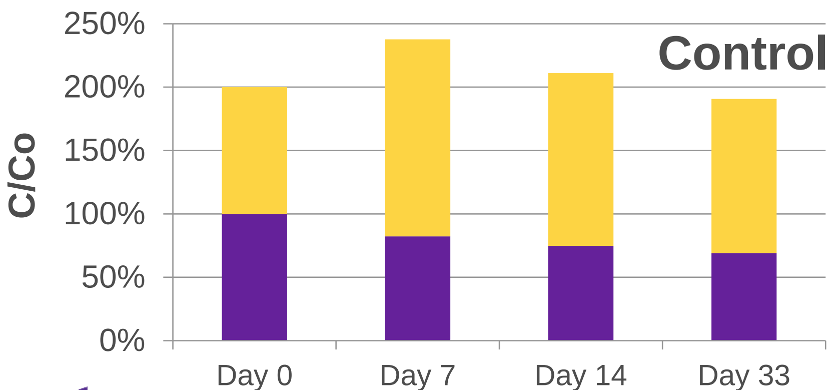


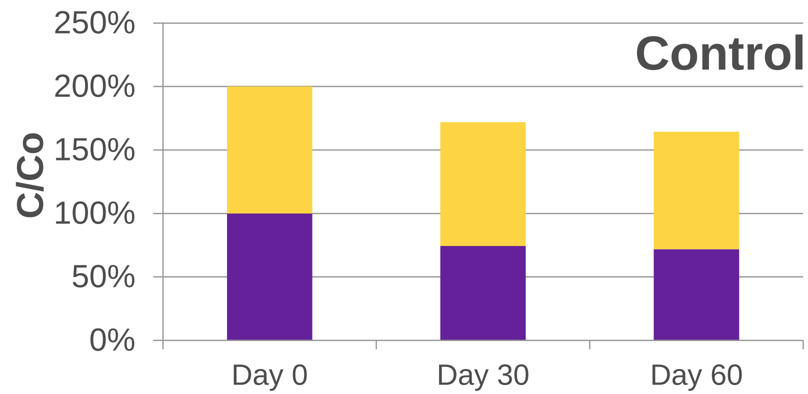
# Sulfate Results

- **Phase 1: Sulfate Only**
  - Treatment reactors dosed with 0.23 grams of sulfate (Epsom salt, $MgSO_4 \cdot 7H_2O$)
  - DO decreased and dissolved iron concentrations increased, limited by low biological activity
- **Phase 2: Sulfate with Lactate**
  - 500 mg/L of sodium lactate was added to stimulate the sulfate reducing conditions



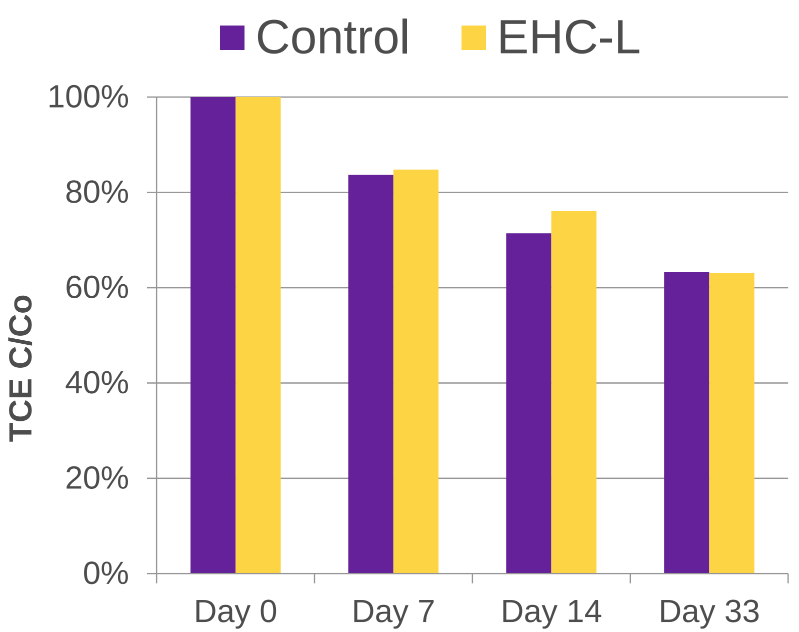



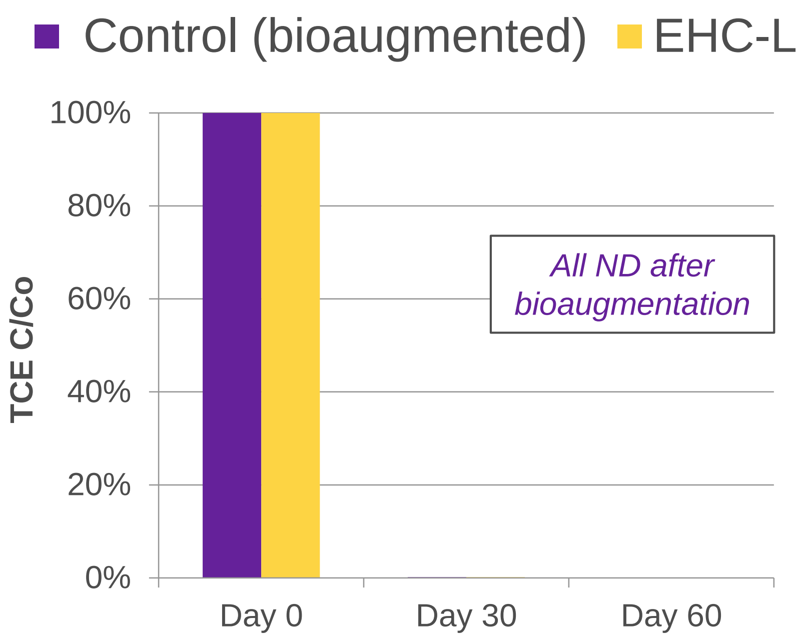



# EHC-L Results

- **Phase 1: EHC-L only**
  - Treatment reactors were dosed with 1.52 grams of EHC-L
  - Dissolved iron and total organic carbon concentrations increased, limited by low biological activity
  - No meaningful decreases in BTEX



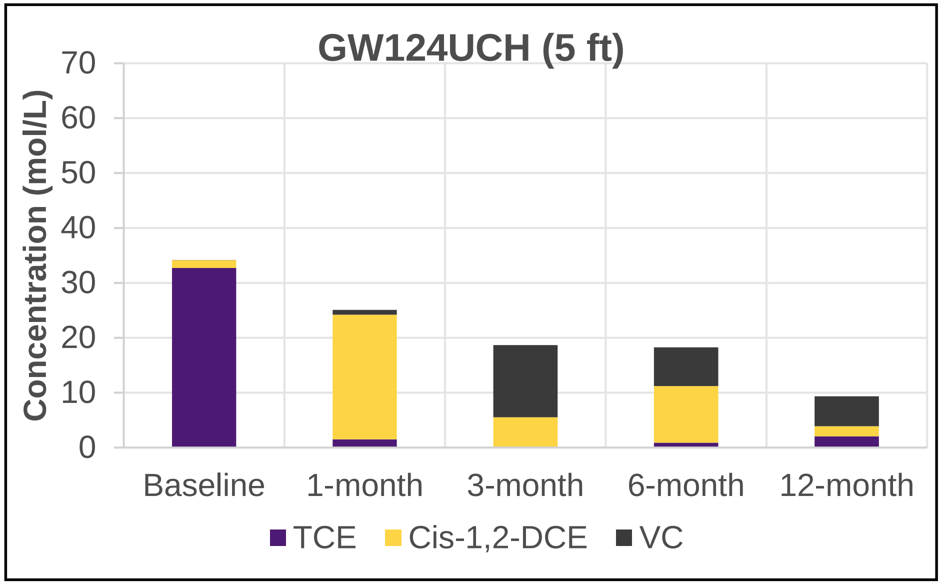

- **Phase 2: EHC-L + Bioaugmentation**
  - The EHC-L reactor and the EHC-L control reactor (without the addition of EHC-L) were inoculated with a 1% dose (by volume) of Terra System's TSI-DC culture
  - No meaningful decreases in BTEX

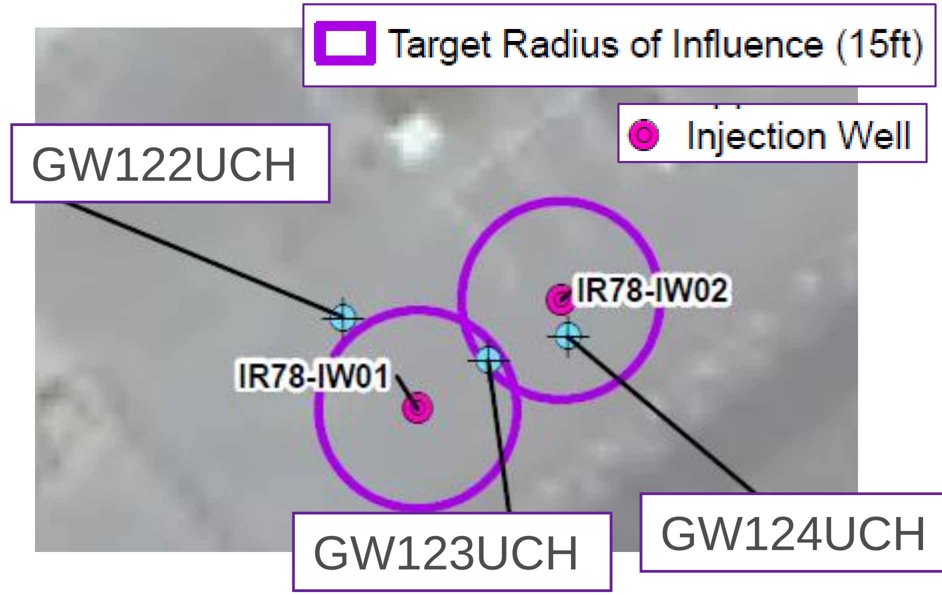


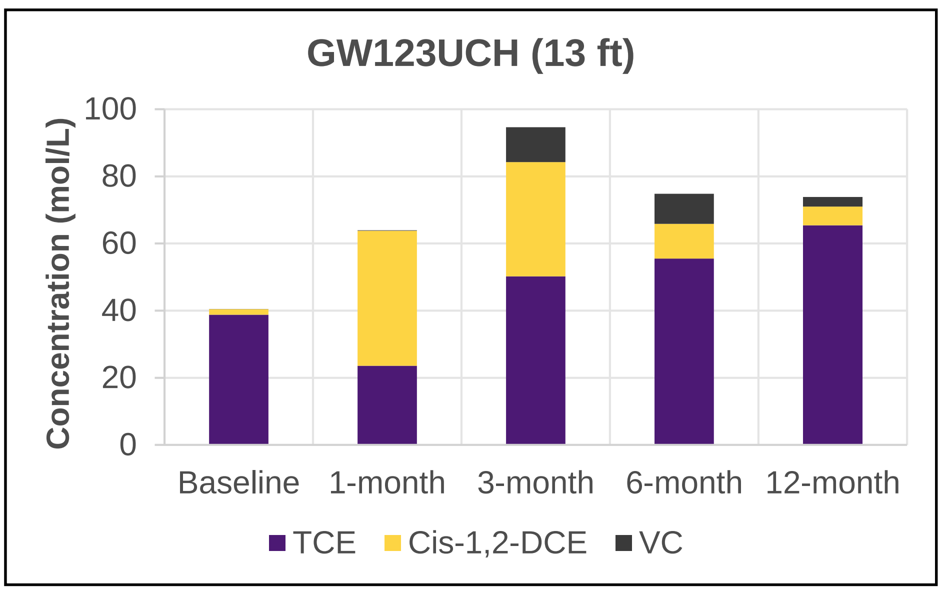
# Conclusions and Field Implementation

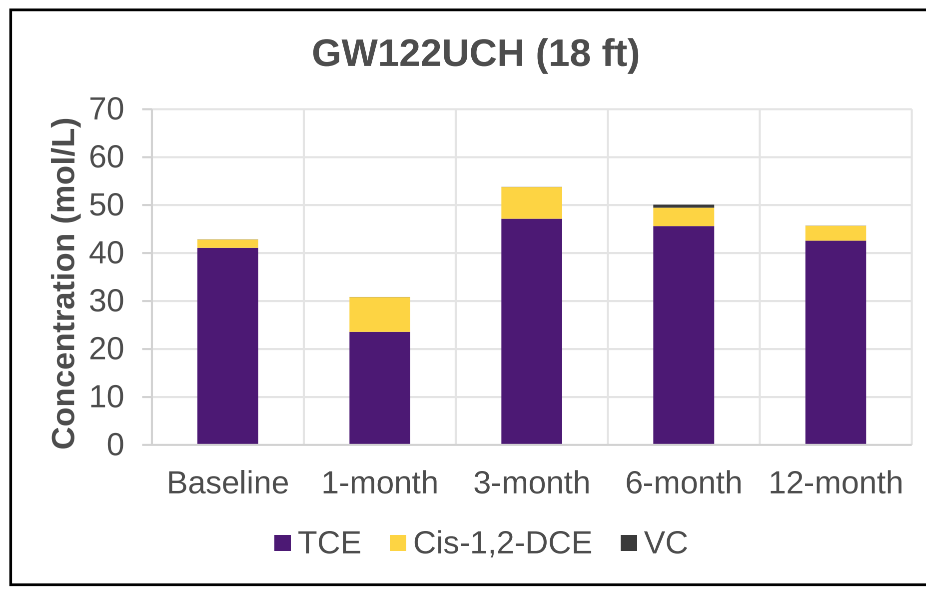
- Pilot Study substrates not effective for petroleum-hydrocarbon degradation.
  - CVOCs determined to be more prevalent and the focus of the field implementation
- EHC-L with bioaugmentation selected for field implementation
- Field-scale approach:
  - Assumed 15 ft ROI
  - Two injection wells
    - 420 lbs EHC-L
    - 8,000 gallons of water
    - 3 L of bioaugmentation culture
- Objective
  - Evaluate effectiveness in the field
  - Obtain information on design parameters for site-wide implementation

# Field-Scale: EHC-L with Bioaugmentation



# Summary

- Cost
  - Construction: $62,000
  - O&M: None
- Findings
  - Base-activated persulfate, iron-activated persulfate, sulfate, and bioaugmented sulfate not effective
  - ERD using EHC-L and TSI-DC bioaugmentation culture effective for TCE in the mixed plume and implemented in the field
- Path Forward
  - Design parameters for potential full scale implementation were developed based on the pilot study. Implementation pending.

# Three Study Summary

| Study | Key Findings | Cost per Unit Volume Treated |
|---|---|---|
| Solar-Powered SBGR | • Created conditions within its zone of influence conducive to reductive dechlorination<br>• May require bioaugmentation for residual VC<br>• May require carbon replenishment | \$170/CY + \$12/CY/yr |
| EVO, Bioaugmentation Culture, and RYR Injections | • Despite inconsistent substrate distribution, successfully stimulated biodegradation and reduced COC concentrations<br>• Distribution of the substrate limited by preferential pathways, RYR did not completely inhibit methane generation | \$190/CY |
| ISCO and ERD Amendment Bench-Scale Study | • ERD using EHC-L and TSI-DC bioaugmentation culture is an effective technology for treating TCE in mixed plumes containing CVOCs and petroleum-related hydrocarbons<br>• Base-activated persulfate, iron-activated persulfate, sulfate, and bioaugmented sulfate were not effective | \$120/CY |

# Thank you!

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