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CREATIVE THINKING
EXCEPTIONAL SOLUTIONS

Successful Cleanup of Low-Level Chlorinated Propanes in Groundwater using an In Situ Bioreactor

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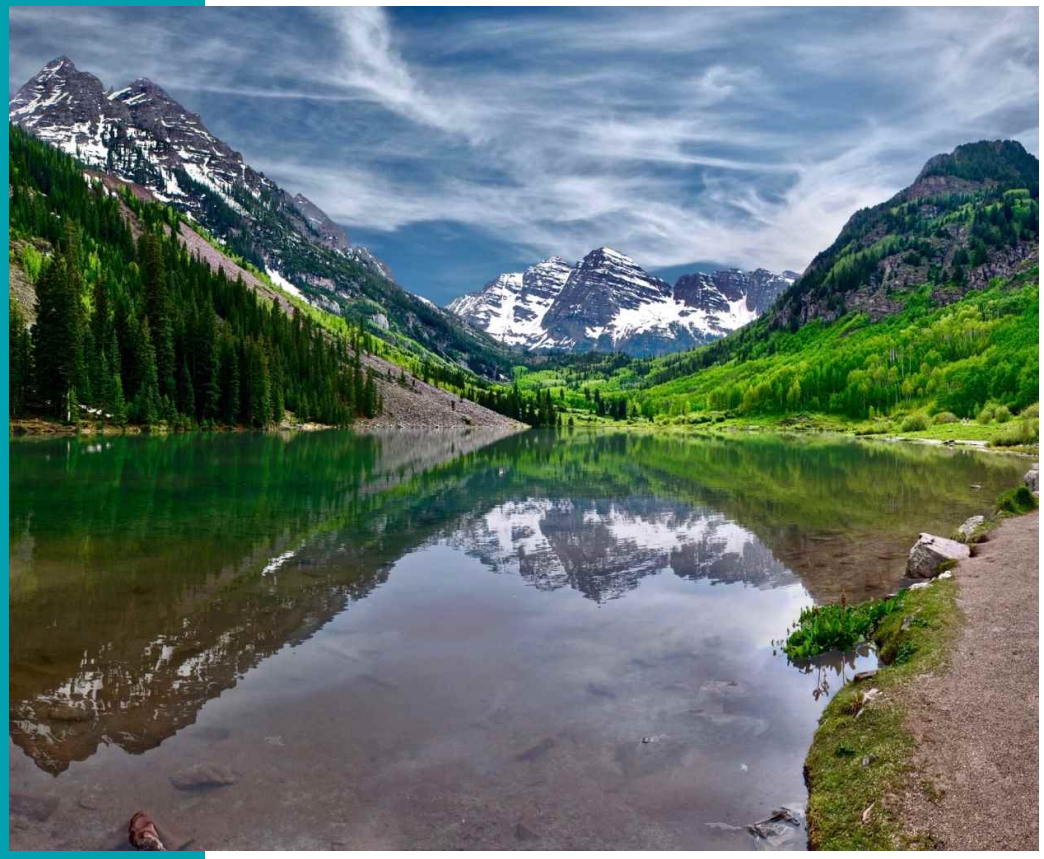


Why is 1,2,3-Trichloropropane an Emerging Concern for Groundwater

Key sources

- Agricultural fumigant formulations
- Specialty polymers and sealants

Typically found at

- Ag-chem facilities
- Chemical manufacturing
- Military facilities
- Waste disposal facilities

Classified as a likely or potential human carcinogen

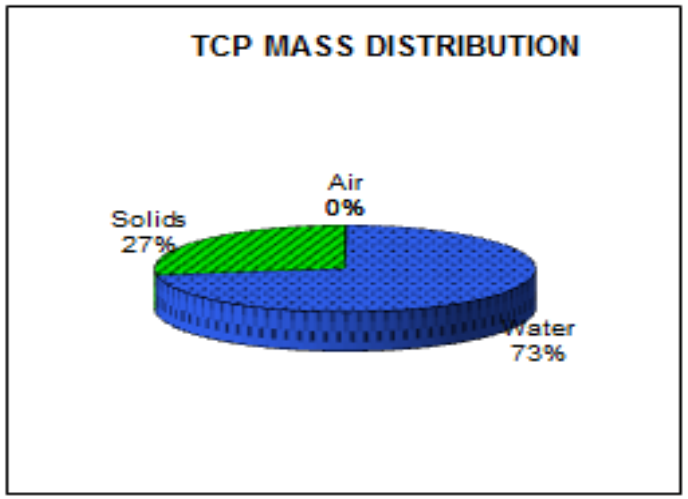
- EPA, NIOSH, ATSDR
- Classified as a carcinogen by California

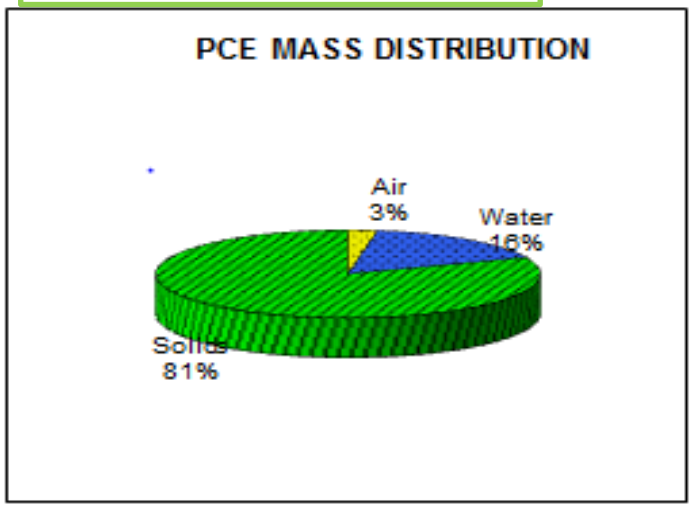
Federal	• USEPA tap water RSL is **0.00075 µg/L**
California	• **0.0007 µg/L** Public Health Goal (est. 2009) • **0.005 µg/L** MCL (adopted 18 July 2017)
Hawaii	• State MCL of **0.6 µg/L** (est. 2011)
Minnesota	• Health Risk Limits (HRL) (est. 2011): • **0.003 µg/L** Cancer HRL
New Jersey	• **0.03 µg/L MCL** (est. 2018)
New York	• Water quality standard (**0.04 µg/L)**
Others	• EPA RSLs (Nebraska, North Carolina, West Virginia)

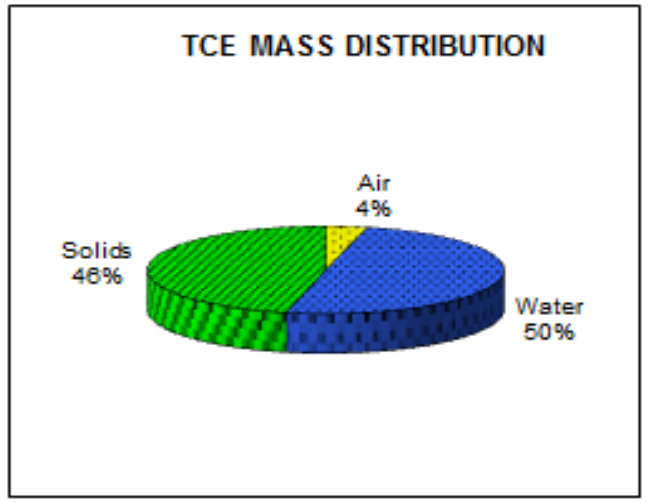
TCP Fate and Transport

Parameter	1,2,3-Trichloropropane (TCP)	1,2-Dichloropropane (DCP)	Tetrachloroethylene (PCE)	Trichloroethylene (TCE)
CASRN	96-18-4	78-87-5	127-18-4	79-01-6
Chemical formula	$C_3H_5Cl_3$	$C_3H_6Cl_2$	C_2Cl_4	C_2HCl_3
Molar mass (g/mol)	147.4	113.0	165.8	131.4
Specific gravity[a]	1.30	1.13	1.58	1.44
Water solubility[b] (g/L)	1.75	2.80	0.20	1.10
Boiling point[b] (°C)	157	96.0	121	87.0
Vapor pressure[b] (mm Hg)	3.69	53.3	18.5	69.0
Henry's law constant[b] (atm-m^3/mol)	3.43×10^{-4}	2.82×10^{-3}	1.77×10^{-2}	9.85×10^{-3}
Octanol-water partition coefficient[b] (log P)	2.27	1.98	3.40	2.42
Soil organic carbon-water partition coefficient[c] (log Koc)	2.117	1.831	2.029	1.831

Merrill et al, 2019







Groundwater Remediation

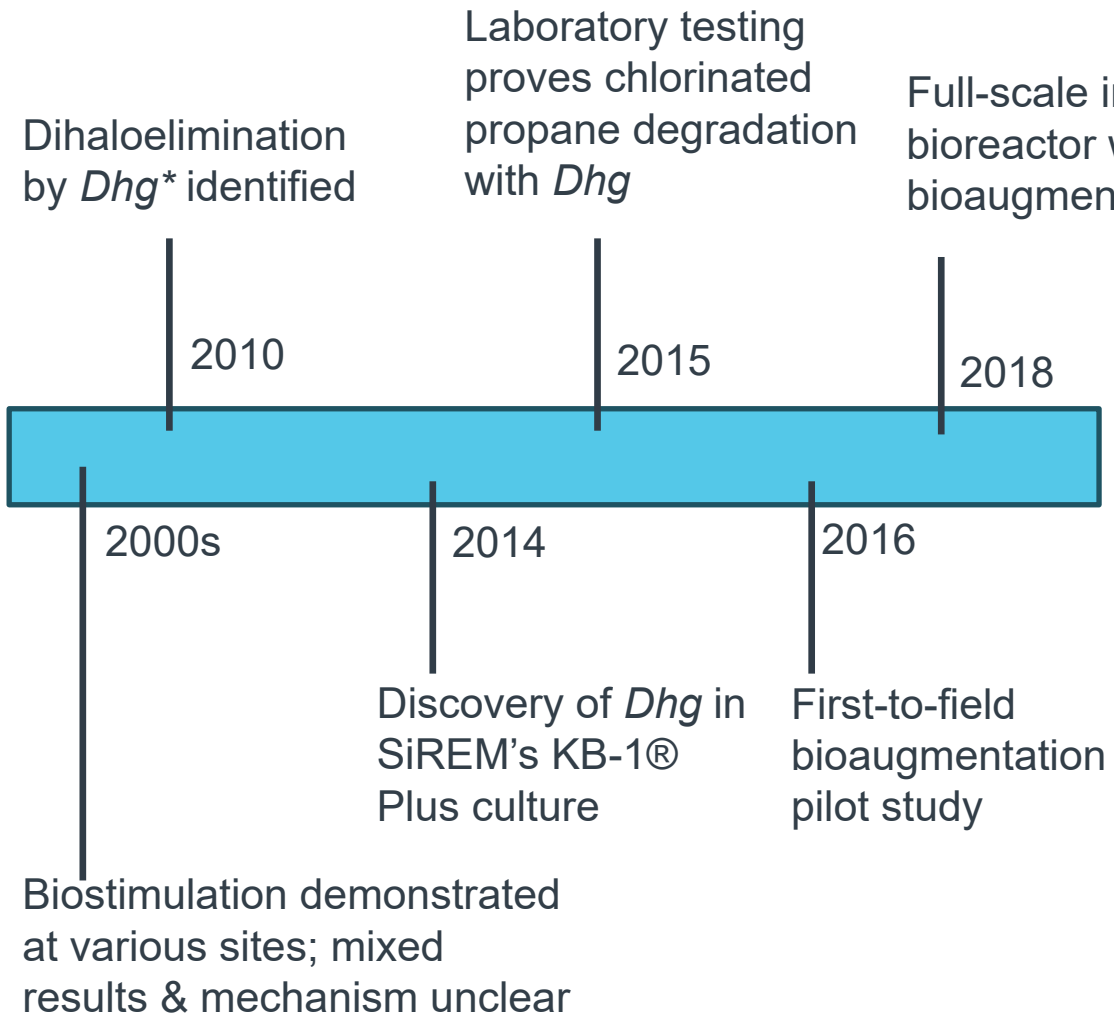
Groundwater ex situ treatment: feasible but potentially costly

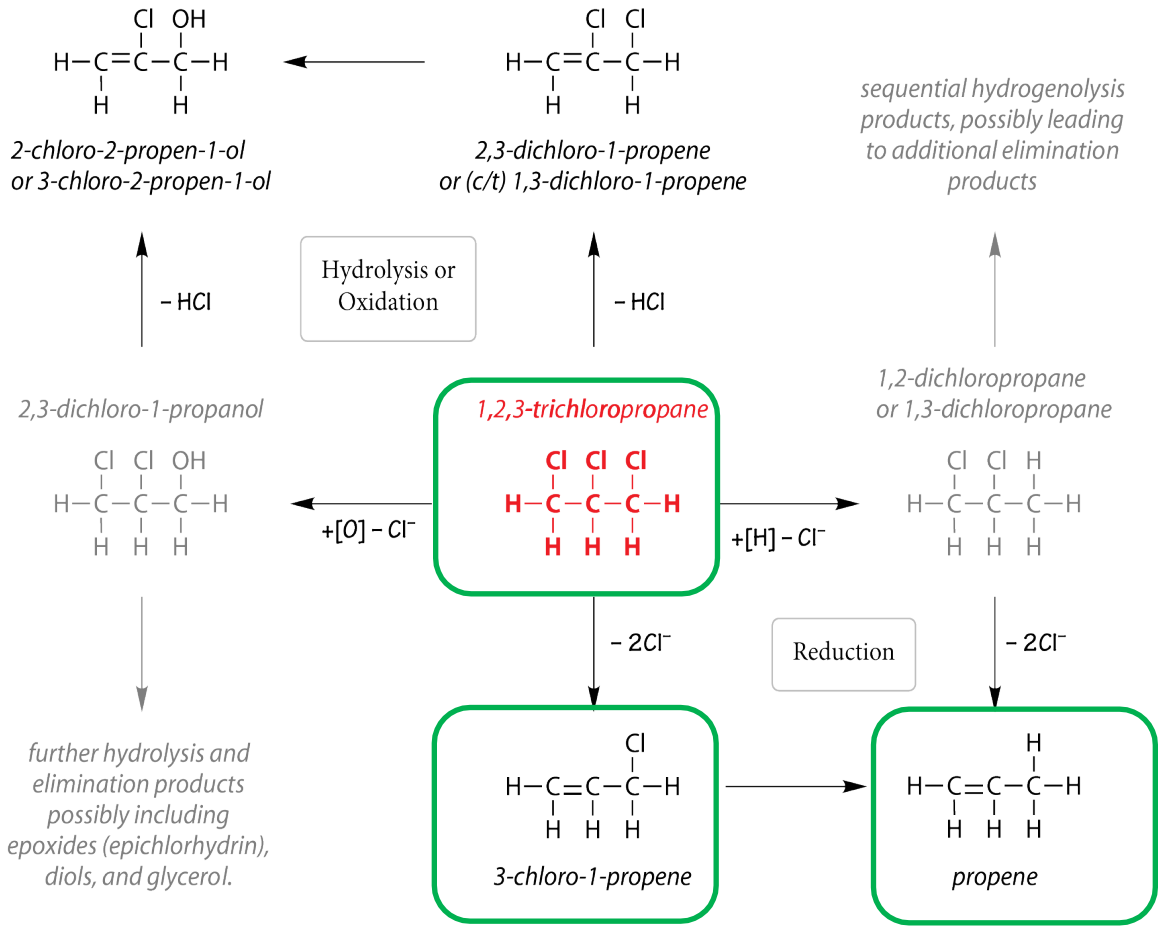
- GAC effective, but long residence time needs
- Advanced oxidation also effective

In situ remediation : effective but only tested at limited sites to date

- **Biological Reduction (ISBR) - full-scale**
- Chemical Reduction: Zero Valent Metals (ISCR) - full-scale
- Phytoremediation – full-scale
- Chemical Oxidation (ISCO) - lab scale

Evolution of Chlorinated Propane Bioremediation





**Dhg* – Dehalogenimonas sp.

Site Setup and Treatability Testing

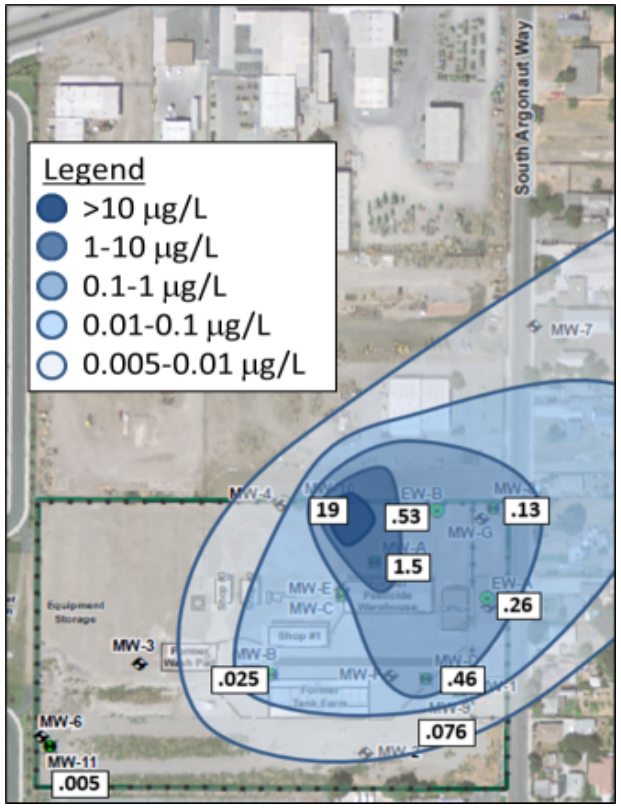
Former agricultural chemical retail facility

Constituent	Max Site Conc.	State Goal
1,2,3-TCP	72 µg/L	0.005 µg/L (MCL)
1,2-DCP	680 µg/L	5 µg/L (MCL)
Nitrate (as N)	1,800 mg/L	--
Sulfate	415 mg/L	--

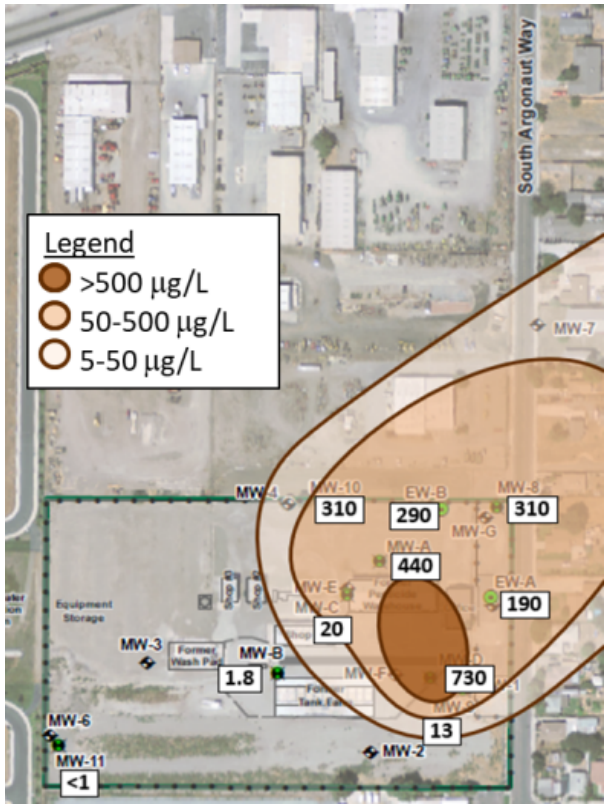
Treatability study elements

- Biostimulation with lactate and emulsified vegetable oil (EVO)
- Bioaugmentation with KB-1®Plus enriched with *Dhg*

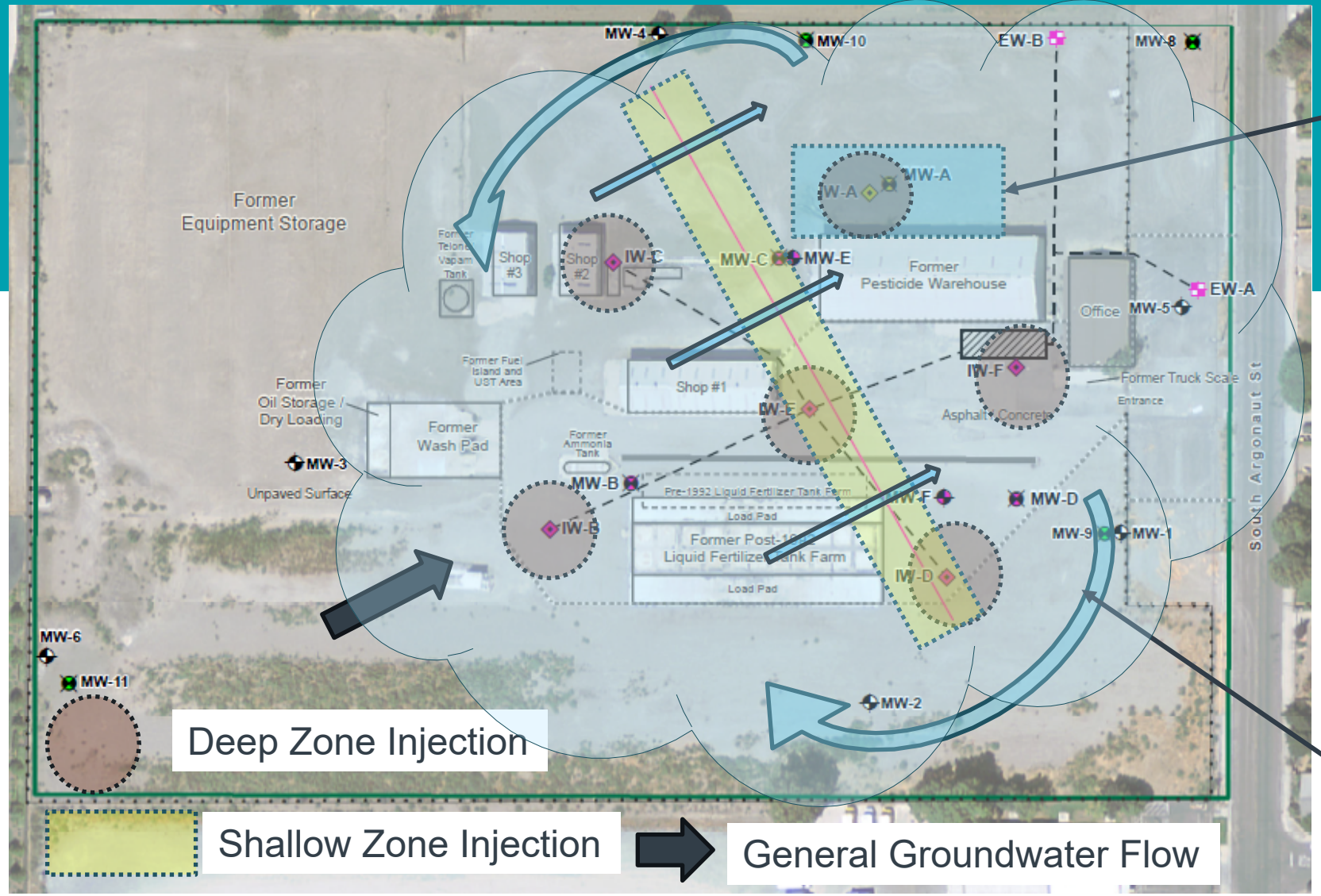
TCP Extent



DCP Extent



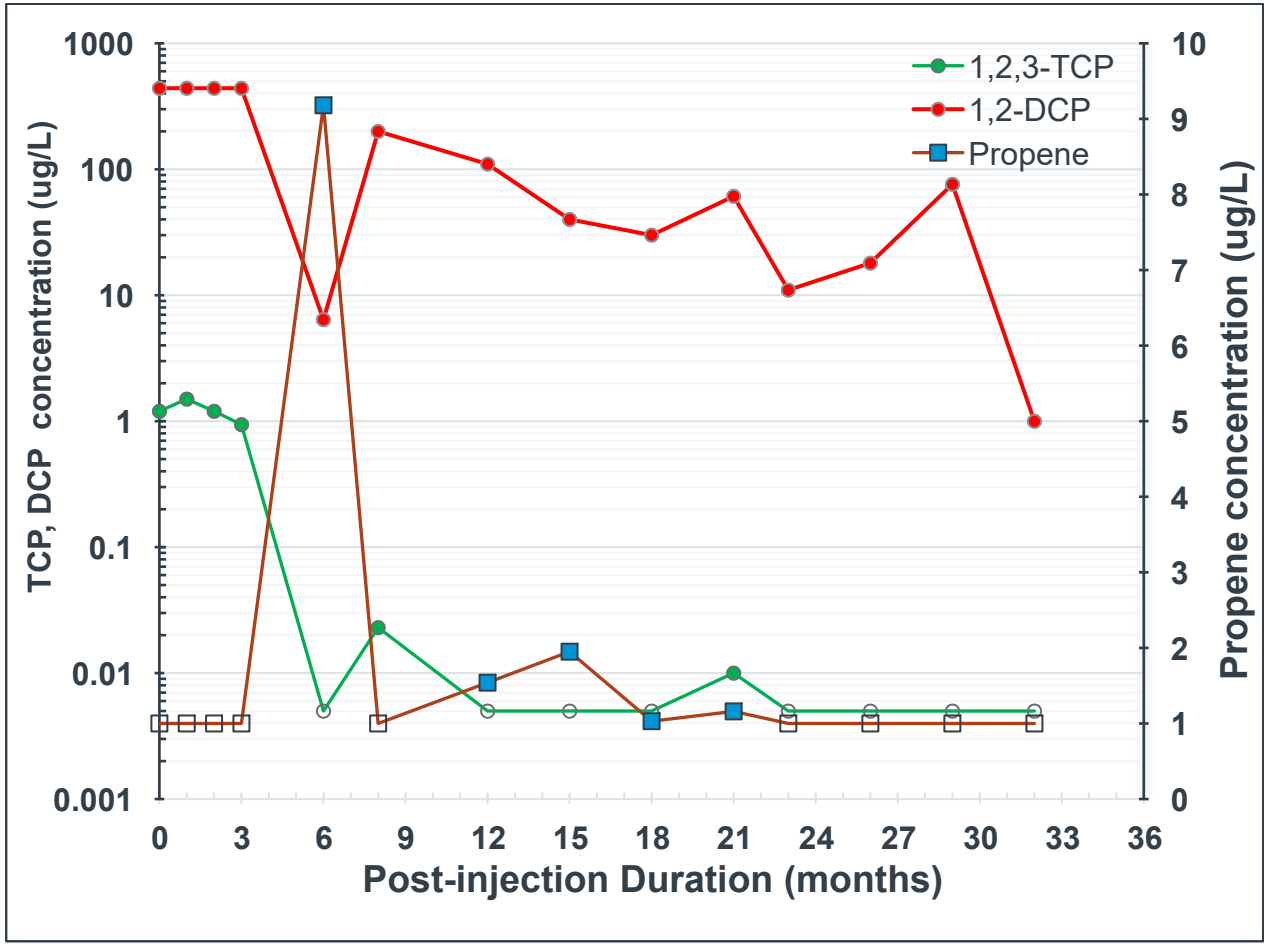
Remedial Setup

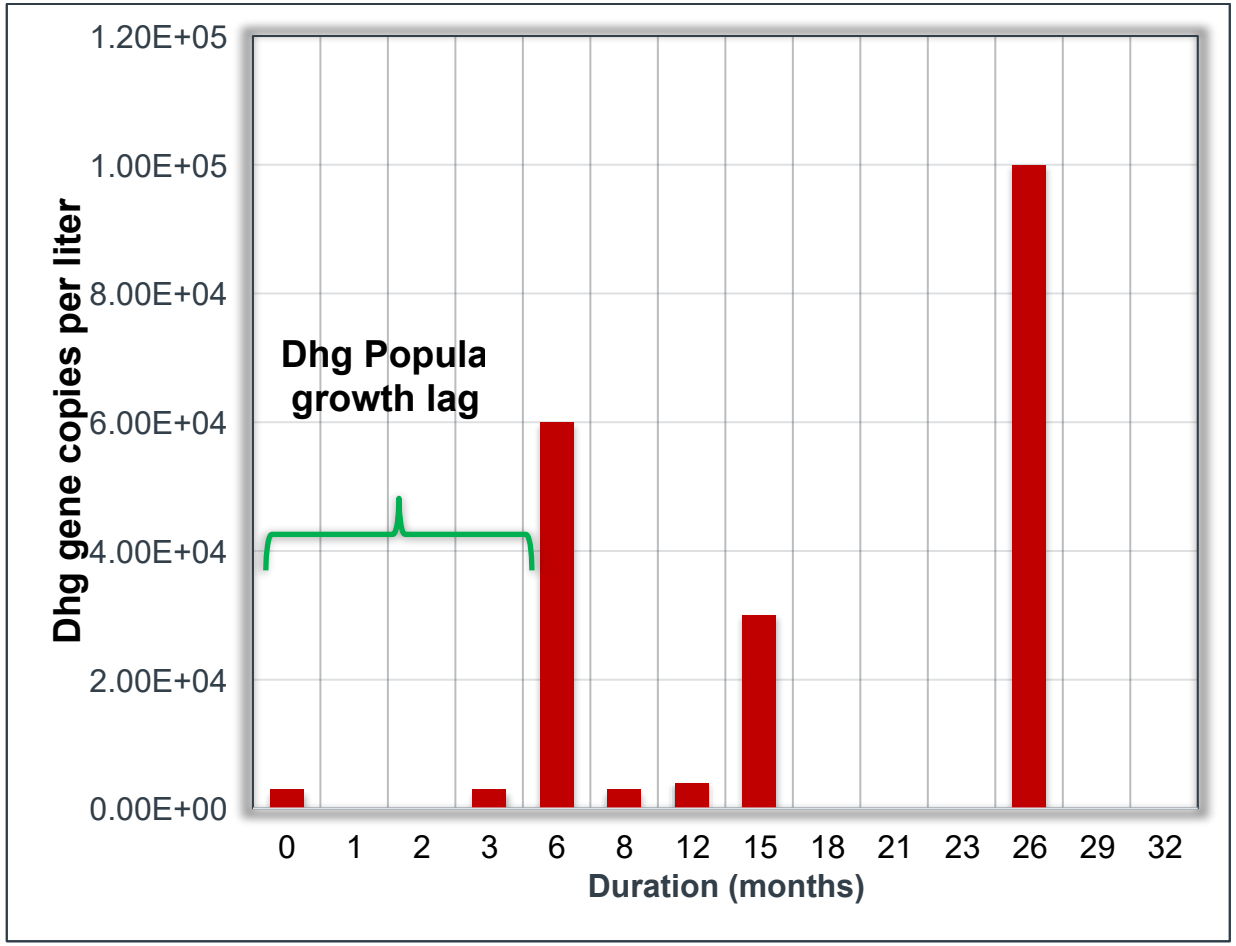


Pilot Test

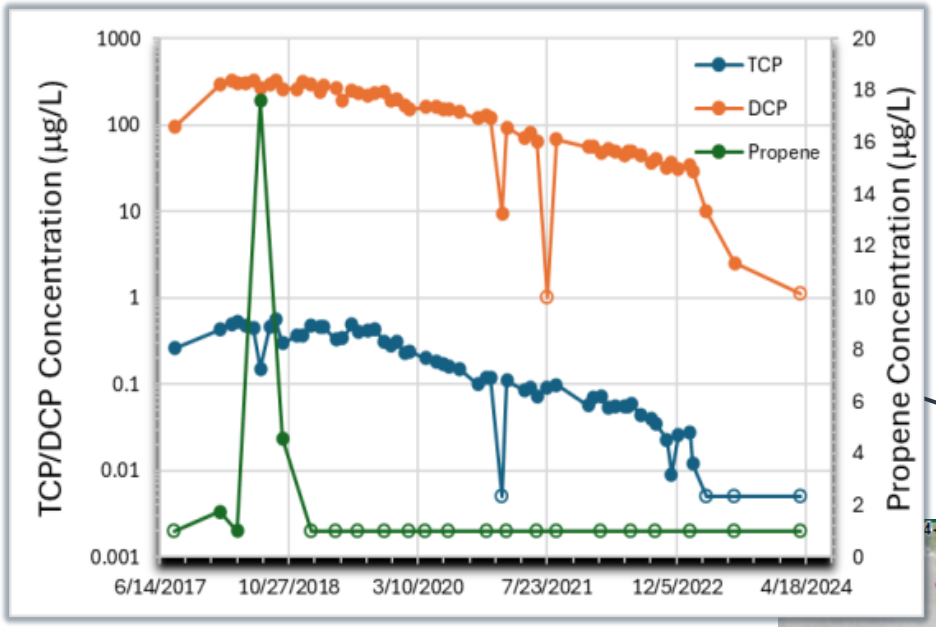
Full-Scale Dosing System

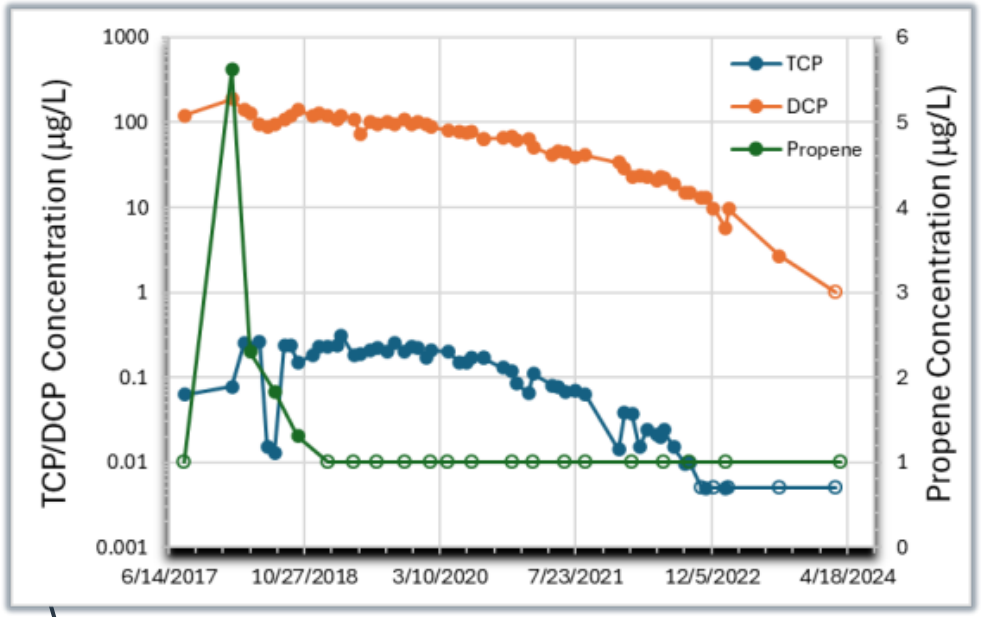
Pilot Performance

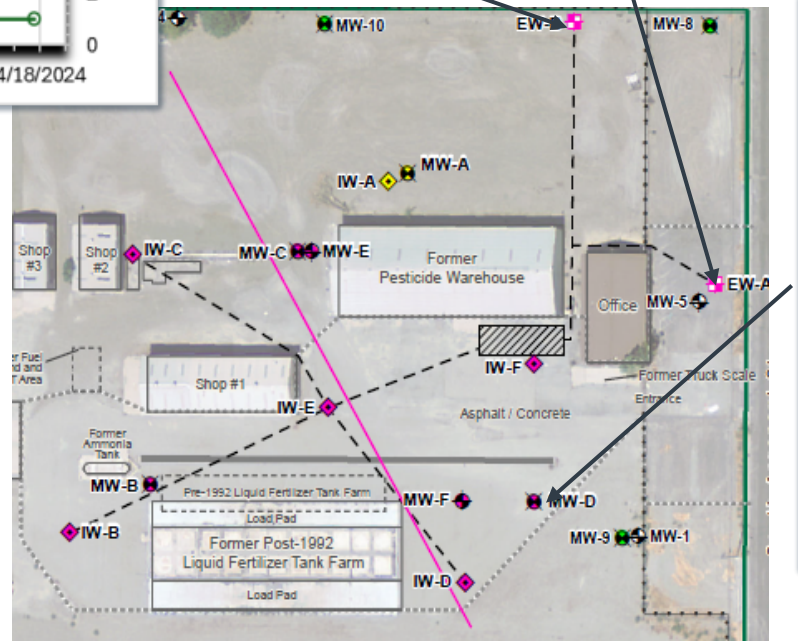


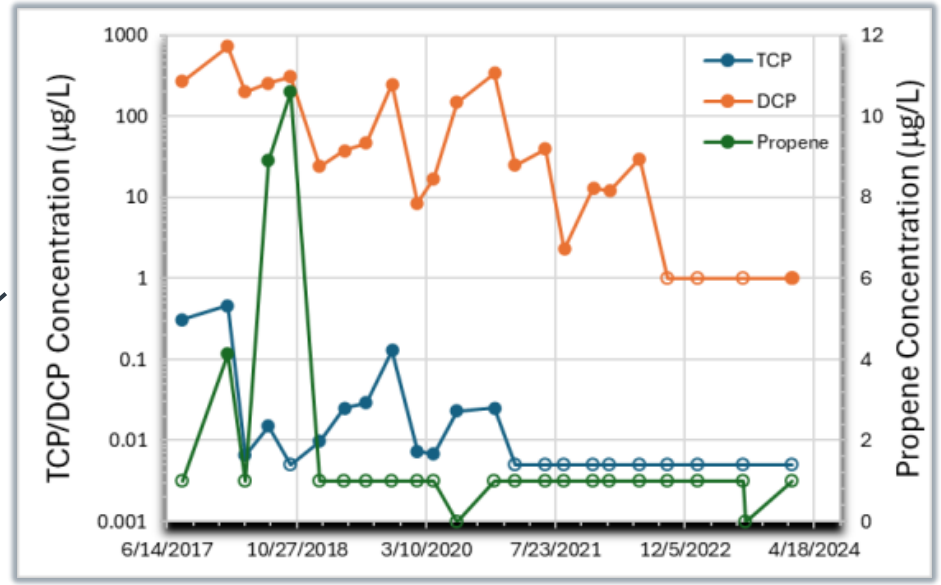


Full-Scale Performance Trends

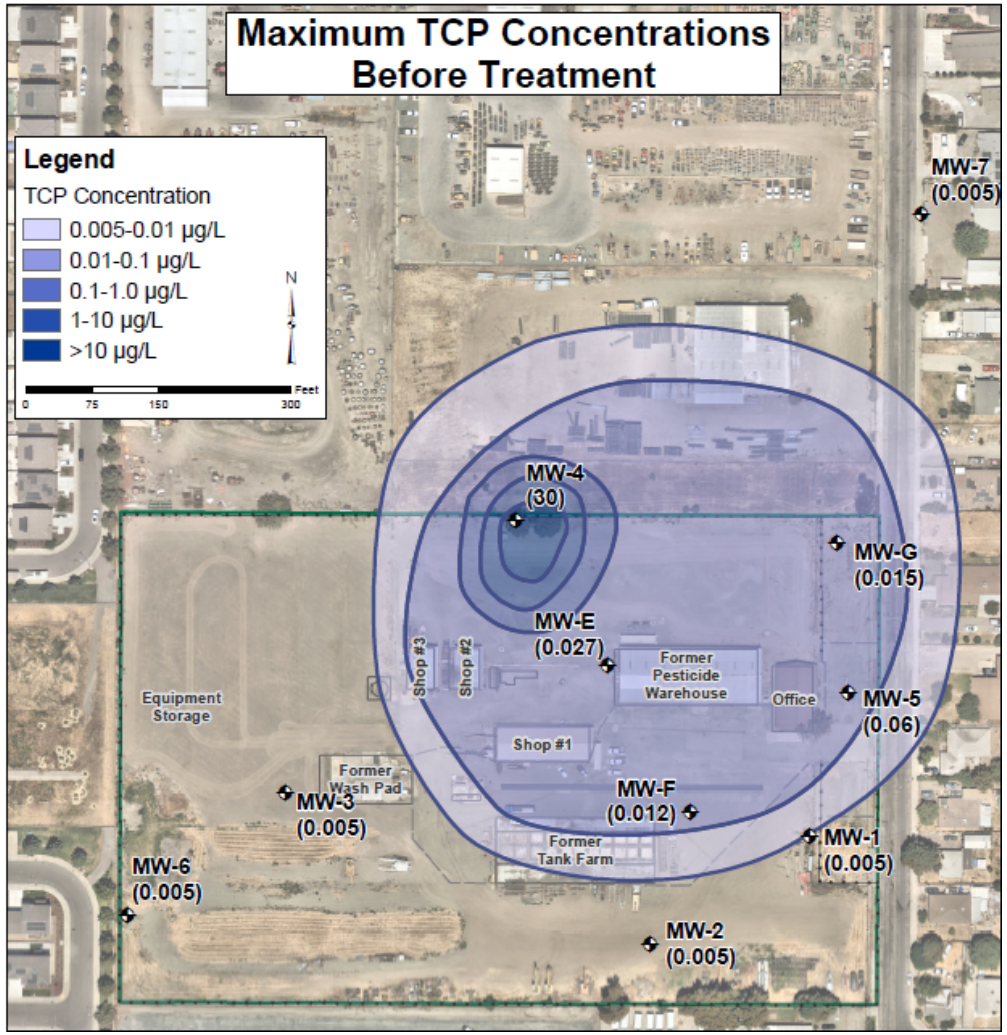


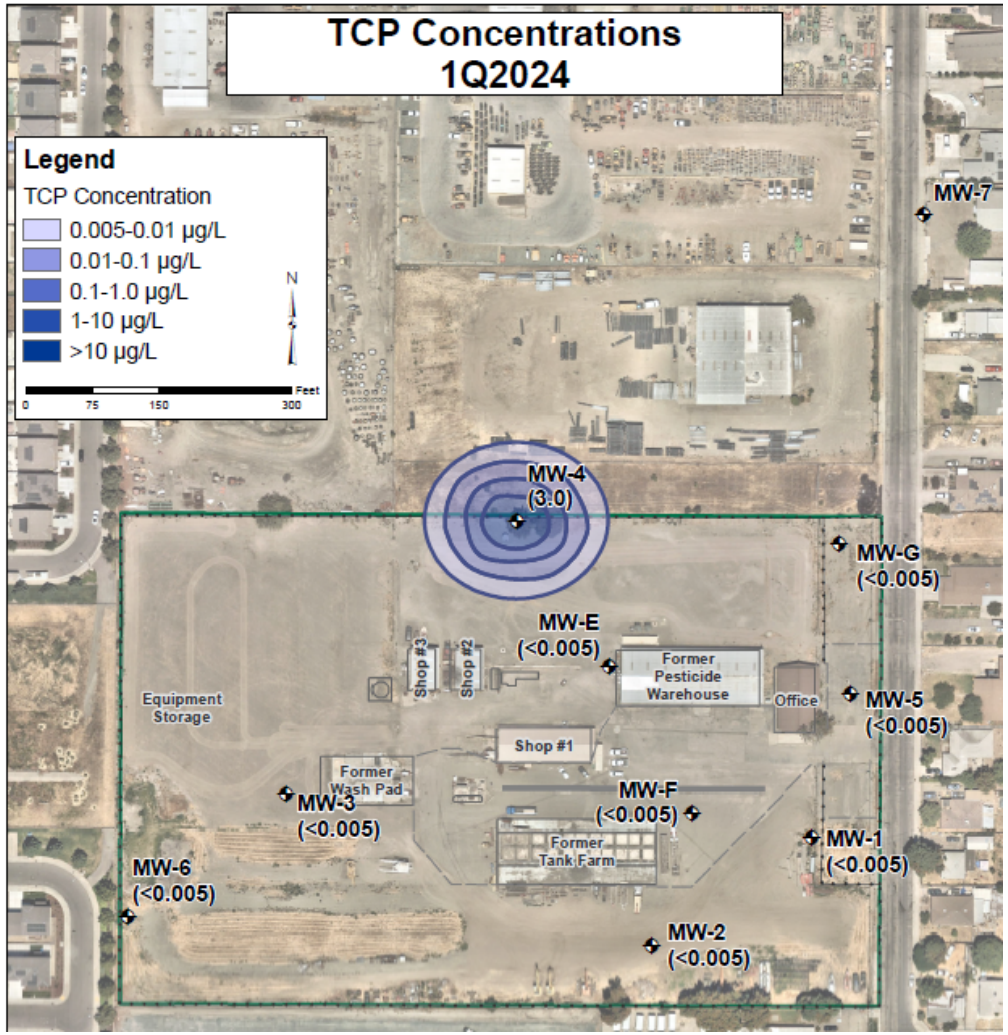




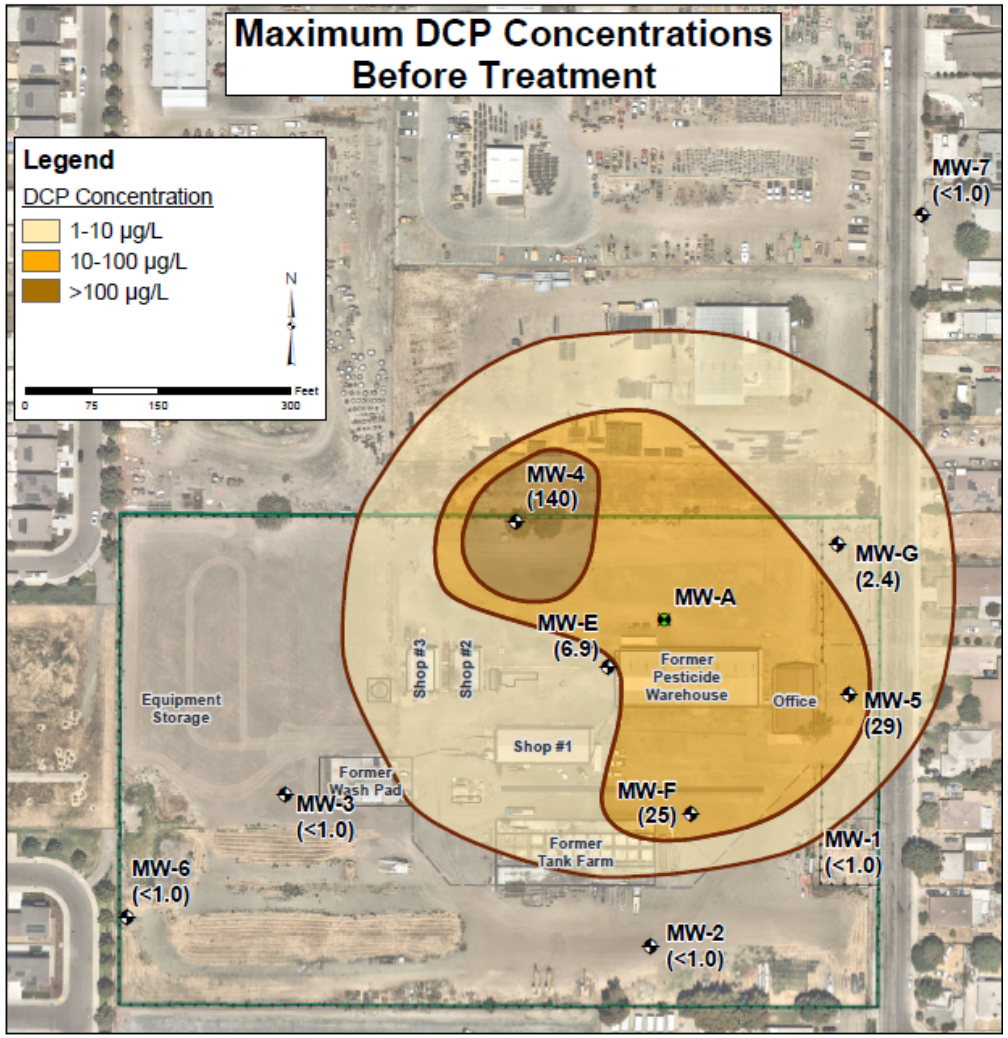


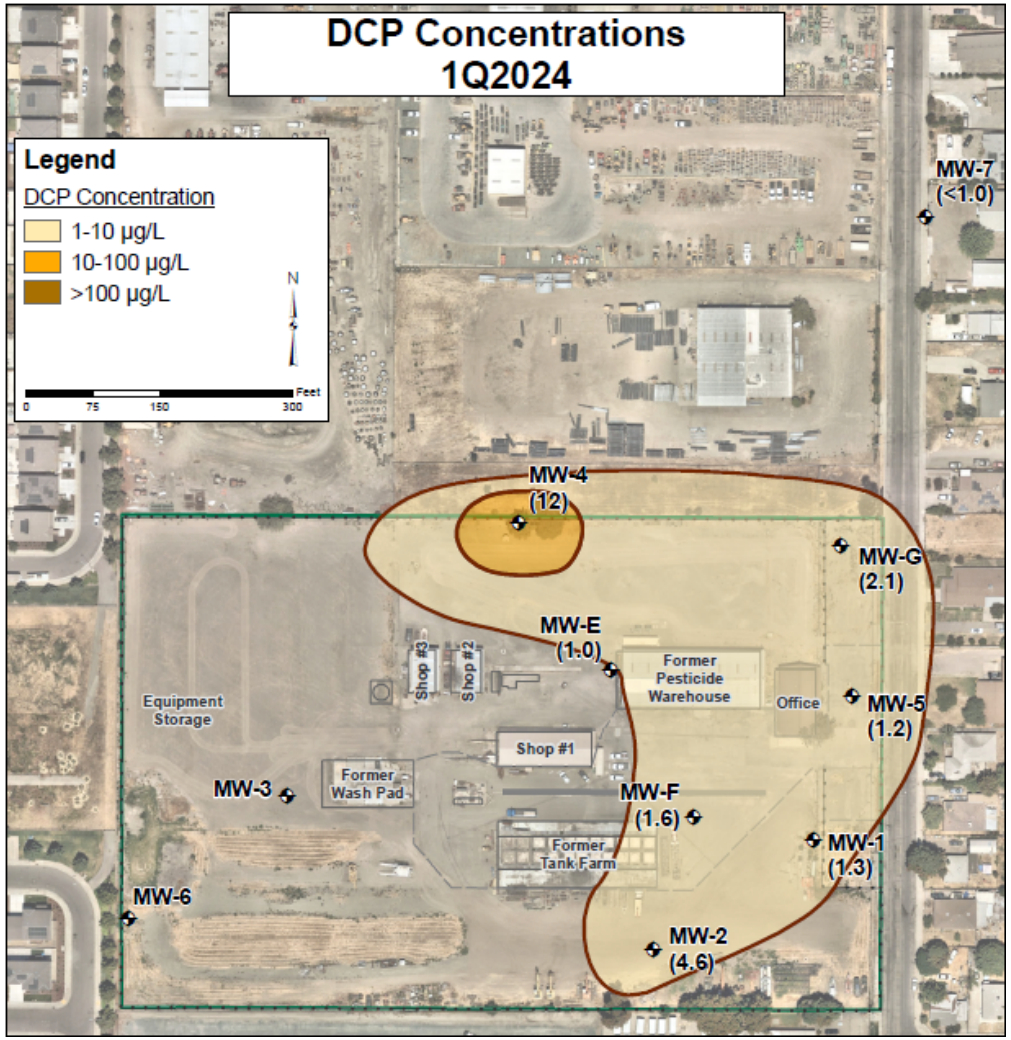
Shallow Zone Performance Summary - TCP



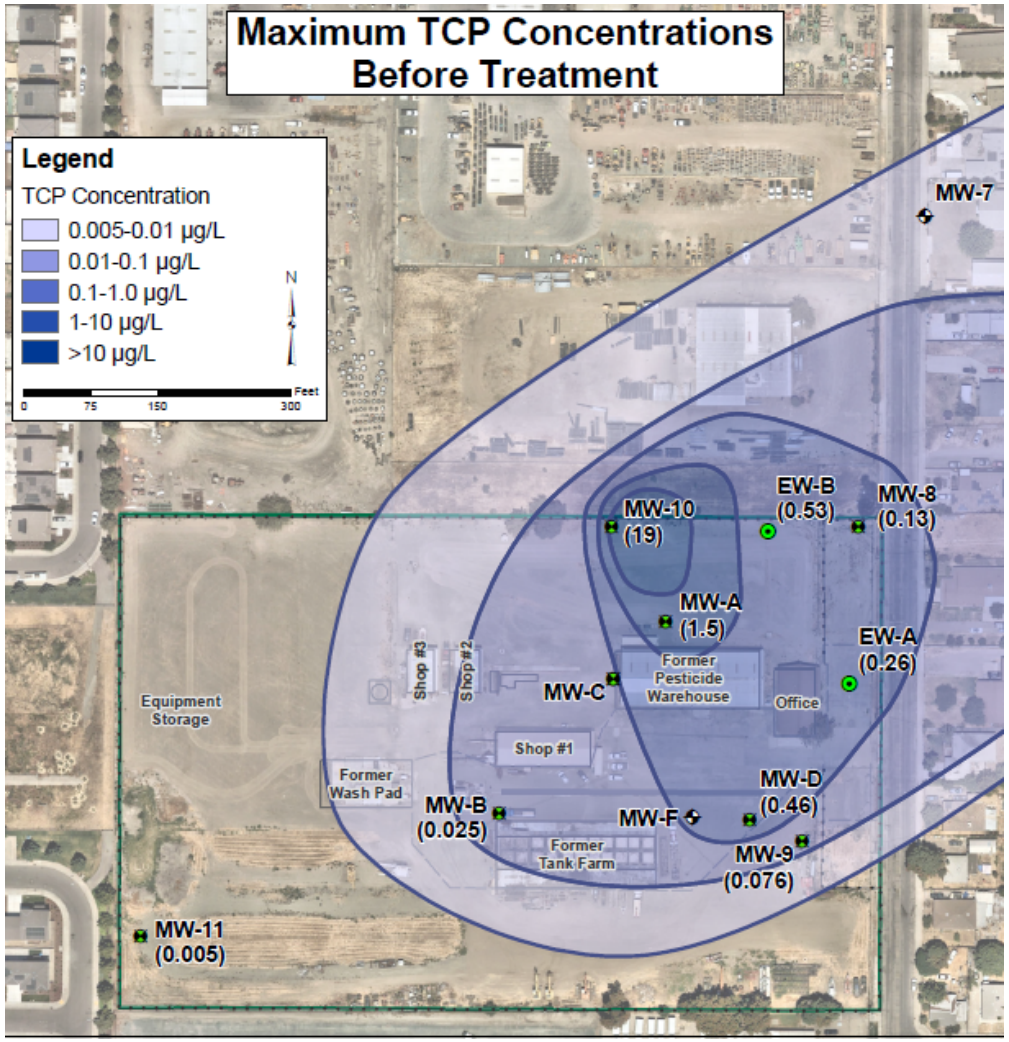


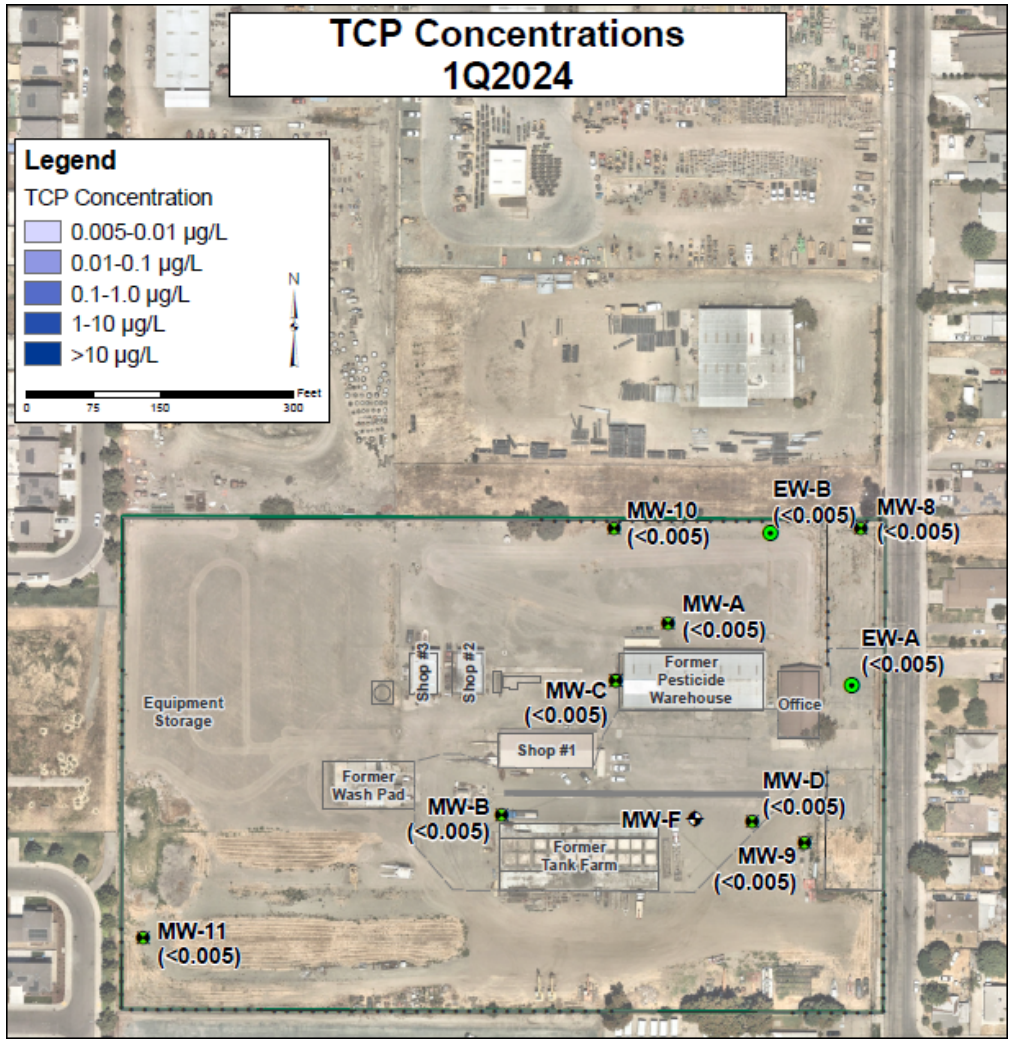
Shallow Zone Performance Summary - DCP



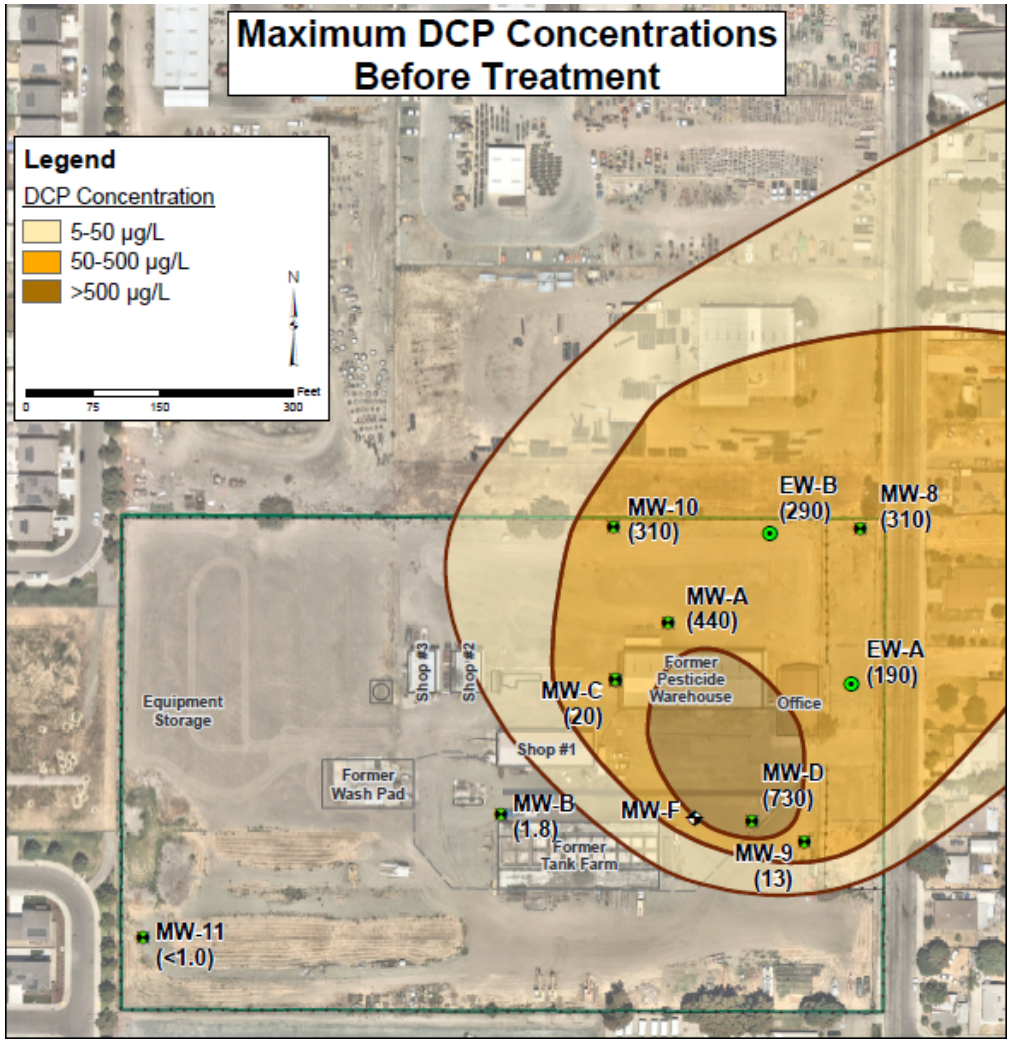


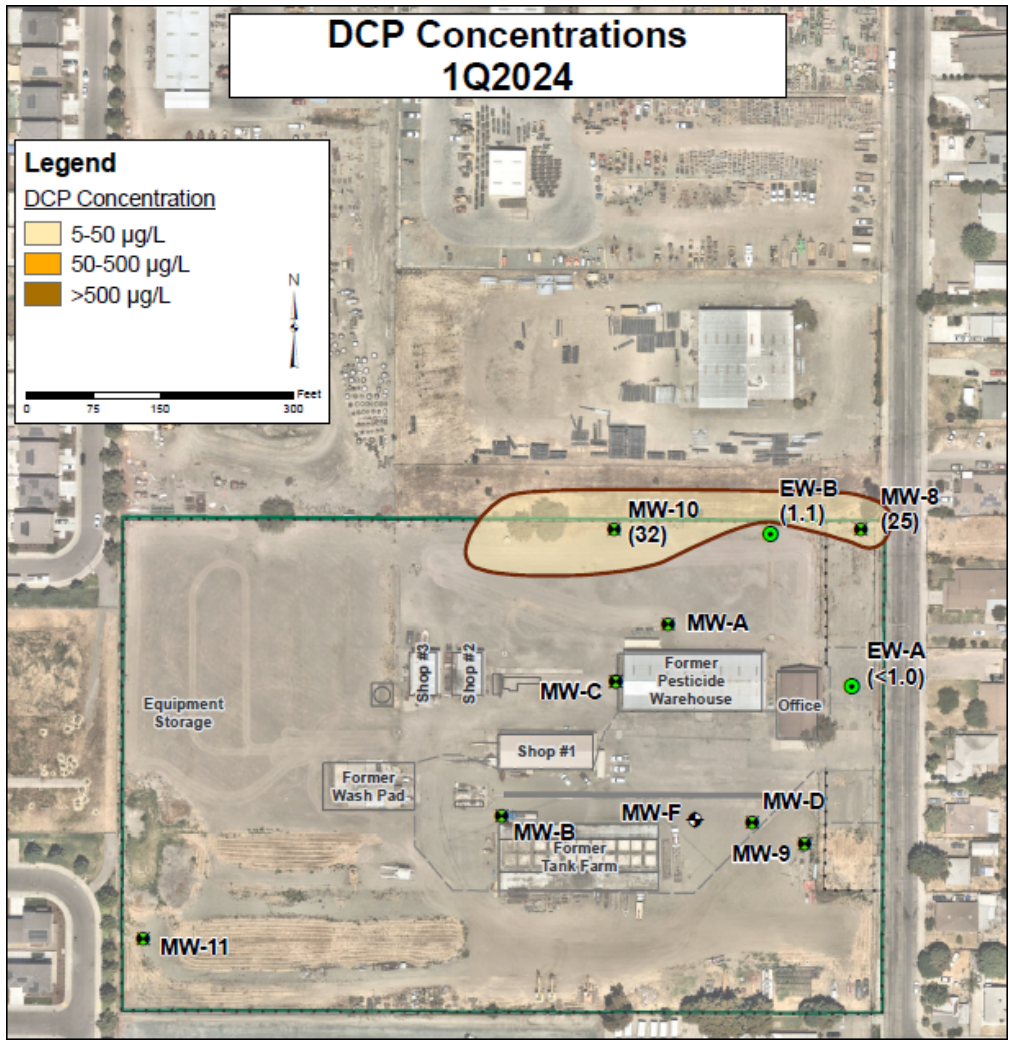
Deep Zone Performance Summary - TCP





Deep Zone Performance Summary - DCP





Key Takeaways

- In-situ bioreactor is a viable chlorinated propane treatment approach
  - *Dhg* bioaugmentation is effective at enhancing degradation
  - Adequate acclimation allows degradation to ppt levels
  - No above ground pre-treatment required
    - Significant reduction in waste generation and footprint

- O&M considerations
  - Adequate hydrogeological characterization and confidence on flow paths and hydraulic containment
  - Robust monitoring to assess dosing needs
  - Dosing optimization needed to manage injection well (bioreactor) fouling
    - Pulsed low dose carbon substrate
    - Steam/hot water injection well redevelopment

Team and Acknowledgements

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