

From Bench Test to Full-Scale Remedy – Combining ZVI with Bioremediation to Treat Mixed VOCs in a Low-Permeability Formation



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Controlled Hydraulic Fracturing Methods



- Traditional DPT
- DPT Jet Injection
- Cased-Hole Jet Fracturing



Controlled Hydraulic Fracturing Methods



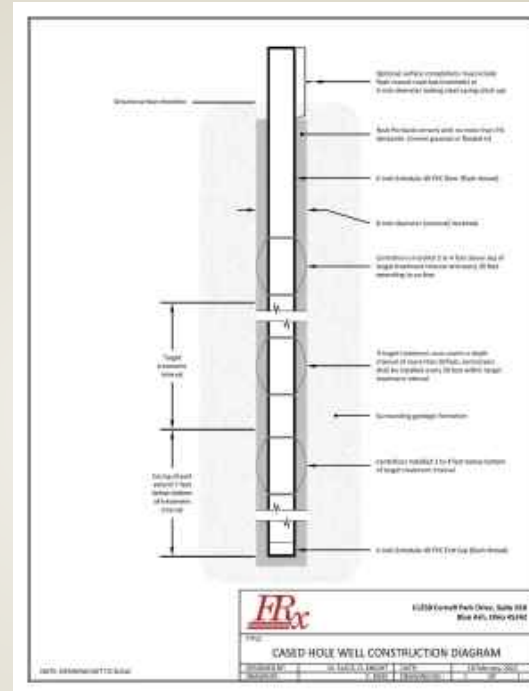
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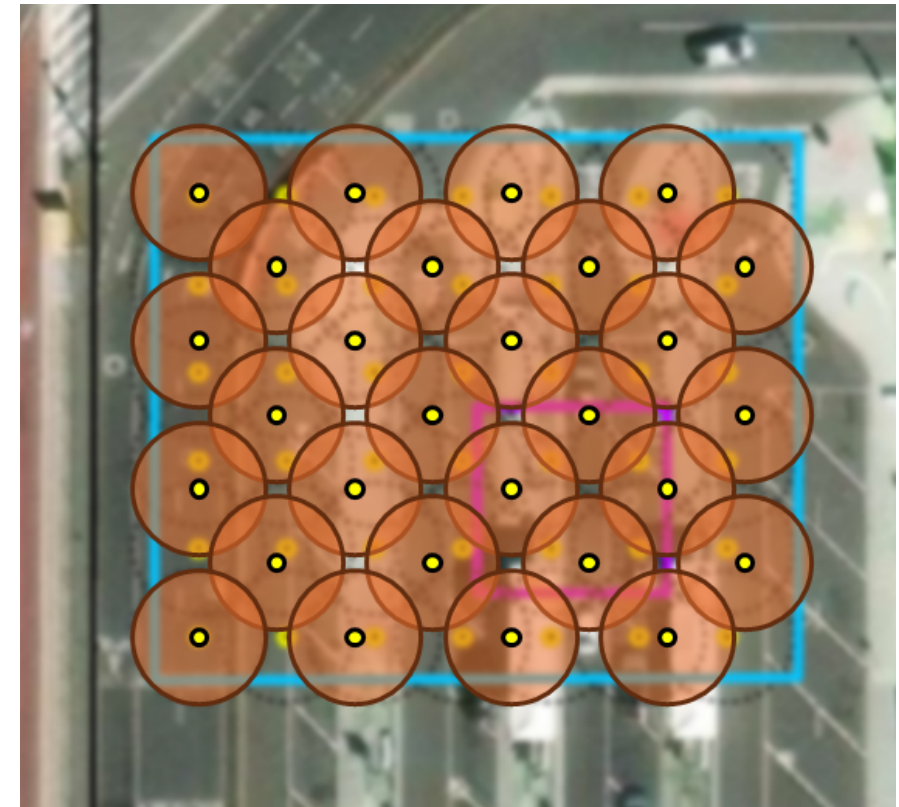
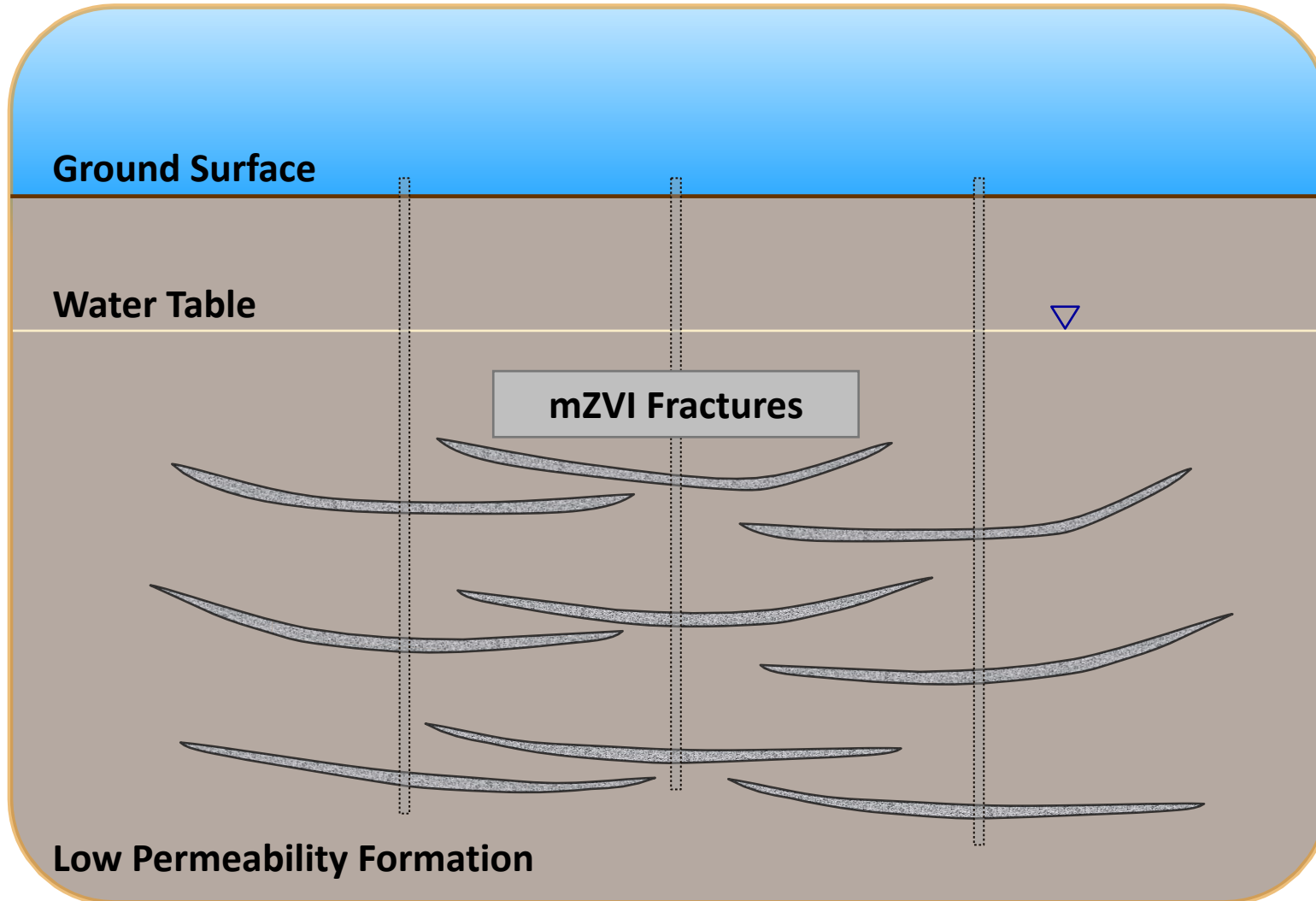


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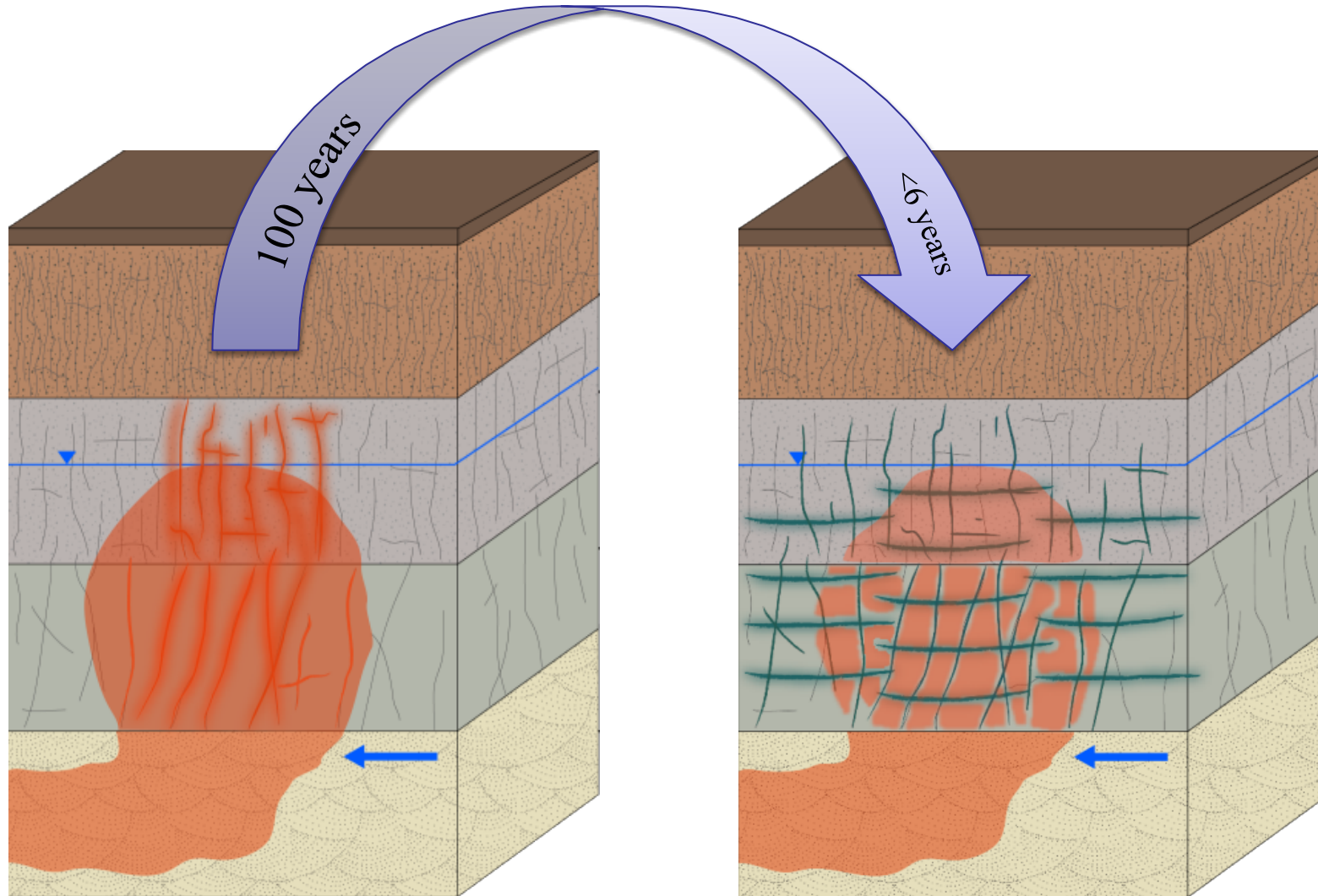




Technology Overview – Controlled Hydraulic Fracturing



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Acknowledgements



- Dan Elliot, Warren Brady, David Toler, Dimin Fan



Case Study – Mixed VOC Site in Louisiana



Historical Operations and Contaminants of Concern



Site Background

- Active chemical facility on Mississippi Alluvial Plain
- Release associated with historical production of chlorine and caustic soda
- Site geology - silts, sandy silts, and clayey silts ($K = 6-7 \times 10^{-4}$ cm/sec)
- Target treatment zone is tight clayey silt formation from 45 to 60 ft bgs

Contaminants of Concern

- Carbon tetrachloride (CT), chloroform (CF), tetrachloroethene (PCE), trichloroethene (TCE), and 1,1,1,2-tetrachloroethane (PCA)



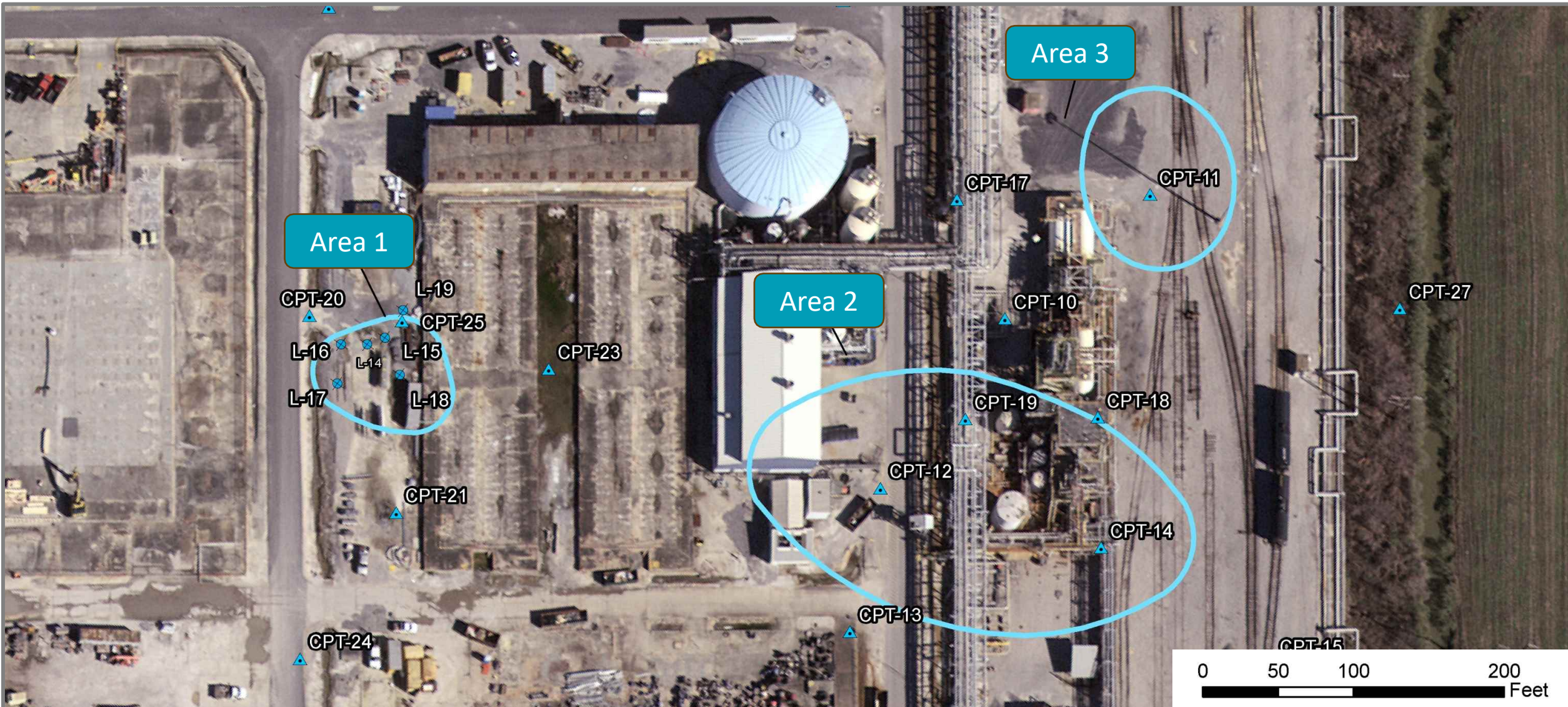
Timeline and Remedial Approach



- Long History of Site Investigation Activities (prior to 2014)



Areas Requiring Treatment



Timeline and Remedial Approach



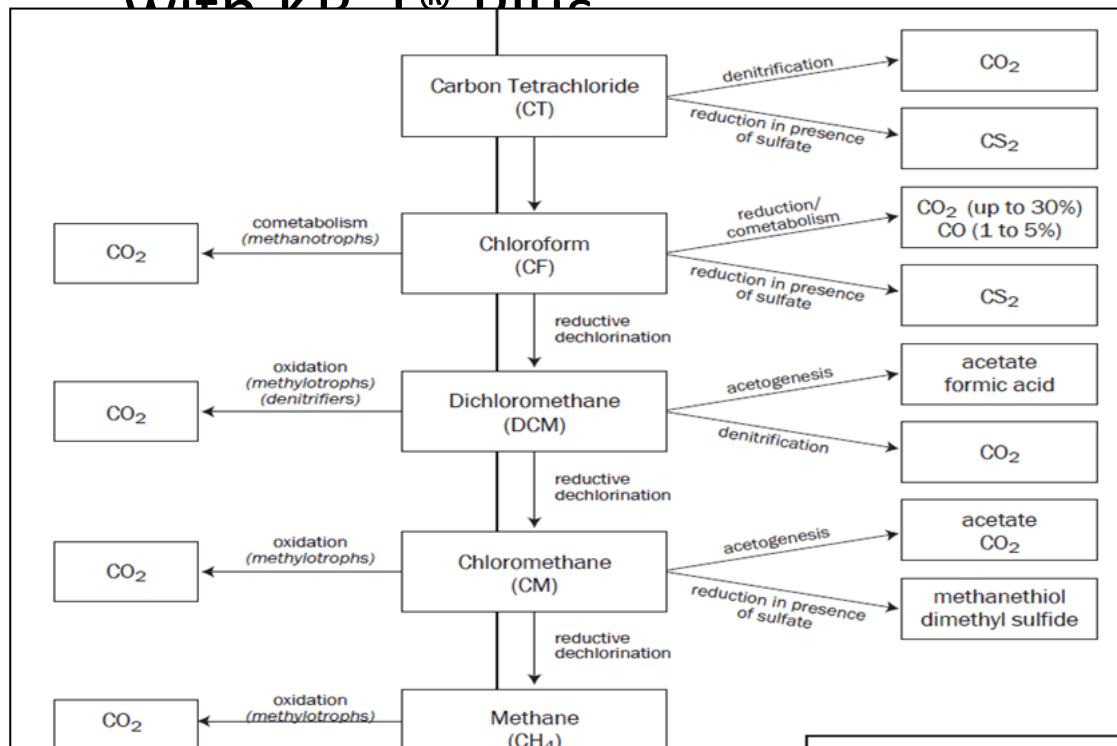
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- Treatability Testing 2014 - 2015
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 - Enhanced anaerobic bioremediation with emulsified vegetable oil + microbial culture



Bench Test Findings



- Mixed VOCs that degrade under different mechanisms.
- Testing evaluated a range of mZVI materials with and without electron donors and included bioaugmentation with *KD 1® Plus*



mZVI,
as mo



Timeline and Remedial Approach



- Long History of Site Investigation Activities (prior to 2014)
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- Pilot Test Design and Implementation 2017 - 2019



Pilot Test Design and Implementation

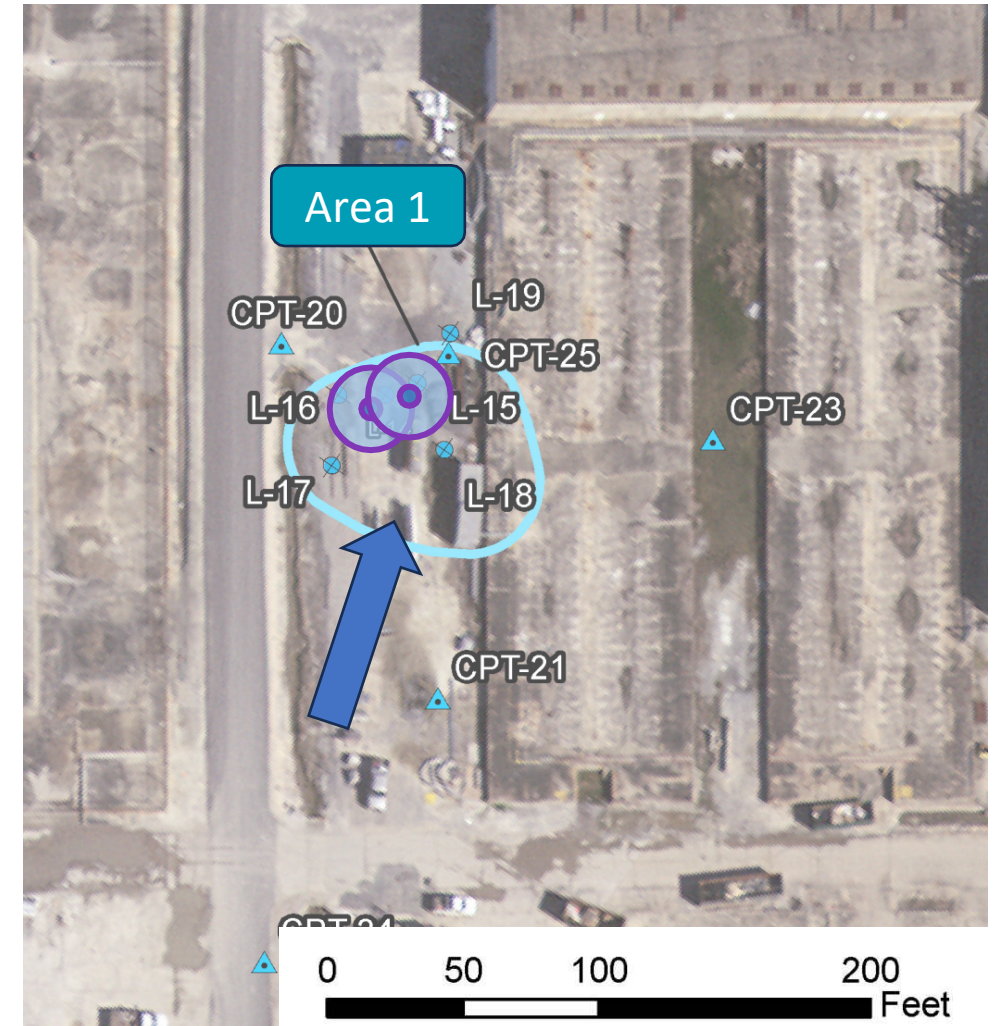


mZVI Injections – Cased-Hole Jet Fracturing

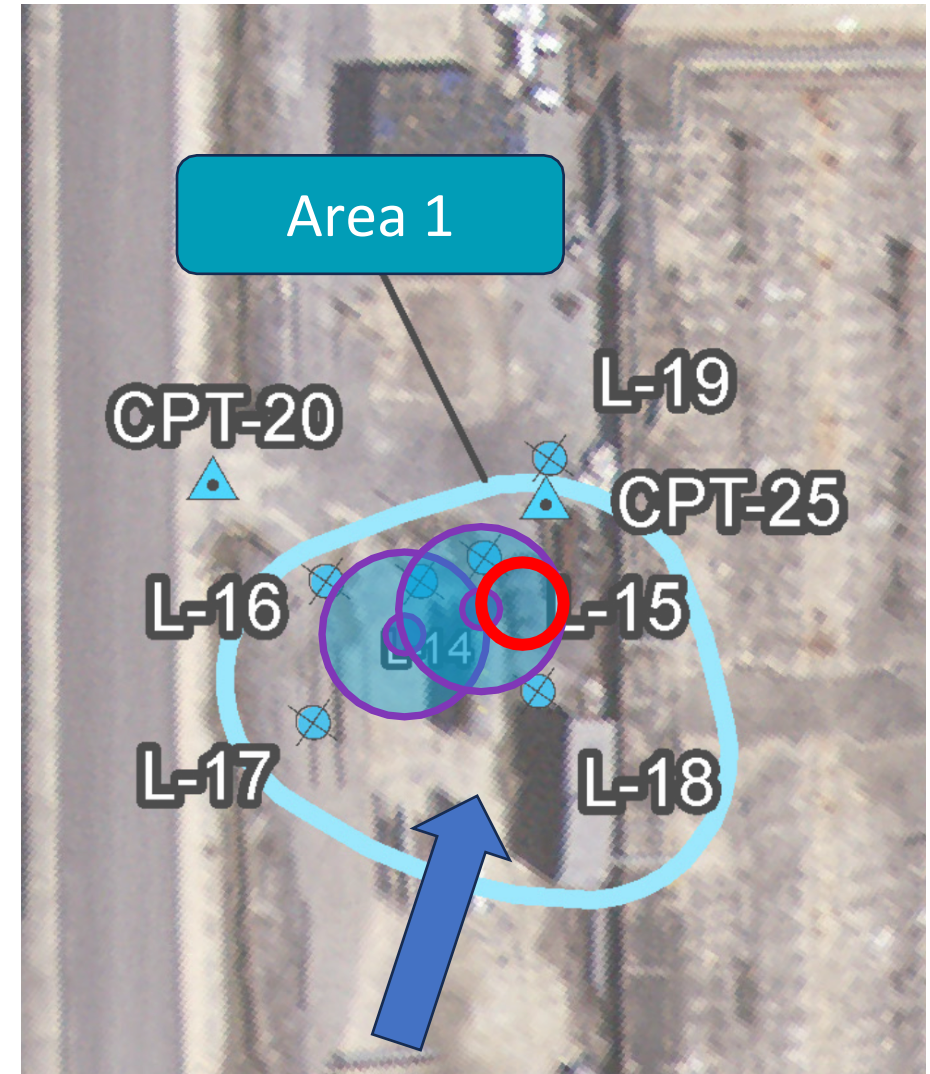
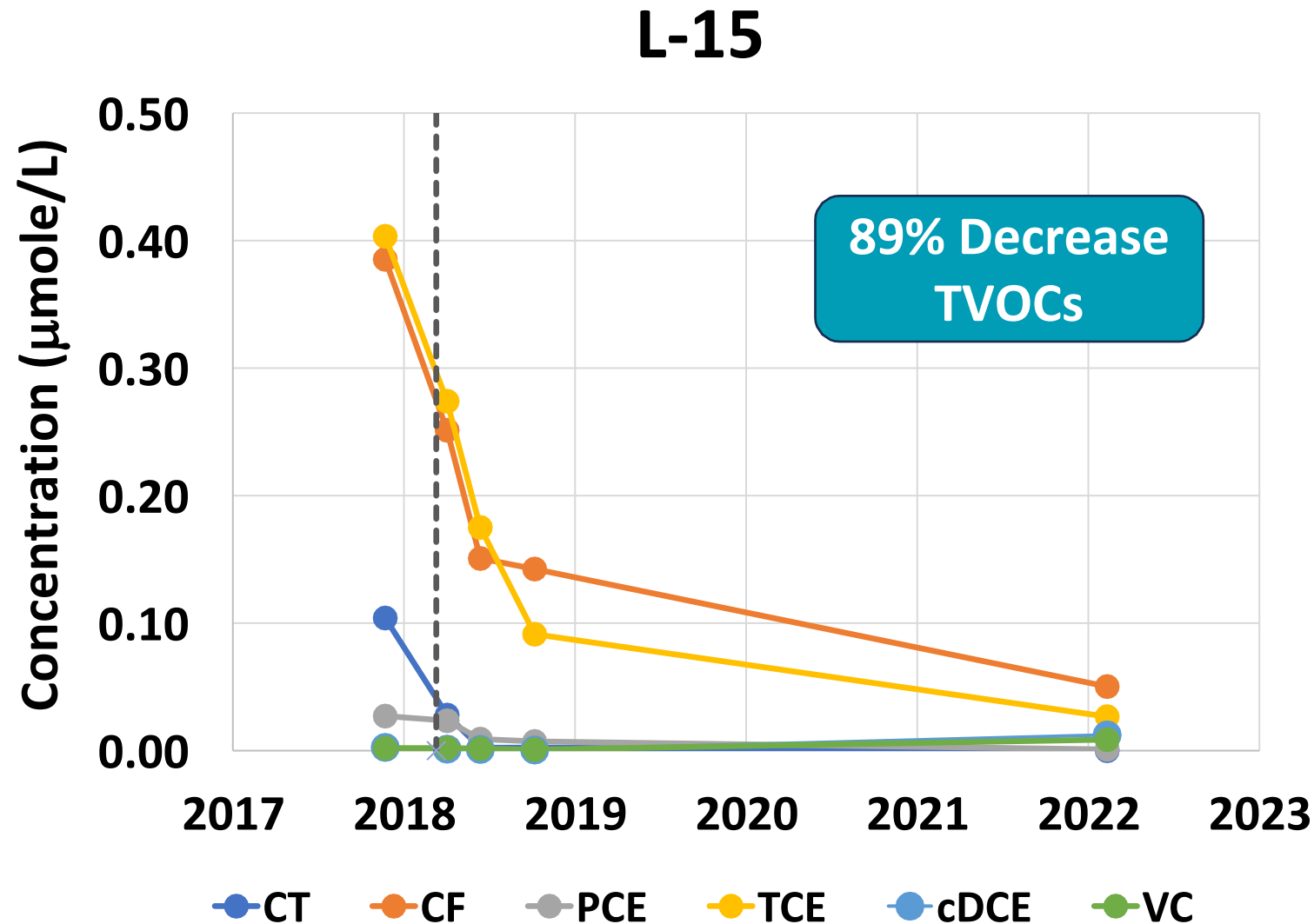
- 1,200 sq ft area; 45-55 ft bgs
- Sonic drilling for well installations
- 2 locations and 6 total mZVI fractures
- 11,880 lbs ZVI, 1,800 lbs sand
- ZVI dosing ~1.0% by dry weight soil

Bioremediation Amendment Injections

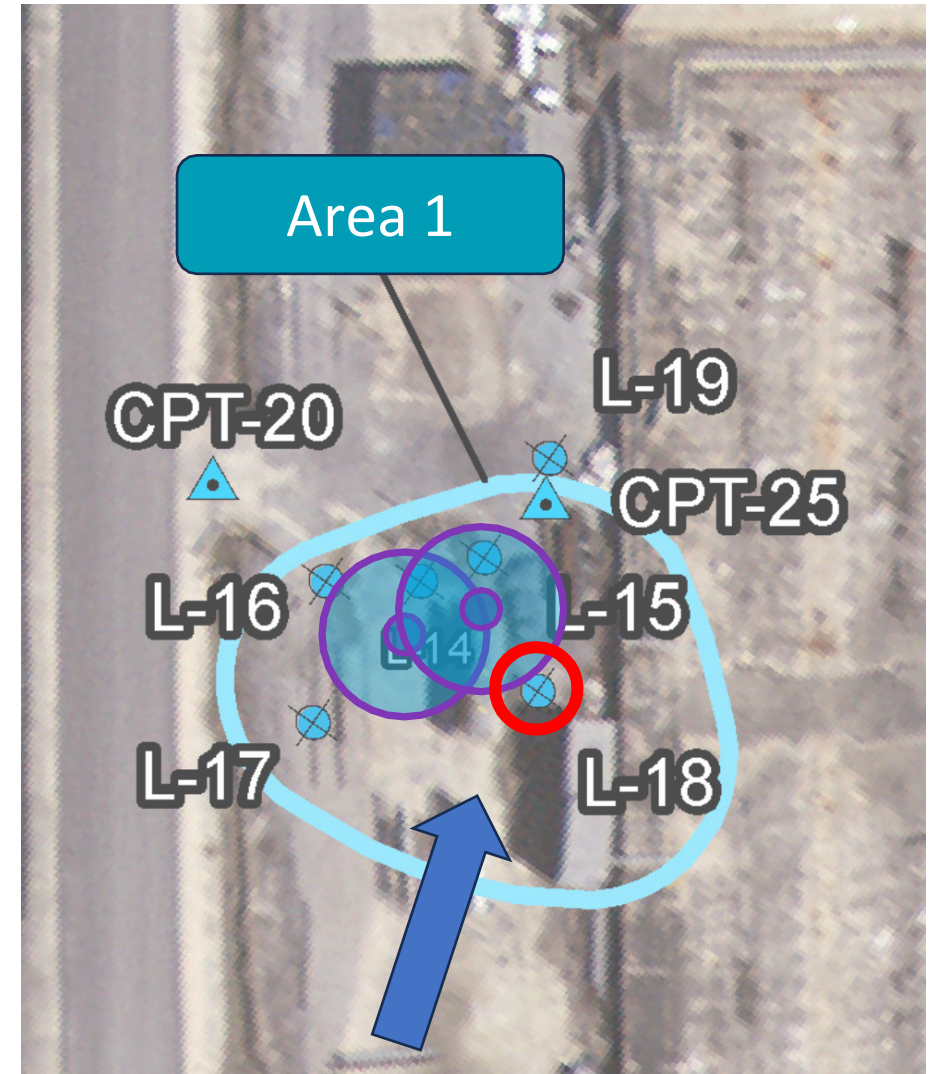
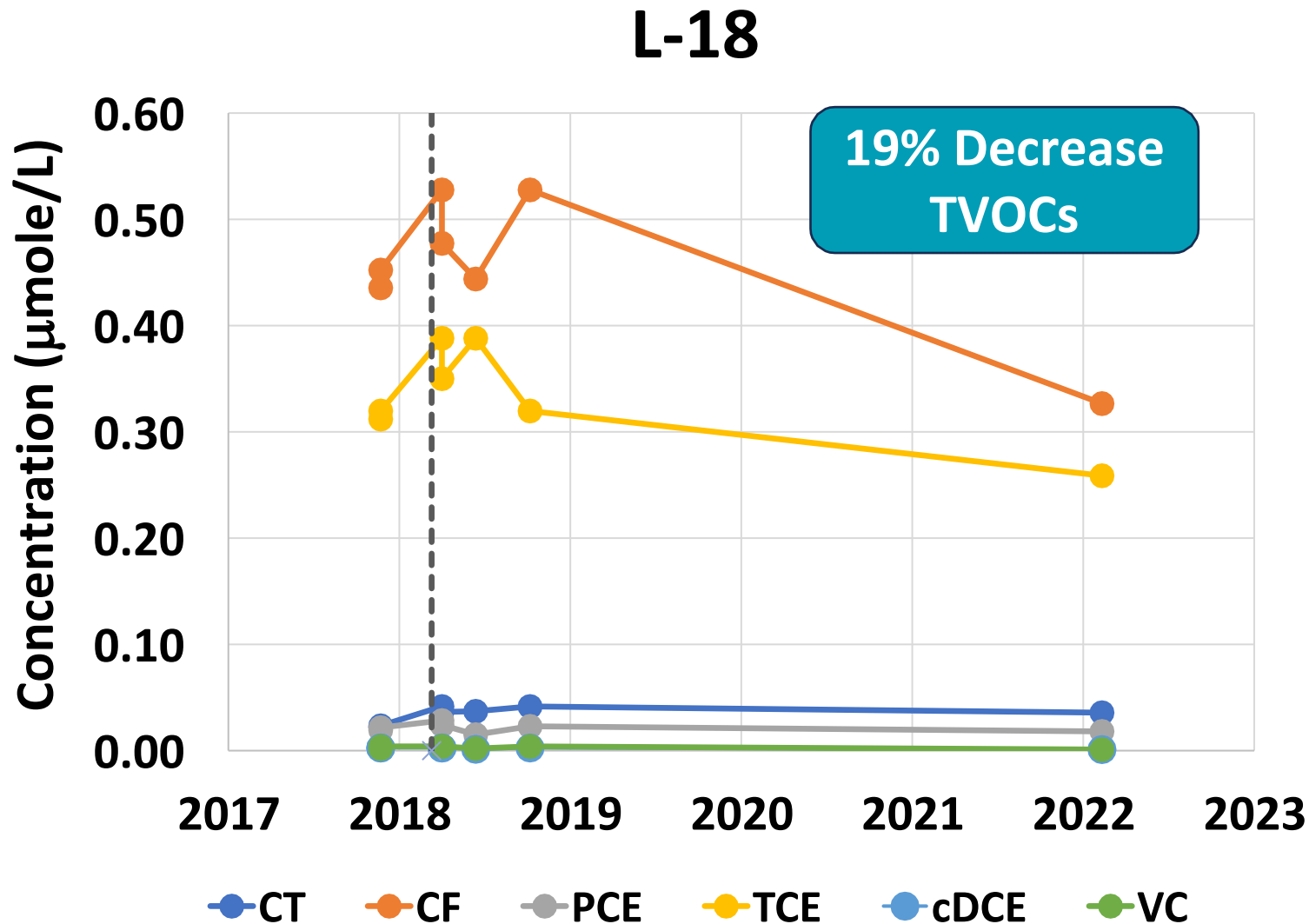
- 2 cased-hole fracture-connected wells
- 500 gal of 20% EVO solution pumped
- 6 L KB-1[®] Plus



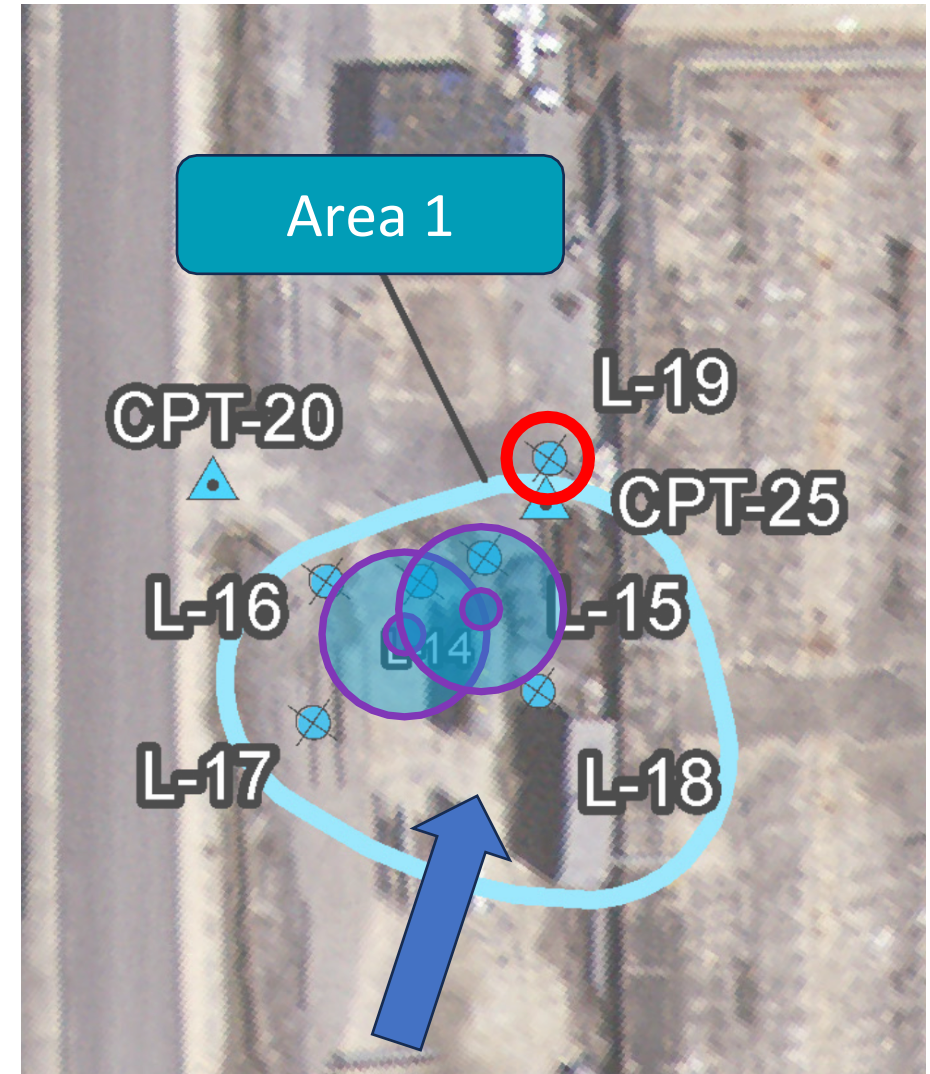
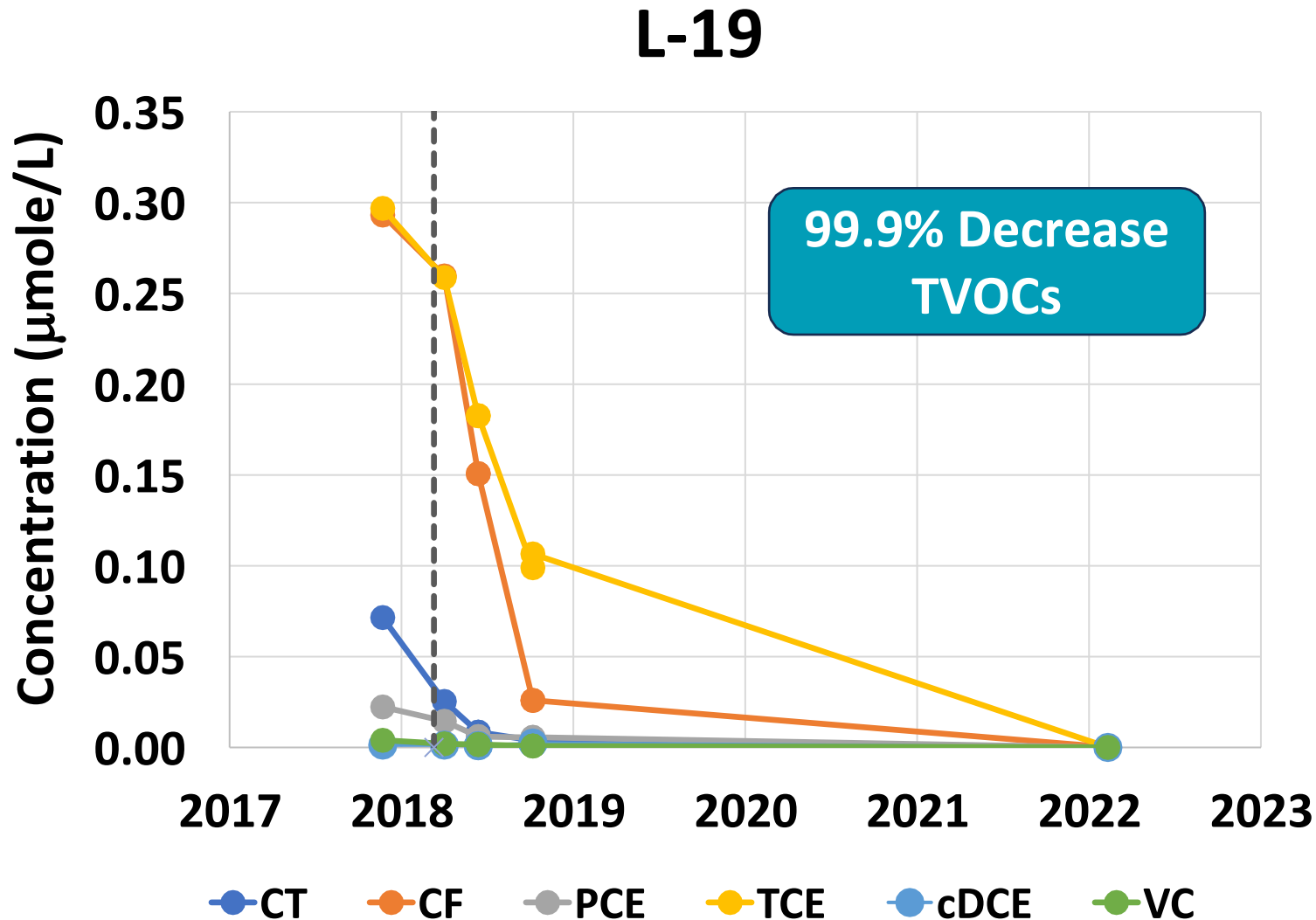
Pilot Test Performance Monitoring – L-15



Pilot Test Performance Monitoring – L-18



Pilot Test Performance Monitoring – L-19



Pilot Test – Conclusions



- Successful pilot injection program completed on budget and on schedule.
- 15-foot ROI confirmed.
- Treatment effective for full range of COCs.
- Complete degradation to methane, ethane, and ethene was observed.
- Combined mZVI/Bio treatment approach carried forward to full-scale.



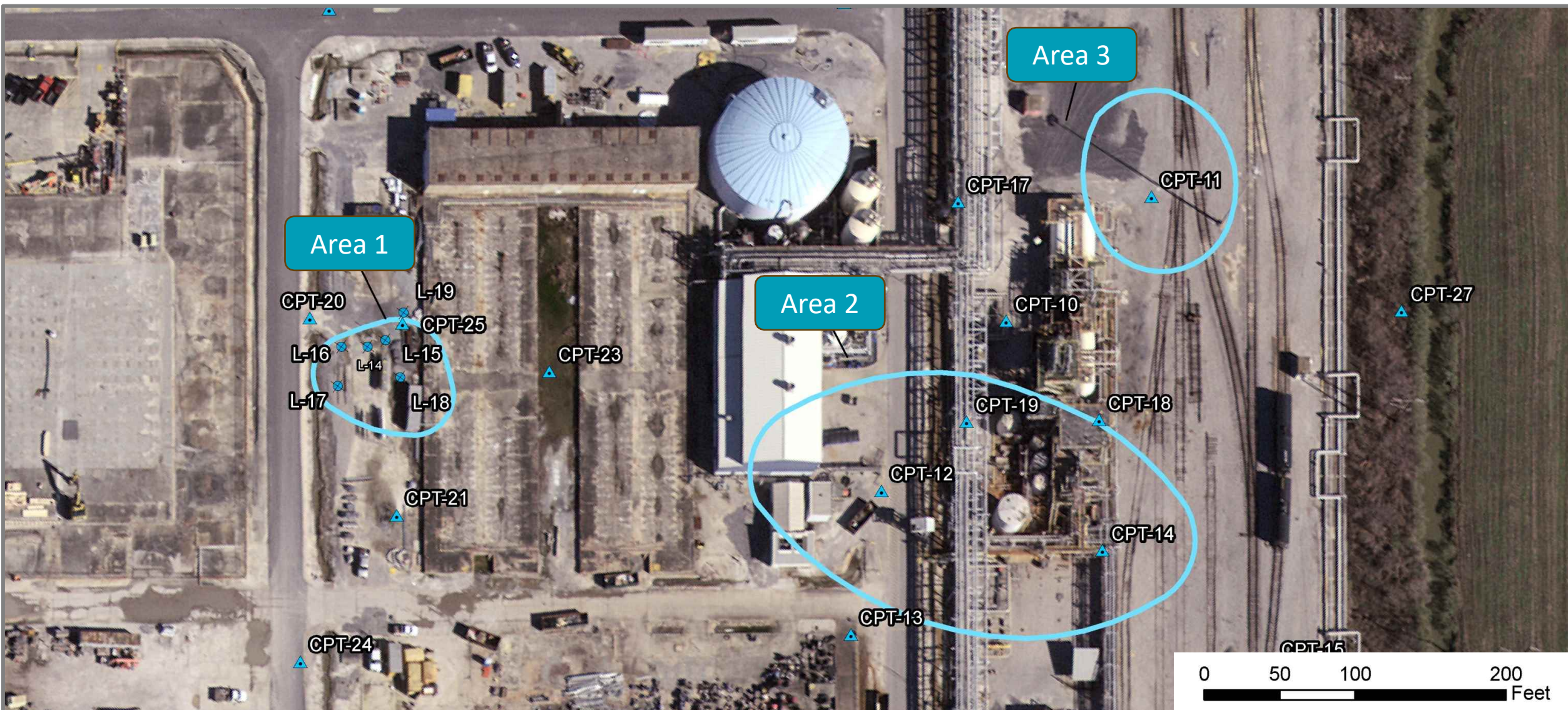
Timeline and Remedial Approach



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- Treatability Testing 2014 - 2015
 - Abiotic treatment with microscale ZVI
 - Enhanced anaerobic bioremediation with emulsified vegetable oil + microbial culture
- Pilot Test Design and Implementation 2017 - 2019
- Additional Treatability Testing 2019 - 2021
- Full-Scale Design and Implementation 2021 – 2022



Full-Scale Remedial Design



Full-Scale Remedial Design



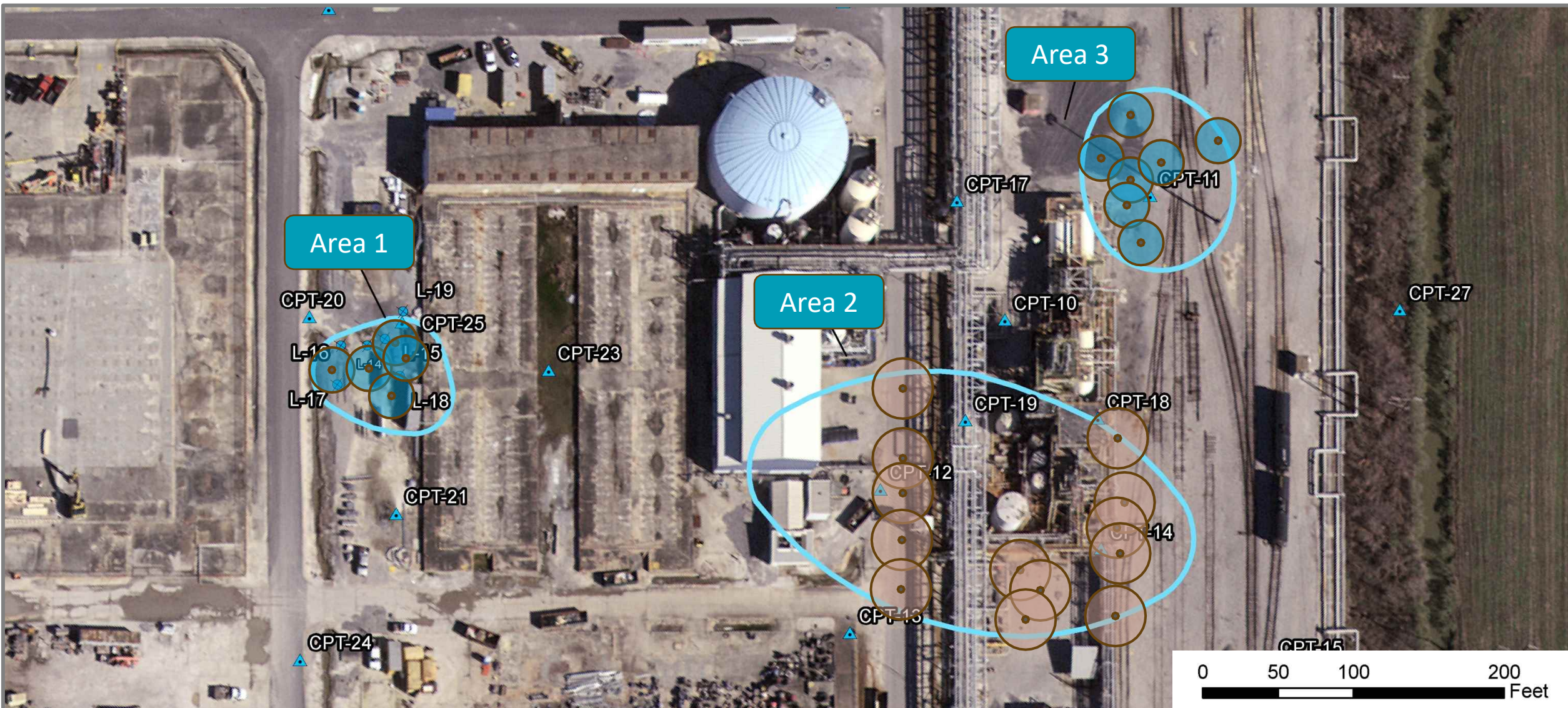
- Expanded mZVI/enhanced bioremediation treatment approach across all three areas, including KB-1[®] Plus.

What did we change in full-scale approach?

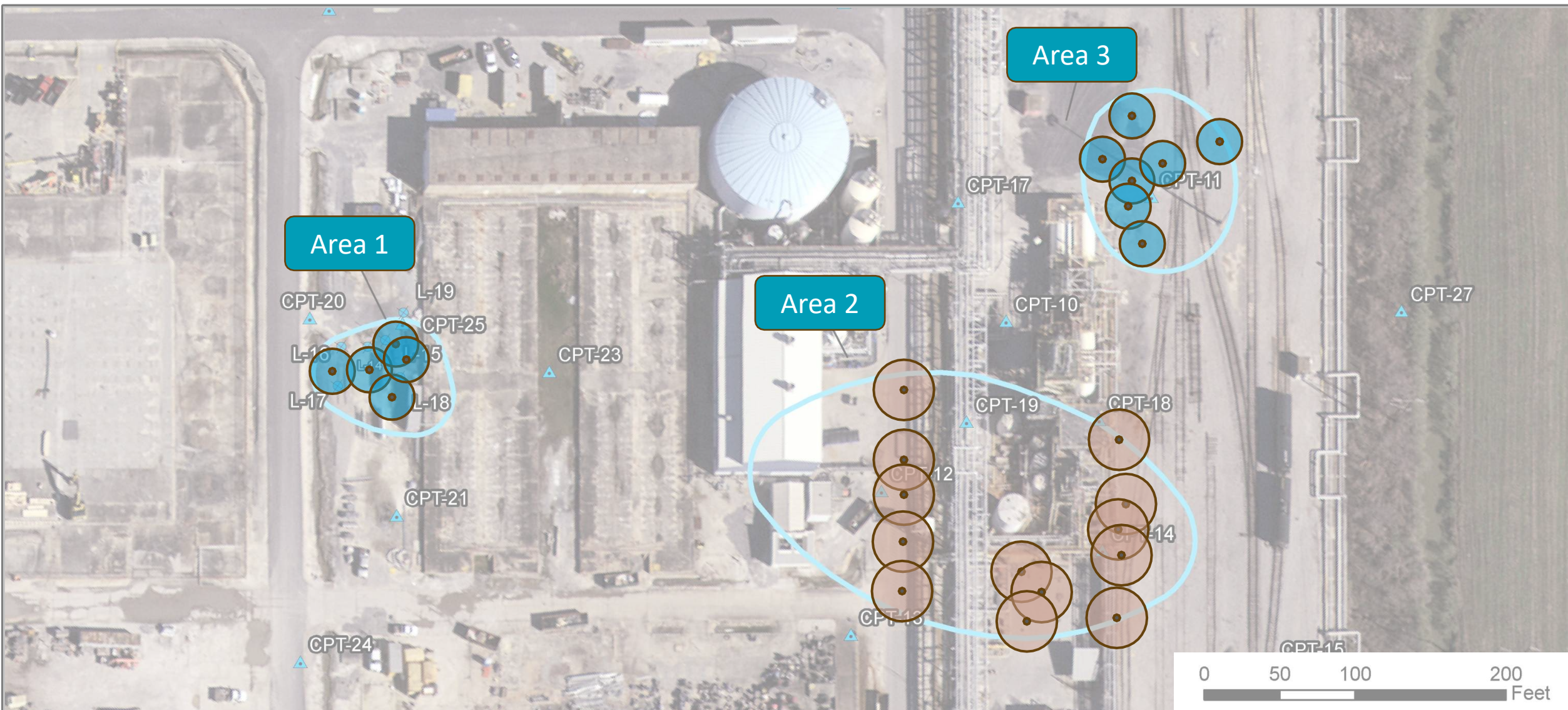
- Co-injected solid (Provectus) and liquid (RNAS) electron donors with our mZVI slurry for one-shot mZVI/enhanced bio application.
- Shifted to DPT drilling method to reduce upfront drilling cost and improve flexibility for injections around existing infrastructure.
- Used 15-foot ROI in two areas and 20-foot ROI in one area to improve performance where access issues were a challenge.



Full-Scale Remedial Design



Full-Scale Remedial Design



Full-Scale Remedial Design



Design Parameter	Area 1	Area 2	Area 3	Unit
Target treatment volume	860	6,080	800	cu yd
Percentage ZVI by soil mass	0.8%	1.2%	0.8%	by wt soil
Mass of ZVI (total: lbs)	24,802	257,939	23,149	lbs
Design ROI	15	20	15	ft
Total number of fracture locations	5	13	7	locations
Fracture depth spacing	4	3	4	ft
Fracture depths per location	3	5	2	
Total number of fractures	15	65	14	
Mass of ZVI per fracture	1,654	3,968	1,654	lbs
Mass of electron donor per fracture	75	150	75	lbs

139 MT ZVI

94 fractures

Full-Scale Implementation - Findings



- Successful injection program completed on budget and ahead of schedule
- DPT drilling successfully met depth requirements and decreased project cost by ~10%
- Combined mZVI/Bio treatment approach saved an extra step of injecting electron donors post-fracturing
- Some key monitoring well locations were suboptimal due to site constraints



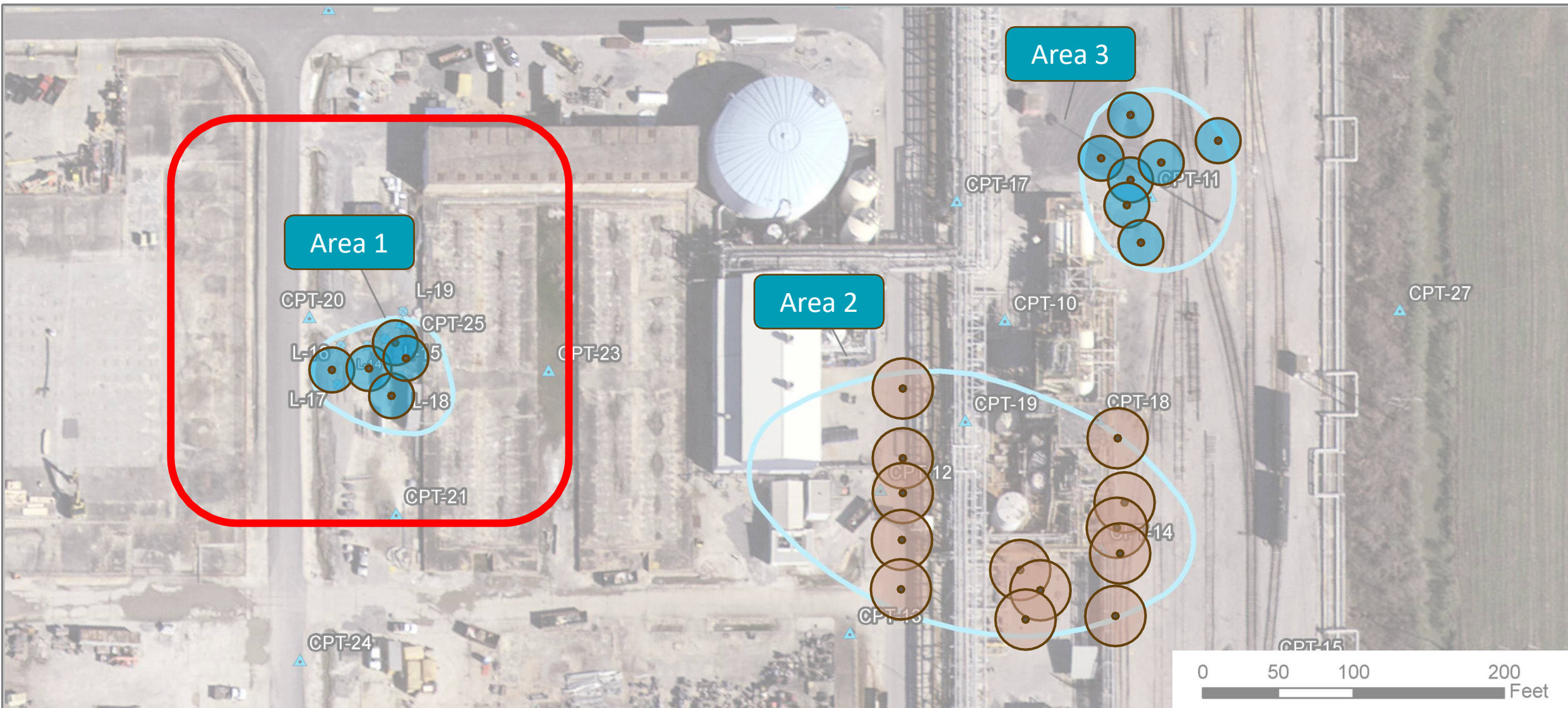
Timeline and Remedial Approach



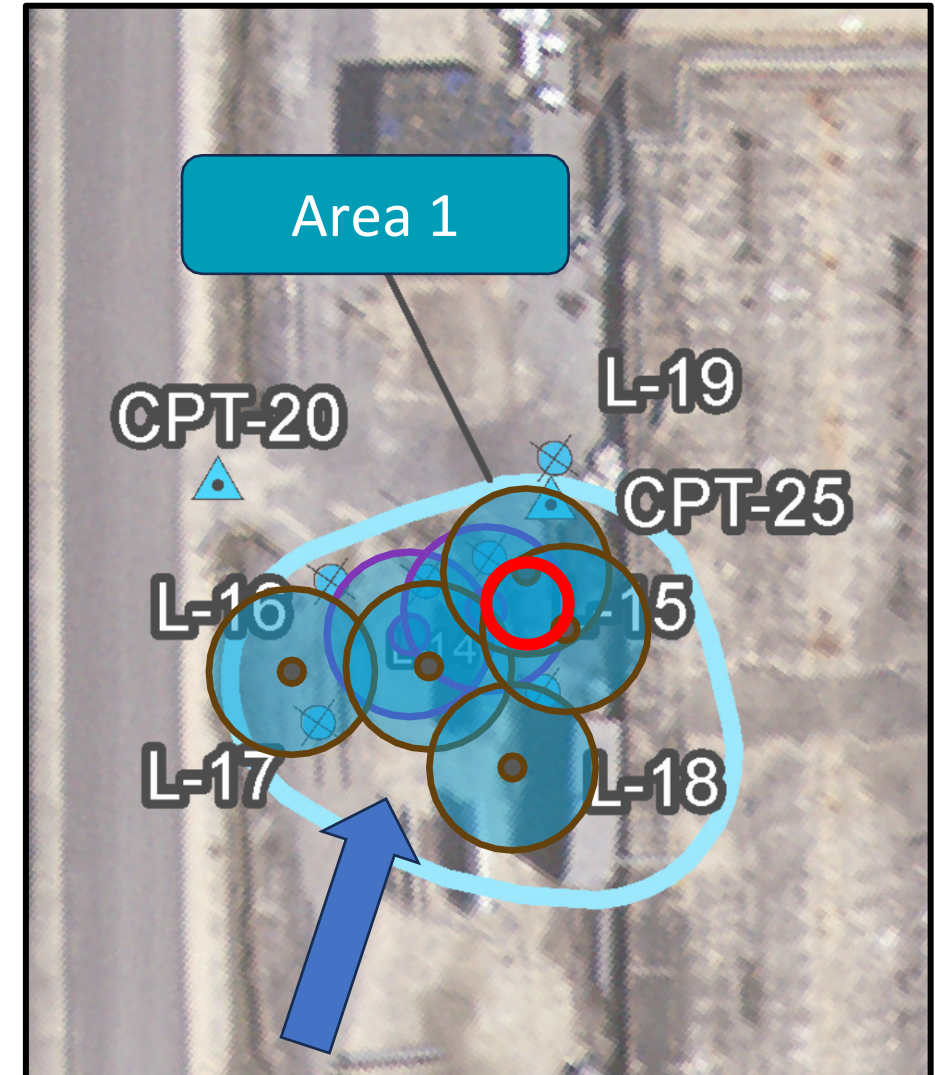
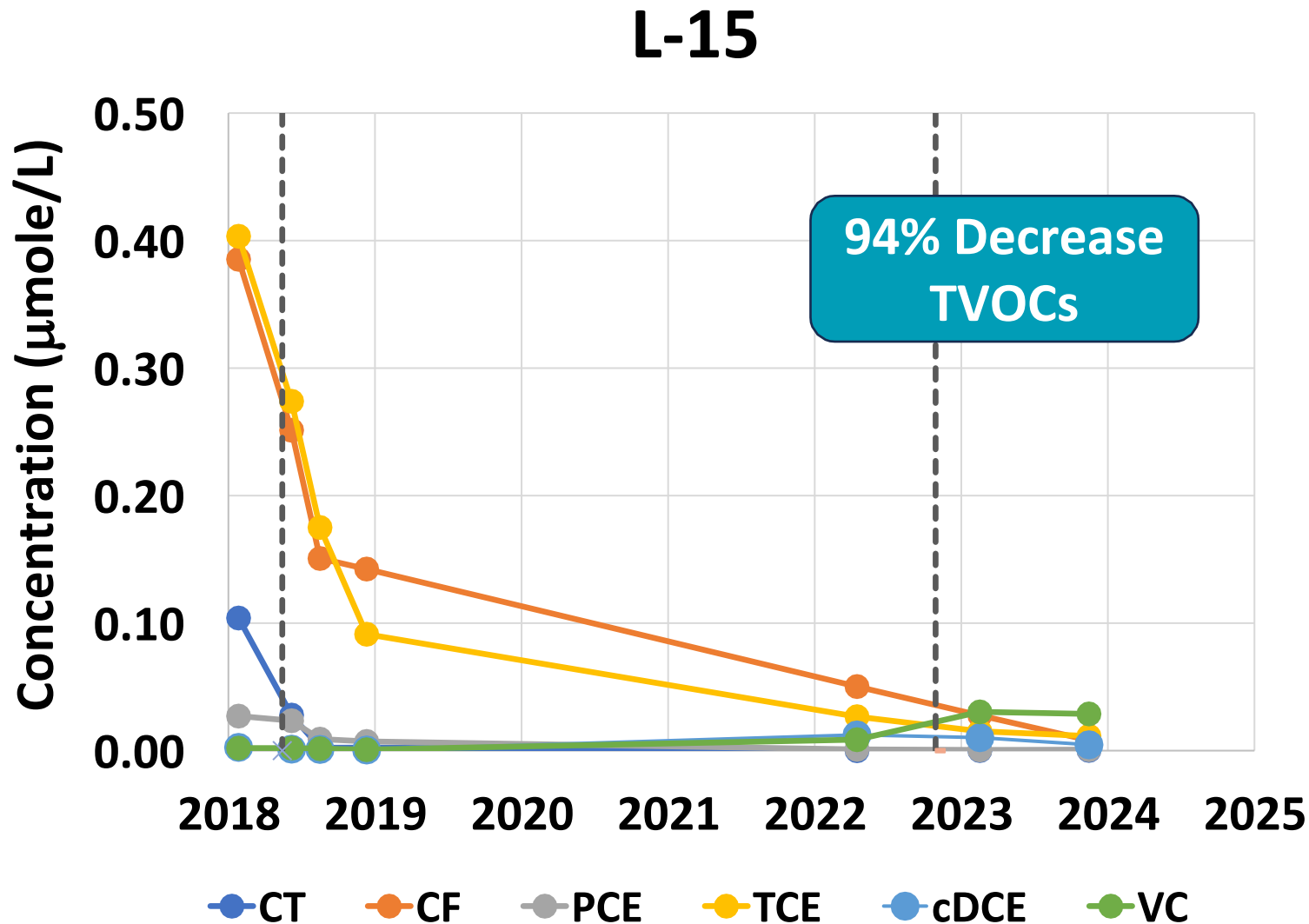
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- Full-Scale Design and Implementation 2021 – 2022
- Full-Scale Performance Monitoring 2022-Present



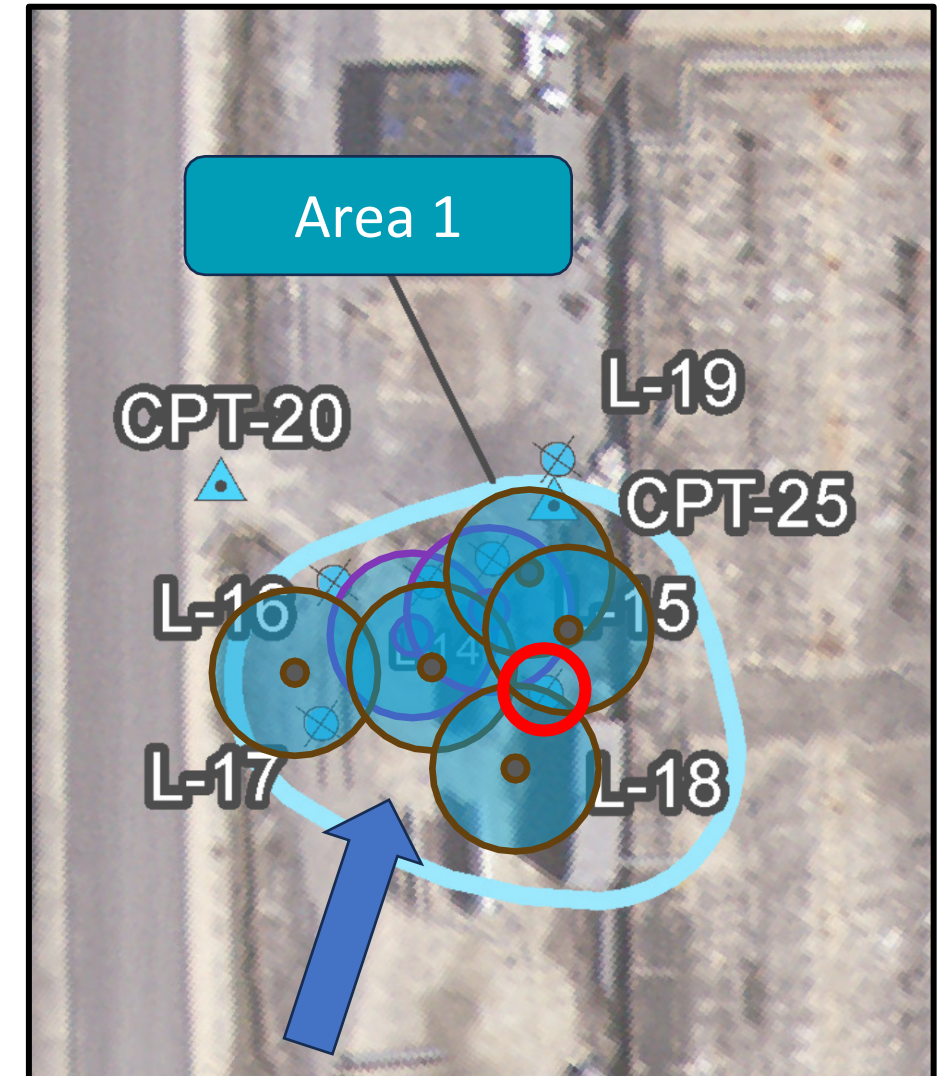
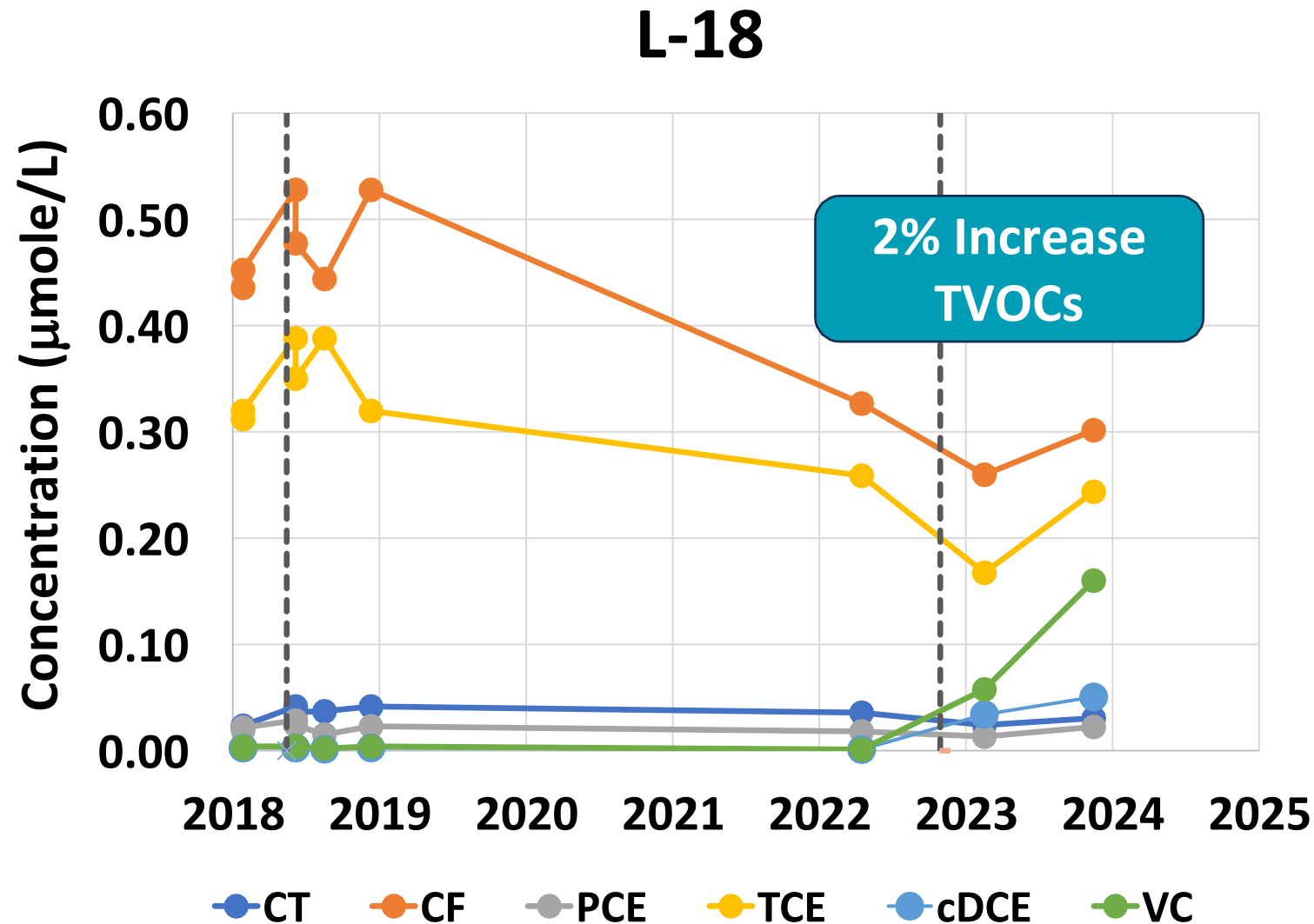
Full-Scale Performance Monitoring – Area 1



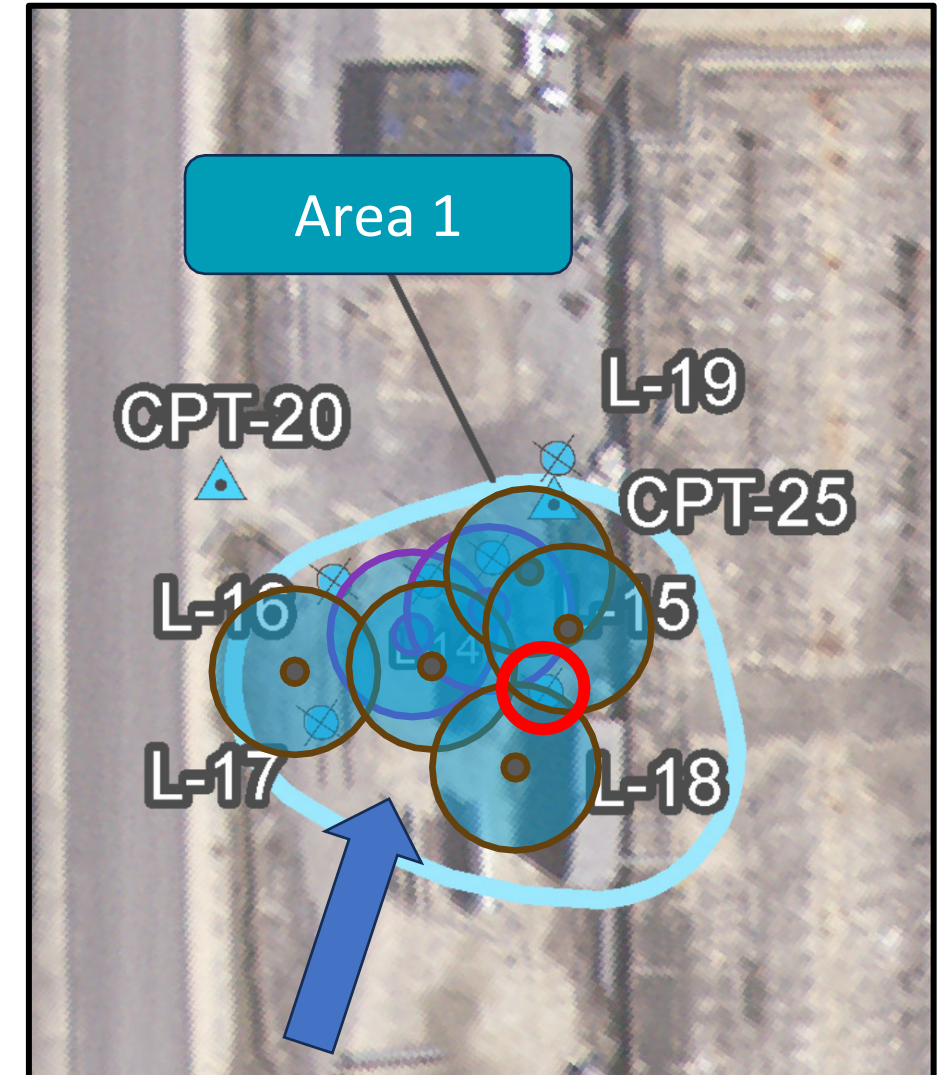
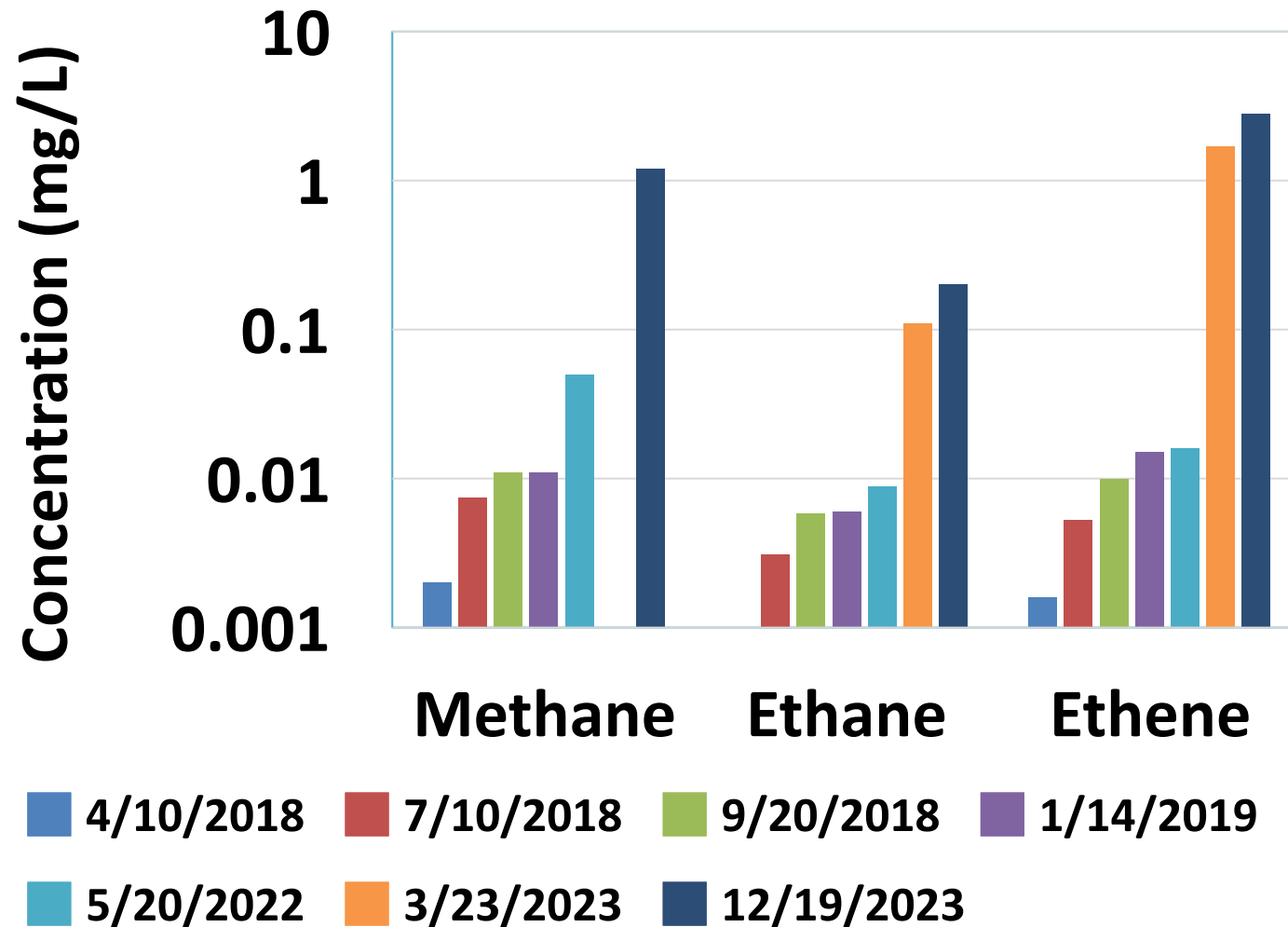
Full-Scale Performance Monitoring – Area 1 – L-15



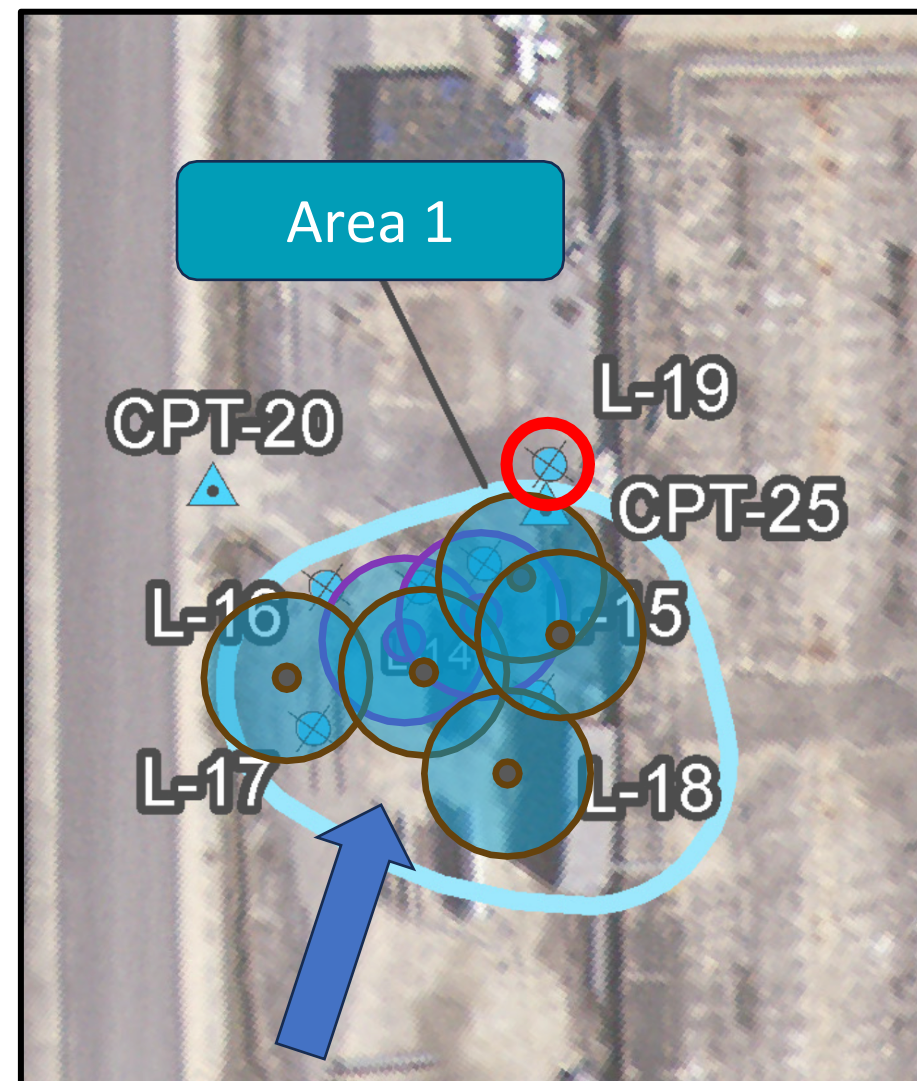
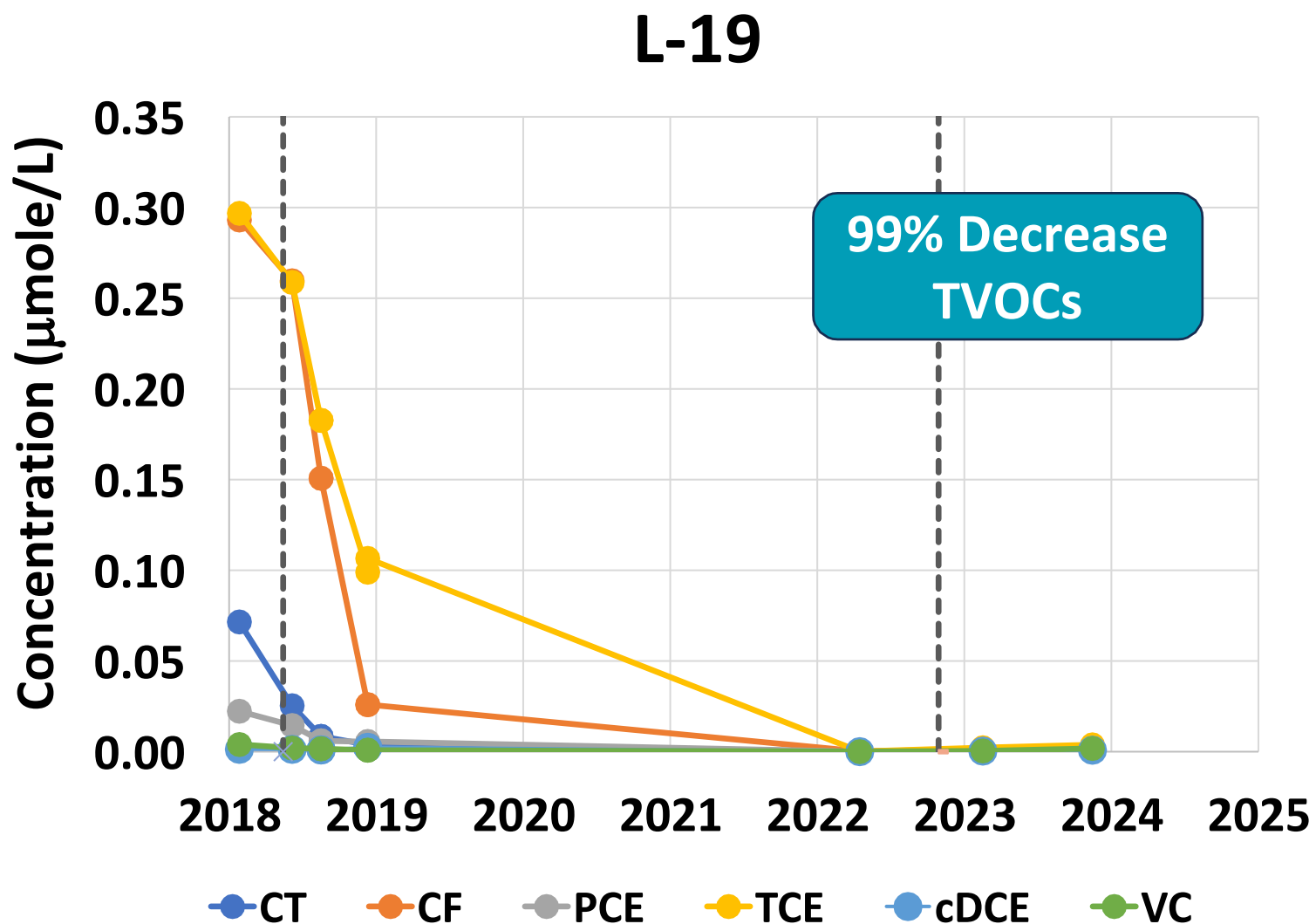
Full-Scale Performance Monitoring – Area 1 – L-18



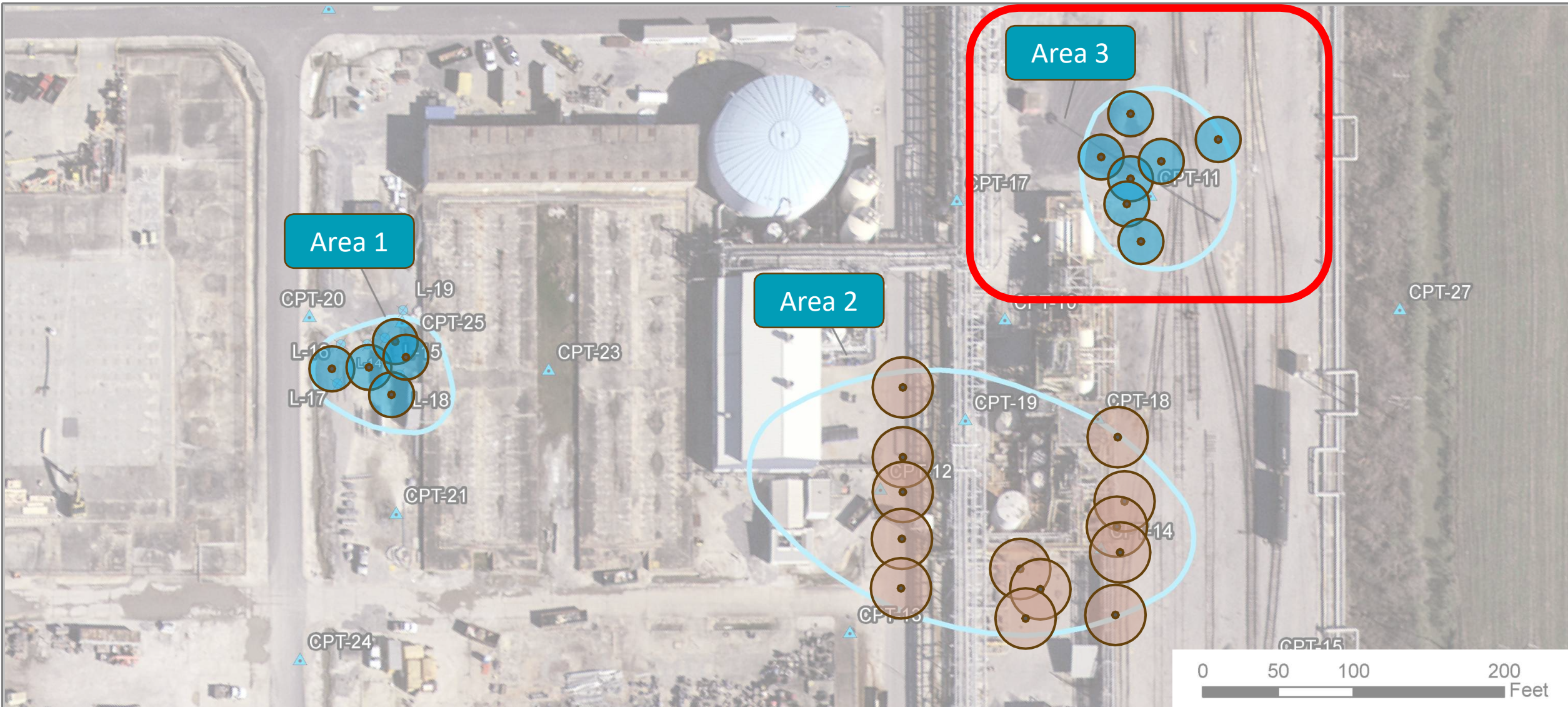
Full-Scale Performance Monitoring – Area 1 – L-18



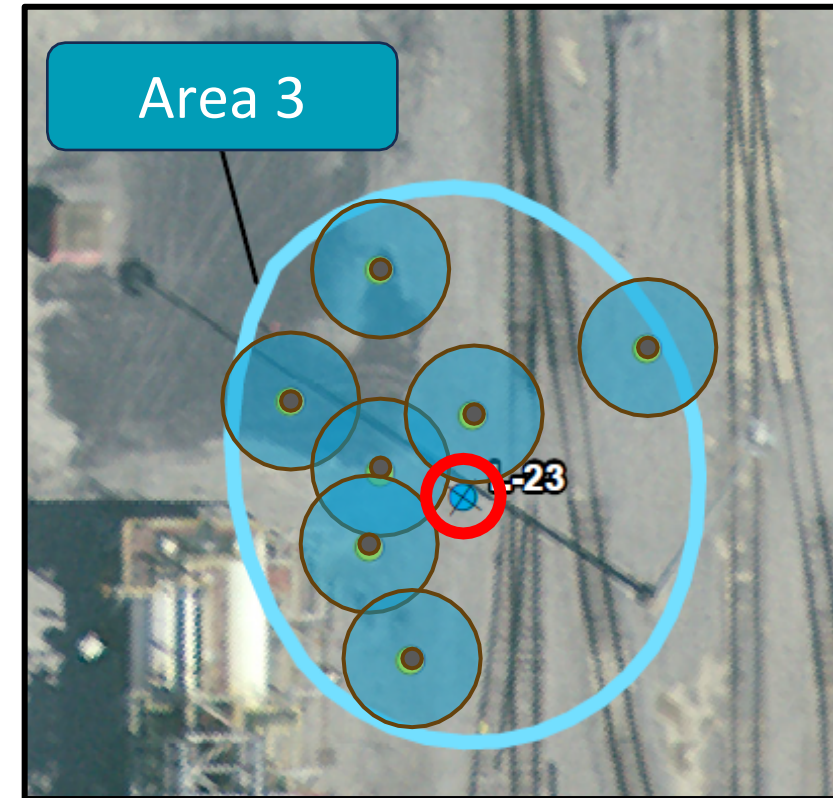
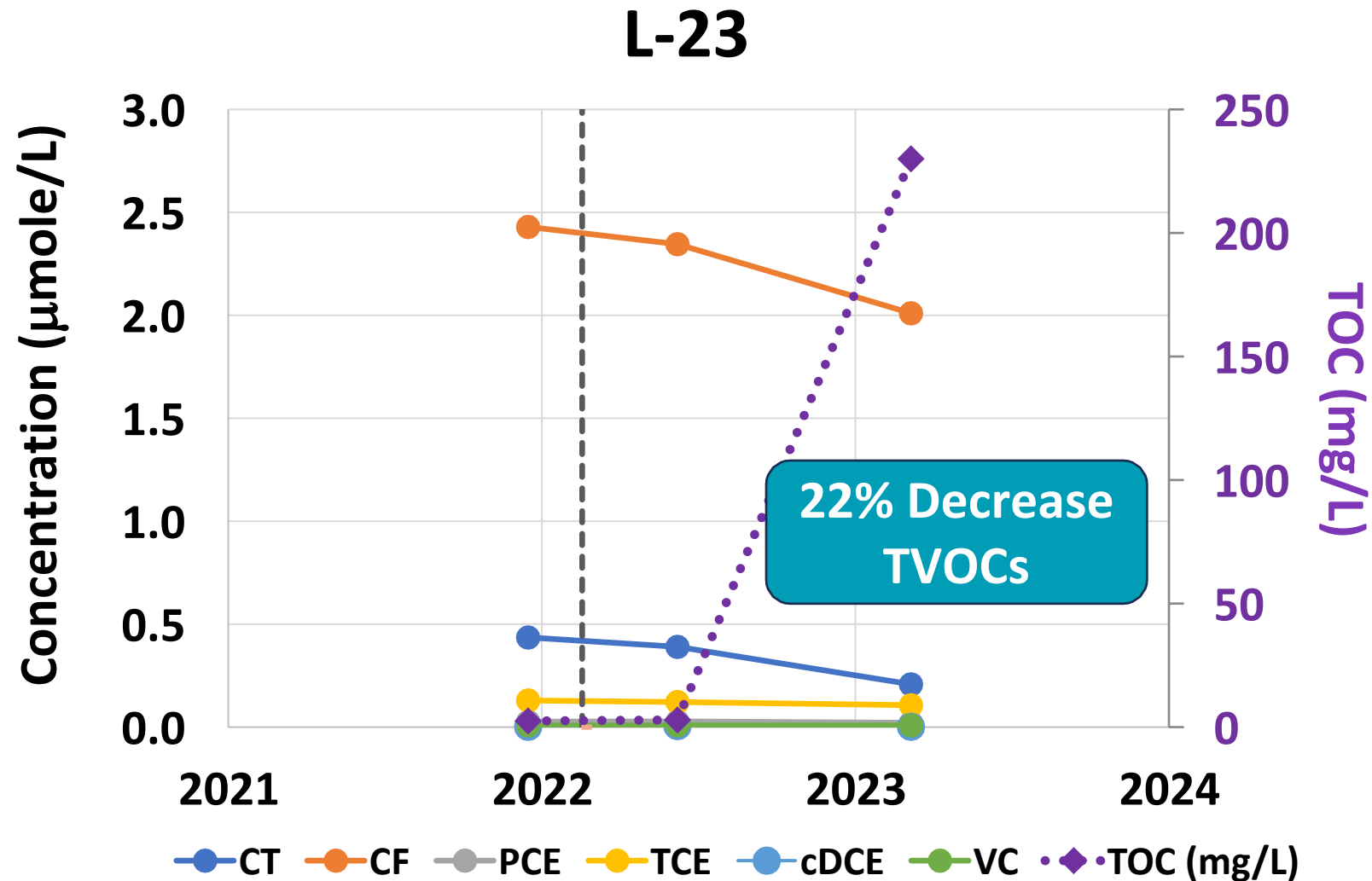
Full-Scale Performance Monitoring – Area 1 – L-19



Full-Scale Performance Monitoring – Area 3



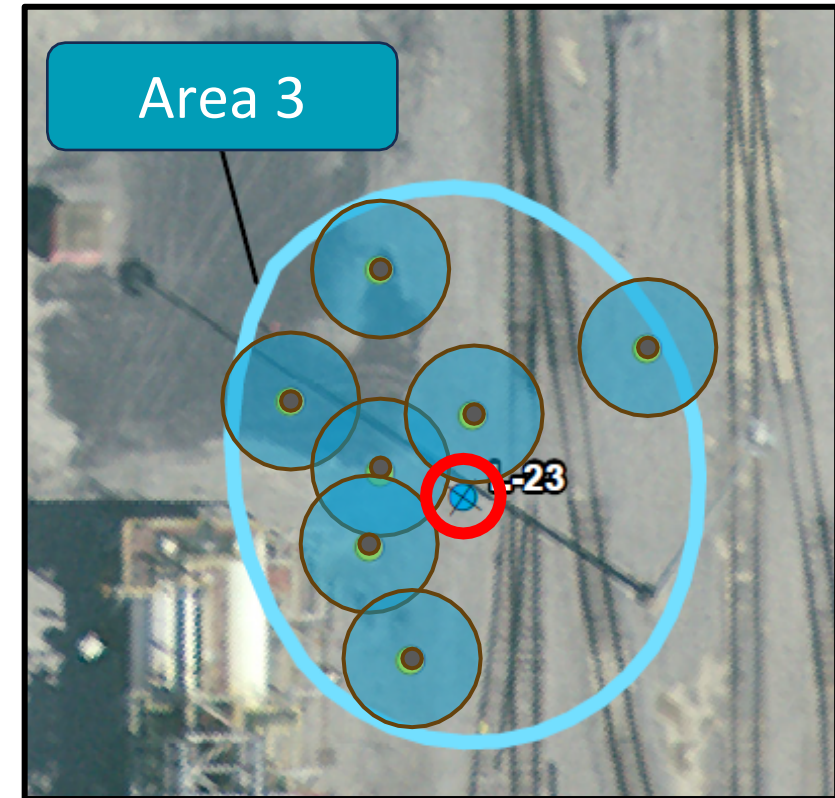
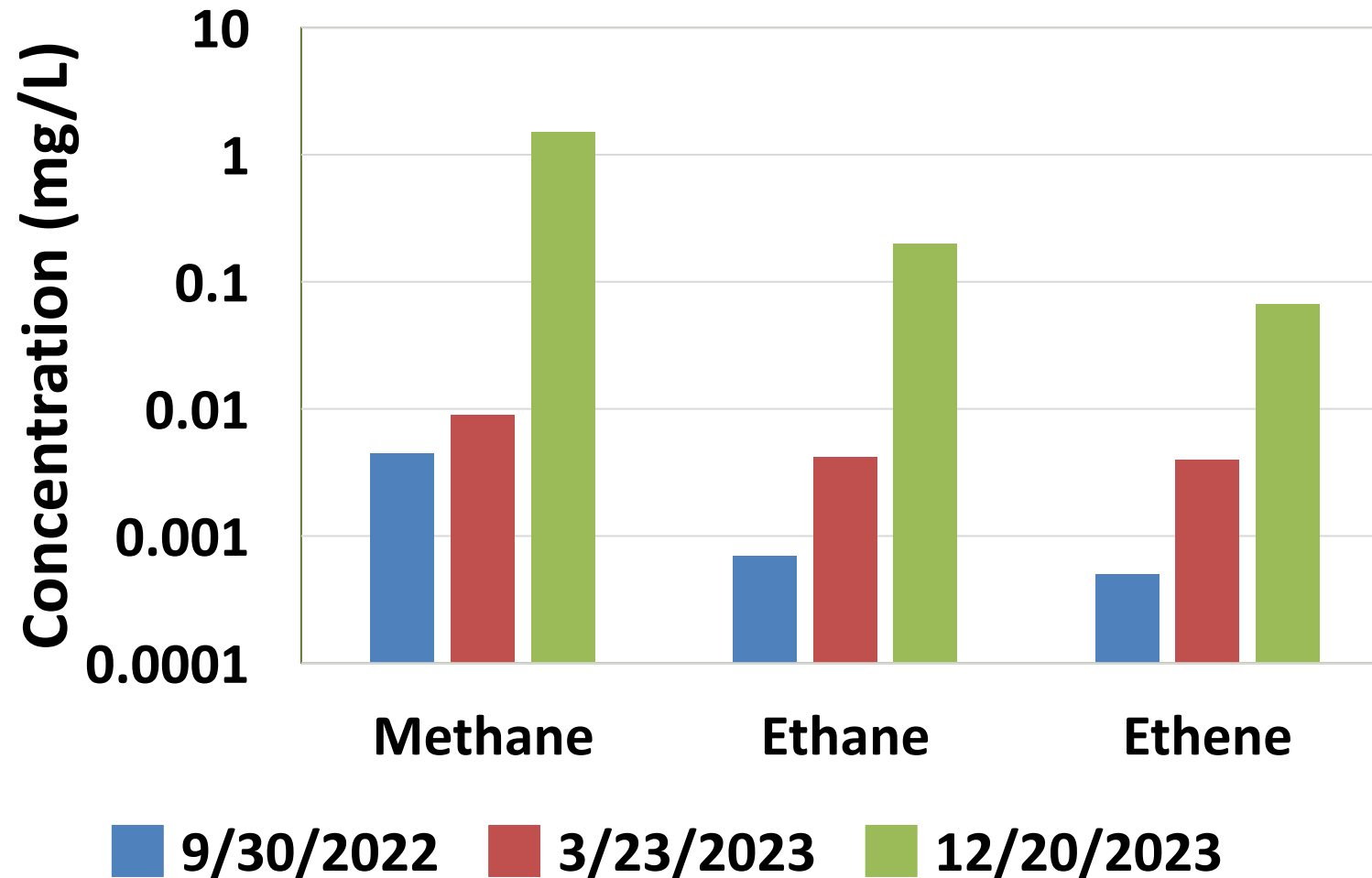
Full-Scale Performance Monitoring – Area 3 – L-23



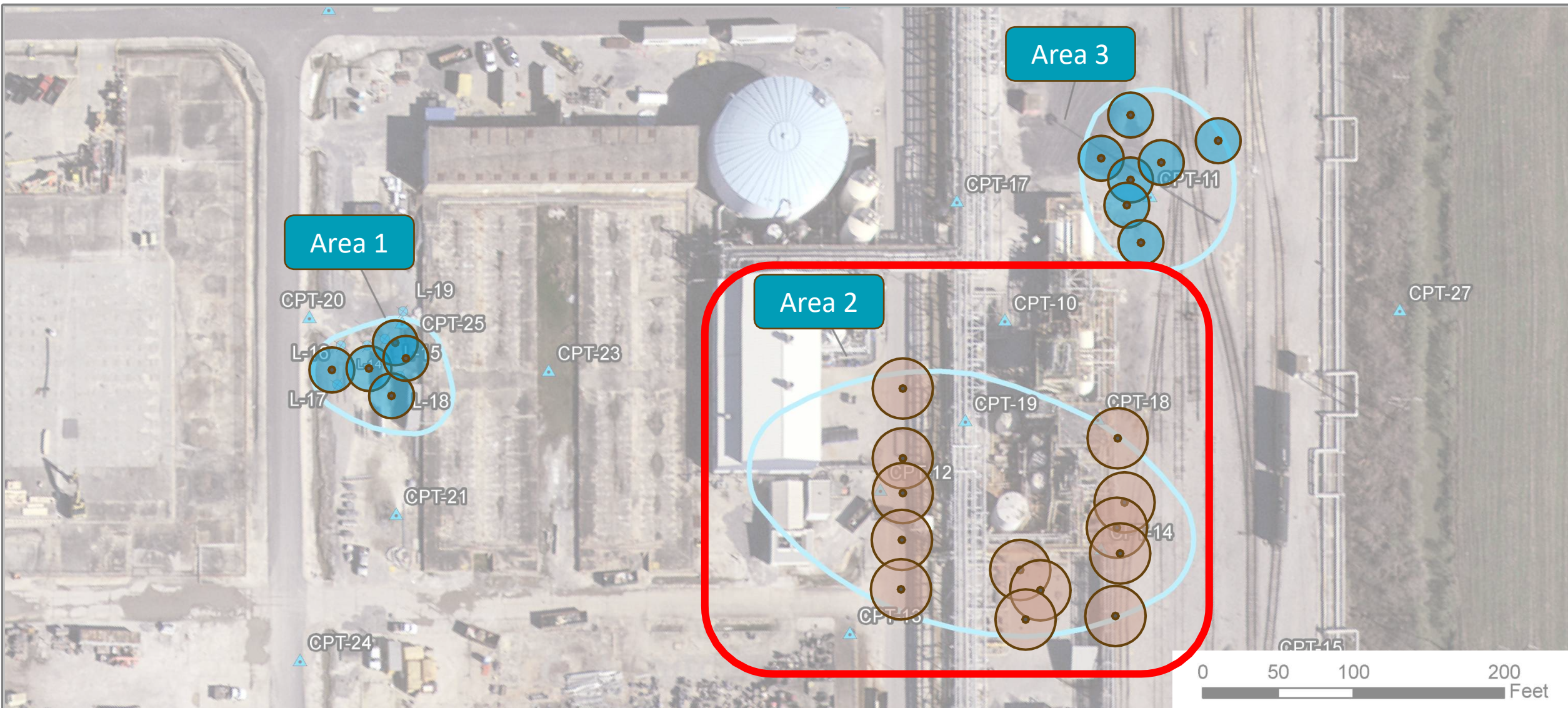
Full-Scale Performance Monitoring – Area 3 – L-23



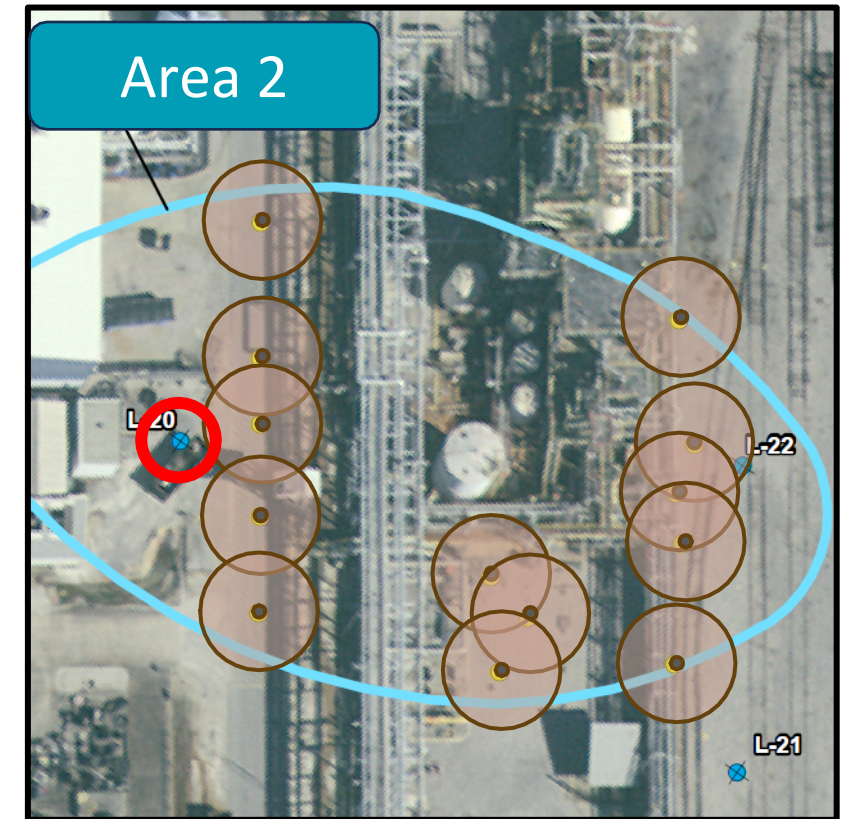
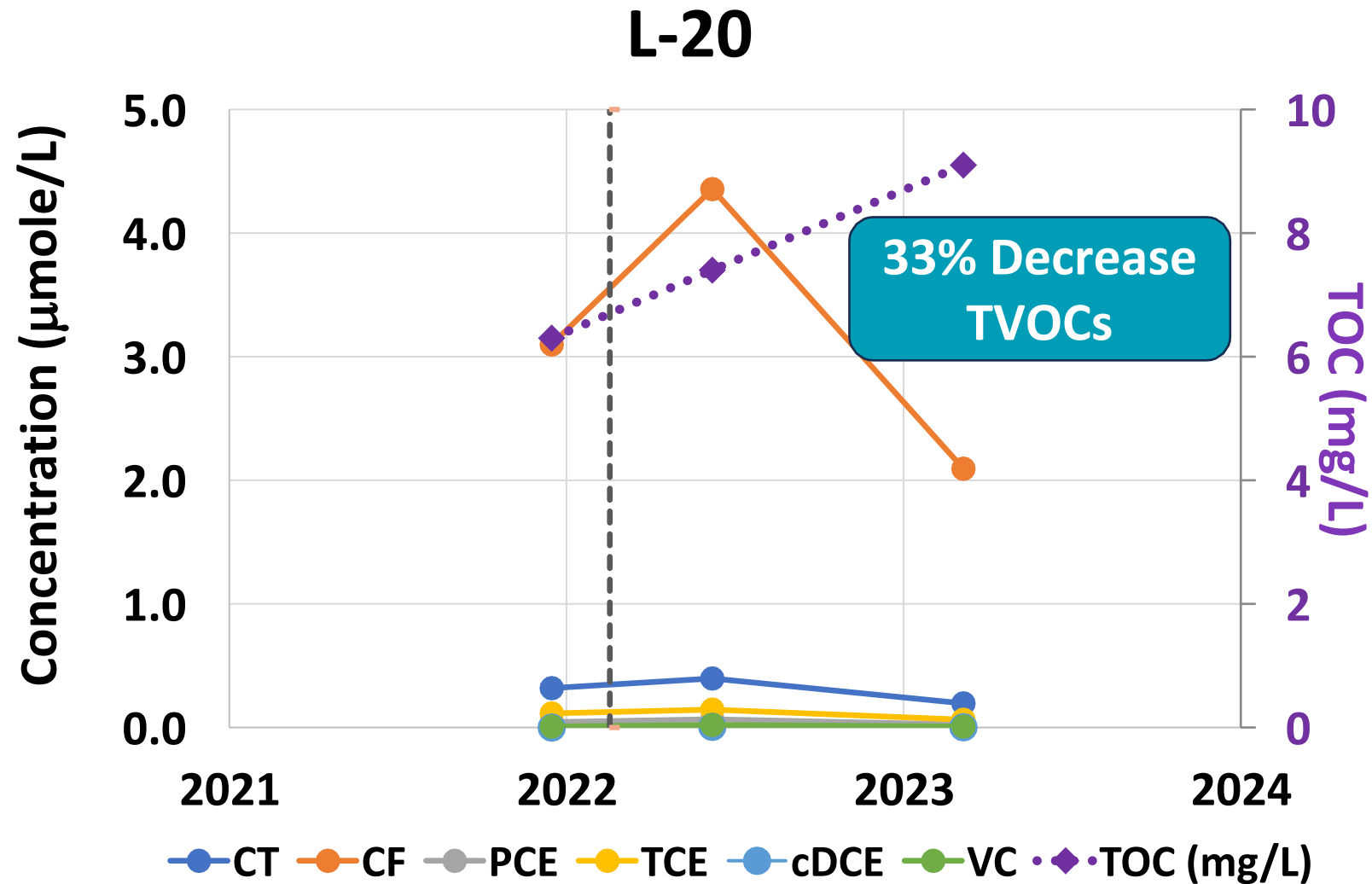
L-23



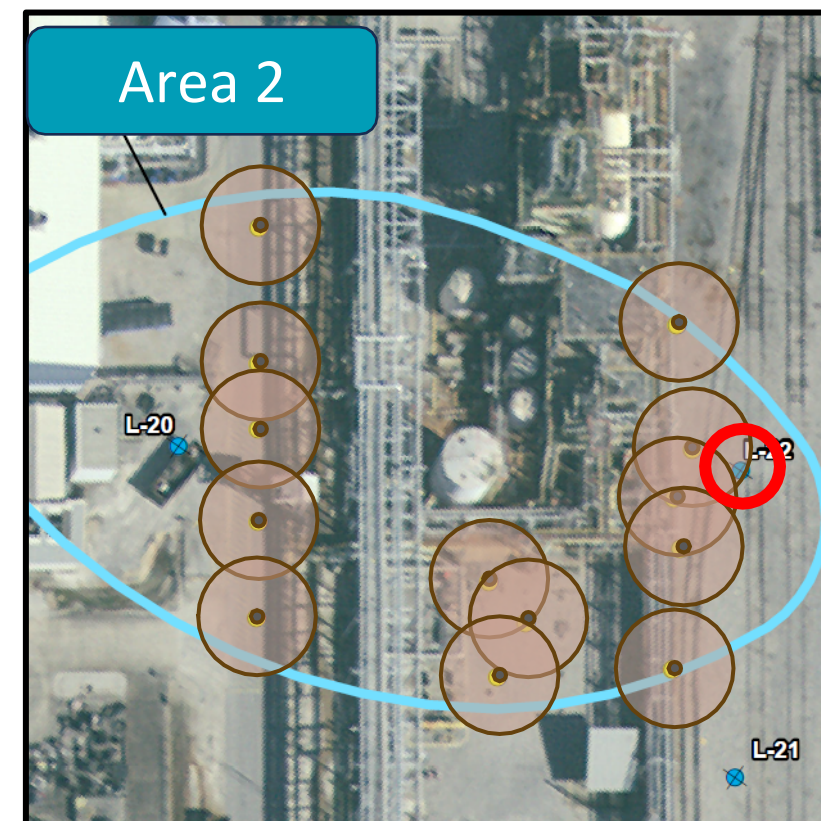
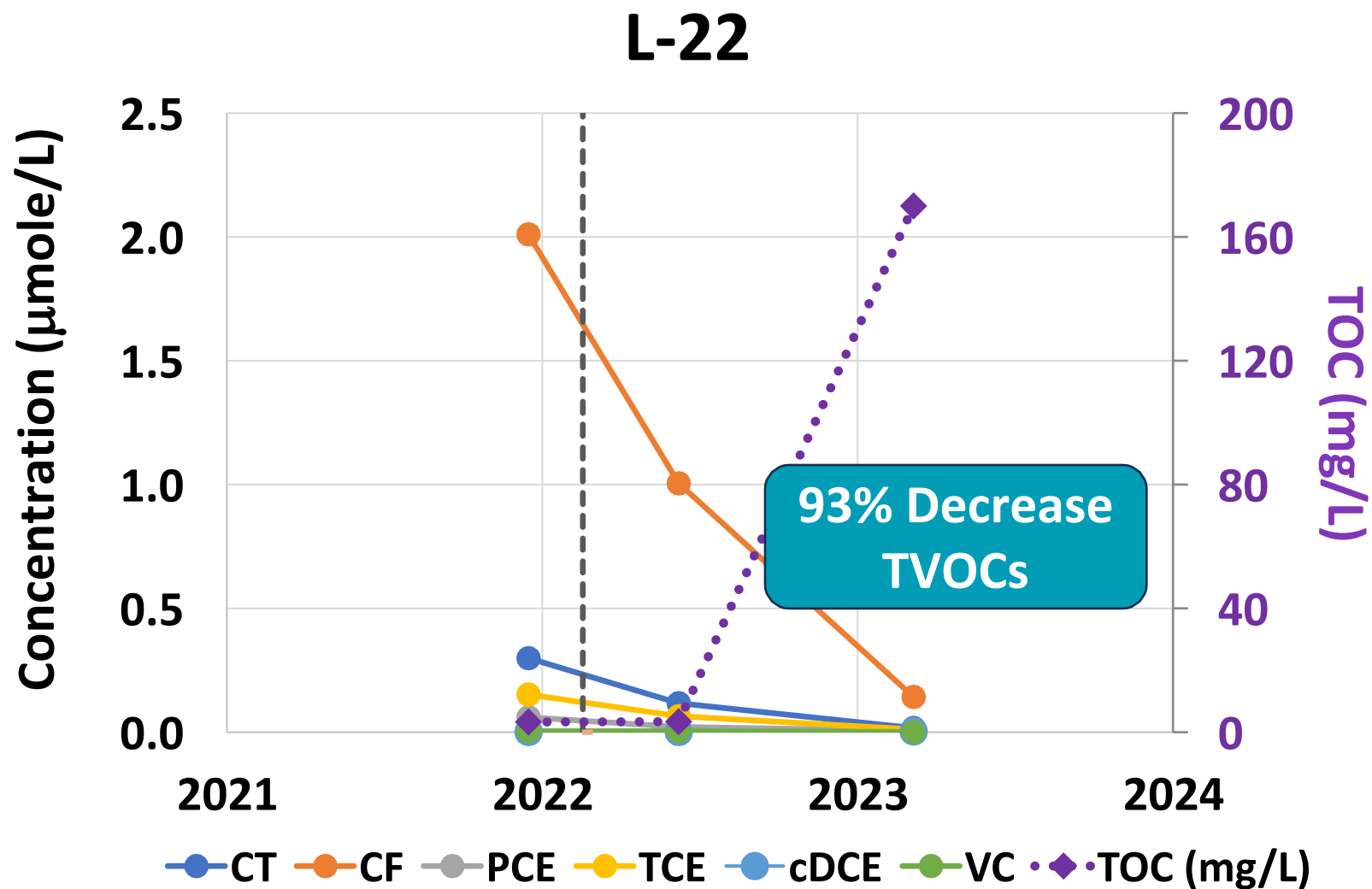
Full-Scale Performance Monitoring – Area 2



Full-Scale Performance Monitoring – Area 2 – L-20



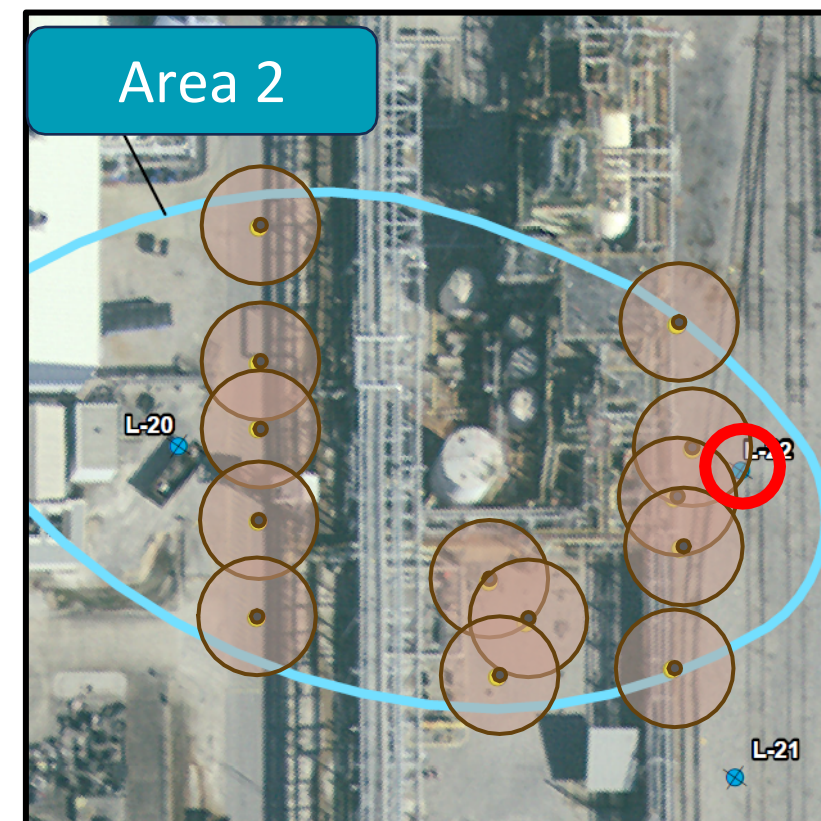
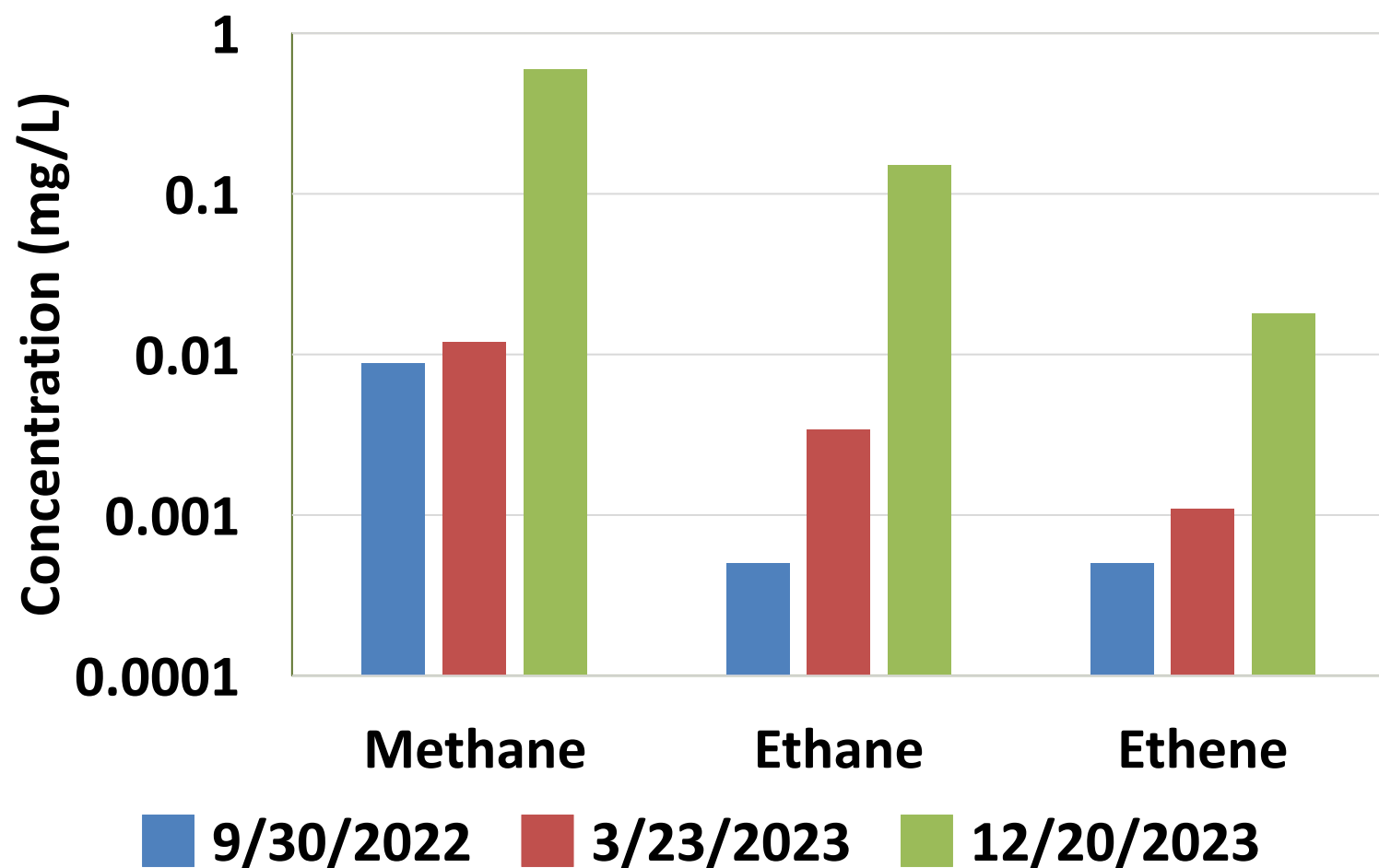
Full-Scale Performance Monitoring – Area 2 – L-22



Full-Scale Performance Monitoring – Area 2 – L-22



L-22



Full-Scale Treatment – Conclusions



- Treatment of all target VOCs was observed in all three treatment areas.
- Area 1 is showing significant VOC treatment with complete degradation to methane, ethane, and ethene.
- Injection locations and monitoring network were both impacted in Areas 2 and 3, but evidence of treatment was still observed.
- TOC results show that our electron donor distribution takes time in this formation.
- Monitoring will continue, and spot treatment with additional electron donor injections is currently being evaluated.



The background of the slide is a close-up photograph of a rock surface. The rock has a mottled appearance with various shades of brown, tan, and grey. A prominent, dark, horizontal crack or fissure runs across the middle of the image. Overlaid on the upper part of the rock is a teal-colored rounded rectangle containing the word "Questions" in white text. At the bottom of the slide, another teal-colored rounded rectangle contains the text "Chapman Ross – cross@frx-inc.com" in white.

Questions

Chapman Ross – cross@frx-inc.com