COMBINED REMEDY ENHANCEMENTS TO TREAT A GROUNDWATER TCE PLUME COMMINGLED WITH Cr(VI) VIA IN SITU CHEMICAL REDUCTION AND ENHANCED ANAEROBIC BIOAUGMENTATION

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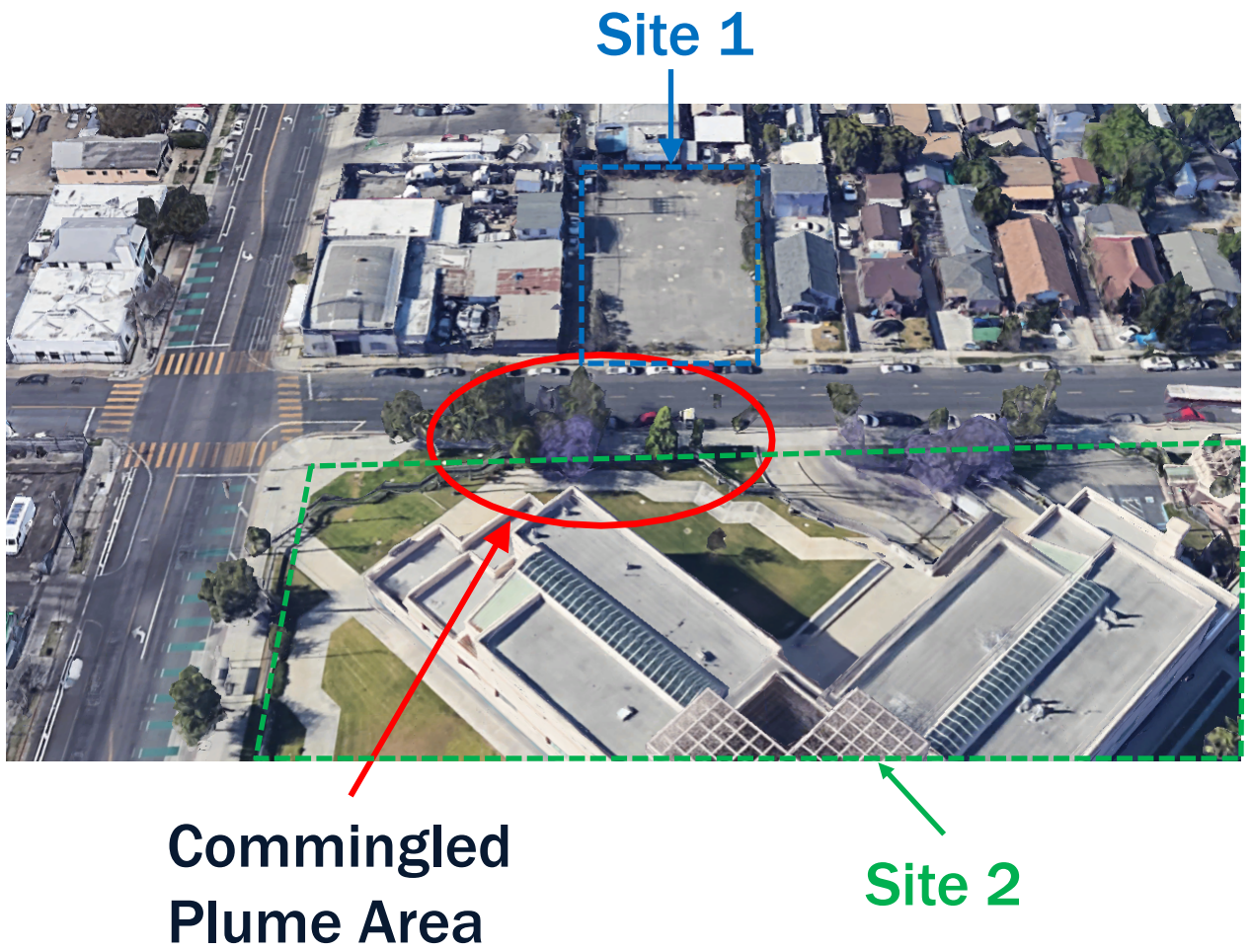
SITE CONDITIONS



- Multiple source areas
  - Site 1 – former chromium plating site
  - Site 2 – former industrial uses, e.g., machine shop, aircraft manufacturing
- Major commingled contaminants of concern
  - Hexavalent Chromium (Cr[VI]) – up to 250 mg/L
  - Trichloroethene (TCE) – up to 1.4 mg/L
- Geology
  - Sand with minor amounts of silt and gravel
- Groundwater
  - Depth – 155 ft bgs
  - Flow direction – generally to north
  - Groundwater depression identified in the commingled plume area

REMEDIATION CHALLENGE & APPROACH

CHALLENGE

- **Commingled contaminants required a unique/phased remedial approach**
- **High Cr(VI) concentrations were found to inhibit TCE degradation**
  - Cr(VI) > 6 mg/L was inhibitory to a commercially available TCE microbial consortium
- **Required a remedy capable of addressing high Cr(VI) concentrations in addition to high TCE concentrations**

APPROACH

- **In-situ chemical reduction (ISCR) with calcium polysulfide (CPS) to initially reduce Cr(VI) concentrations**
  - Focus on reduction of unacceptable secondary impacts to soil permeability and groundwater geochemistry
- **Combination of ISCR and enhanced anaerobic bioremediation (EAB) to degrade TCE to background concentrations**
  - Methods combine to create strong reducing conditions in-situ to further reduce Cr(VI) concentrations to levels that will allow TCE dechlorination to proceed uninhibited

PRECIPITATION OBSERVED FROM TYPICAL CPS INJECTION

Difficulty operating injection equipment

Increased injection pressure

Decreased injection flow rate

Clogging injection well screen

Decreased aquifer permeability

Decreased radius of influence (ROI)

CPS STABILITY

- Precipitation suggests instability of CPS solution before injection
- Stability of CPS solution is mainly controlled by pH
- CPS is more stable at higher pH
- Dilution of CPS with water lowered the pH and consequently precipitated the calcium

$$CaS_X + H_2O \rightarrow Ca(SH)(OH)$$

$$Ca(SH)(OH) + H_2O \rightarrow Ca(OH)_2 + H_2S$$

BENCH TEST OF pH-ADJUSTED CPS SOLUTIONS

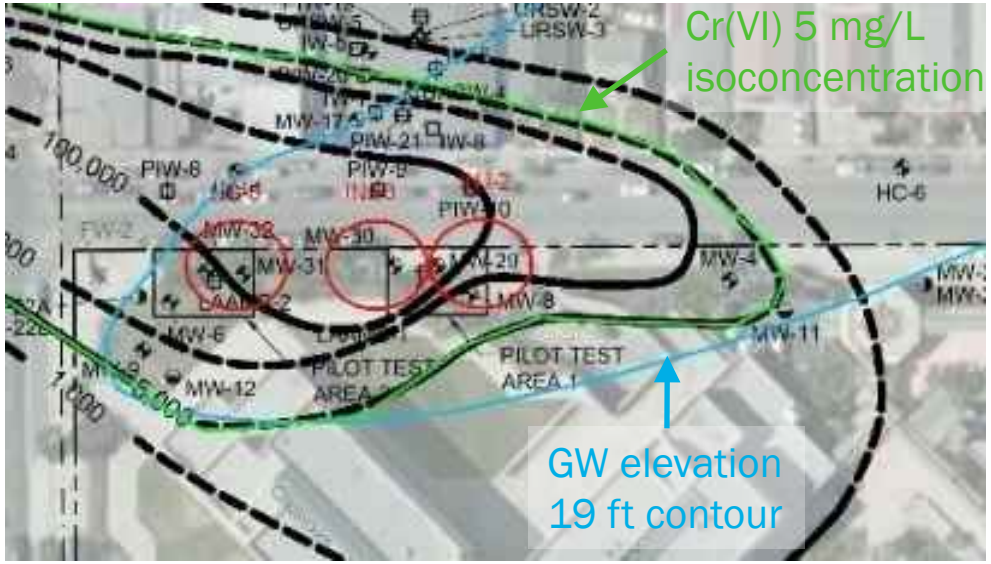
- **Objective**
  - Identify pH corresponding to a stable 5% CPS
  - Identify amount of alkaline needed
- **Approach – precipitation observation**
  - potable water 5% CPS
  - pH adjusted 5% CPS
- **Result**
  - potable water 5% CPS - coarse and settled particles
  - pH adjusted 5% CPS - fine and suspended particles
- **Conclusion – settled precipitate was not observed for high pH (> 11) 5% CPS solution**

Potable Water 5% CPS Solution

pH-Adjusted 5% CPS Solution

FULL SCALE PH-ADJUSTED CPS INJECTION

- Injection wells – 3
  - Locations indicated on map by red circles showing 25 ft ROIs
- Well screen – 155 – 175 ft bgs
- Mixing tank – water + alkaline + buffer + CPS (pH > 11)
- Flow rate – 19 to 25 gpm
- Injection volume – 24,700 to 29,700 gal per well (adjusted based on lithology along well screen)
- Injection time – 4 days



FIELD OBSERVATIONS

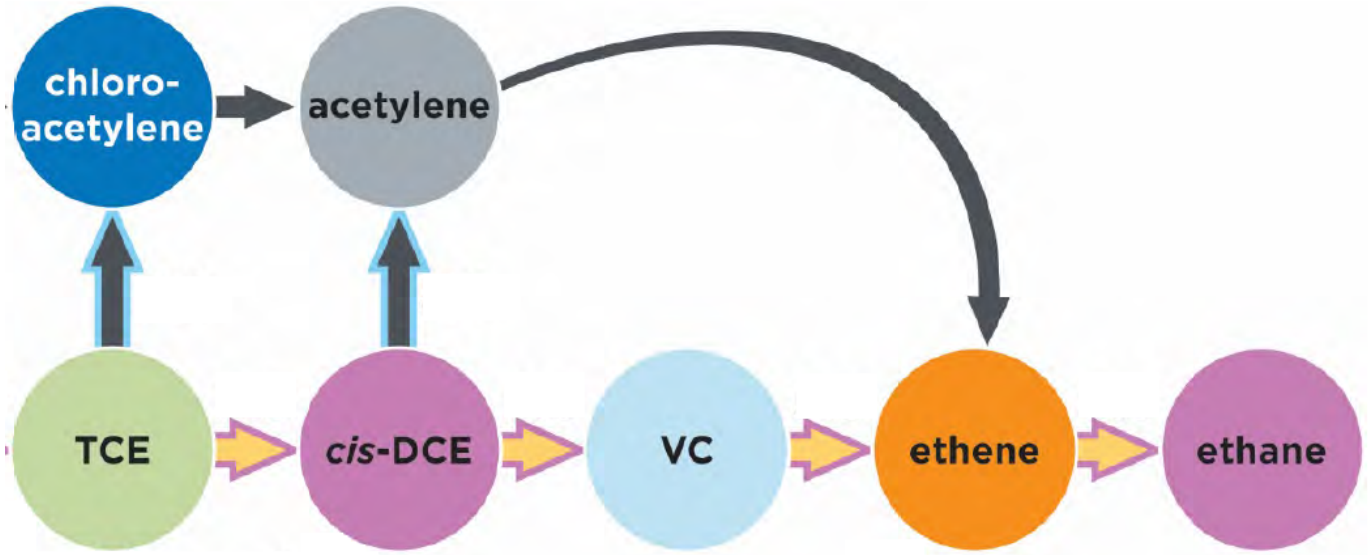
- pH-adjusted solution showed good stability with no Ca precipitation in mixing tanks/pumps/pipes
- No increase in CPS delivery pressure indicated no major precipitation in the injection wells
- Absence of localized Ca precipitation means:
  - More CPS available to treat Cr(VI)
  - Opportunity of reusing injection wells
  - Better CPS delivery
  - Radius of influence exceeding 20 feet

CR(VI) CONCENTRATION REDUCTION FOLLOWING CPS INJECTION

Monitoring Wells (< 25 ft ROI)	Before Injection (µg/L)	1 Month after Injection (µg/L)	5 Years after Injection (µg/L)
MW-8 (12.5 ft. to INJ-2)	5,300	ND	0.7
LAAMS-2 (17 ft. to INJ-1)	12,000	ND	ND
LAAMS-1 (23 ft. to INJ-2)	110,000	ND	ND

FOLLOW-ON COMBINED ISCR AND EAB

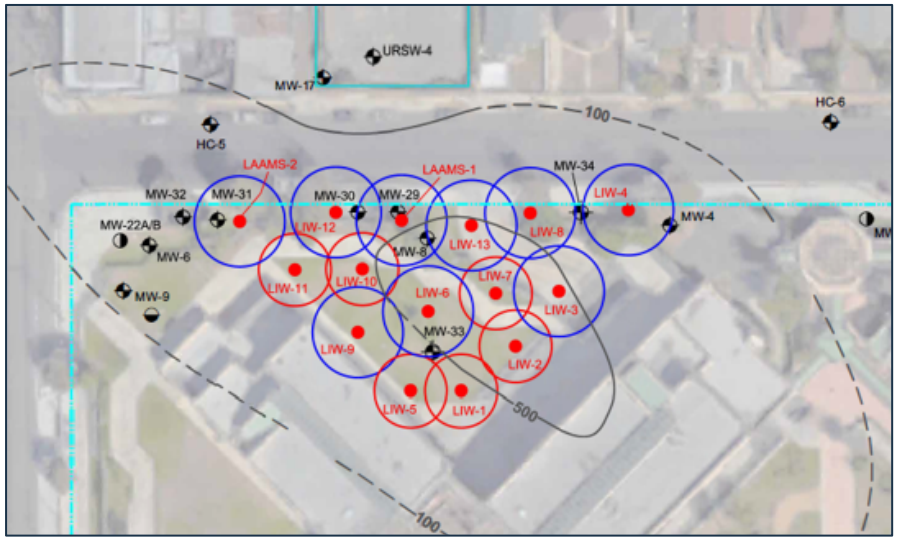
- Injected reagents and substrates induce strongly reducing conditions ideal for degradation of both Cr(VI) and TCE
- ISCR – injected reducing agent (ferrous lactate) to drive abiotic degradation
- EAB – injected organic substrate (electron donor) to be a carbon source to stimulate biological dechlorination
- pH buffer included to maintain neutral pH conditions
- Microbial culture injected to ensure the right population of microbes available for complete dechlorination



Modified from: TR-NAVFAC EXWC-EV-1601

ISCR AND EAB INJECTION

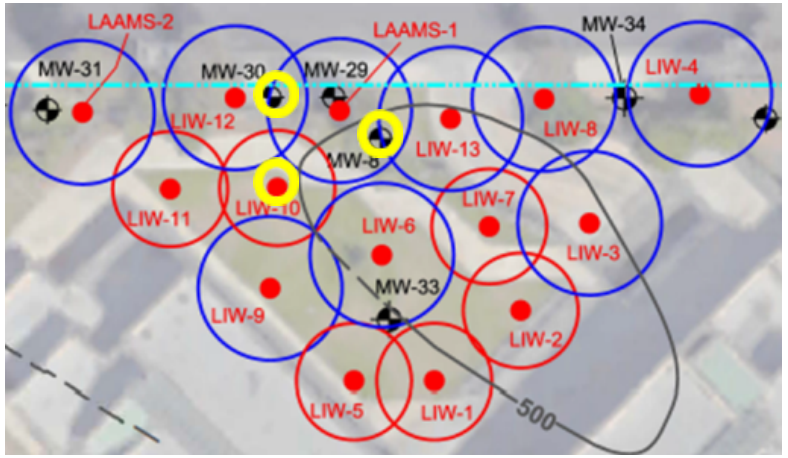
- Injection wells – 15 newly installed wells
- Well screen – 149 to 190 ft bgs
- Injection time – 14 days
- Flow fate – 0.2 to 12.1 gpm
- Injection volume
  - 56,556 pounds of organic substrate (Newman Zone®)
  - 25,194 pounds of ferrous lactate
  - 66,359 pounds of pH buffer (Neutral Zone®)
  - 380,850 gallons of dilution water
  - 78 liters of bioaugmentation culture (KB-1®)



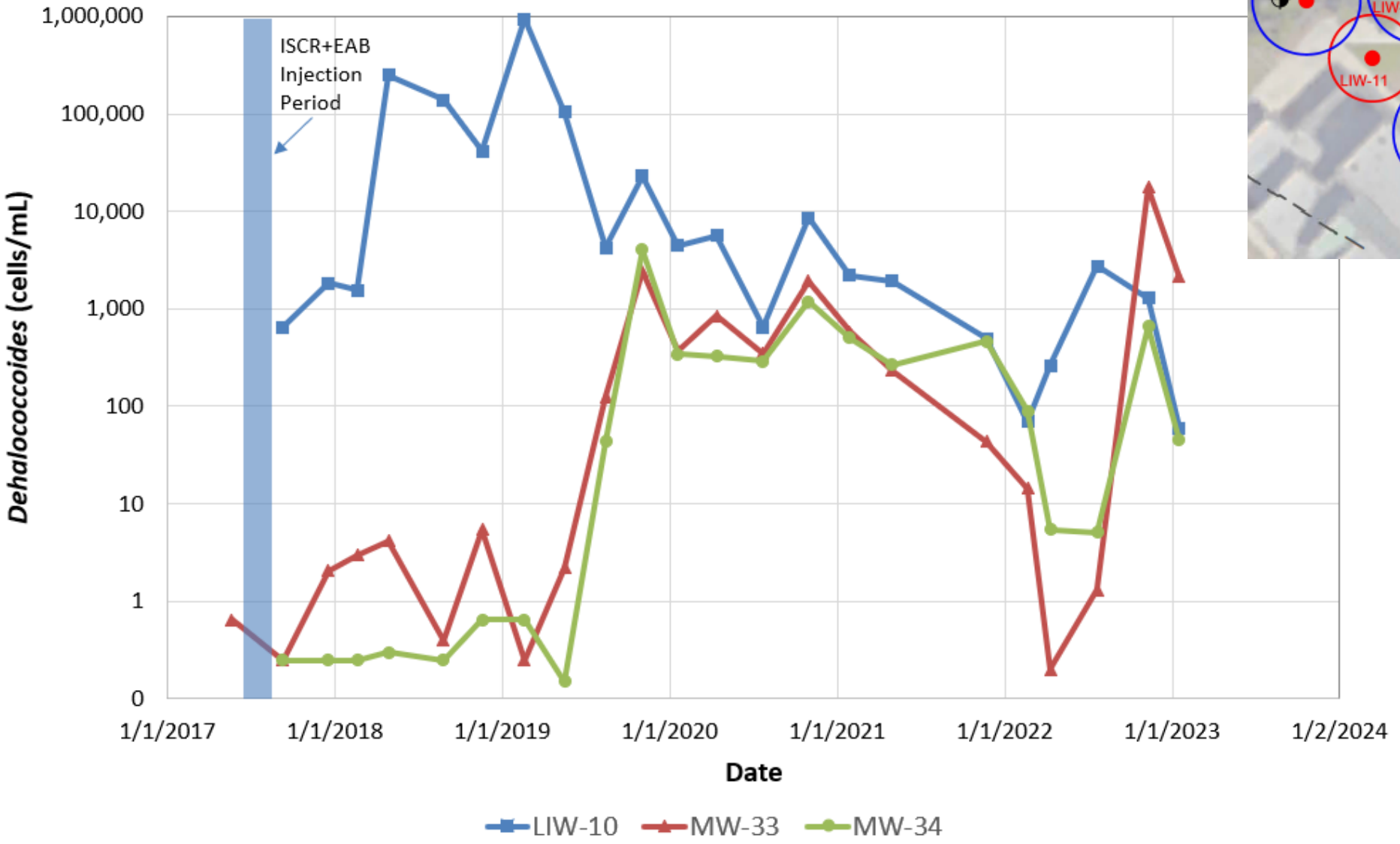
GEOCHEMICAL AND GENERAL CHEMISTRY RESULTS

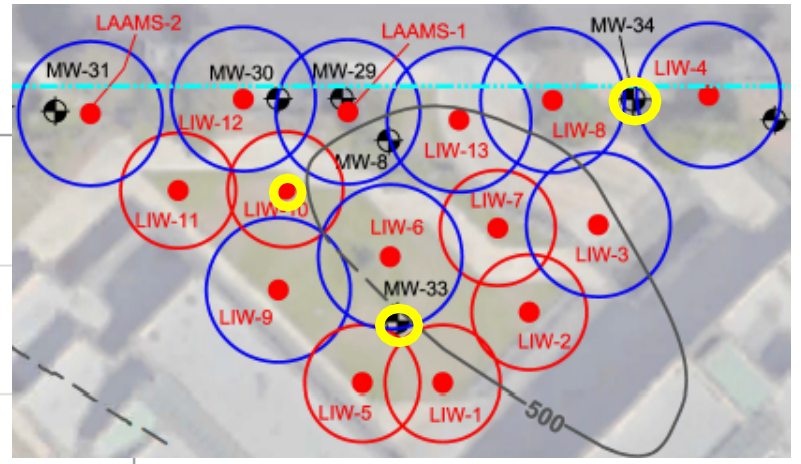
BASELINE (PRE-INJECTION)				
Monitoring Well	TOC (mg/L)	Ferrous Iron (mg/L)	ORP (mV)	DO (mg/L)
LIW-10	NM	NM	-4.9	1.12
MW-30	ND <5.0	ND <0.1	83.9	0.97
MW-8	2.7 J	ND <0.05	-445.6	0.29

POST-INJECTION				
Monitoring Well	TOC (mg/L)	Ferrous Iron (mg/L)	ORP (mV)	DO (mg/L)
LIW-10	2,500	230	-287	0.33
MW-30	540	3	-256	0.63
MW-8	14	1.2	-396.8	0.34



DECHLORINATING BACTERIA RESULTS



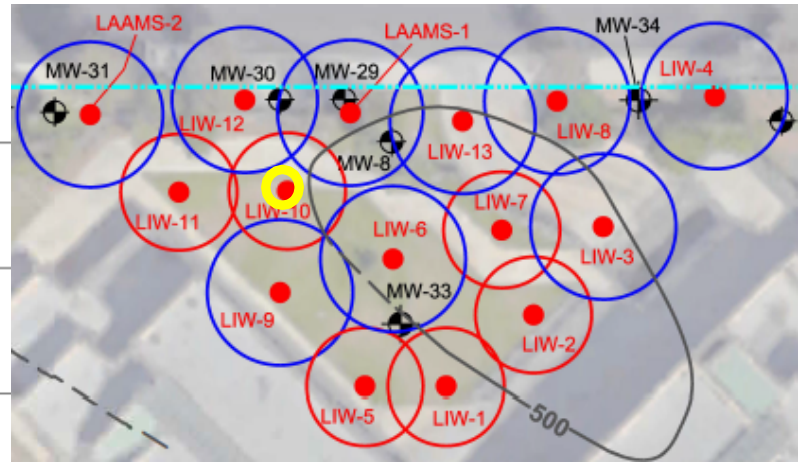


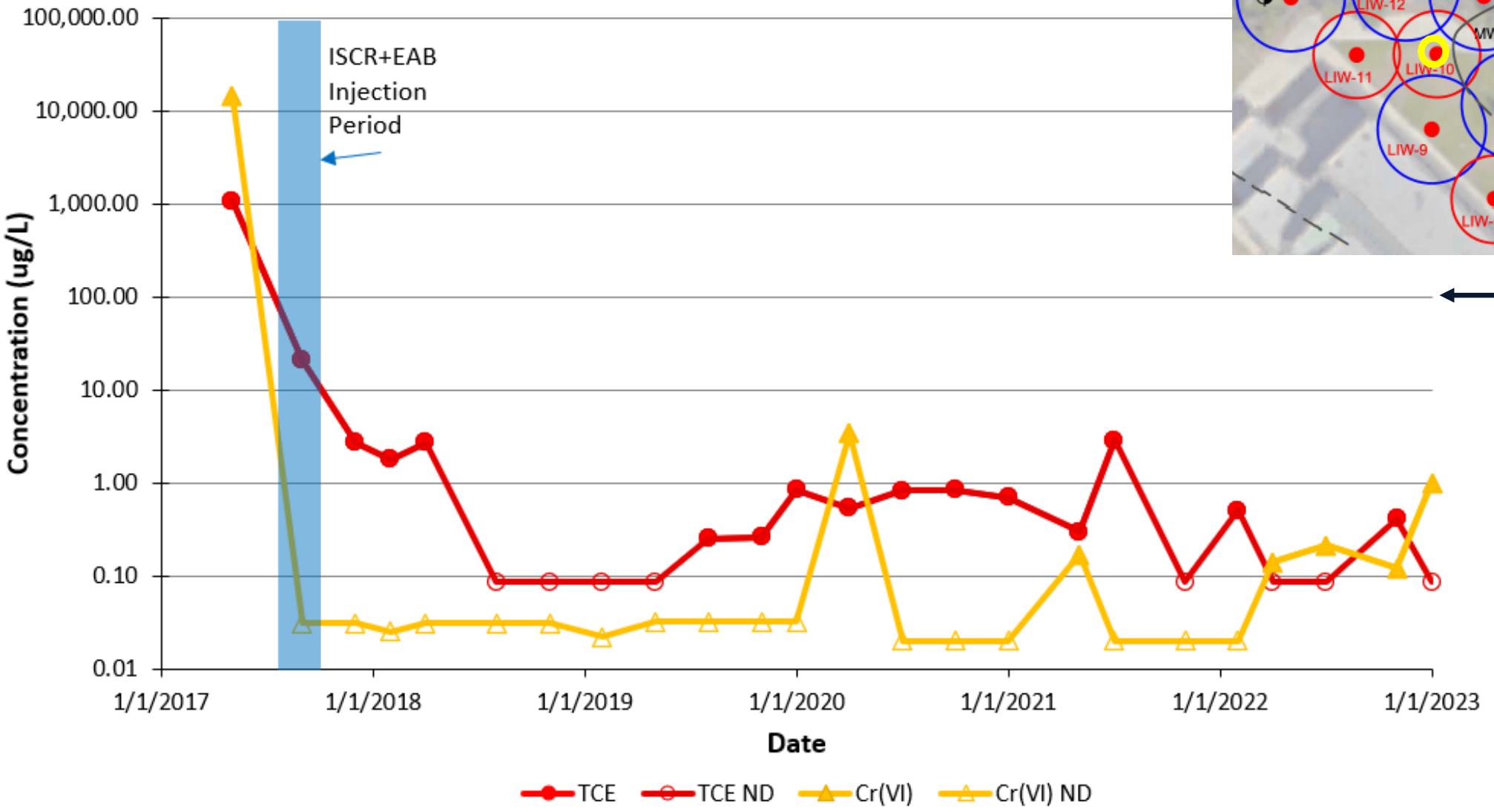
DECHLORINATING BACTERIA RESULTS

May 2021				
Monitoring Well	*Dehalococcoides* (cells/mL)	tceA TCE Reductase (cells/mL)	bvcA Vinyl Chloride Reductase (cells/mL)	vcrA Vinyl Chloride Reductase (cells/mL)
LIW-10	1,920	310	ND	578
MW-33	234	0.2 J	ND	23
MW-34	265	40	ND	40.2

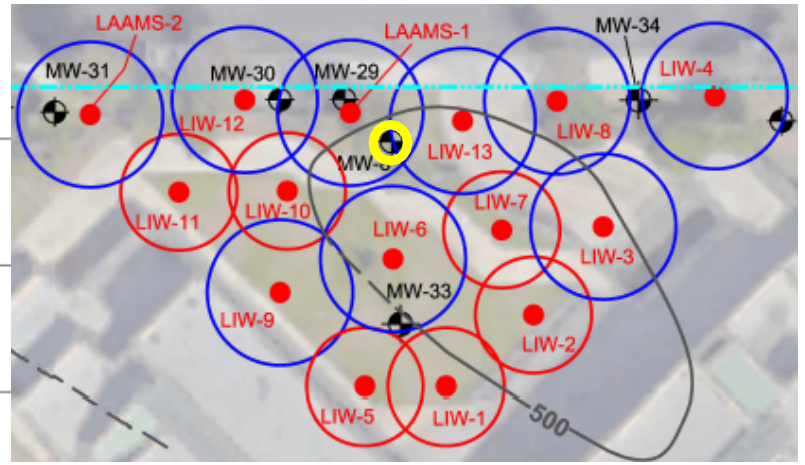
- **The presence of Dehalococcoides, tce reductase, and vinyl chloride reductase genes in the microbial analyses indicate that the appropriate microbial populations are present in the treatment area for complete reductive dechlorination of TCE to ethene**

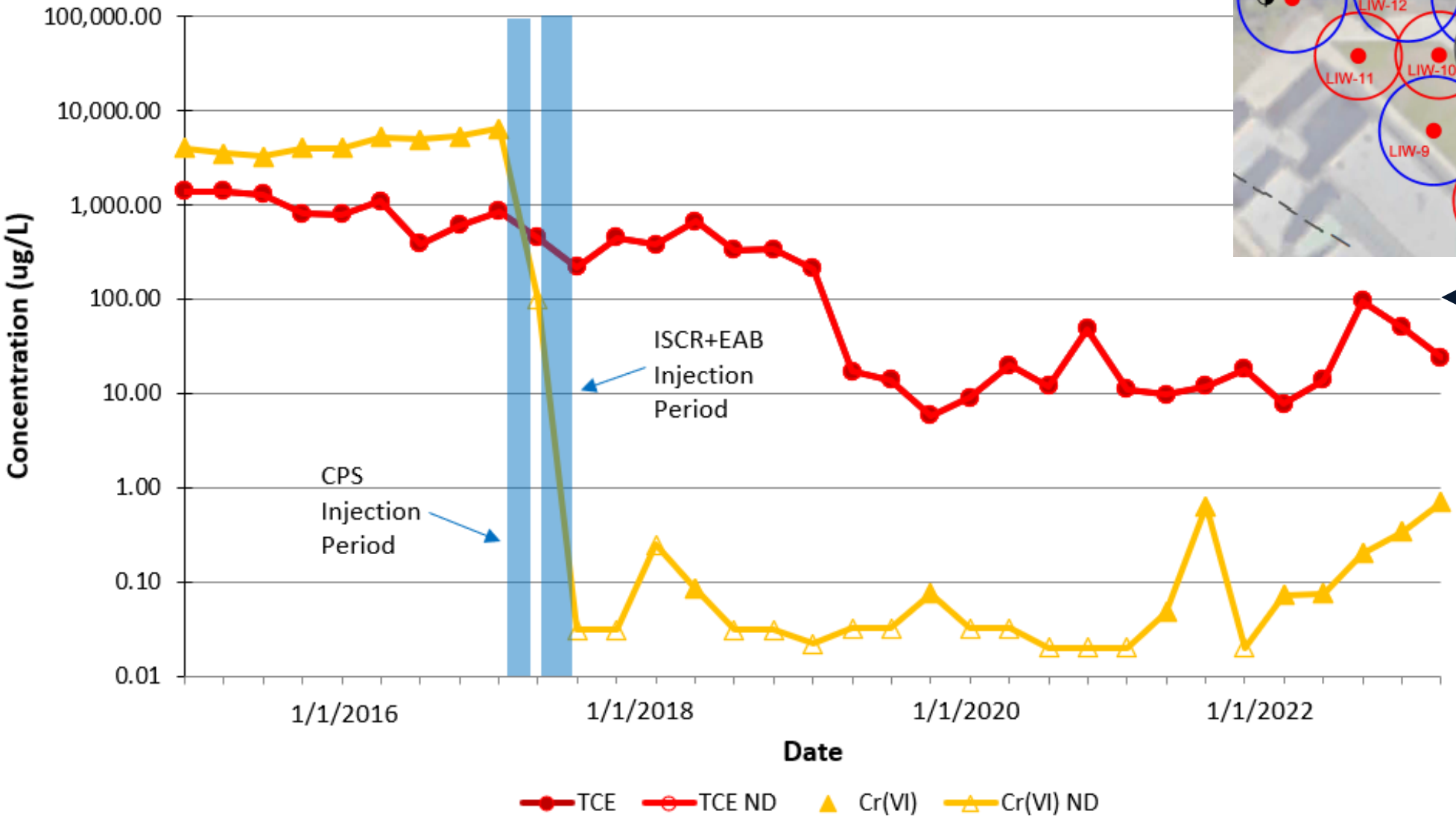
CONTAMINANT CONCENTRATIONS OVER TIME AT INJECTION WELL LIW-10



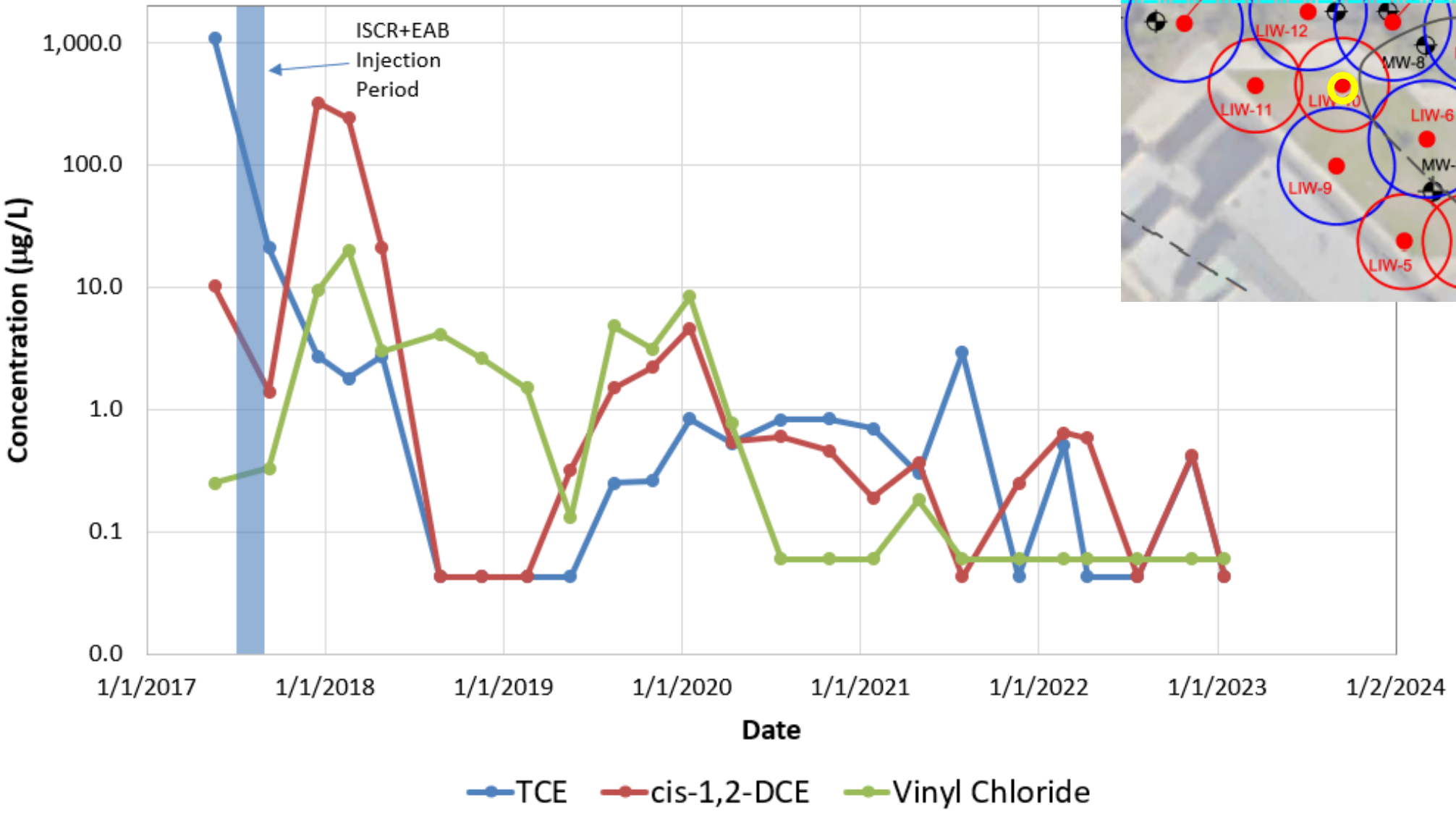


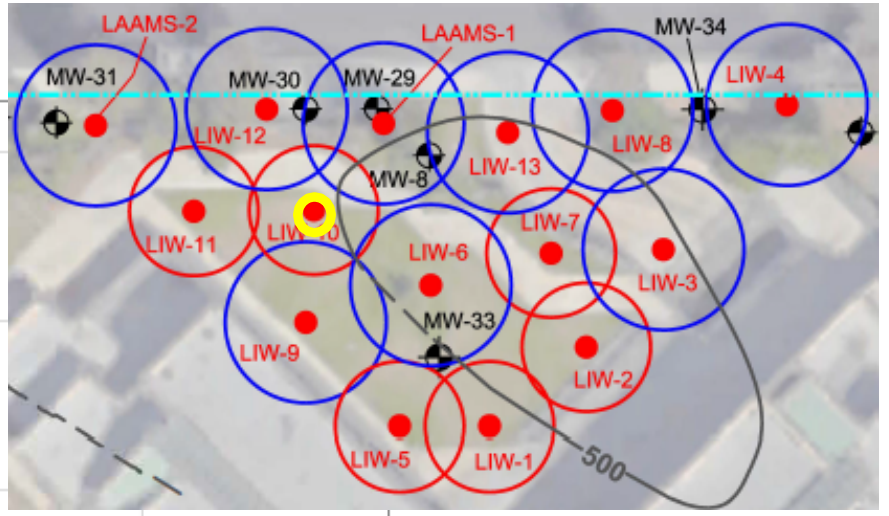
CONTAMINANT CONCENTRATIONS OVER TIME AT MONITORING WELL MW-8





DECHLORINATION OVER TIME AT INJECTION WELL LIW-10





KEY TAKEAWAYS

- **Commingled Cr(VI) and TCE plume required a unique combined remedy approach**
  - Overcome Cr(VI)'s inhibitory effect on TCE biodegradation
  - Prevent unacceptable secondary impacts to soil permeability and groundwater geochemistry

- **pH-adjusted CPS injections treated Cr(VI)**
  - Eliminated the typical negative impacts due to Ca precipitation
  - Provided favorable environmental conditions for the follow-on ISCR and EAB

- **Subsequent combined ISCR and EAB injections simultaneously treated Cr(VI) and TCE**
  - Cr(VI) and TCE plumes continue to shrink and rebound has not occurred
  - No additional injections or remedies have been required

- **Combined approach was cost effective and sustainable**

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Thank you!

QUESTIONS?

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