



EVALUATION OF CAT 100 SEQUESTRATION, REDUCTIVE DECHLORINATION, AND BIODEGRADATION OF A MIXTURE OF CHLORINATED SOLVENTS, PFAS, AND 1,4-DIOXANE

BATTELLE CHLORINATED CONFERENCE 2024



Raymond Vaské
Sr. Remediation Engineer
ICE Commercial
Cincinnati, OH
rvaske@trihydro.com

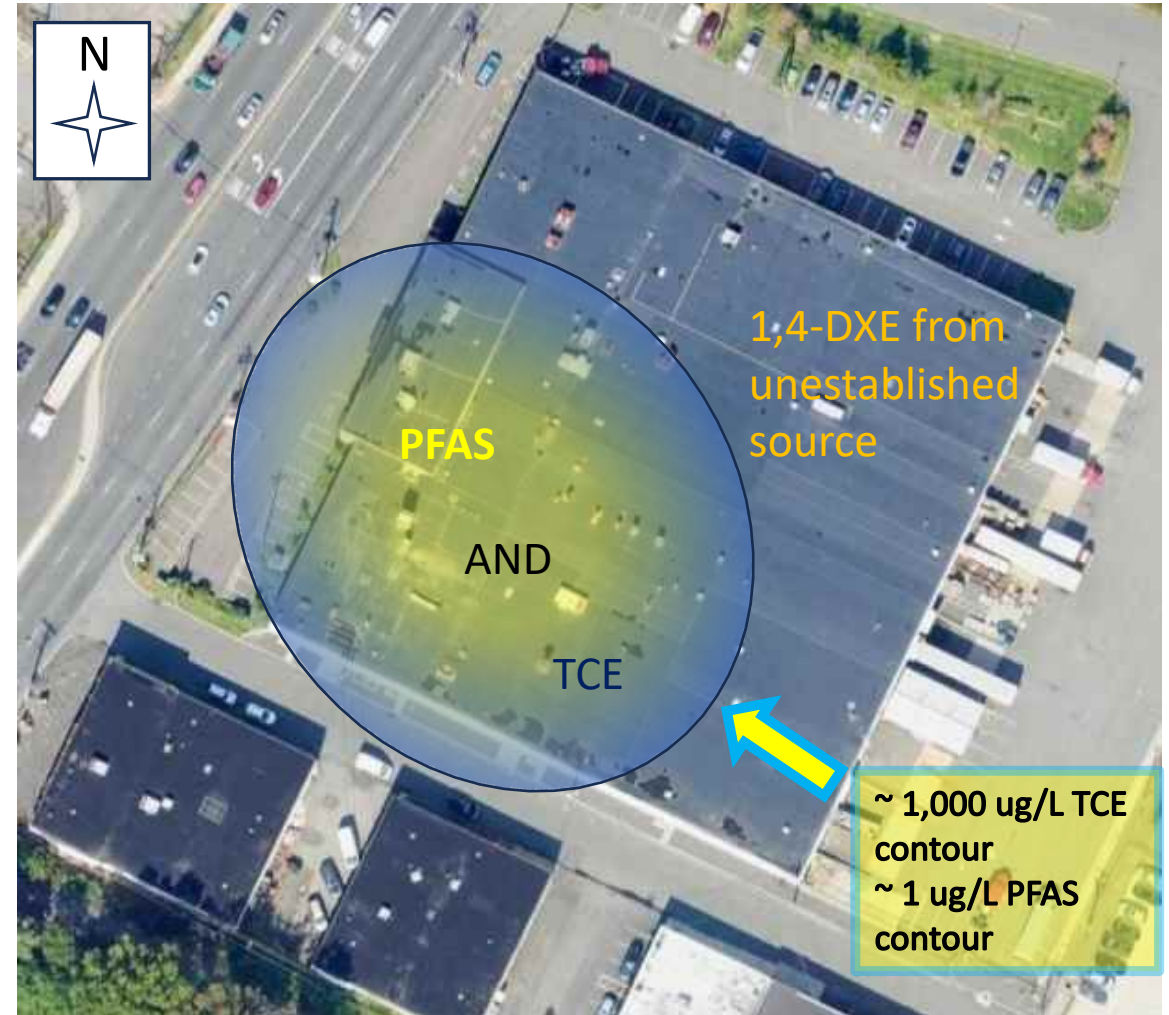
ACKNOWLEDGEMENT OF PROJECT TEAM

- AST Environmental – D. Guilfoil (President; Engineer), C. Hogg (Geo.), L. Brown (Geo.), N. Thacker (Geo.), and dedicated field engineers and scientists
- RPI, Inc. – S. Noland, President
- Trihydro – A. Riffel, B. Martinek, T. Beal
- Summit Drilling, Falcon Drilling
- Eurofins Laboratories, Microbial Insights, Microbac



SITE DISPOSITION

- 80,000 square-foot building
- >45,000 square feet of underlying soil and groundwater contaminated
- Comingled plumes of onsite- and offsite-derived chlorinated VOCs, PFAS, 1,4-DXE
- >100 mg/L TCE in overburden groundwater



Former manufacturing plant, New Jersey

SITE DISPOSITION

- Building under aggressive renovation
- Active operations
- Interim characterization and remediation of VOCs
- Remediation conducted under permit-by-rule



Former manufacturing plant, New Jersey

SITE HYDROGEOLOGY

- Glacial till – silt and clay with some sand and gravel; ~30 ft thick
- Depth to groundwater ~ 5 - 10 feet
- Saturated till monitored in 2 zones:
 - Shallow zone 5 - 15 feet bgs
 - Intermediate zone 15 – 35 ft bgs typical
- Underlying low permeability siltstone-shale bedrock; GW flow in weathered rock and fractures
- K in glacial till = 0.05 to 2 ft/day
- Average Hydraulic Gradient = 0.005 ft/ft
- Seepage velocity = ~ 1 to 15 ft/yr

PROJECT: Confidential					DATE STARTED: January 17, 2023			
BORING IDENTIFICATION: BCIP-01					NORTHING: DATE FINISHED: January 17, 2023			
DRILLING CONTRACTOR:					EASTING: TOTAL DEPTH: 40'		SCREEN INTERVAL: 26'-36'	
DRILLING METHOD: Sonic					ELEVATION: DEPTH TO WATER: 6		CASING:	
DRILLING EQUIPMENT: TSi 150 CC					LOGGED BY: Colin Hogg			
SAMPLING METHOD: Sonic					PROJECT MANAGER: Duane Guilfoil			REG. NO.
DEPTH (feet)	W/C OVERLY (%)	LAB I.D.	PID READING (ppm)	TCE (soil) (µg/kg)	DESCRIPTION NAME (USCS): color, sorting, plasticity, moisture, sorting, grain size, packing		WELL CONSTRUCTION DETAILS AND/OR DRILLING REMARKS	
0								
4	75				GC	Clayey sand and gravel, cobbles		
8					CL	Silty clay, trace gravel, low plasticity		
12					CH	Moderate plasticity silty clay, trace gravel		
16	100				GC	Gravelly clay, dense, wet, gravel up to 4" scale		
20					GM	Sand and gravel, coarse, poorly sorted		
24					GC	Gravelly clay, wet, mod plasticity		
28		BCIP-01 (26)	0.6	2.2		Weathered shale/siltstone, grey mottling, brittle		
32		BCIP-01 (28)	0.7	<0.5				
36		BCIP-01 (30)	1.1	<0.5				
40	150	BCIP-01 (32)	0.6	<0.5		Sand and gravel, coarse, lenses of soft grey mottled clayey sand, 4" core of siltstone at 32', fissile structure		
44		BCIP-01 (34)	1.3	<0.5				
48		BCIP-01 (35)	1	140	CH	Clay, high plasticity, wet		
		BCIP-01 (36)	1	530		Competent rock core of slightly weathered dense siltstone		
	100	BCIP-01 (37)	2.5	<0.5	GM	Weathered sand and angular cobbles, trace grey mottles		
60		BCIP-01 (39)	1.6	<0.5		Fractured siltstone, up to 6" of solid rock core, vertical joints/faults at 44' with grey color and mineralized vugs containing coarse grained sediment		
48						Boring Terminated		

AST Environmental Inc.

Project No. 5152369

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GW FLOW - SHALLOW TILL

**Inferred flow direction is variable;
may in part reflect locally perched
conditions, building footprint, and
influence of utility corridors**



GW FLOW – LOWER TILL

Consistent flow direction to the east - southeast across most of the site



BASELINE GROUNDWATER CHEMISTRY

- DO levels typically at or below 1 mg/L
- ORP levels from -150 mV to +200 mV
- pH values near neutral
- Little to no organic carbon present
- Very low levels of magnetically susceptible materials
- Sulfate levels from 22 mg/L to 620 mg/L, typically >100 mg/L
- *Dehalococcoides mccartyi* detected at 10^1 cells per mL (shallow/intermediate GW) to 10^4 cells per mL (bedrock GW), with tceA, BAV1 VC (BVC), and Vinyl Chloride (VCR) reductases at 10^3 cells per mL in bedrock GW (200 feet bgs)
- 10^1 to 10^4 cells per mL of sMMO, PHE, RDEG, RMO, EtnC oxygenases
- Methanogens detected at up to 10^2 cells per mL
- 10^4 cells per mL sulfate-reducing bacteria

REMEDIATION OBJECTIVES

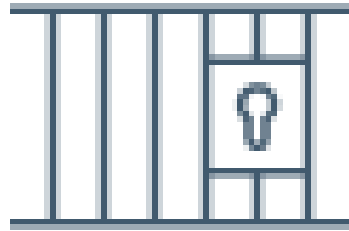


Target/reduce TCE in overburden saturated zone
within 1,000 µg/L isocontour



Target/reduce PFAS in overburden saturated zone
within 1 µg/L isocontour

REMEDIATION PROCESSES

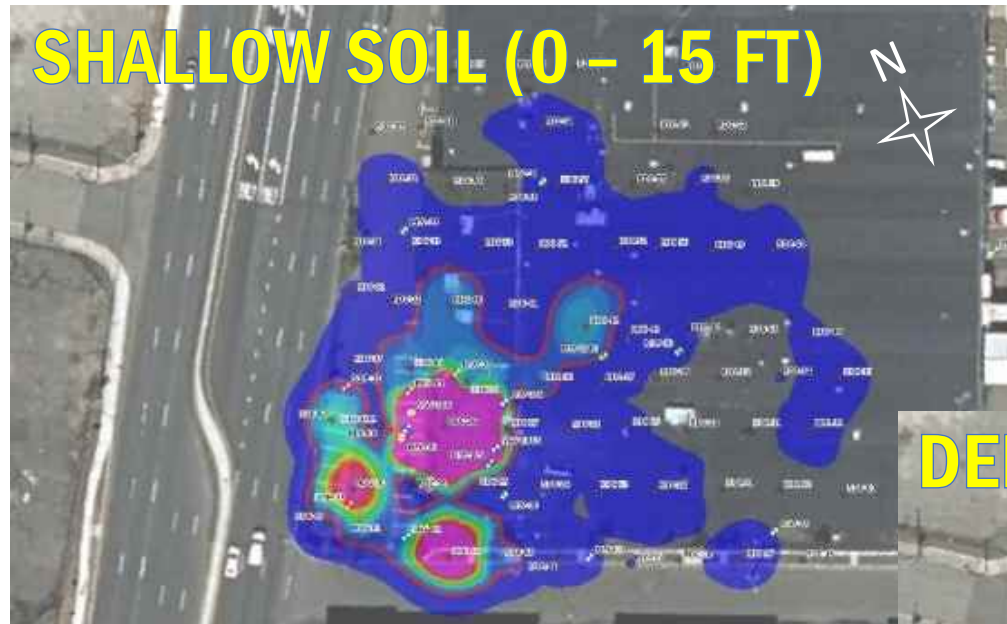


Sequestration of chlorinated VOCs, PFAS, and 1,4-dioxane – reduce mass flux across property boundary



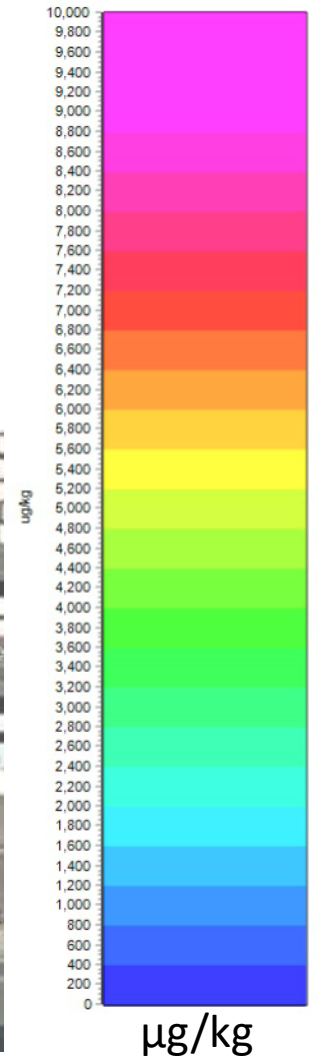
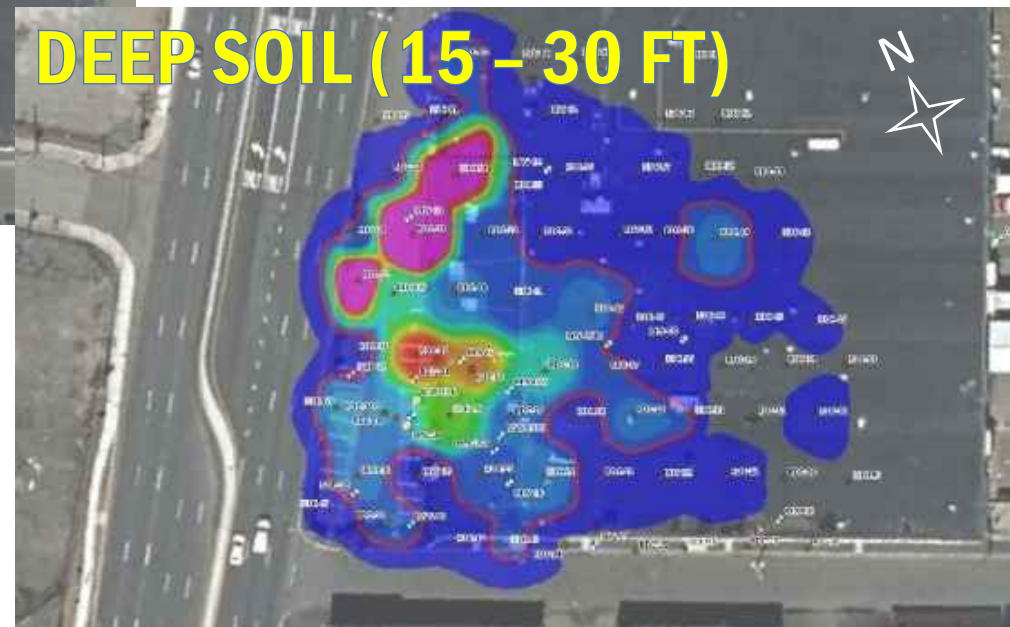
Abiotic and biotic reductive dechlorination of high concentrations of chlorinated ethenes

SUPPLEMENTAL CHARACTERIZATION



**TCE DETECTED AT
UP TO
179,000 $\mu\text{g}/\text{kg}$**

**650+ SOIL SAMPLES
COLLECTED FROM
70 BORING LOCATIONS**

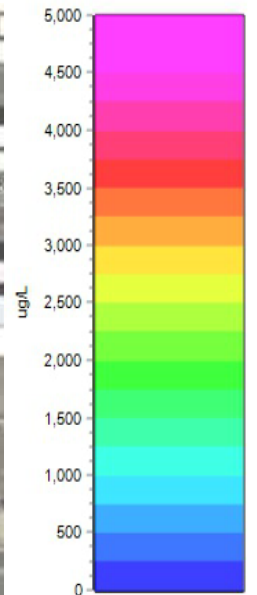
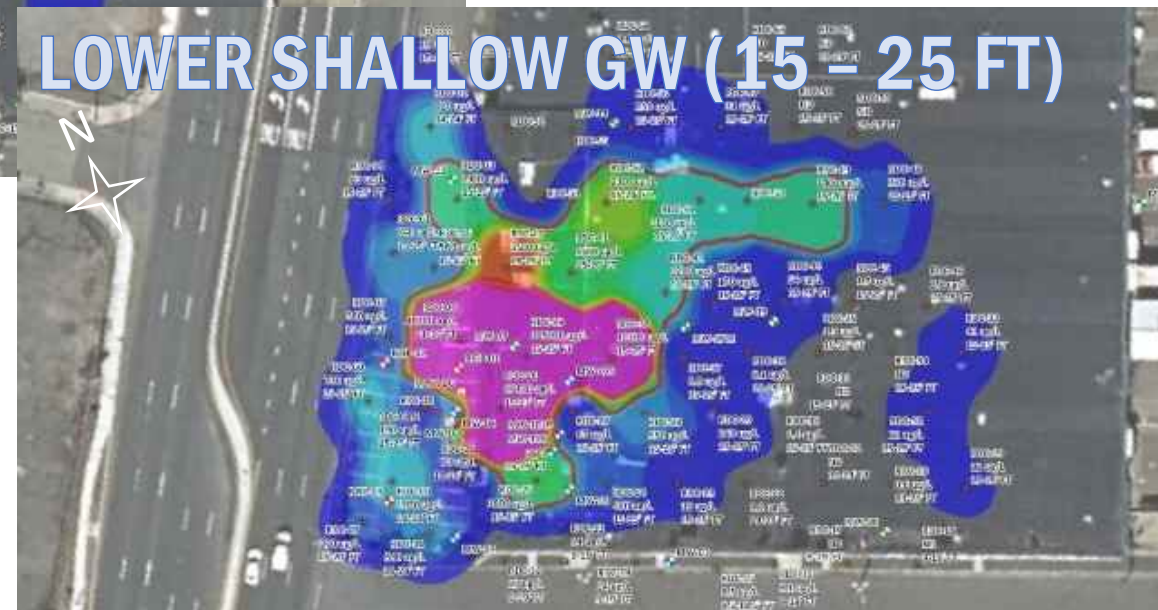


SUPPLEMENTAL CHARACTERIZATION

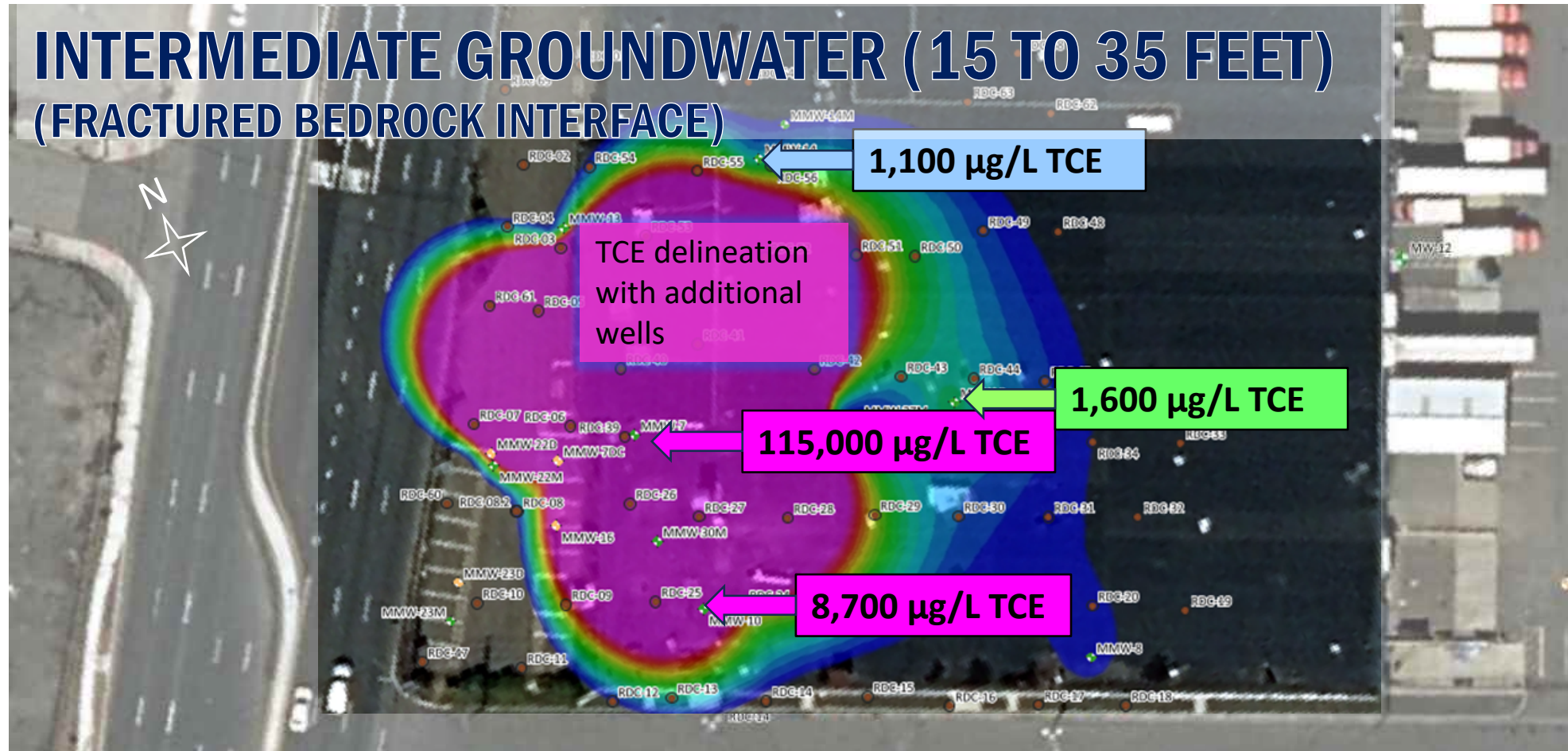


**TCE DETECTED AT
UP TO
136,000 µg/L**

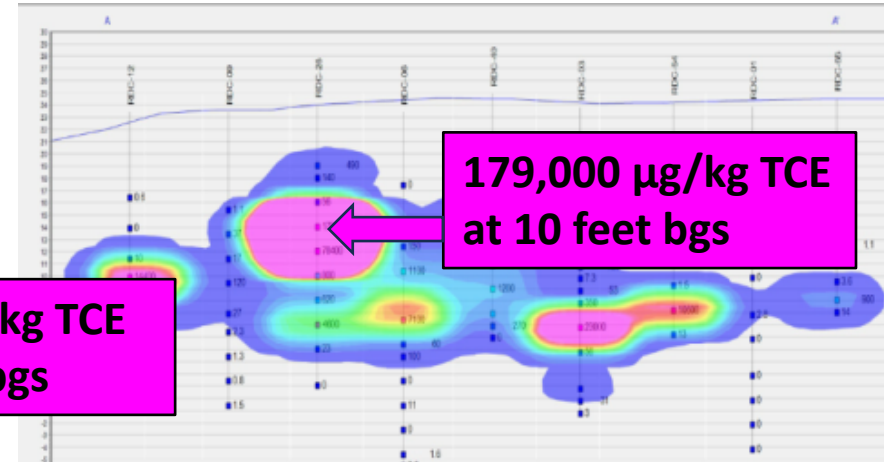
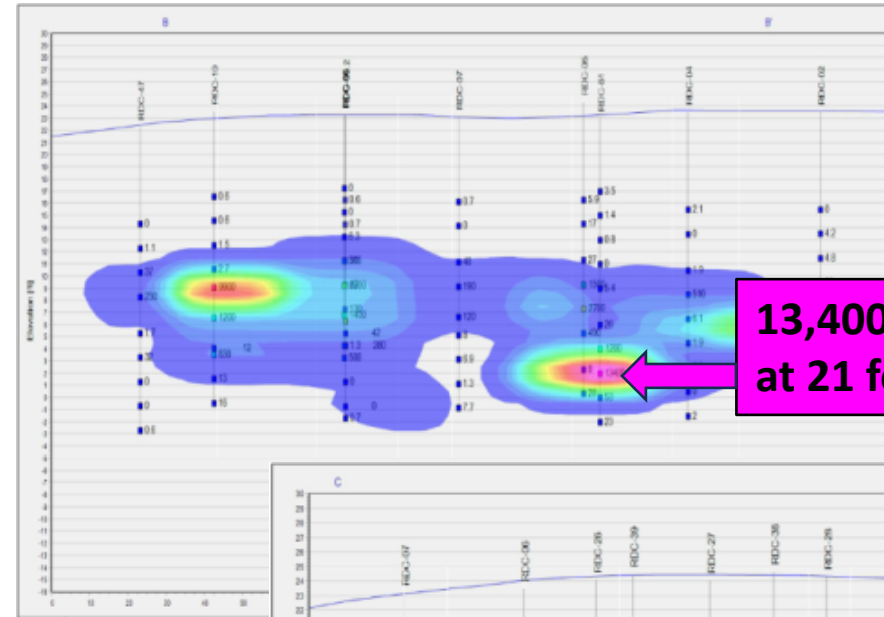
**200+ GW SAMPLES
COLLECTED FROM
140 TEMPORARY WELLS
AND
20 MONITORING WELLS**



SUPPLEMENTAL CHARACTERIZATION

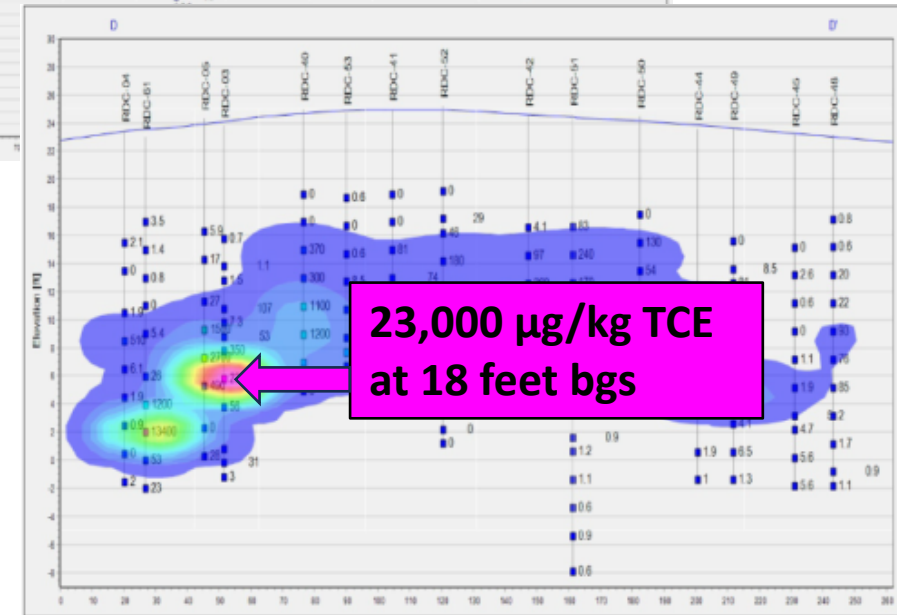
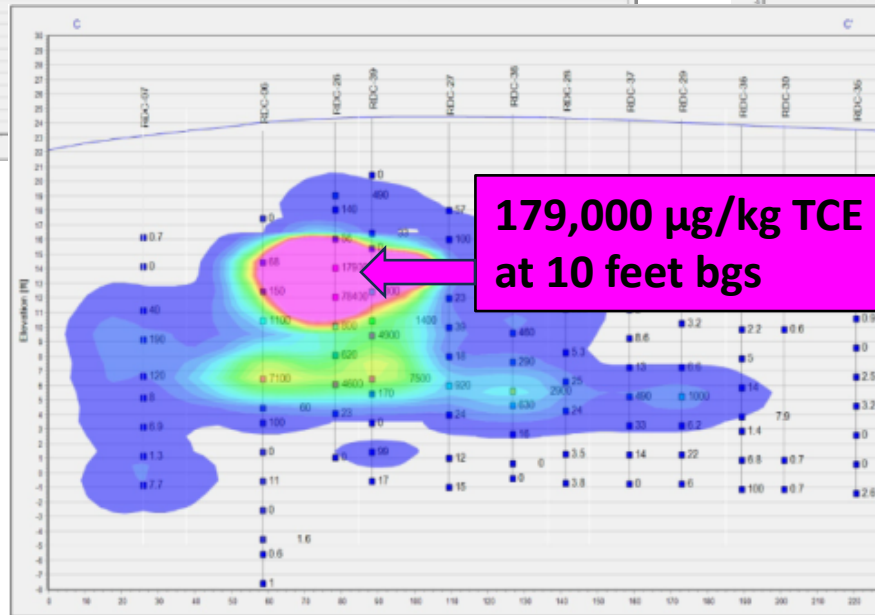


SUPPLEMENTAL CHARACTERIZATION



SOIL

SOIL



RPI CAT 100 AMENDMENT & DESIGN

CAT 100 REMEDICATION PRODUCTS INC.

Primary Use

Soils and groundwater highly impacted with halogenated compounds and complex mixes of recalcitrant contaminants typically addressed through combined remedies.

Treatment Mechanism

Catalytic degradation of a broad spectrum of halogenated and recalcitrant organic compounds through surface reactions on a conductive platform fed with a continuous source of electrons.

- CAT 100 is a combination of metallic iron-impregnated carbon (BOS 100[®]) and degradable organic substrates (corn starch and pea fiber), yeast extract, and vitamin B-12, that synergistically catalyze the reductive dechlorination of chlorinated VOCs, including PCE, TCE, and associated daughter compounds.
- In an anaerobic setting, the fused iron and carbon are believed to facilitate the transfer of electrons produced when substrates are fermented under biogeochemically favorable conditions.

RPI CAT 100 AMENDMENT & DESIGN

CAT 100
REMEDICATION
PRODUCTS INC.

Primary Use
Soils and groundwater highly impacted with halogenated compounds and complex mixes of recalcitrant contaminants typically addressed through combined remedies.

Treatment Mechanism
Catalytic degradation of a broad spectrum of halogenated and recalcitrant organic compounds through surface reactions on a conductive platform fed with a continuous source of electrons.

- Proposed mechanisms at target site:
 - Sequestration of VOCs (within high-surface-area GAC)
 - Abiotic reduction of chlorinated VOCs (metallic iron contact)
 - Bioaugmentation and microbial community enhancement with a proprietary blend of bacteria. Indigenous populations *Dehalococcoides mccartyi* and other beneficial anaerobic bacteria were previously confirmed, and not added.
 - Complex combination of anaerobic biodegradation, cometabolic oxidation (accompanying the formation of methane), and potentially, microbially mediated reduction by iron-bearing minerals



QUANTITIES

- 199,700 pounds CAT 100, including:
 - 110,000 pounds BOS 100
 - 77,700 pounds corn starch
 - 9,100 pounds pea fiber
 - 1,900 pounds yeast extract
 - 225 gallons bacteria
- Slurry injected on 2-foot intervals
- Up to 35 gpm in shallow soil
- Up to 110 gpm near top of bedrock (fractured)



LOGISTICAL CHALLENGES



9-foot OH clearance



11-foot OH clearance



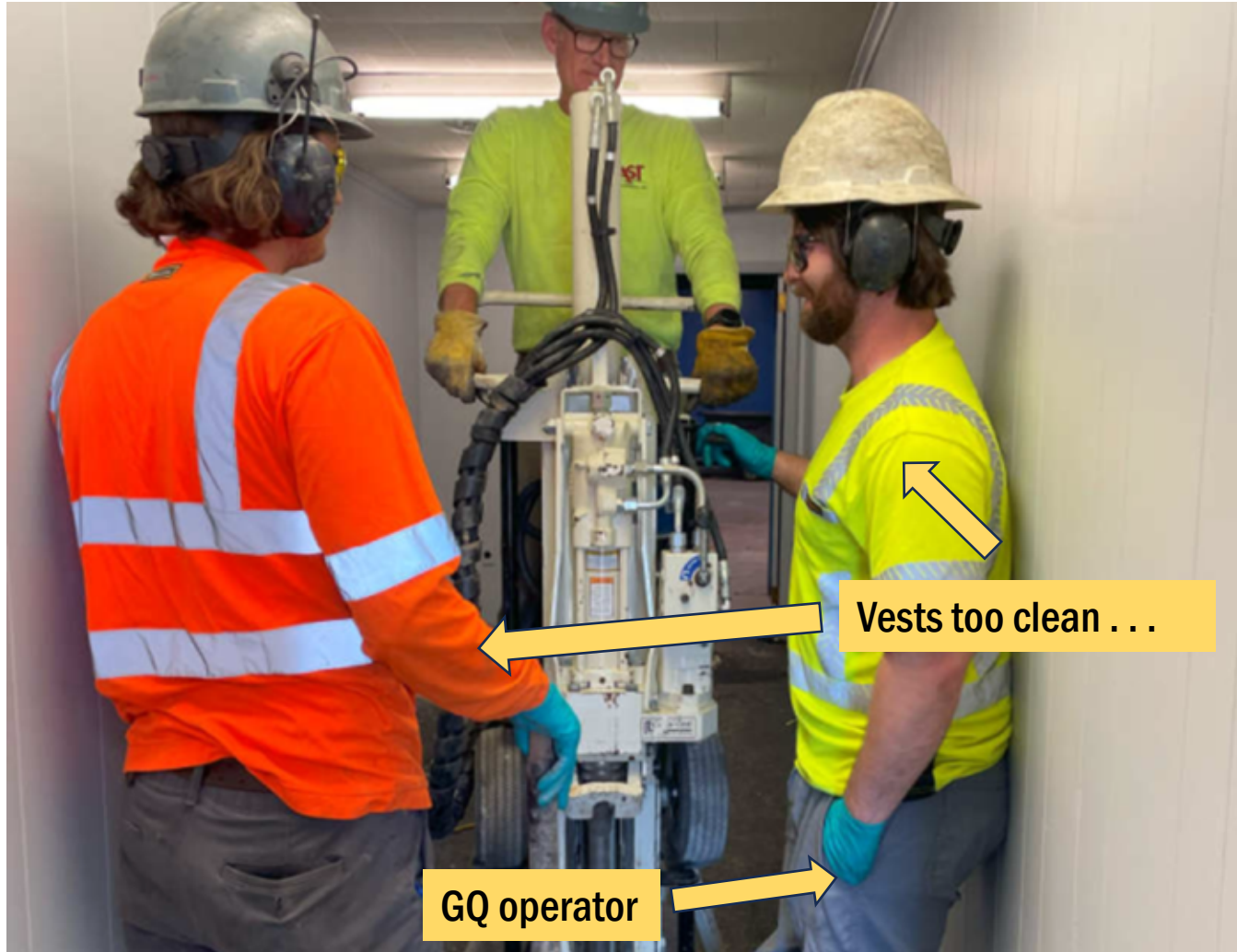
Traffic and overhead electrical power

LOGISTICAL CHALLENGES

- New construction (yellow)
- Limited second-story demolition permitted by client for well installation
- Unmarked underground sewer drain



DOLLY RIG IN CONFINED SPACE



- Injection in . . .
 - Hallways
 - Bathrooms
 - Cafeteria
 - Production Areas
 - Utility Corridors
 - Parking Lot
- Second-story demolition conducted near PFAS source area



PRE- AND POST-INJECTION EVALUATION

MEASUREMENT

- Chlorine number examined for short-term performance evaluation
 - Molar concentrations of PCE, TCE, DCE, VC, and ethane/ethene are calculated for all well samples.
 - Total atoms of chlorine in the targeted chlorinated ethenes is divided by total moles of chlorinated ethenes, ethene, and ethane = chlorine number.
 - PCE = 4 chlorines
 - TCE = 3 chlorines
 - DCE = 2 chlorines
 - VC = 1 chlorine
 - Ethene and ethane (possible end products) = zero chlorines

MEASUREMENT

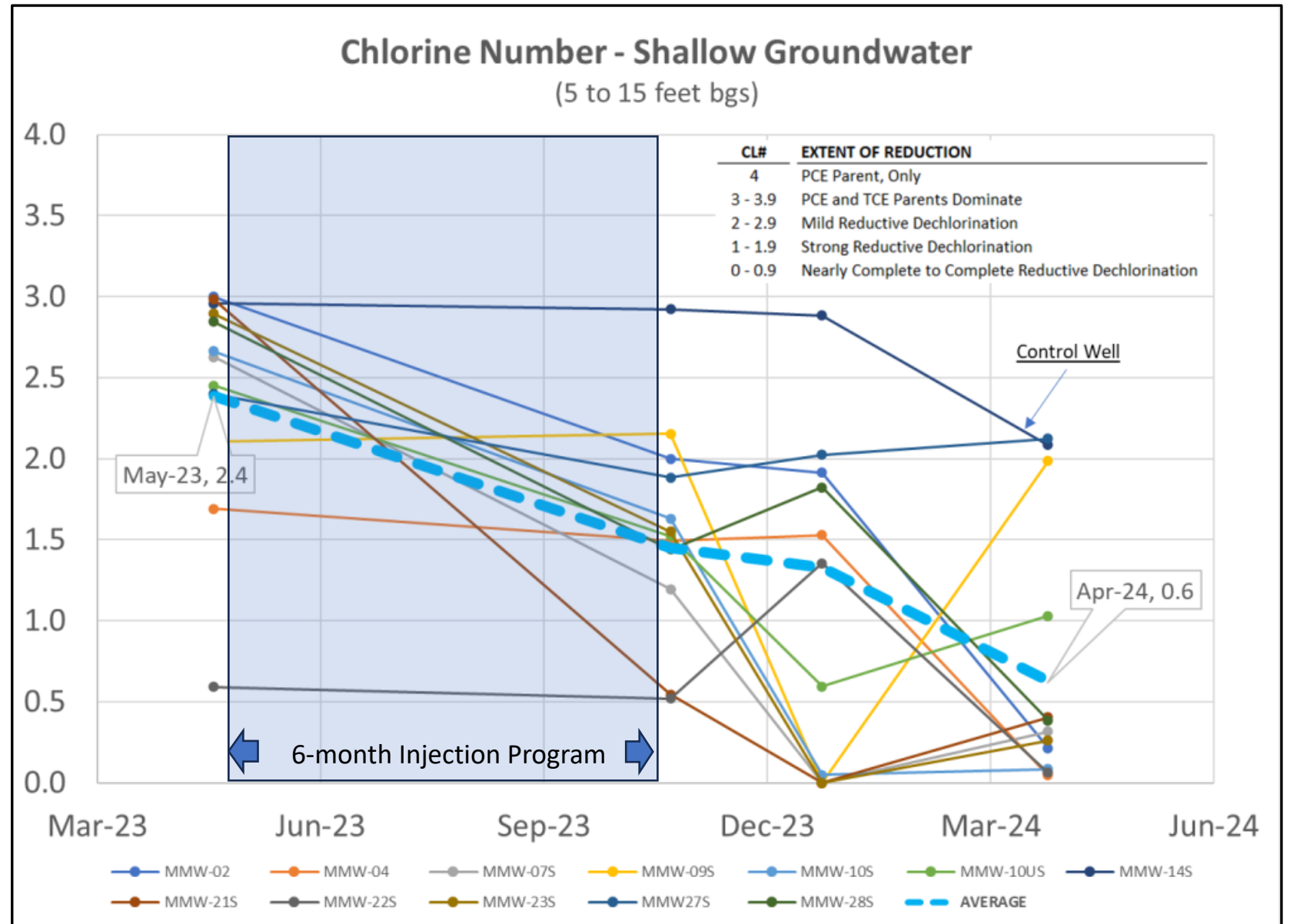
Chlorine Number and Graphical Interpretation

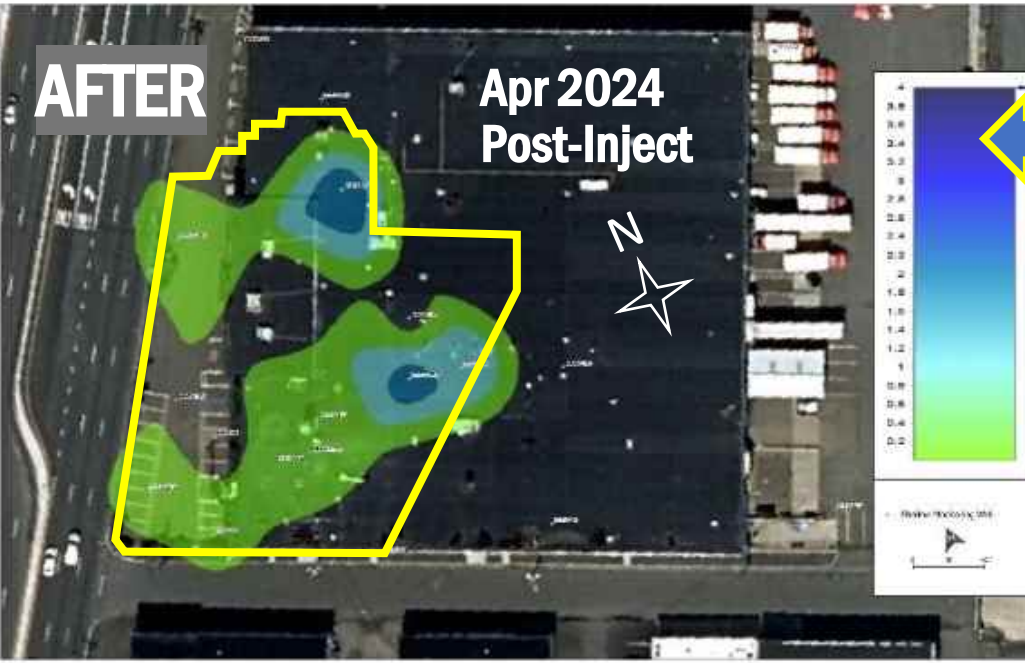
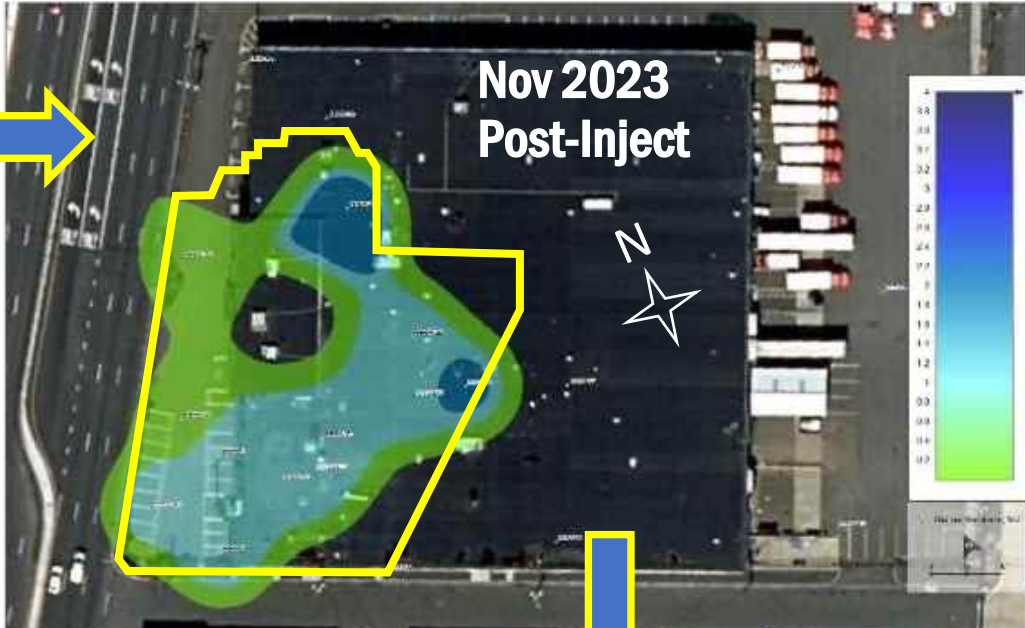
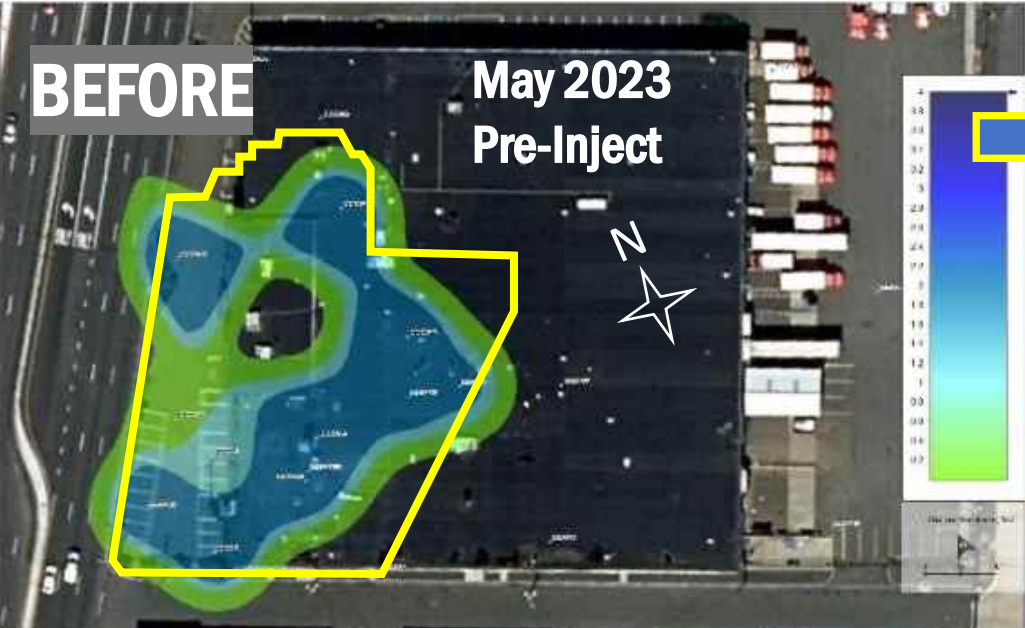
CL#	EXTENT OF REDUCTION
4	PCE Parent, Only
3 - 3.9	PCE and TCE Parents Dominate
2 - 2.9	Mild Reductive Dechlorination
1 - 1.9	Strong Reductive Dechlorination
0 - 0.9	Nearly Complete to Complete Reductive Dechlorination

*Caveat: CL# is useful primarily where high concentrations of parent compounds dominate prior to remediation, i.e., where large changes can be observed. Less applicable where, for example, 1 ug/L of PCE (Cl# 4) – and nothing else – might suggest an apparent lack of reduction, or where, say 10,000 ug/L of only VC (Cl# 1) might be misleading regarding the amount of reductive dechlorination to go.

RESULTS

- Shallow Groundwater
- Decrease in Cl# average from 2.4 to 0.6
- Average TCE decreased from 711 $\mu\text{g/L}$ to 37 $\mu\text{g/L}$
- Maximum TCE decreased from 9,700 $\mu\text{g/L}$ to <5 $\mu\text{g/L}$

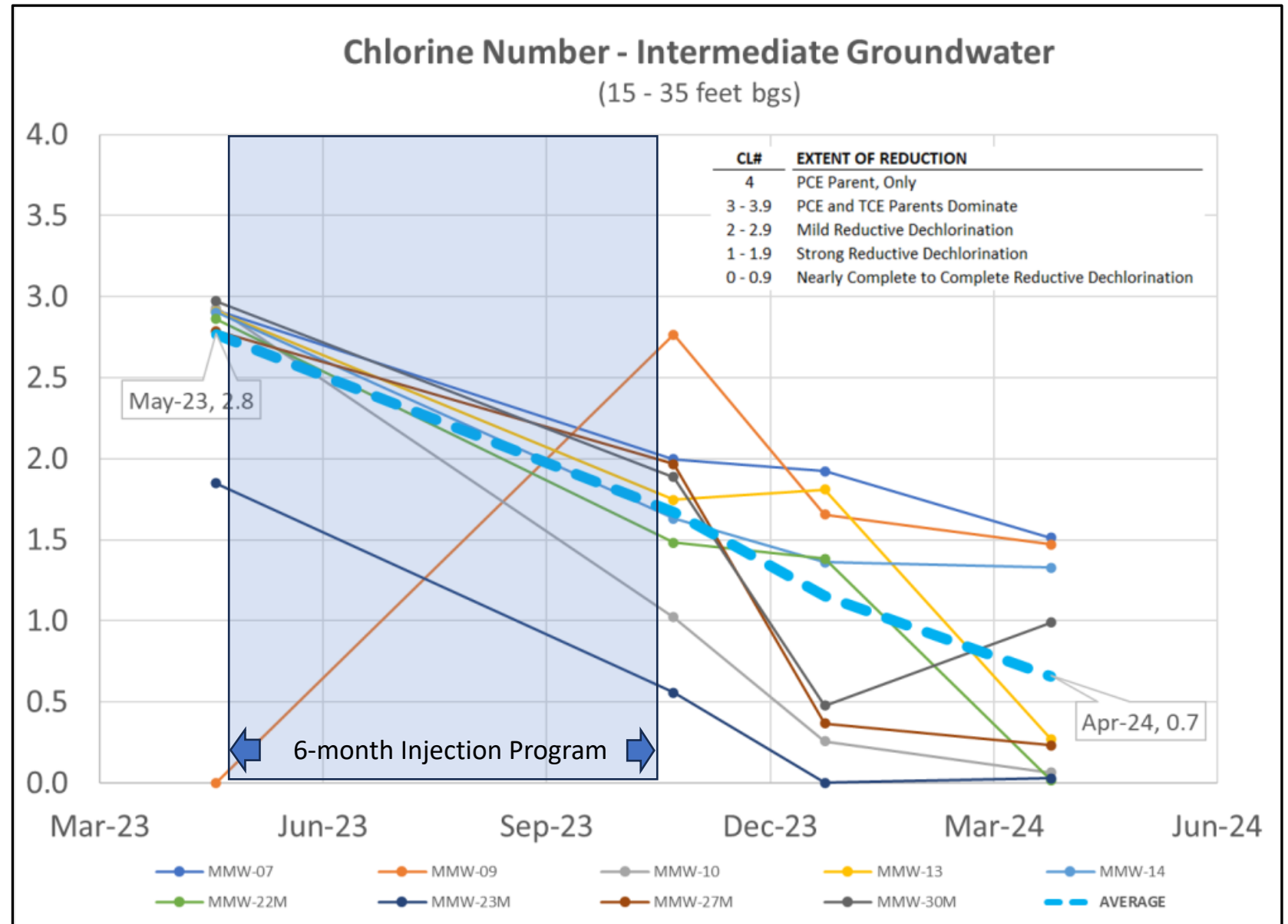


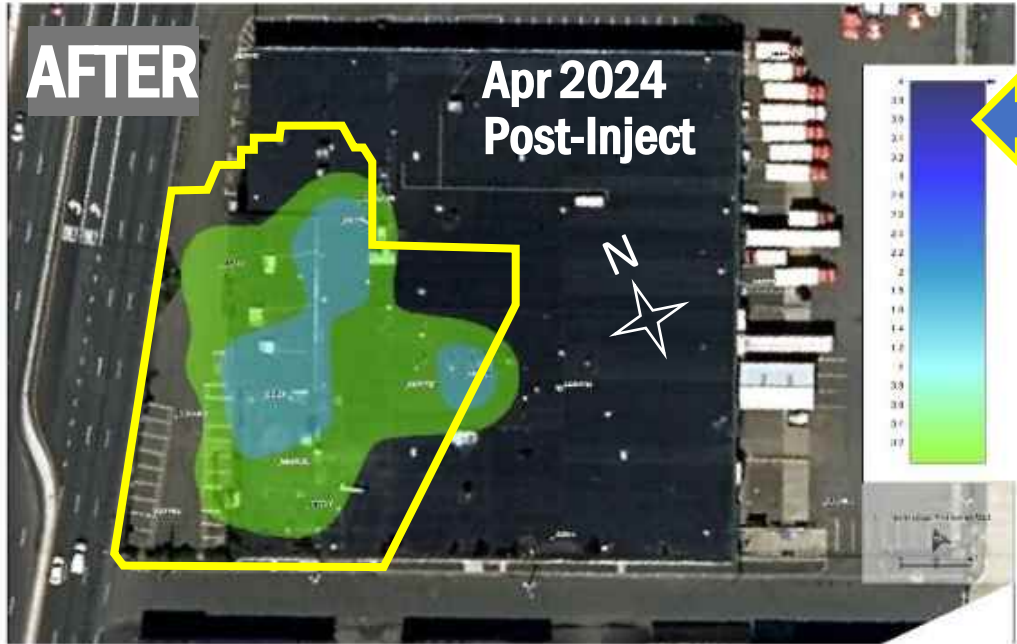
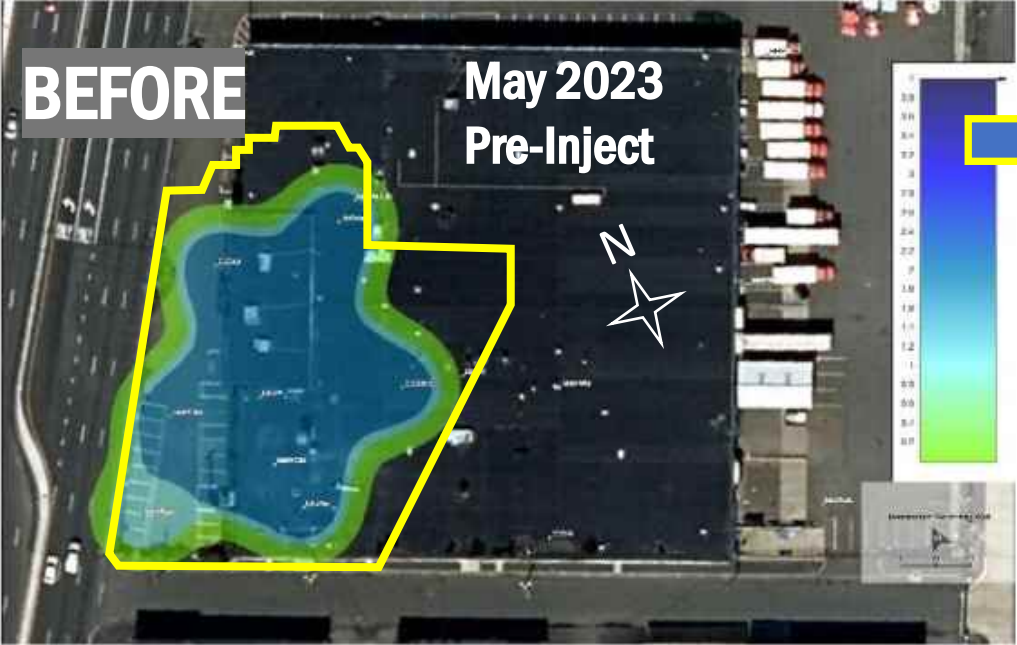


Shallow
Groundwater

RESULTS

- Intermediate Groundwater
- Decrease in Cl# average from 2.8 to 0.7
- Average TCE decreased from 14,909 $\mu\text{g/L}$ to 6.6 $\mu\text{g/L}$
- Maximum TCE decreased from 136,000 $\mu\text{g/L}$ to <100 $\mu\text{g/L}$



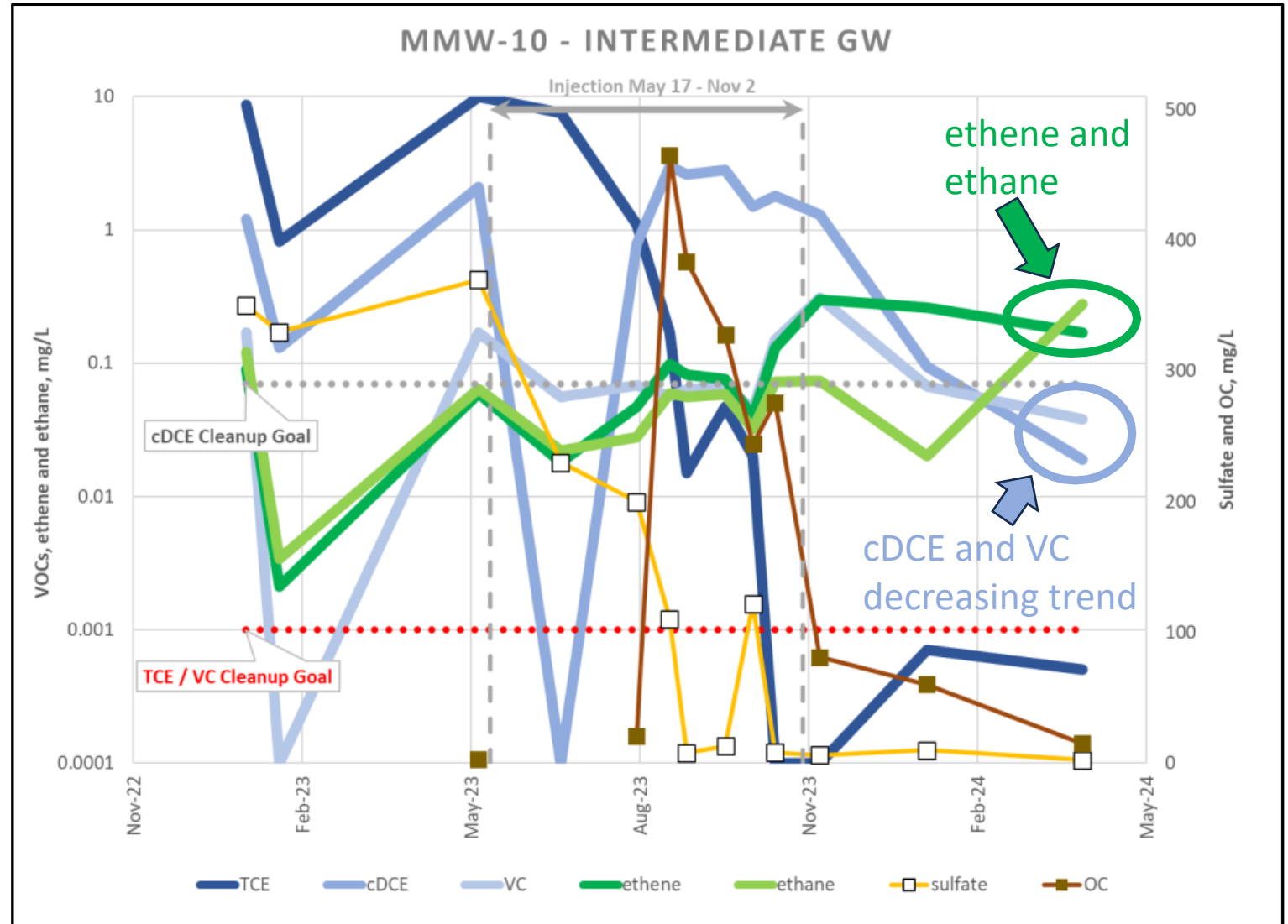


Intermediate
Groundwater

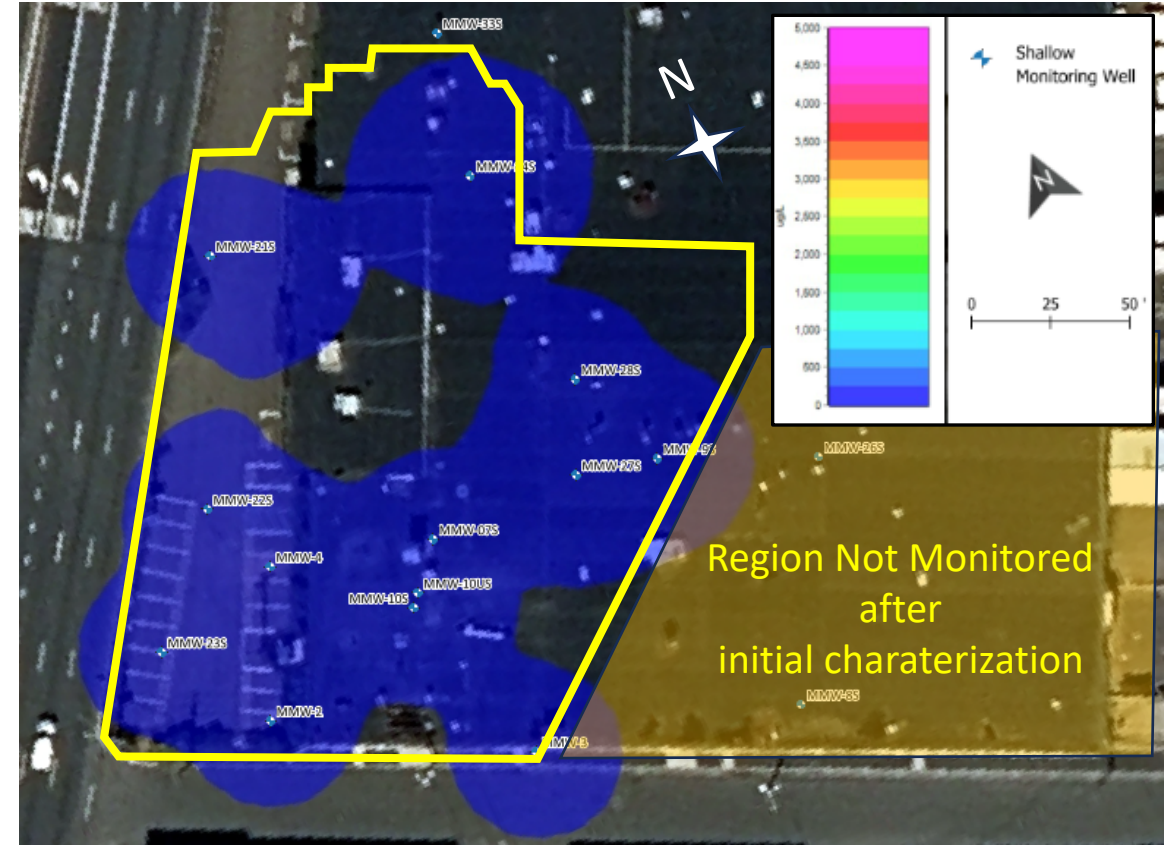
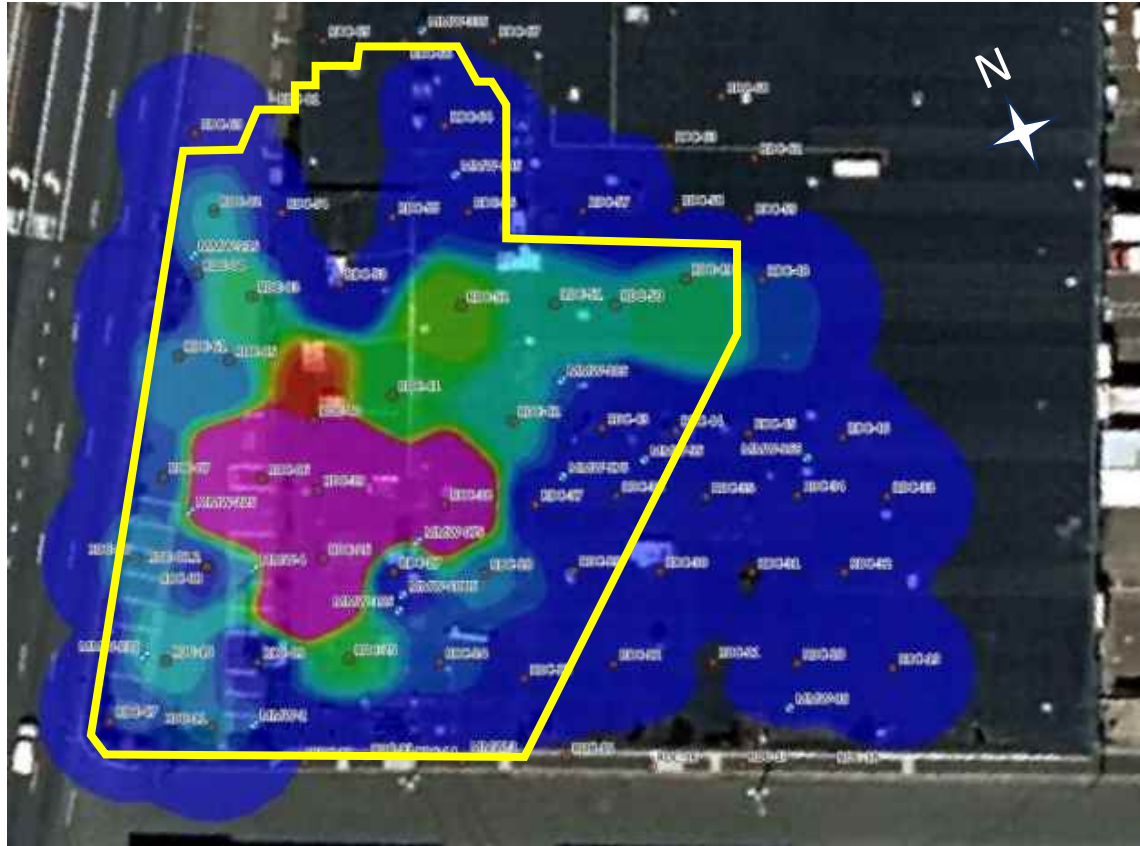
-
- MMW-02 - SHALLOW GW**
- Injection May 17 - Nov 2
- cDCE Cleanup Goal
- TCE / VC Cleanup Goal
- ethene
- sulfate
- Organic Carbon
- Legend: TCE, cDCE, VC, ethene, sulfate, Organic Carbon

SELECT CHARTS

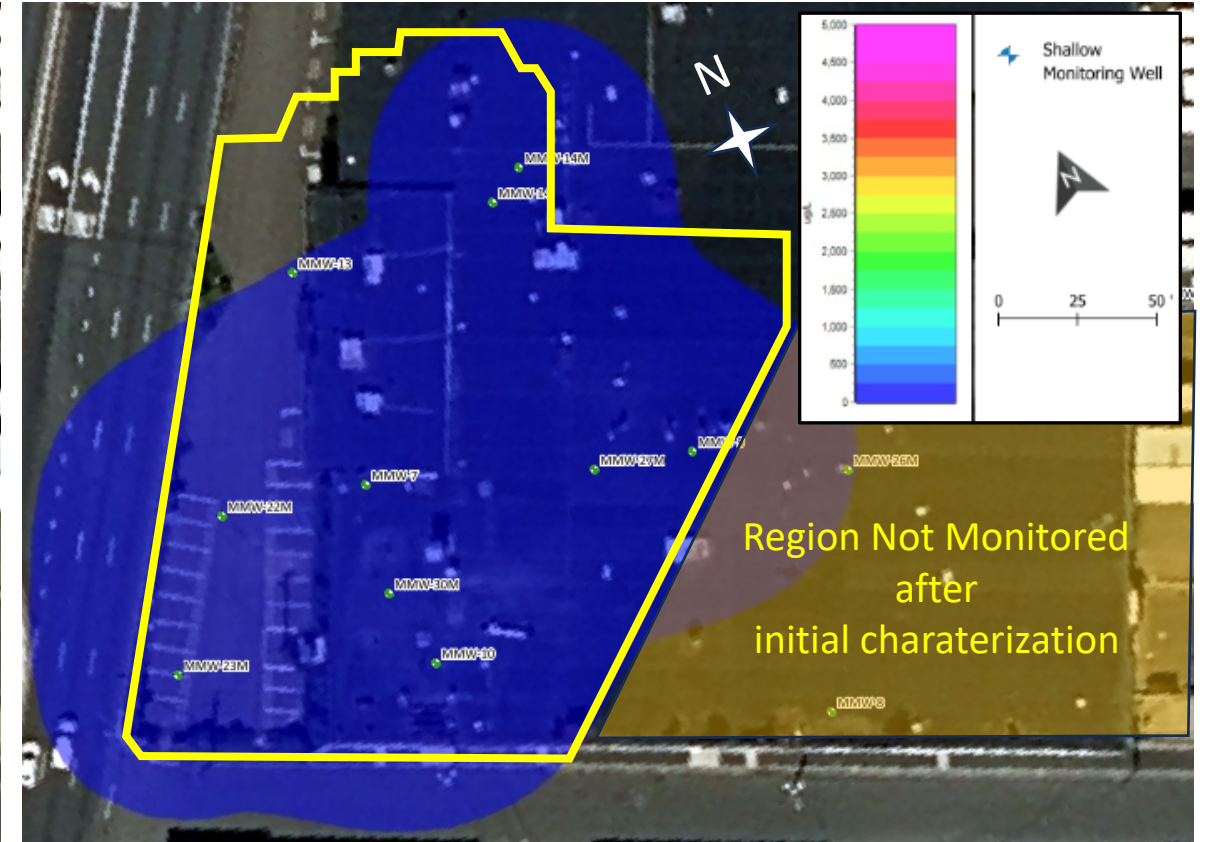
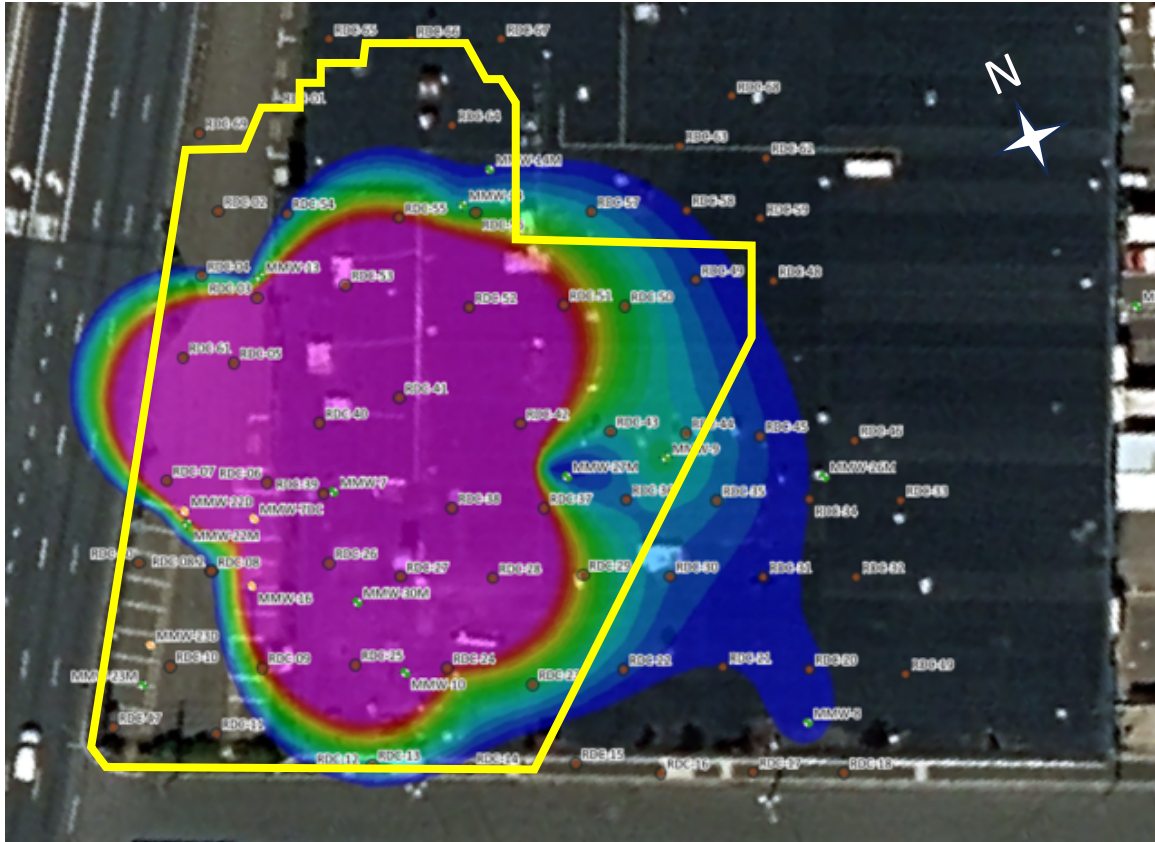
- Intermediate Groundwater
- PPM VOCs reduced to PPB VOCs
- TCE and cDCE below cleanup goal
- Only VC (0.038 mg/L) exceeds cleanup goal
- VC and cDCE decreasing
- Ethene and ethane dominate under sulfate-reducing conditions



TCE – SHALLOW GW BEFORE / AFTER (5 – 15 FEET BGS)

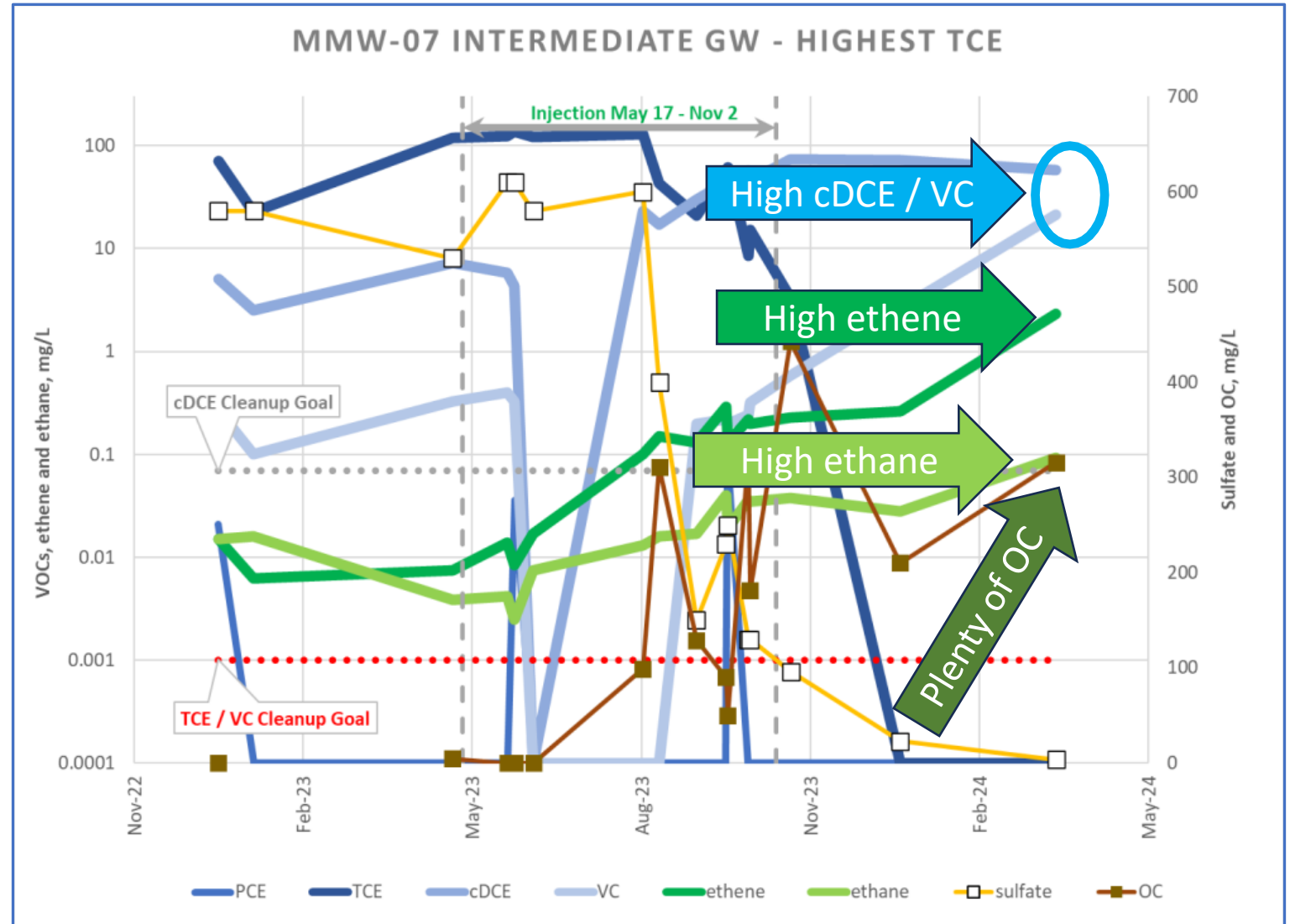


TCE – INTERMEDIATE GW BEFORE / AFTER (15 – 35 FEET BGS)



STAY-TUNED FOR cDCE AND VC . . .

- Intermediate Groundwater – SOURCE AREA ONLY
- 100+ mg/L TCE reduced to ND (0.100 mg/L)
- cDCE at 58 mg/L and decreasing
- VC at 21.2 mg/L and increasing
- Ethene and ethane at 2.3 mg/L and 0.093 mg/L respectively
- Plenty of organic carbon remaining under sulfate-reducing conditions



PFAS – BEFORE AND AFTER



	PFAS Baseline and 8-Month Sequestration Monitoring					
	<i>Perfluorooctanesulfonic Acid</i> (ng/L)		<i>Perfluorooctanoic Acid</i> (ng/L)		<i>Perfluoronanoic Acid</i> (ng/L)	
	<u>May-23</u>	<u>Jan-24</u>	<u>May-23</u>	<u>Jan-24</u>	<u>May-23</u>	<u>Jan-24</u>
MMW-2	37	14.7	27	33.3	2.5	2.2
MMW-4	130	5.8	470	42.7	7.8	0.83
MMW-7	52	98.7	3100	2340	4.4	2
MMW-9	37	ND (3.8)	4500	21.5	4.1	ND (3.8)
MMW-10US	450	87.2	1500	976	10	1.6
MMW-10S	220	33.7	570	320	3.7	ND (4.1)
MMW-13	18	2.6	410	164	6	1.4
MMW-14S	22	13.6	6500	5400	7.8	3
MMW-27M	42	1.8	1300	291	2.2	ND (3.7)
MMW-28S	30	2.4	2400	433	ND (1.8)	ND (3.8)
MMW-30M	32	1.7	1000	353	ND (1.8)	ND (3.8)
Averages	<i>97</i>	<i>26</i>	<i>1980</i>	<i>943</i>	<i>5</i>	<i>2</i>
Average % Reduction		73%		52%		66%

1,4-DIOXANE – BEFORE AND AFTER



	<i>1,4-Dioxane</i> (µg/L)	
	<u>May-23</u>	<u>Jan-24</u>
MMW -2	ND (0.4)	ND (0.4)
MMW -4	ND (0.4)	ND (0.4)
MMW -7	ND (500)	ND (250)
MMW -9	25	7.9
MMW -1 OUS	7.4	7.1
MMW -1 OS	3.1	0.72
MMW -1 O	41	17
MMW -1 3	6.9	7.6
MMW -1 4S	16	13
MMW -27M	19	12
MMW -28S	49	22
MMW -30M	18	15
Averages	21	11
Average % Reduction		45%

11-MONTH GROUNDWATER CHEMISTRY

- ✓ DO levels typically at or below 1 mg/L
- ✓ Negative ORP levels in all wells to -350 mV
- ✓ pH values from 6 S.U. to 7 S.U. (no pH crash)
- ✓ Organic carbon present in most GW samples > 20 mg/L
- ✓ Sulfate levels from ND to 100 mg/L, typically <50 mg/L
- ✓ mg/L levels of methane present to support cometabolism of chlorinated ethenes

- ✓ Up to 10^4 cells per mL *Dehalococcoides mccartyi* detected, with tceA and bvcA at 10^3 cells per mL and Vinyl Chloride (VCR) reductase at 10^4 cells per mL (1,000X increase in shallow and intermediate groundwater)
- ✓ *Dehalobacter* spp., *Dehalogenimonas* spp., *Geobacter* spp., detected > 10^3 cells per mL

CONCLUSIONS

- CAT 100 highly effective . . .
 - >99.9 percent reduction in TCE in shallow and intermediate GW within 11 months – **contract-required performance-based objectives achieved through the use of CAT 100**
 - Source area accumulations of DCE isomers and VC are high; complete reduction is expected based on favorable GW chemistry and presence and abundance of DCE/VC-degrading bacteria and oxidases
 - Collateral sequestration results promising for chlorinated VOCs, PFAS, and 1,4-dioxane



QUESTIONS



Raymond Vaské
Sr. Remediation Engineer
ICE Commercial
Cincinnati, OH
rvaske@trihydro.com