APPLICATION OF MULTIPLE INJECTION TECHNIQUES FOR THE REMEDIATION OF CHLORINATED SOLVENTS, PFAS, AND 1,4-DIOXANE IN A COMPLEX GEOLOGICAL SETTING

Mike Mazzarese

Senior Remediation Engineer, AST Environmental, Inc.

Denver, CO, USA

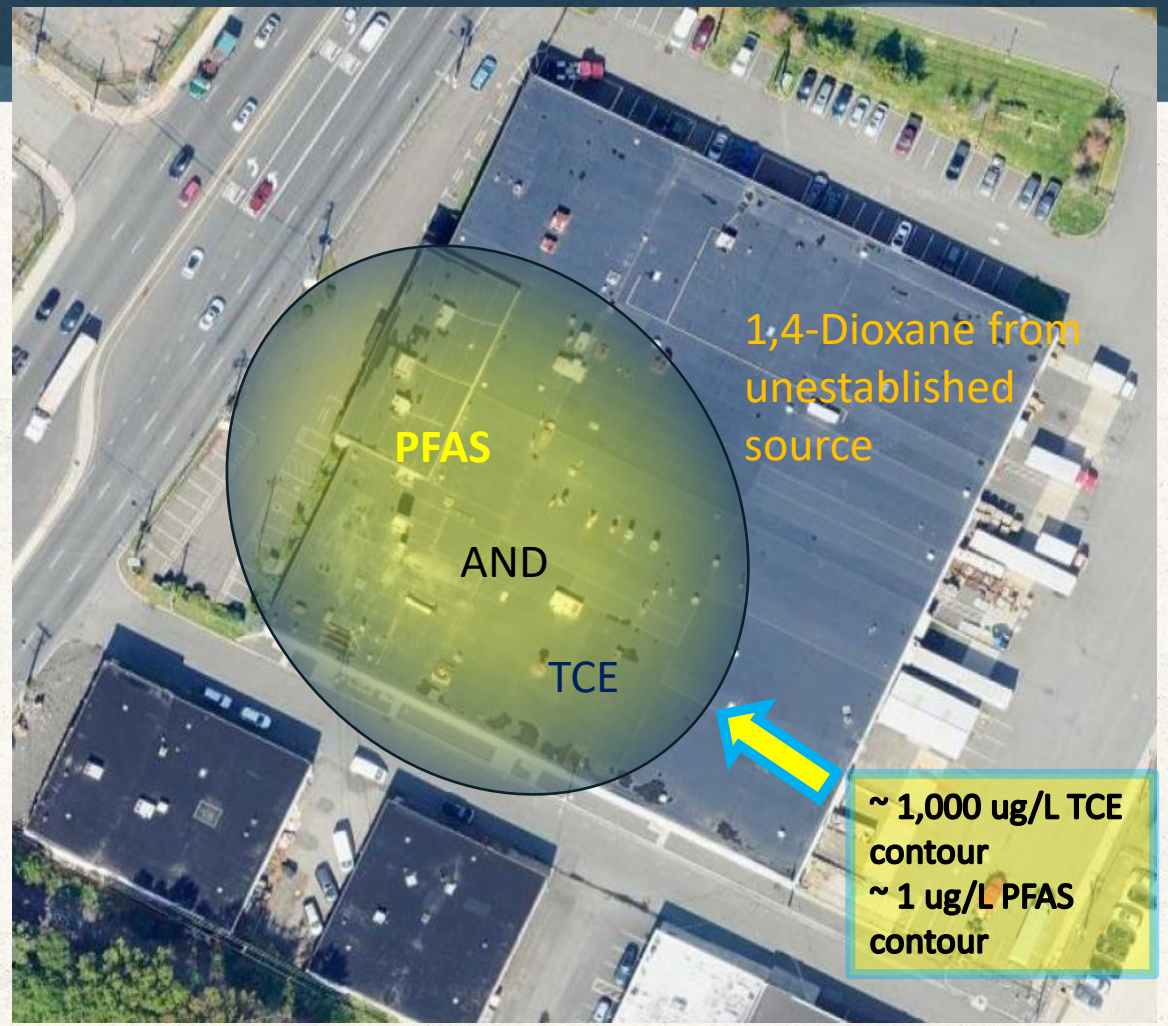
AST ENVIRONMENTAL, INC.

Remediation Technologies Symposium 2026

RPI GROUP

Project/Site General Information

- Former manufacturing site located in northeast US
  - 7,400 m^2 building
- Property purchase required an expedited remedial timeframe
  - Renovation concurrent with remediation works
- Significant soil and groundwater impacts
  - >4,000 m^2 impacted with CVOCs, PFAS, and 1,4-dioxane
  - >100 mg/L TCE in groundwater
- Remediation work completed under a Performance Based Contract (PBC)



Objectives and Processes

- Objective #1: Target/reduce TCE in overburden saturated zone to an onsite 1,000 µg/L isocontour (basis for PBC)
- Process: Abiotic and biotic reductive dechlorination of high concentrations of CVOCs.
- Objective #2: Target/reduce PFAS and 1,4-dioxane in overburden saturated zone
- Process: Sequestration to reduce mass flux across property boundary

Technology Selection

- Tech A: ZVI impregnated GAC with electron donor and bacteria
- Tech B: Colloidal activated carbon combined with ZVI (physical mixture)
- Tech C: Emulsified vegetable oil combined with ZVI

- Tech A selected based upon track record remediating DNAPL and GAC content (to adsorb PFAS and 1,4-dioxane)

Technology Information

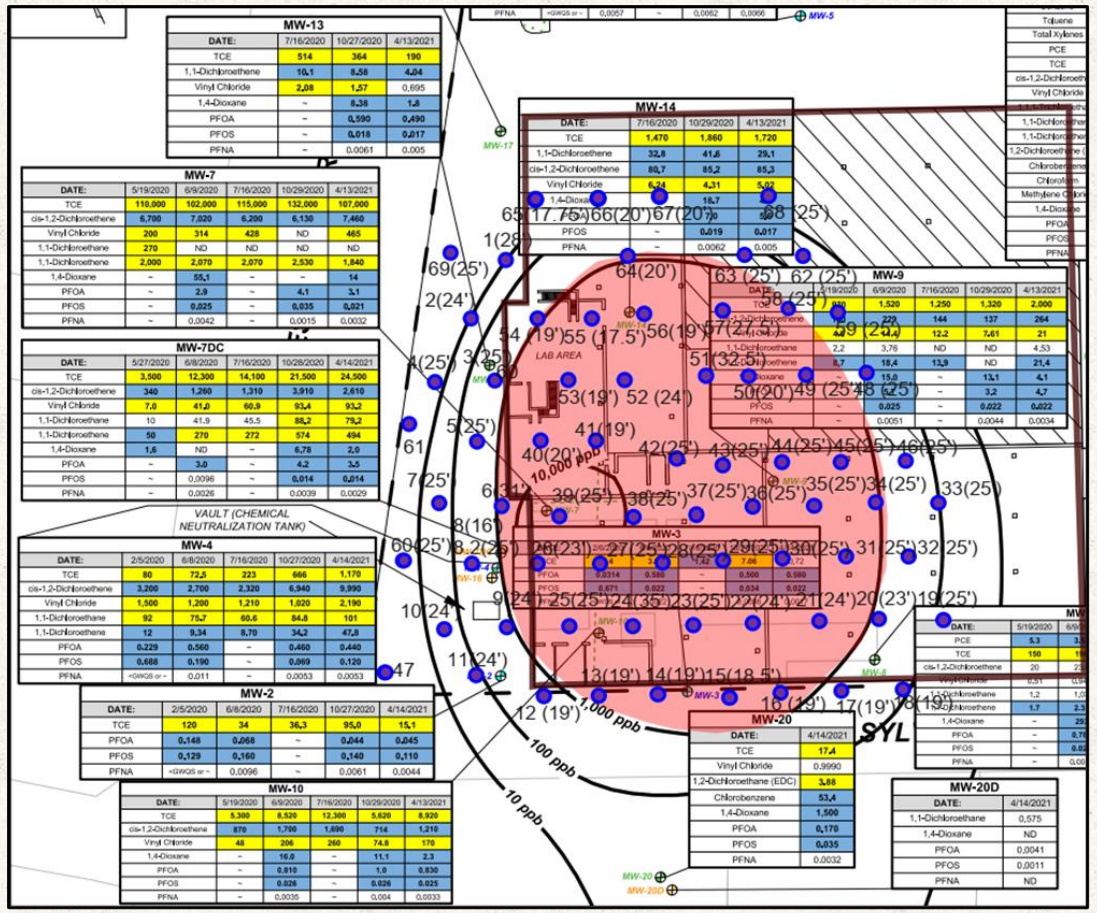
- Commercially known as CAT 100
  - >70 applications in North America, Europe, and Australia
  - Combination of metallic iron-impregnated activated carbon (BOS 100®) and degradable organic substrates (corn starch and pea fiber), yeast extract, and bacterial blends
    - Contaminants sorb to activated carbon (“Trap”)
    - Degradation mechanisms (“Treat”)
      - Abiotic reduction of chlorinated VOCs (metallic iron contact)
      - Bioaugmentation and microbial community enhancement
      - Indigenous populations of Dehalococcoides mccartyi confirmed

Site Geology and Hydrogeology

- Glacial till (silt and clay with some sand and gravel) ~ surface to 8 to 10 m
  - K = 10^{-4} to 10^{-5} cm/s
  - Seepage velocity = <1 to 5 m/yr
- Weathered siltstone shale bedrock (~ 3 m thick) over competent bedrock
- Depth to water 1.5 to 3 m

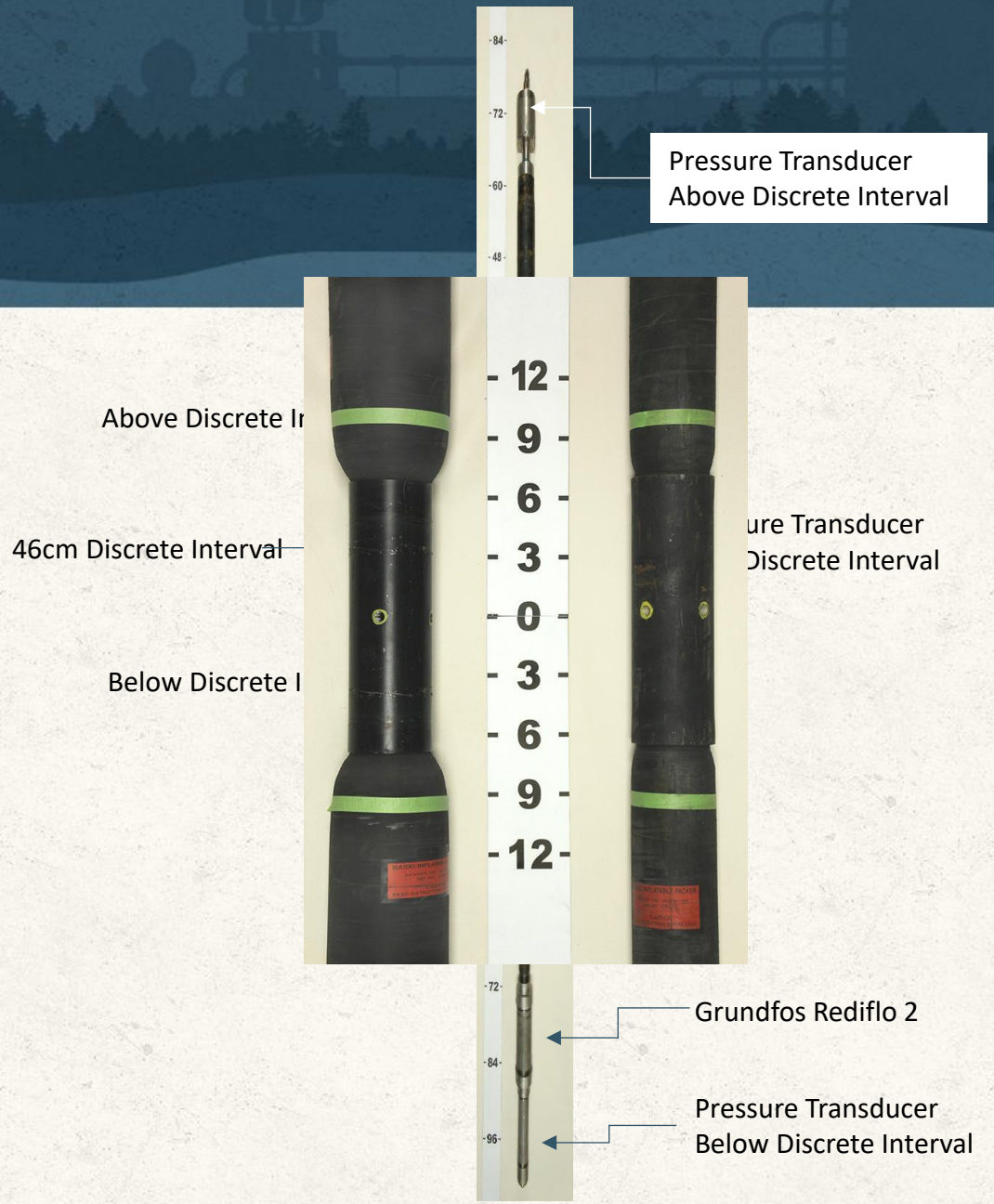
CSM Development

- Remedial Design Characterization (RDC) process used to create quantitative CSM
- Analyses performed at in-house lab at no cost to client
- Overburden
  - 69 DPT borings, 623 soil samples, 124 temp MWs (shallow/deep)
- Weathered bedrock
  - 6 sonic borings, 43 soil/rock samples, 6 groundwater samples
  - 10 interface sounding borings using 3230DT (avg depth = 10 m)

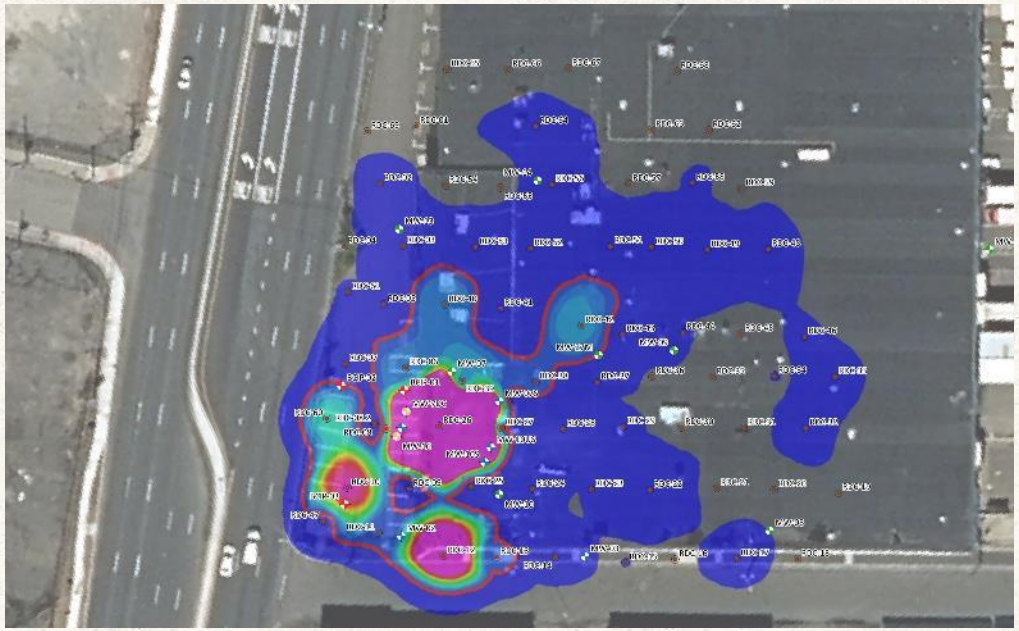


CSM Development

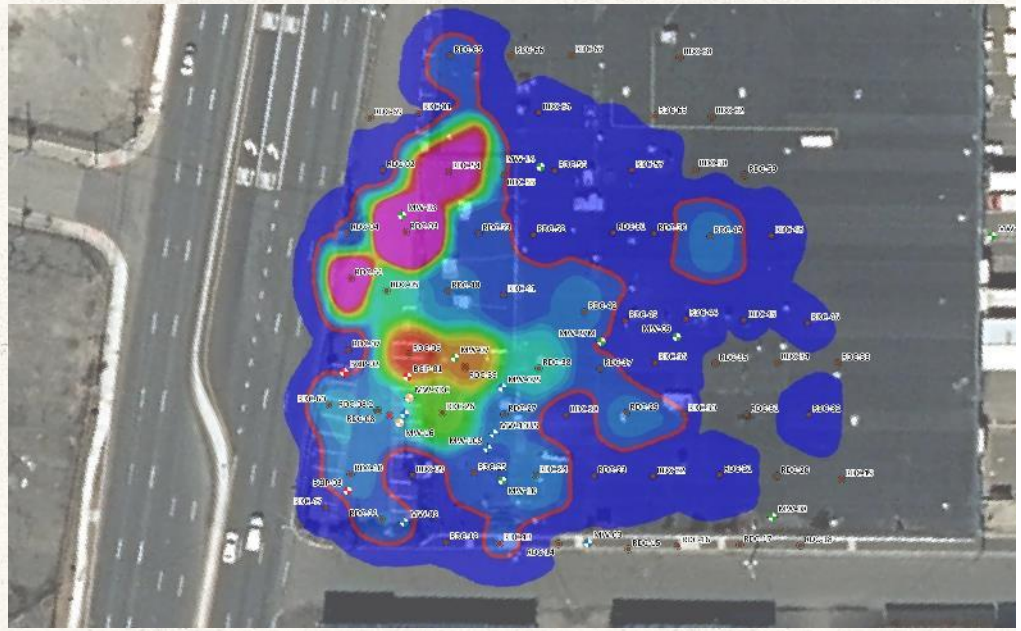
- Bedrock
  - 3 clusters (12 to 27 m)
  - 44 rock samples
  - Open borehole geophysics
  - Groundwater characterization via straddle packers (discrete sampling based on geophysics, 46 cm interval)
  - Pressure transducers in pumping and surrounding wells



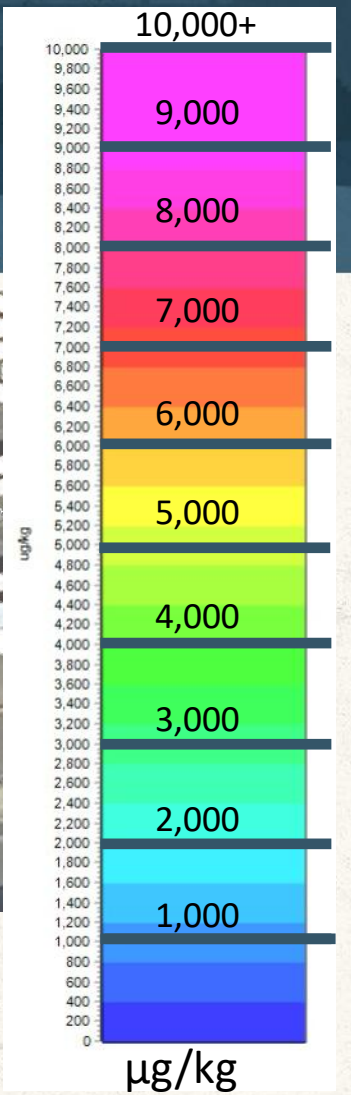
Findings – Soil Mass



Shallow Soil (0-4.5 m)

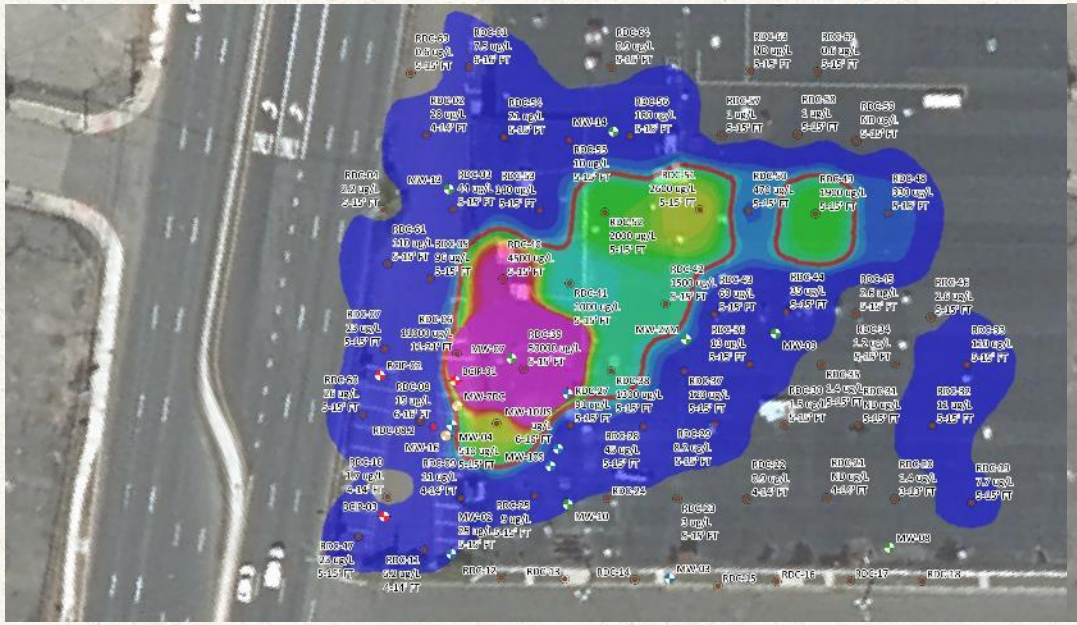


Deep Soil (4.5-9.0 m)

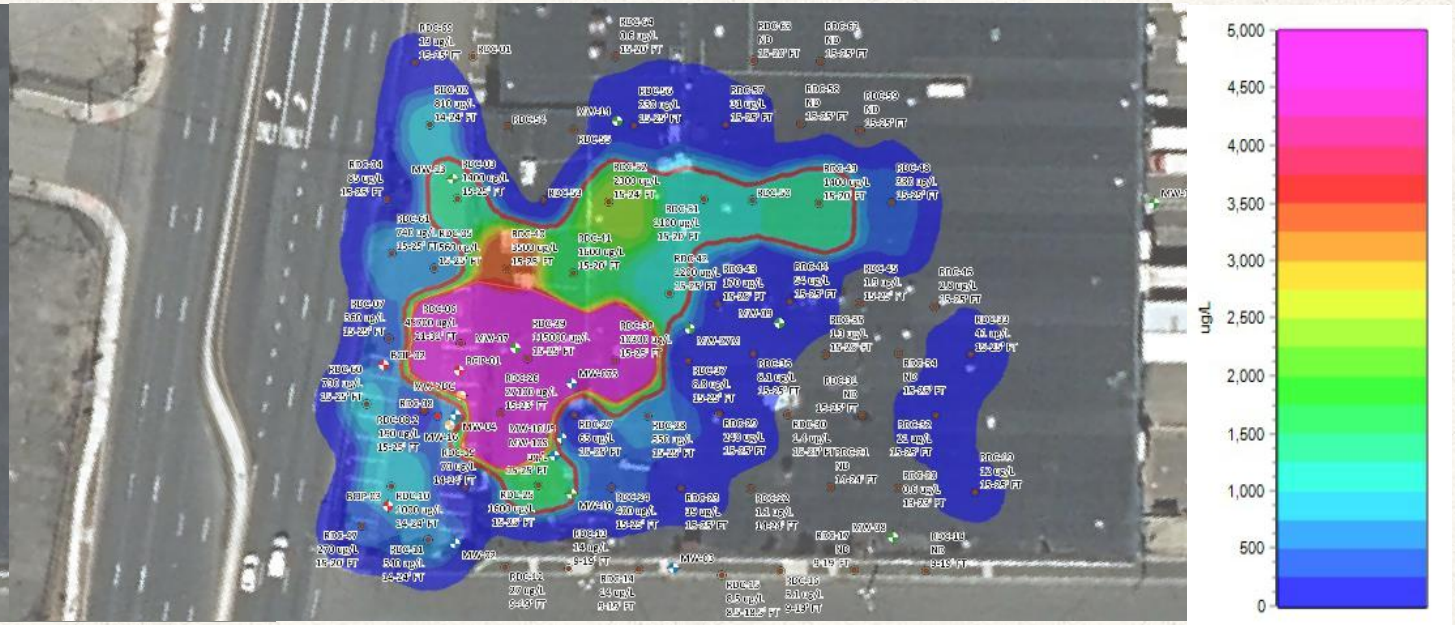


TCE Max Detection =
179,000 µg/kg

Findings – Groundwater



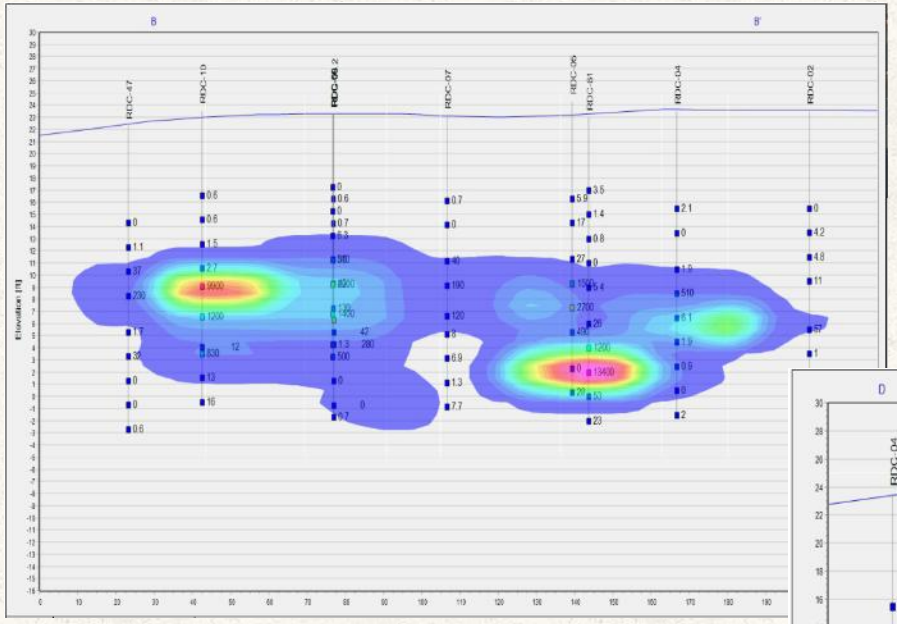
Shallow GW (1.5-4.5 m)

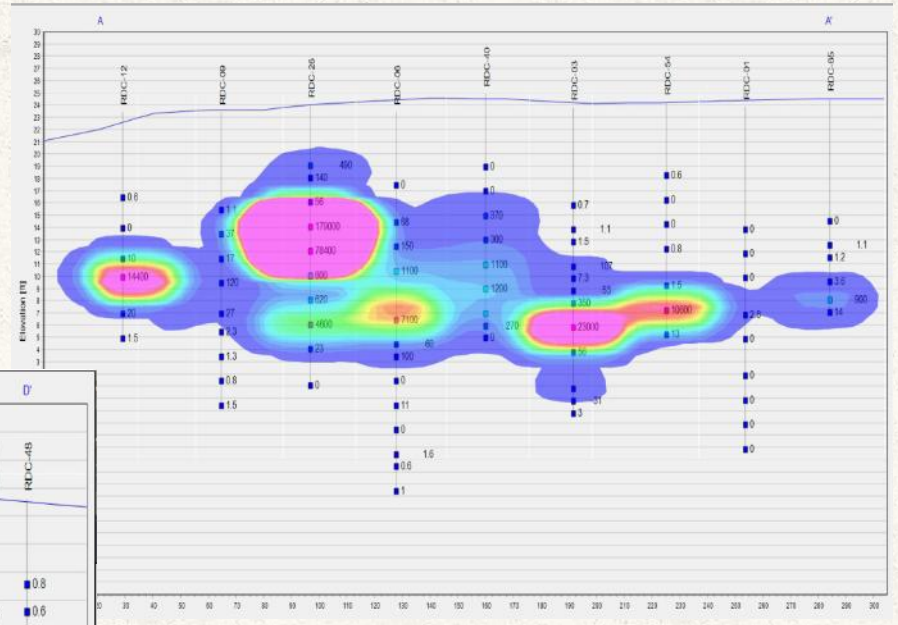


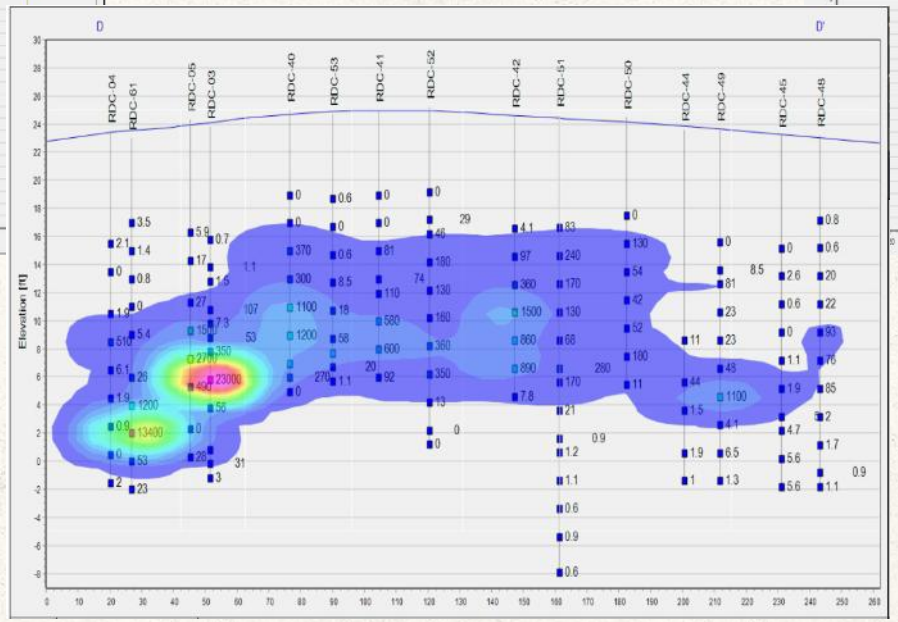
Deep GW (4.5-7.5 m)

TCE Max Detection =
136,000 µg/L

Findings – Cross Sections (Soil)







Findings – Bedrock

SAMPLING METHOD: NQ Core | PROJECT MANAGER: Duane Guilfoil | REG. NO.

DEPTH (feet)	REC-OVERY (%)	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
40						
44	40				1"-2" Red/grey sections of horizontally fractured and weathered siltstone	
48	100	NQ-01 (46') NQ-01 (46.5') NQ-01 (48') NQ-01 (48.2')		1100 390 530 190	Same as above, grey clay in fracture 48.2, up to 4" sections of red silstone	
52	100	NQ-01 (50') NQ-01 (51.6') NQ-01 (52.5') NQ-01 (54') NQ-01 (54.5')		380 300 1.3 <0.5 <0.5	4"-6" sections of fractured red silstone, vertical fractures @ 52' and 53', mineralized vugs at 53', grey clay within fractures at 52.5', 54', and 54.5'	
56		NQ-01 (56') NQ-01 (57') NQ-01 (57.3') NQ-01 (58.2')		35 32 150 11	Highly fractured red siltstone, 2"-4" sections with thin (<1") grey beds throughout	
60	100	NQ-01 (61.2') NQ-01 (63')		7 25	Amaglamated siltstone to 61', red/grey clay at 61.2', vertical fractures @ 62' and 63', red/grey clay at 64.2' and 64.5'	
64		NQ-01 (64.2') NQ-01 (64.5') NQ-01 (65.5') NQ-01 (66.6')		<0.5 1.4 <5.42 <5.62	JTrp	
68	100	NQ-01 (67') NQ-01 (67.3') NQ-01 (68.2')		3.2 0.9 <6.75	Vertical fracture 65'-65.5', 3"-8" sections of amalgamated siltstone to 67', grey clay @ 67' and 67.3', highly fractured red siltstone to 69.5', vertical fracture 69.5-70'	
72	100	NQ-01 (69.2) NQ-01 (71.8') NQ-01 (72') NQ-01 (73.4') NQ-01 (74.5')		20 16 110 <7.0 <5.01	Vertical fracture to 71', 2" sections and highly weatherd grey siltstone @ 72.5', 72.5'-74' 4"-8" sections w/ vugs present throughout, grey fracture at 74.5', clay at 75'	
76	100	NQ-01 (75') NQ-01 (75.9') NQ-01 (77.4') NQ-01 (78')		1.7 <5.56 <4.87 <6.6	Grey vugs at 75.5', highly fractures red siltstone,,2"-3" sections	
80		NQ-01 (79.5')		6.4		
84	100	NQ-01 (80.8') NQ-01 (81.8') NQ-01 (82.1') NQ-01 (82.2') NQ-01 (82.8')		1.2 <4.61 <0.5 <7.57 <5.78	Weathered red siltstone w/ grey subvertical veins, grey clay at 80.8', grey vugs at 81.5', highly fractured siltstone 45 degree fracture at 84', vugs throughout	
88	100	NQ-01 (83.6') NQ-01 (83.8') NQ-01 (84.2') NQ-01 (85.2') NQ-01 (86.8') NQ-01 (87.5')		<6.51 <0.5 <6.06 <4.86 <6.02 <0.5	Red fractured siltstone, grey within fractures, vugs, 2"-4" sections, clay at 88.3', long solid core from 88.3'-90'	
92		NQ-01 (87.6') NQ-01 (88.3')		<8.19 1		

AST Environmental Inc. | Project No. 5152369 | Page 1 of 1

Sample location	Sample date	Sample Depth (ft)	Chemical of Concern (ug/L)		
			Trichloroethene	cis-Dichloroethene	Vinyl Chloride
BCIP-01	4/5/2023	41	17900	2600	<50
BCIP-01	4/5/2023	42.5	19800	2900	<50
BCIP-01	4/5/2023	44	14800	2500	<50
BCIP-01	4/5/2023	45.5	18900	2800	<50
BCIP-01	4/5/2023	47	19500	2800	<50
BCIP-01	4/5/2023	48.5	17200	2700	<50
BCIP-01	4/5/2023	50	20600	2800	<50
BCIP-01	4/5/2023	51.5	20600	2700	<50
BCIP-01	4/5/2023	53	20900	2600	<50
BCIP-01	4/5/2023	54.5	18200	2400	<50
BCIP-01	4/5/2023	55.5	17100	2300	<50
BCIP-01	4/5/2023	Open Hole	13800	2100	<50
BCIP-01D	4/4/2023	67	2900	310	<5
BCIP-01D	4/4/2023	68.5	2000	280	<5
BCIP-01D	4/4/2023	71.5	4700	460	16
BCIP-01D	4/4/2023	77.5	3800	360	13
BCIP-01D	4/4/2023	Open Hole	3100	330	14

Design Recalibration

Overburden

- DPT injections to
- Total treatment ar
- Number of injecti
- Number of injecti (every 0.6 m): 8,2
- Total CAT 100: >8
- Workdays to insta



drock

-drill) injections

2 m

nt area: ~3,700 m^2

jection points: 20

jection intervals

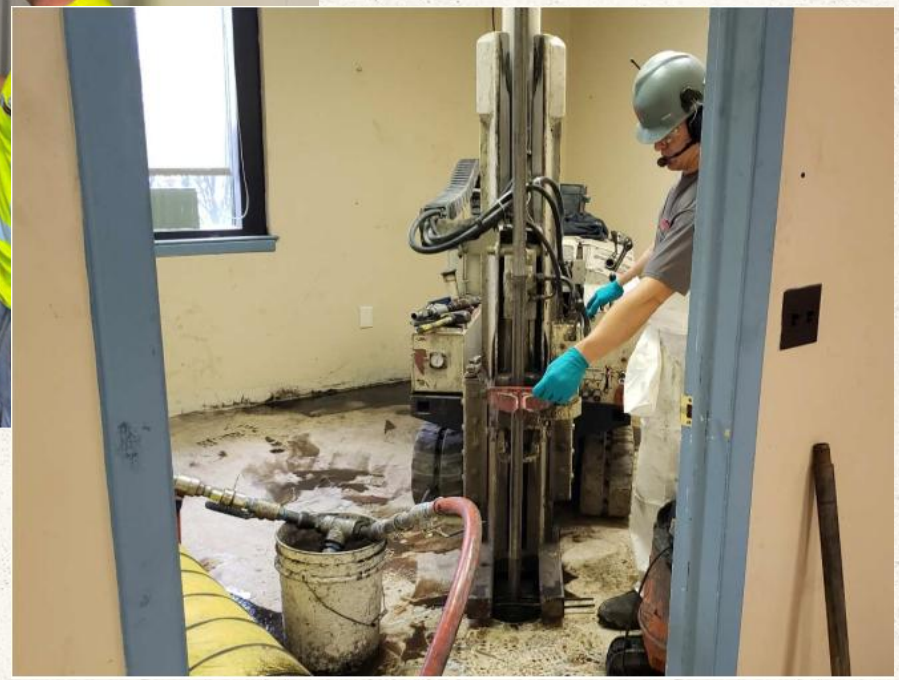
): 70

0: ~9,000 kg

install: 7

Logistical Challenges





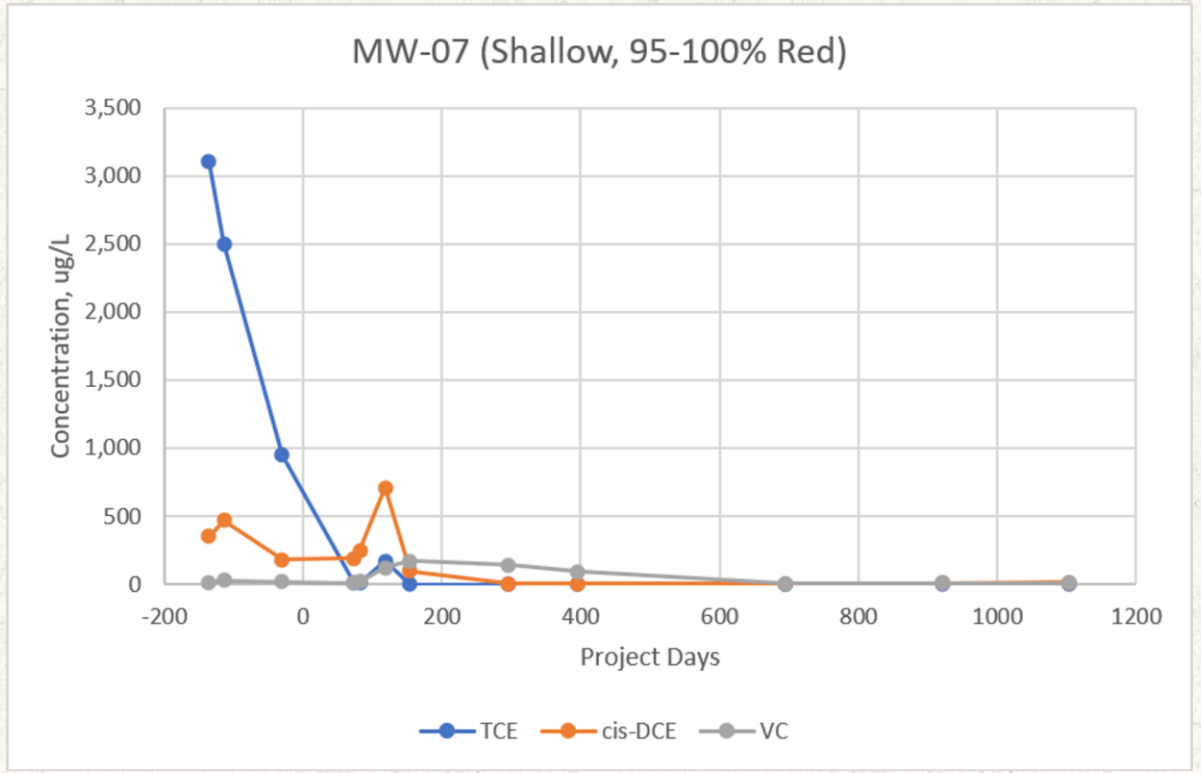
- Overburden Injection
  - Hallways, Bathrooms – Dolly Rig
  - Cafeteria – 54 LT
  - Production Areas - 7822
  - Warehouse/Parking Lot- 3230
- Weathered Bedrock
  - Warehouse/Parking Lot – Mini Sonic 8150LS and 3230

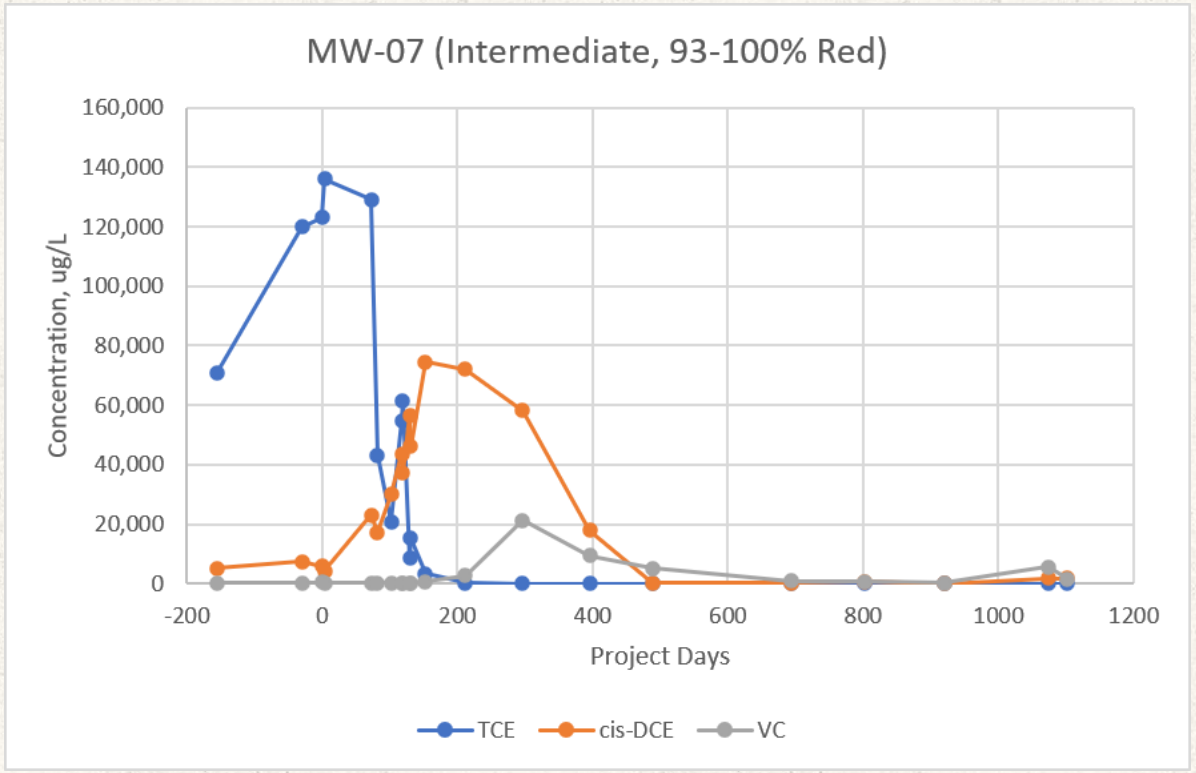
Pre-Drill Technique (GeoTAP™)

- Sites where DPT cannot be used due to refusal and geology will not allow packers to seat properly
  - e.g. gravel/cobble zones, glacial till, weathered bedrock, historic fill, etc.
- Pre-drill each location
  - Augers, air rotary, or sonic to the target/total depth
- Backfill borehole with bentonite chips or coated pellets; hydrate; build up in lifts
- Probe through bentonite using DPT
- High energy injection cuts though bentonite
- 50+ sites in various geologies/regions completed to date (15+ in Canada)

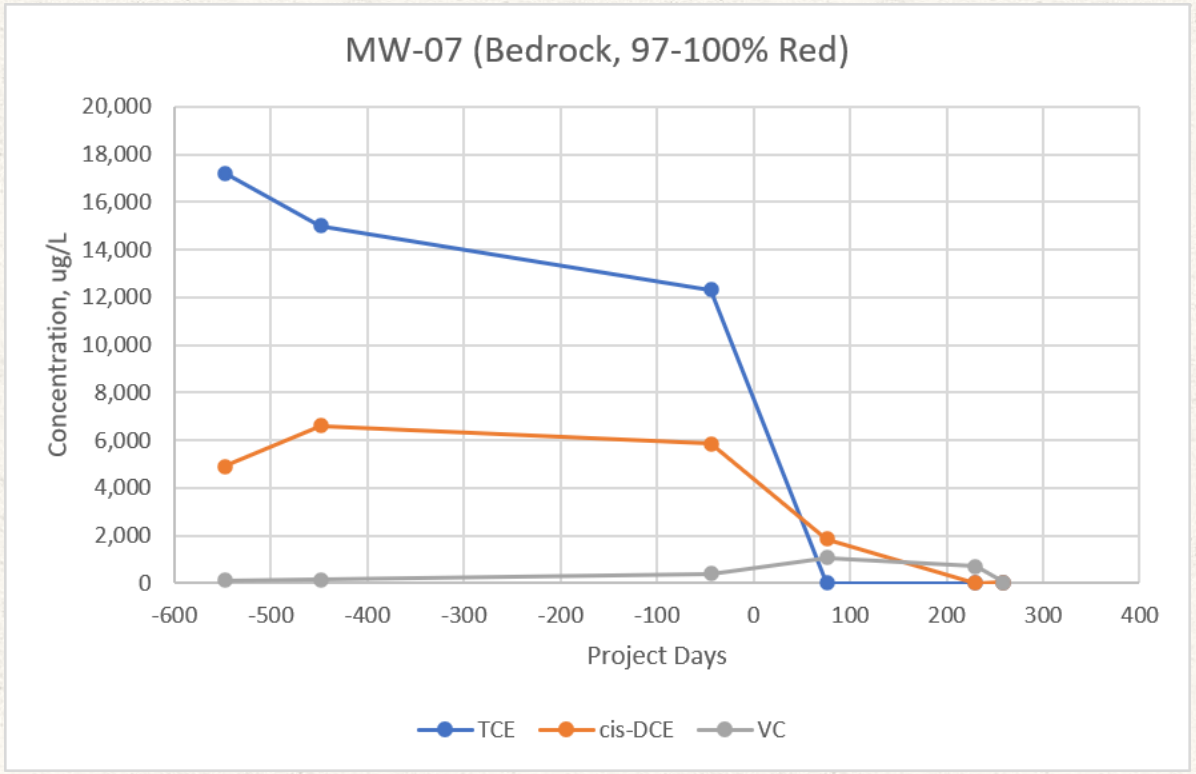


Shallow and Weathered Bedrock Results (Phase 1)



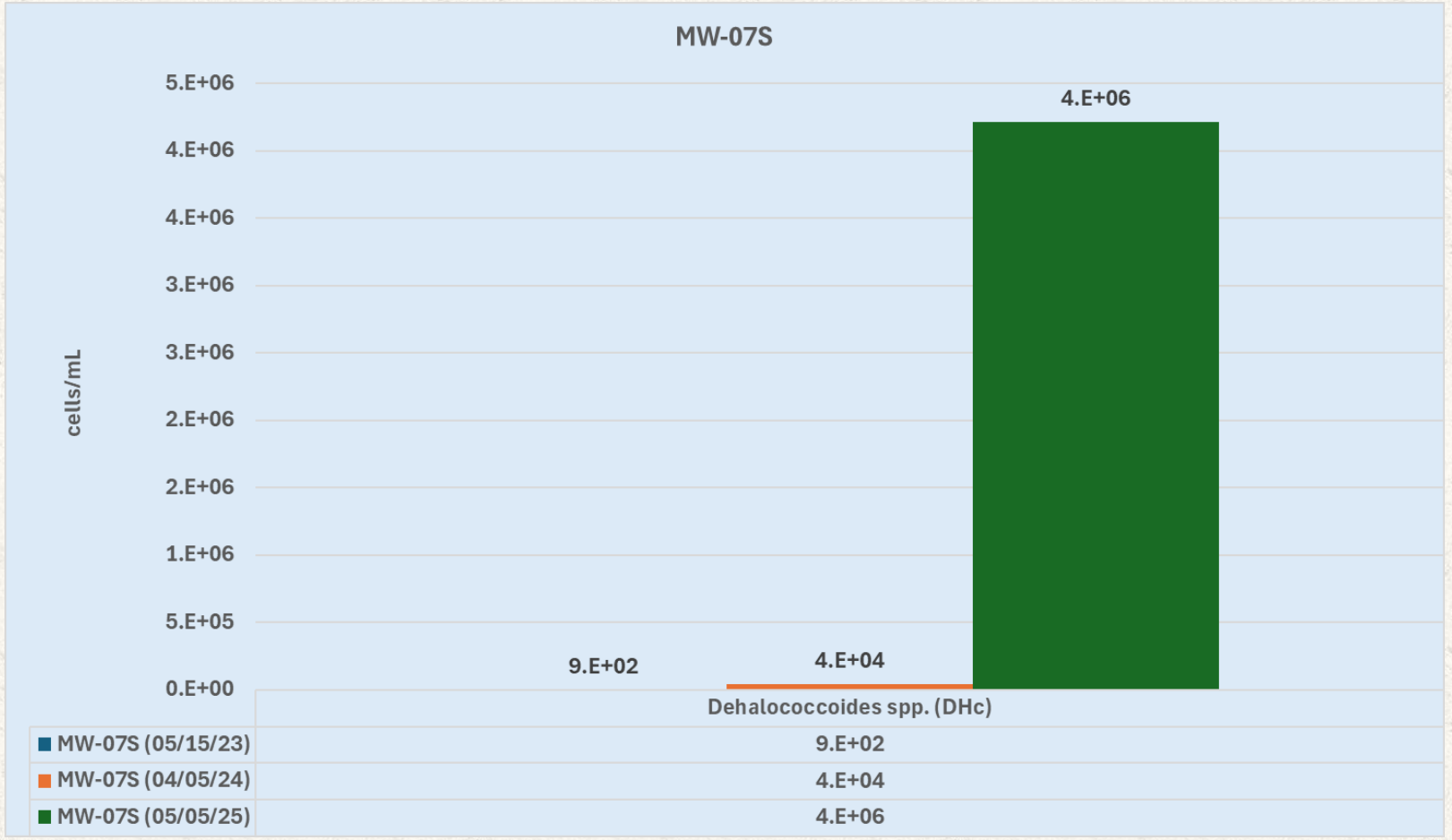


Bedrock Results (Phase 2)



Sample location	Sample date	Chemical of Concern (ug/L)			
		PCE	TCE	cis-DCE	VC
MW-07DC	1/10/2023	<10	4100	1400	<10
MW-07DC	5/8/2023	<10	1300	2800	16
MW-07DC	11/14/2023	<5	6100	9900	85
MW-07DC	1/4/2024	<50	11000	13000	190
MW-07DC	4/1/2024	<10	17200	4900	120
MW-07DC	7/9/2024	<50	15000	6600	160
MW-07DC	8/18/2025	0.28	12300	5850	406
MW-07DC	12/16/2025	<1	1	1860	1070
MW-07DC	5/19/2026	<0.5	1.4	12	710
MW-16-1	5/10/2023	<10	2100	800	85
MW-16-1	8/20/2025	<0.2	740	751	91
MW-16-1	12/17/2025	<1	<1	29.5	12.3
MW-22D	11/14/2023	<0.5	61	1900	710
MW-22D	4/1/2024	<5	<5	42	<5
MW-22D	10/11/2024	<0.5	1500	1900	540
MW-22D	5/6/2025	<5	420	3100	530
MW-22D	8/18/2025	<0.2	24.7	2470	643
MW-22D DUP	8/18/2025	<0.2	23.6	2630	670
MW-22D	12/15/2025	<10	<10	9.6	12.1
MW-22D	5/19/2026	<0.5	<0.5	0.7	5.5
MW-23D	11/14/2023	<0.5	3400	9600	160
MW-23D	4/1/2024	<0.5	15	710	34
MW-23D	10/11/2024	<5	960	2500	290
MW-23D	5/5/2025	<5	1900	3900	340
MW-23D	8/18/2025	<0.2	1920	3770	420
MW-23D	12/15/2025	<5	<5	77.3	37.5
MW-23D	5/19/2026	<0.5	<0.5	7.6	130

DHC – MW07S


MW-07S
5.E+06
4.E+06
4.E+06
3.E+06
3.E+06
2.E+06
2.E+06
1.E+06
5.E+05
0.E+00
cells/mL
4.E+06
9.E+02
4.E+04
Dehalococcoides spp. (DHc)
MW-07S (05/15/23) 9.E+02
MW-07S (04/05/24) 4.E+04
MW-07S (05/05/25) 4.E+06

PFAS and 1,4-Dioxane Results (30 mo)

	Perfluorooctanesulfonic acid (PFOS) ng/L			*Perfluorooctanoic acid (PFOA) ng/L*	
	Baseline	30 mo		Baseline	30 mo
MMW-2	37	19.2		27	70.7
MMW-4	130	2.6		470	8.6
MMW-7	52	38.8		3100	1450
MMW-9	37	2		4500	34.4
MMW-10US	450	76.5		1500	511
MMW-10S	220	36.5		570	226
MMW-13	18	1.9		410	123
MMW-27M	42	0.69		1300	122
MMW-28S	30	2		2400	17.1
MMW-30M	32	2		1000	447
Averages	95	18		1389	301
Average % Reduction		**81%**			**78%**

	1,4-Dioxane ug/L	
	Baseline	30 mo
MMW-2	0.4	0.1
MMW-4	0.4	0.1
MMW-7	500.0	8.1
MMW-9	25.0	2.1
MMW-10US	7.4	0.3
MMW-10S	3.1	0.1
MW-10	41.0	7.9
MMW-13	6.9	2.0
MMW-14S	16.0	5.2
MMW-27M	19.0	0.9
MMW-28S	49.0	6.0
MMW-30M	18.0	5.0
Averages	57.2	3.2
Average % Reduction		**94.5%**

Summary

- RDC, real-time sampling, GeoTAP, and bedrock injections critical to project success
- >99+ percent reduction in TCE in shallow and intermediate groundwater (21 MWs) within 12 months (sustained for 30 months) => Performance Based Contract criteria achieved
- DCE/VC are low and decreasing (robust DHC in source area)
- Collateral sequestration results promising for PFAS and 1,4-dioxane
- Existing injection areas in long term monitoring (MNA)

Thank you for your time! Questions?

mmazzarese@astenv.com

www.astenv.com

Injection Systems









Intermediate Zone/TCE Time Lapse

