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Demonstration of Multiple Amendment Delivery Technologies for DNAPL Remediation in Fractured Crystalline Bedrock

CVOC Plume Containment in Fractured Bedrock

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Project Overview

Remediation approach: construct a groundwater remediation barrier at the site boundary, with future source treatment

Pre-design investigation: better understand bedrock characteristics, site hydrogeology, and contaminant extent

Conduct bench scale testing and pilot study

Create final remedial design

Procure contractor and construct remediation barrier

Implement source treatment as necessary

Conceptual Site Model

- DNAPL fractured bedrock MW-4
- Contaminant distribution NE to SW fracture strike & down dip (S-SW) – outcrop
- Contaminant distribution cross gradient to regional flow
- Strong upward gradient near property line
- Off-site impacts
- Pre-Design Focused Areas

Pre-Design Investigation

Pre-Design Investigation

- Further define **bedrock hydrogeology, groundwater chemistry, and extent of contamination** using:
  - Surface geophysics and test pits
  - Overburden and bedrock well installation
  - Borehole geophysics
  - Packer testing
  - Injection testing
  - Groundwater sampling
  - Bench scale sampling
  - Well survey

Well drilling

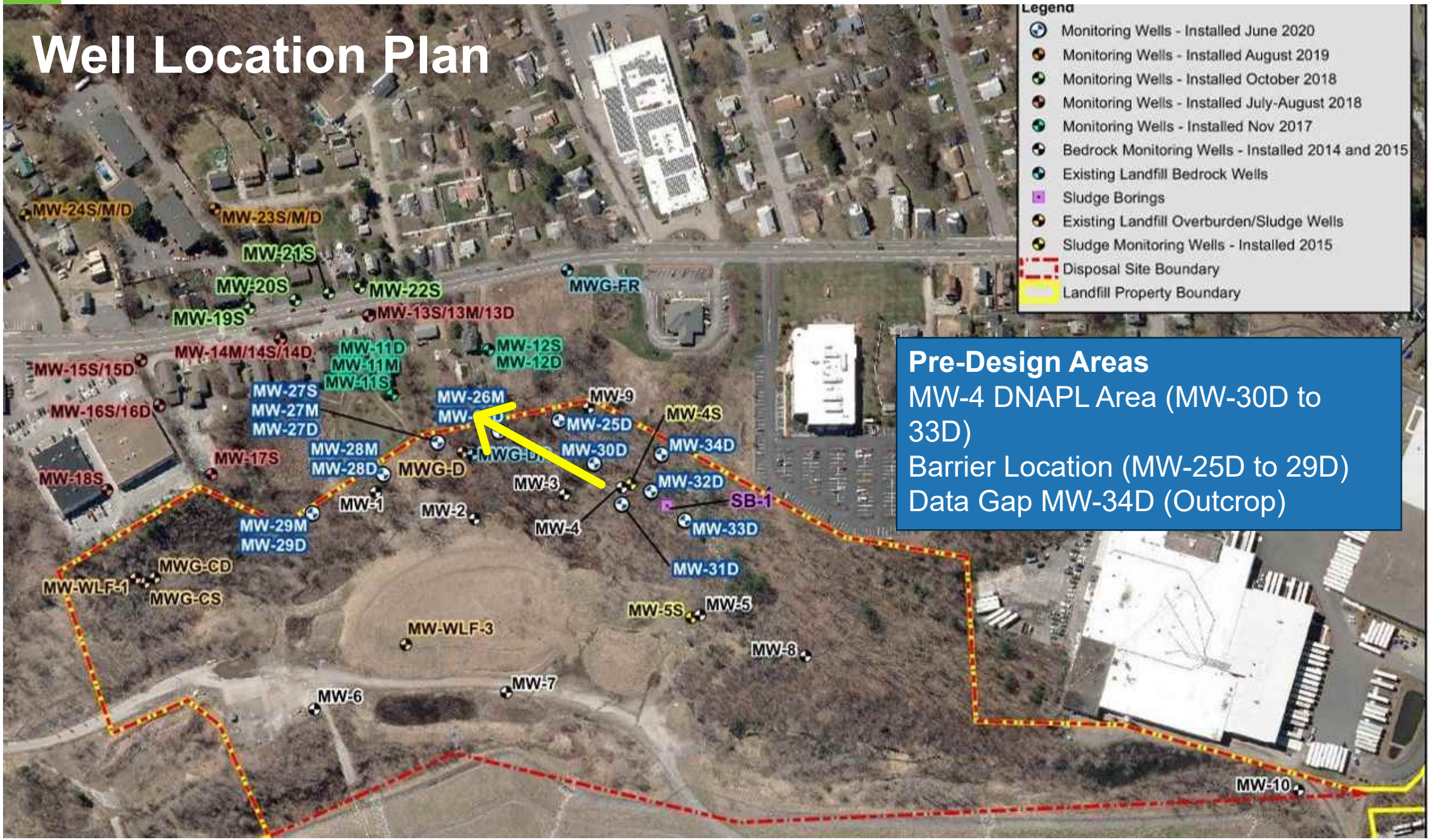
Overburden and Bedrock Borehole Well Installation

- Four bedrock wells next to MW-4: investigate DNAPL presence/extent
- One bedrock well along the northwest property line (MW-34)
- Five overburden and bedrock well couplets in the groundwater remediation barrier area
- Pressure transducers installed during drilling–fracture connections between wells

Site photo

Monitoring well

Well Location Plan

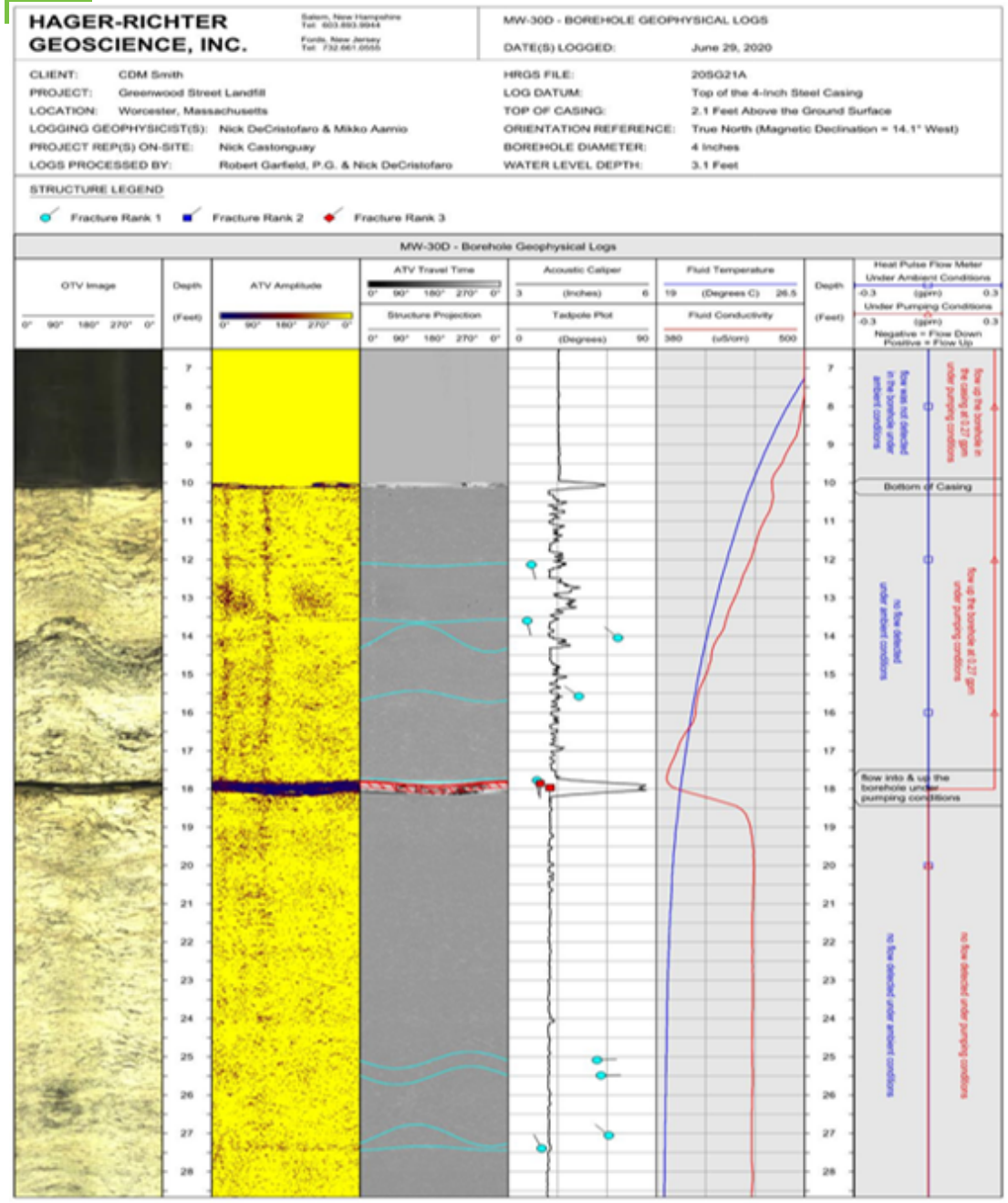


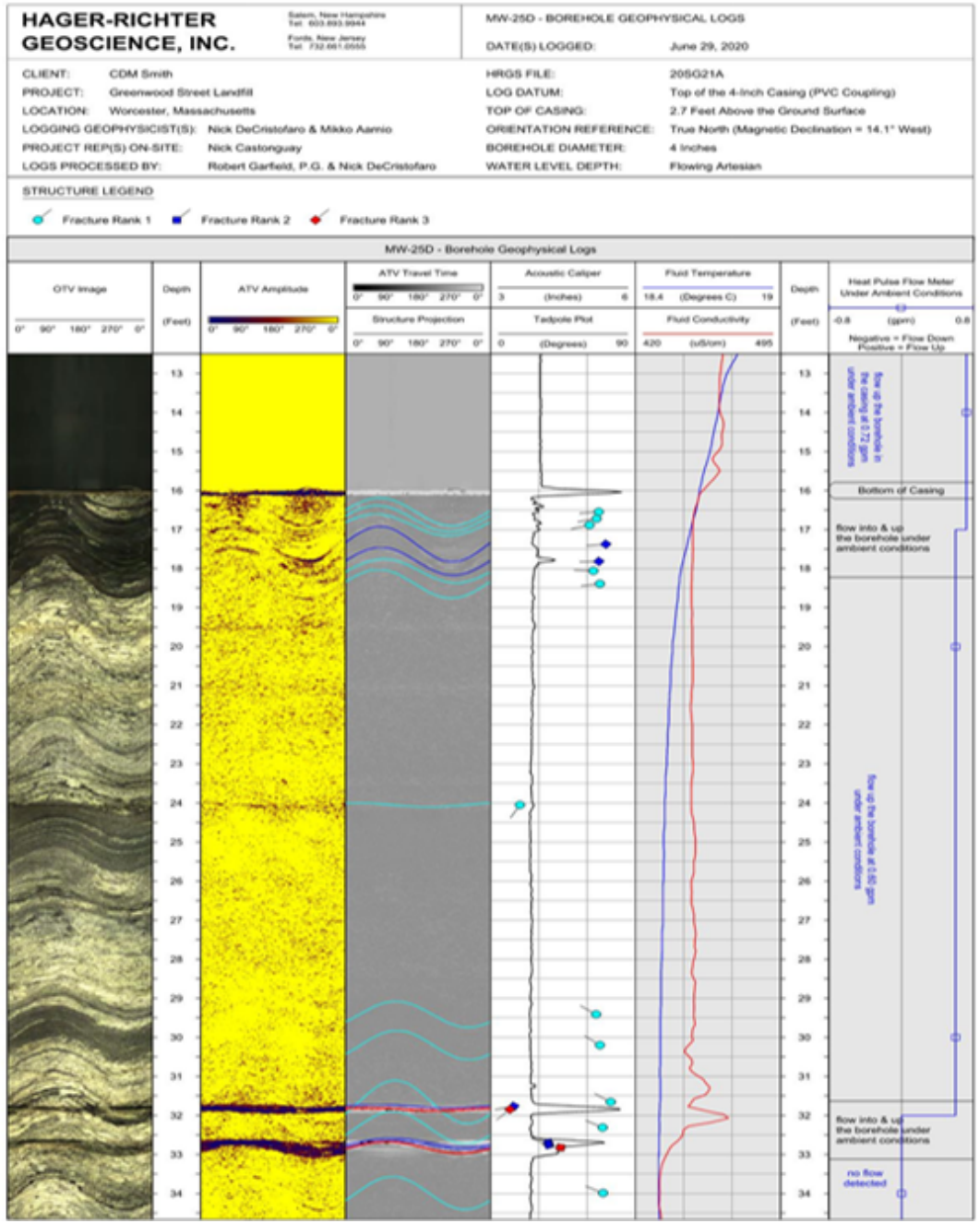
Pre-Design Areas

MW-4 DNAPL Area (MW-30D to 33D)

Barrier Location (MW-25D to 29D)

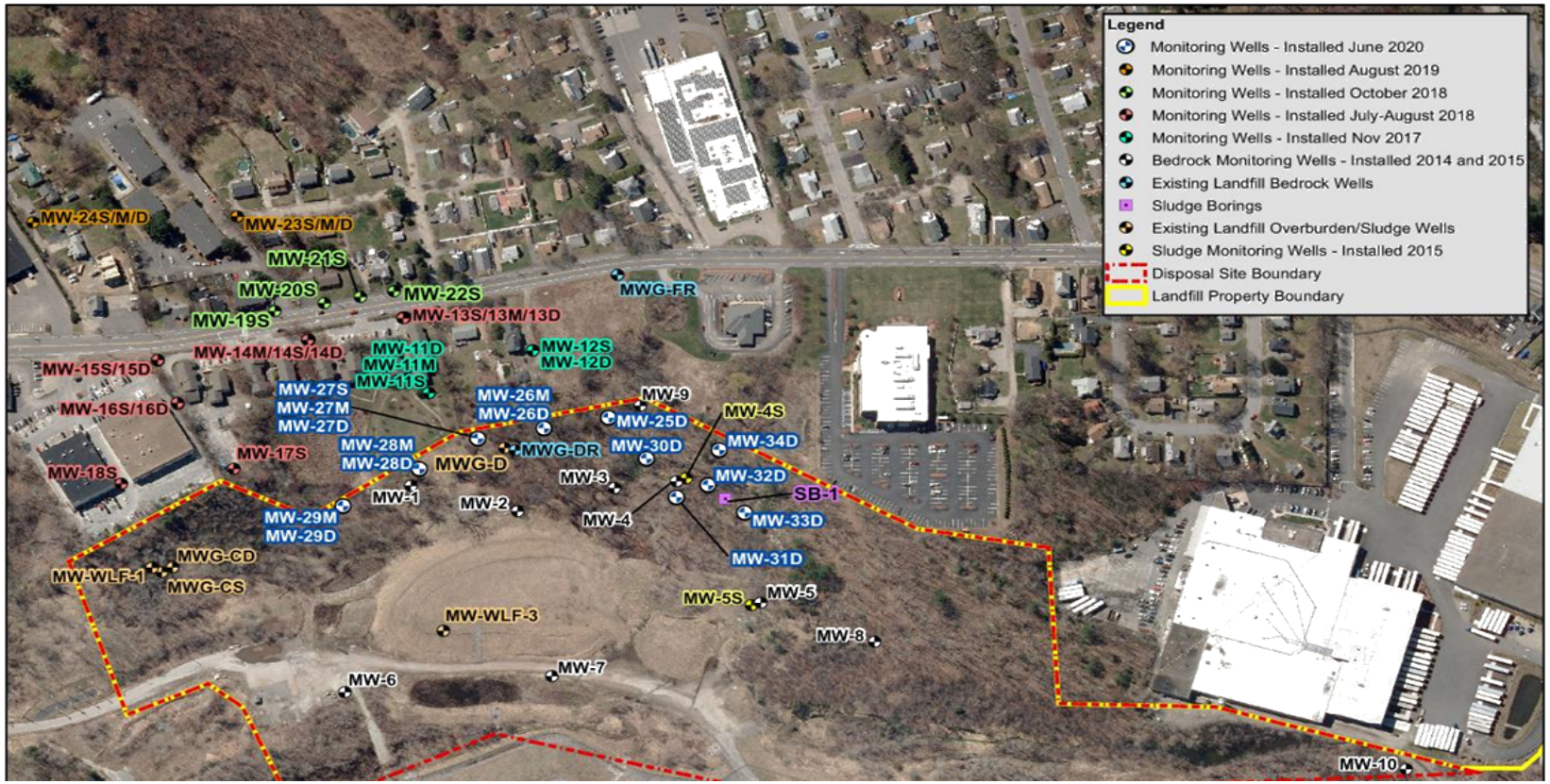
Data Gap MW-34D (Outcrop)





Integrated Borehole Logs

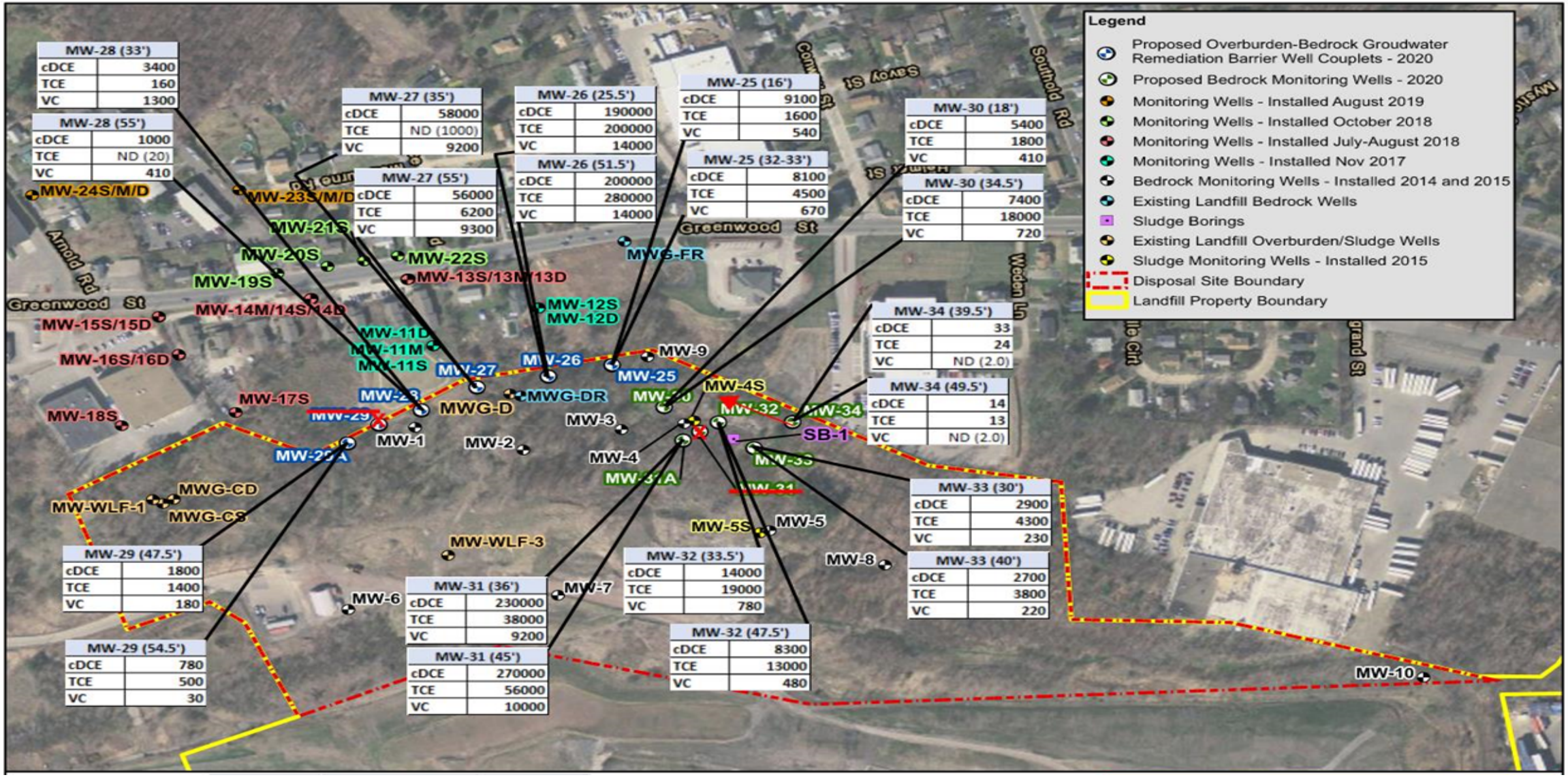
Borehole Packer Testing



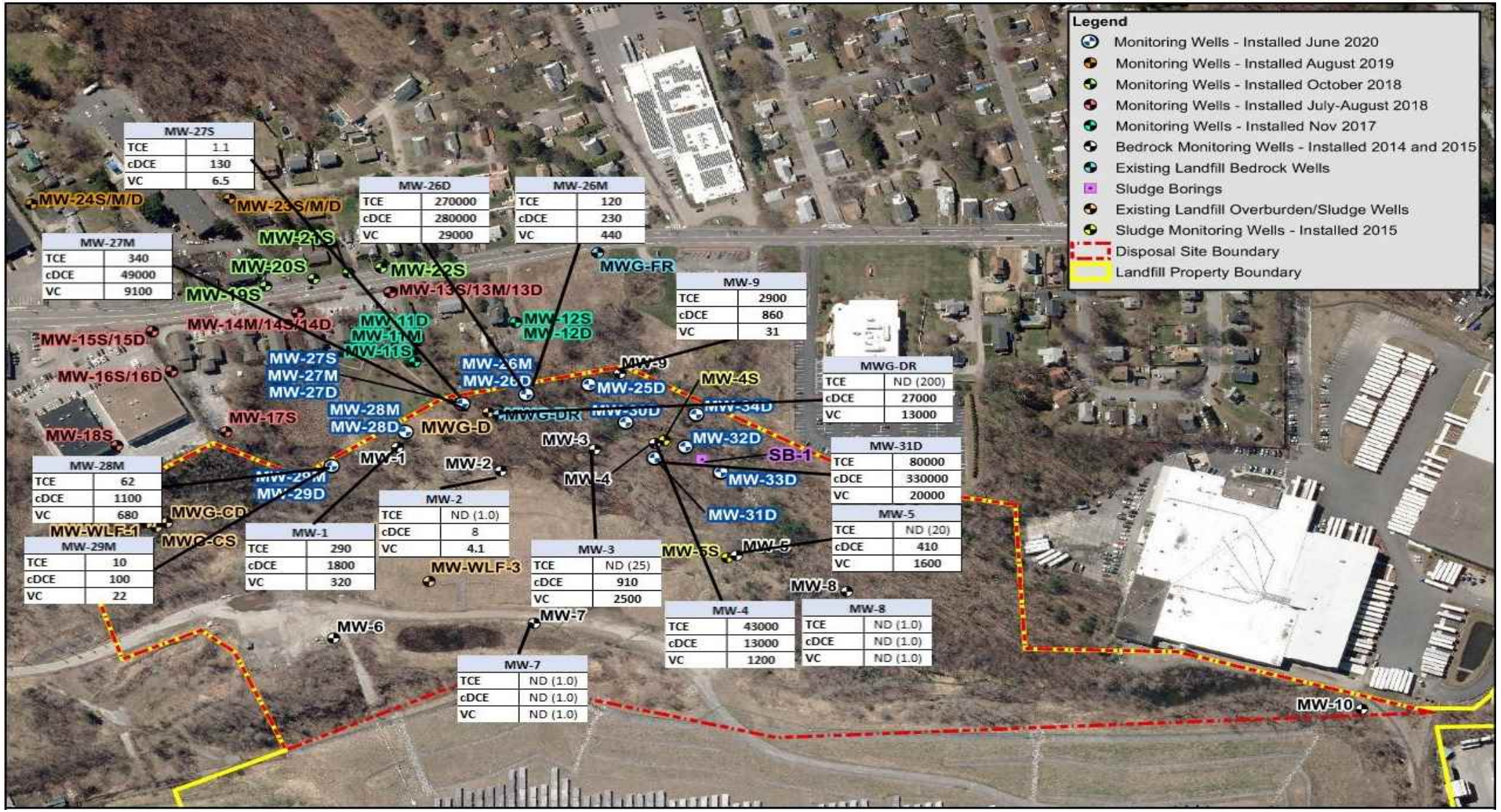
Site Layout

WELL IDENTIFICATION	FRACTURE DEPTH (FT BTOC)	TRANSMISSIVITY (ft/day)	HYDRAULIC CONDUCTIVITY (ft/day)	HYDRAULIC CONDUCTIVITY (m/sec)
MW-25D	16	88	17.6	6.21E-05
MW-25D	32-33	309	61.8	2.18E-04
MW-26D	25.5	2.58	0.516	1.82E-06
MW-26D	51.5	1.63	0.326	1.15E-06
MW-27D	35	4.4	0.88	3.10E-06
MW-27D	55	5.51	1.102	3.89E-06
MW-28D	33	2.03	0.406	1.43E-06
MW-28D	55	1.64	0.328	1.16E-06
MW-29D	47.5	1.2	0.24	8.47E-07
MW-29D	54.5	1.38	0.276	9.74E-07
MW-30D	18	599	119.8	4.23E-04
MW-30D	34.5	1.81	0.362	1.28E-06
MW-31D	36	2.05	0.41	1.45E-06
MW-31D	45	3.2	0.64	2.26E-06
MW-32D	33.5	129	25.8	9.10E-05
MW-32D	47.5	1.9	0.38	1.34E-06
MW-33D	30	23	4.6	1.62E-05
MW-33D	40	5.2	1.04	3.67E-06
MW-34D	38.5	8.99	1.798	6.34E-06
MW-34D	49.5	4.4	0.88	3.10E-06
Transmissivity > 100 ft/day				
Transmissivity 10-100 ft/day				
Transmissivity <10 ft/day				

Depth-Discrete VOC Results



Groundwater Sampling – Existing Wells



VOC Results

Updated Conceptual Site Model

- DNAPL in fractured bedrock beneath former quarry (MW-4)
- Contaminant distribution primarily along fracture strike (NE-SW), dipping NW (cross-gradient to the regional flow)
- High transmissivity with large well connected shallow fractures (MW-4, MW-30, MW-25D) – carrying contaminant load
- Remaining wells generally have low transmissivity, which appears to decrease with depth
- Moderate to strongly reducing conditions with c-DCE and VC production, along with native dehalogenating populations

Bench and Pilot Testing

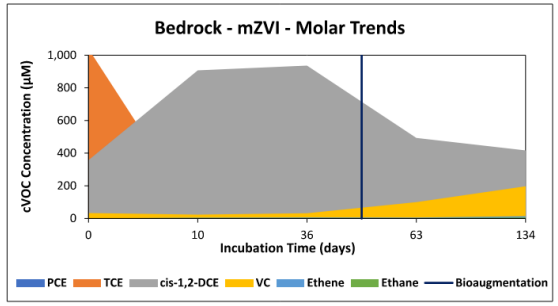
- Overburden microcosm (MW-27D soil and MWG-DR groundwater)
- Bedrock microcosm (MW-27D rock and MW-4 groundwater)
- Bench test conditions (Control, Lactate, EVO, mZVI Suspension)
- Bioaugmentation (two rounds)

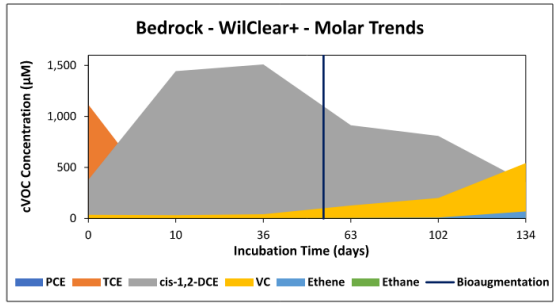
Mircocosm Study

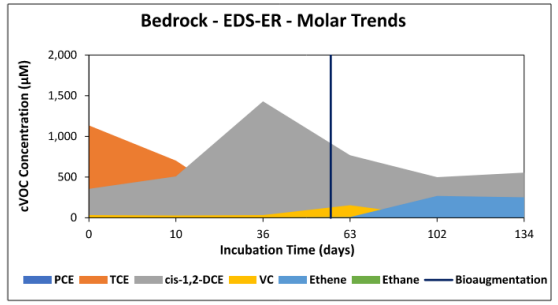
Laboratory setup

Bench Scale Results

- All formulations stimulated some dechlorination in both bedrock and overburden
- Combination of ZVI, EVO, and sodium lactate was selected for the full-scale remedy







Event	Test Condition ID	Location	PCE	TCE	cis-1,2-DCE	trans-1,2-DCE	Vinyl Chloride
			µg/L	µg/L	µg/L	µg/L	µg/L
T0	GW-BR-EDS-ER-A	Bedrock	10	70,961	17,008	140	968
T0	GW-BR-EDS-ER-B	Bedrock	9	73,332	16,902	125	858
T10	GW-BR-EDS-ER-A	Bedrock	13	41,014	29,964	425	830
T10	GW-BR-EDS-ER-B	Bedrock	10	49,688	20,542	249	786
T36	GW-BR-EDS-ER-A	Bedrock	7	136	76,388	971	904
T36	GW-BR-EDS-ER-B	Bedrock	6	77	69,815	935	902
T63	GW-BR-EDS-ER-A	Bedrock	4	26	49,993	788	684
T63	GW-BR-EDS-ER-B	Bedrock	4	10	30,577	681	8,149
T0	GW-BR-mZVI-A	Bedrock	7	66,261	16,987	351	937
T0	GW-BR-mZVI-B	Bedrock	7	65,986	17,164	344	959
T10	GW-BR-mZVI-A	Bedrock	5	793	28,312	409	612
T10	GW-BR-mZVI-B	Bedrock	4	128	61,945	807	722
T36	GW-BR-mZVI-A	Bedrock	5	283	22,822	254	601
T36	GW-BR-mZVI-B	Bedrock	4	24	72,784	696	1,228
T63	GW-BR-mZVI-A	Bedrock	3	16	13,109	72	1,517
T63	GW-BR-mZVI-B	Bedrock	3	1	38,627	334	4,217
T0	GW-BR-WC-A	Bedrock	18	69,076	17,972	148	992
T0	GW-BR-WC-B	Bedrock	15	72,875	18,297	152	1,031
T10	GW-BR-WC-A	Bedrock	47	85	71,159	921	960
T10	GW-BR-WC-B	Bedrock	23	47	72,441	910	900
T36	GW-BR-WC-A	Bedrock	12	174	75,348	789	1,217
T36	GW-BR-WC-B	Bedrock	9	90	78,670	842	1,239
T63	GW-BR-WC-A	Bedrock	8	60	44,493	565	3,590
T63	GW-BR-WC-B	Bedrock	6	30	48,833	585	3,654

Pilot Testing Overview

90% Remedial Design prepared in parallel with pilot planning

Pilot testing evaluated amendment distribution in overburden and bedrock

- Overburden: inject amendment and tracer into existing wells and monitor at 5- to 10-foot distances
- Bedrock: use hydraulic fracturing to emplace the amendment into existing fractures and monitor with tiltmeters

Primary objective: amendment distribution/radius of influence

Secondary objective: degradation

Pilot Testing Results Summary

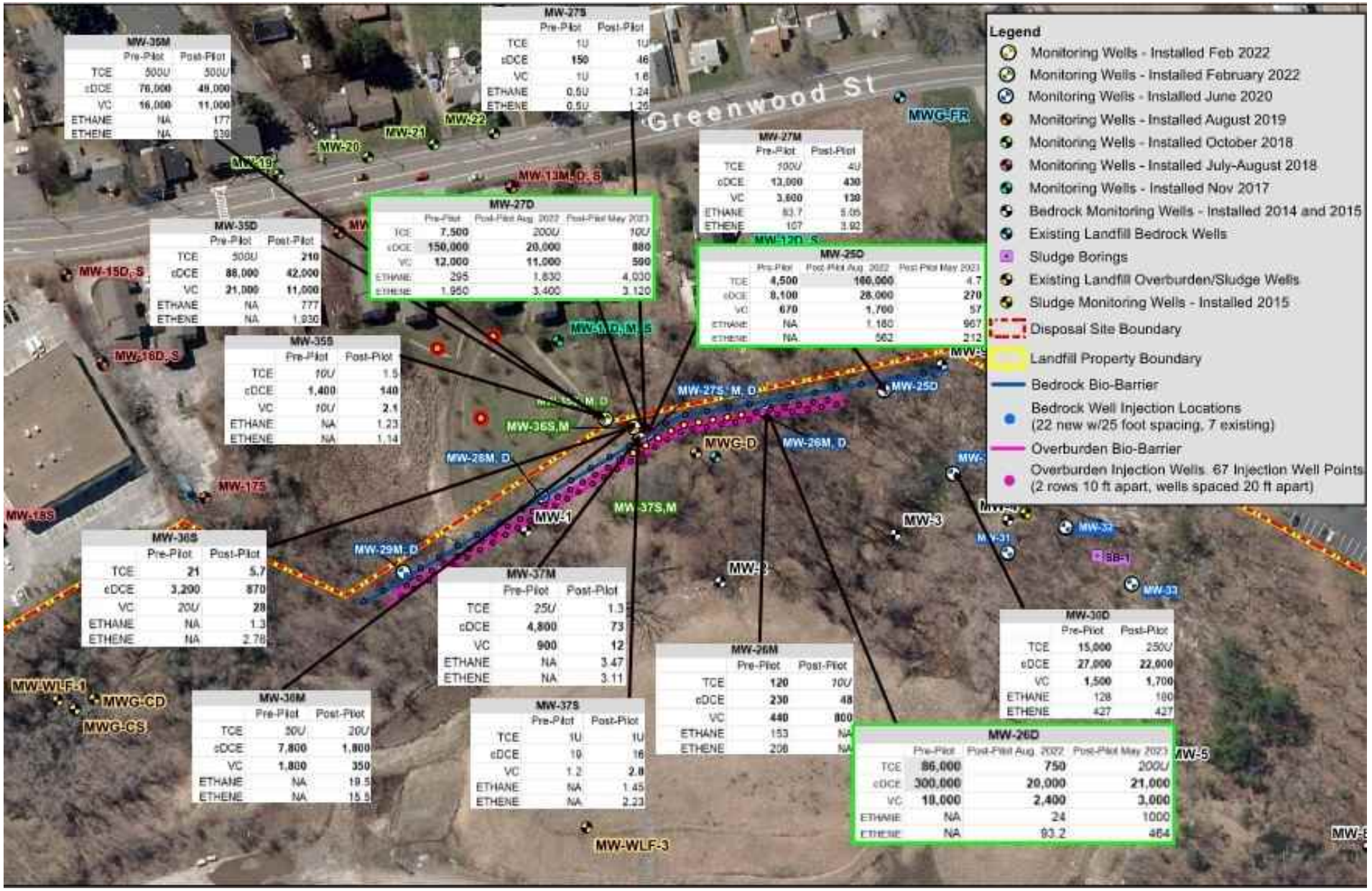
Overburden: Amendment distribution beyond 10 feet achieved with acceptable injection flow rates

Bedrock: Amendment distribution achieved along barrier orientation beyond 15 feet in all fractures tested except one. Fracture propagation dominant N-NE and S-SW

Limited sampling for geochemistry, redox parameters, and VOCs indicates onset of dechlorination (two rounds)

Pilot results verified design assumptions and helped complete 100% remedial design

Pre and Post Pilot Groundwater Sampling Results



Final Remediation Barrier Design

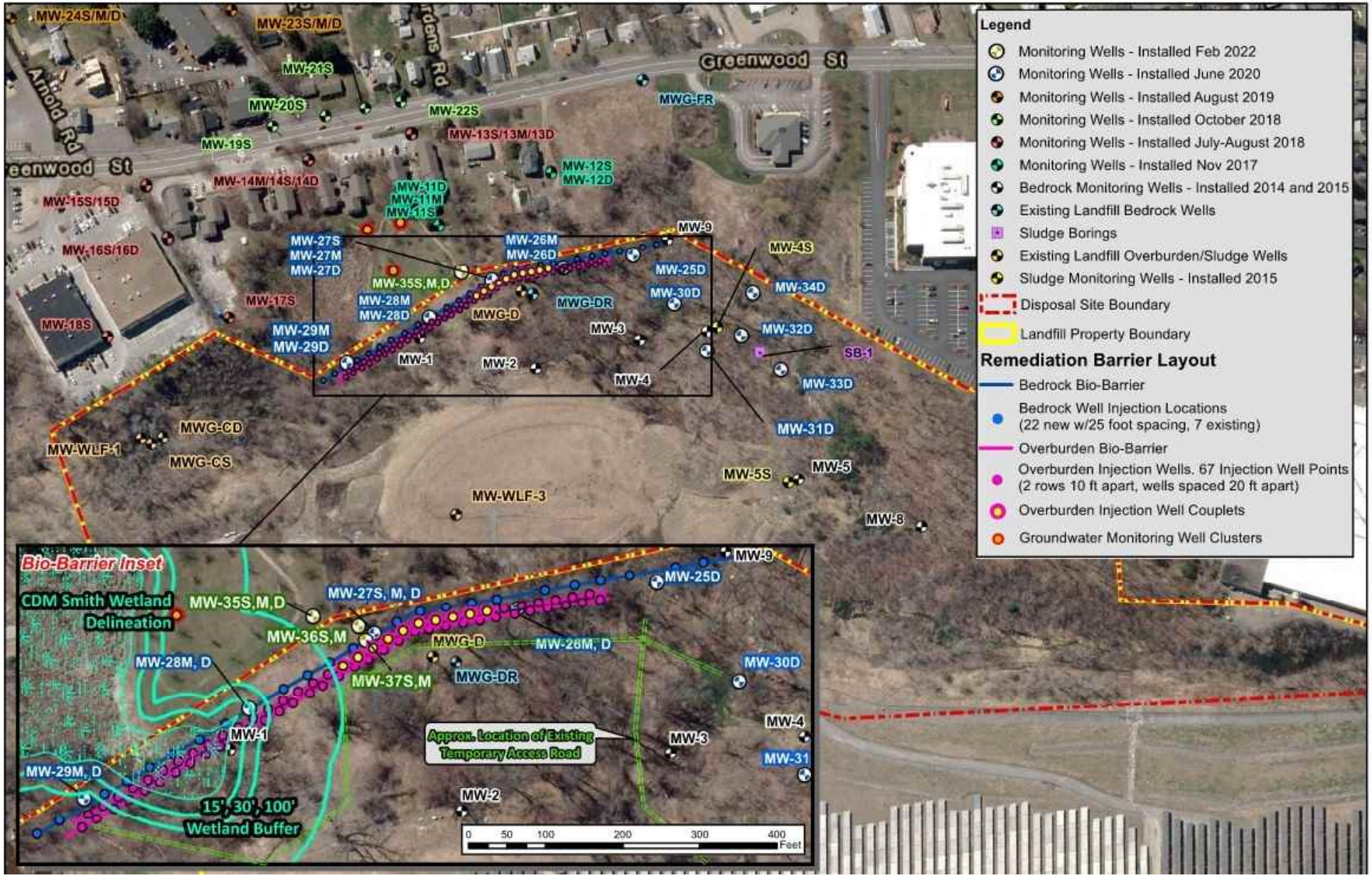
Remediation Barrier Design - Bedrock

- 22 bedrock boreholes installed 25 feet apart (15 ft ROI) along property boundary to maximum depth of 70 feet (7 existing bedrock boreholes)
- Geophysical logging to identify bedrock fracture locations in the borehole wells to conduct hydraulic fracturing/amendment slurry injections
- Packer Sampling
- Hydraulic fracture injection of EVO and ZVI into existing fractures with tilt meter monitoring
- Follow-on injection of lactate with bioaugmentation
- Additional bedrock monitoring wells off-site

Remediation Barrier Design - Overburden

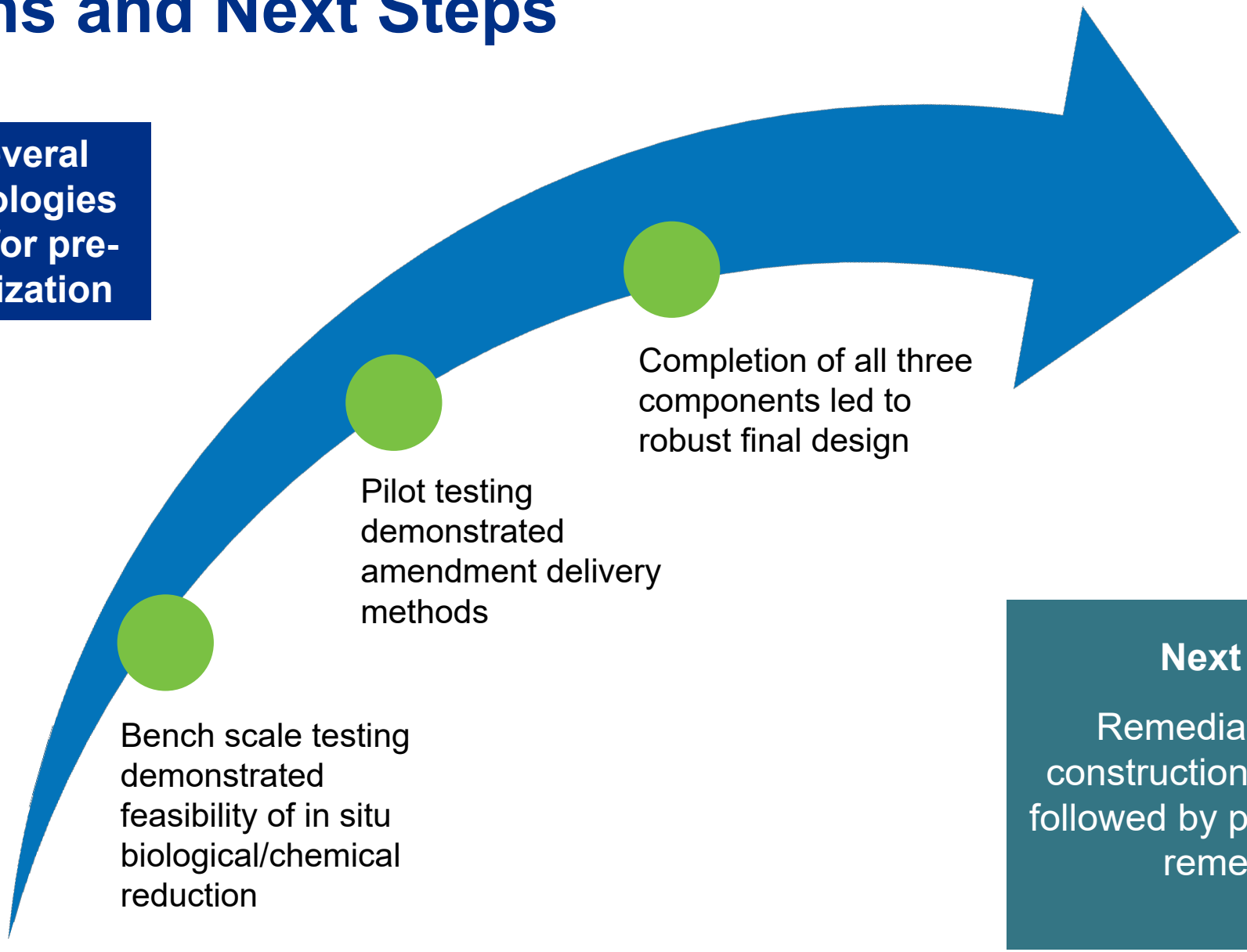
- 67 overburden injection wells (2 offset rows, wells 10 feet apart, 6 ft ROI). Well spaced 20 feet apart installed to the top of bedrock (maximum depth of 40 feet)
- 10 of the wells are couplets in the central part of the barrier
- Injection of EVO, lactate with bioaugmentation
- Additional overburden monitoring wells off-site (next slide)

Remediation Barrier Design



Conclusions and Next Steps

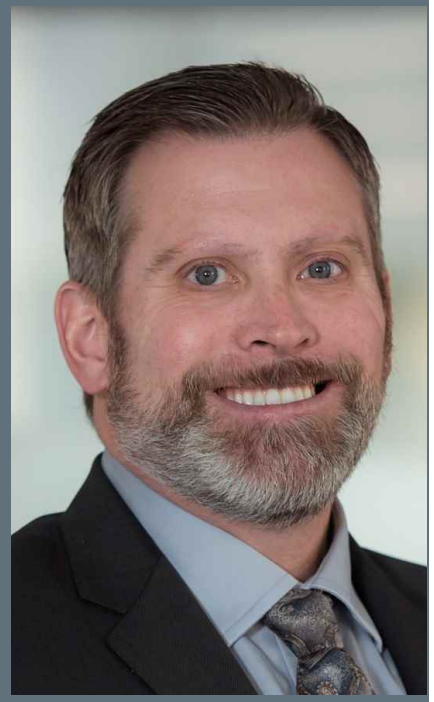
Implemented several innovative technologies and approaches for pre-design characterization



Next steps:

Remediation barrier construction later in 2024, followed by potential source remediation

Thank you!



To learn more, contact:

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