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Characterization and Pilot Testing to Demonstrate Innovative Amendment Emplacement for In Situ Biological/Chemical Reduction of VOCs (as DNAPL) in 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

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

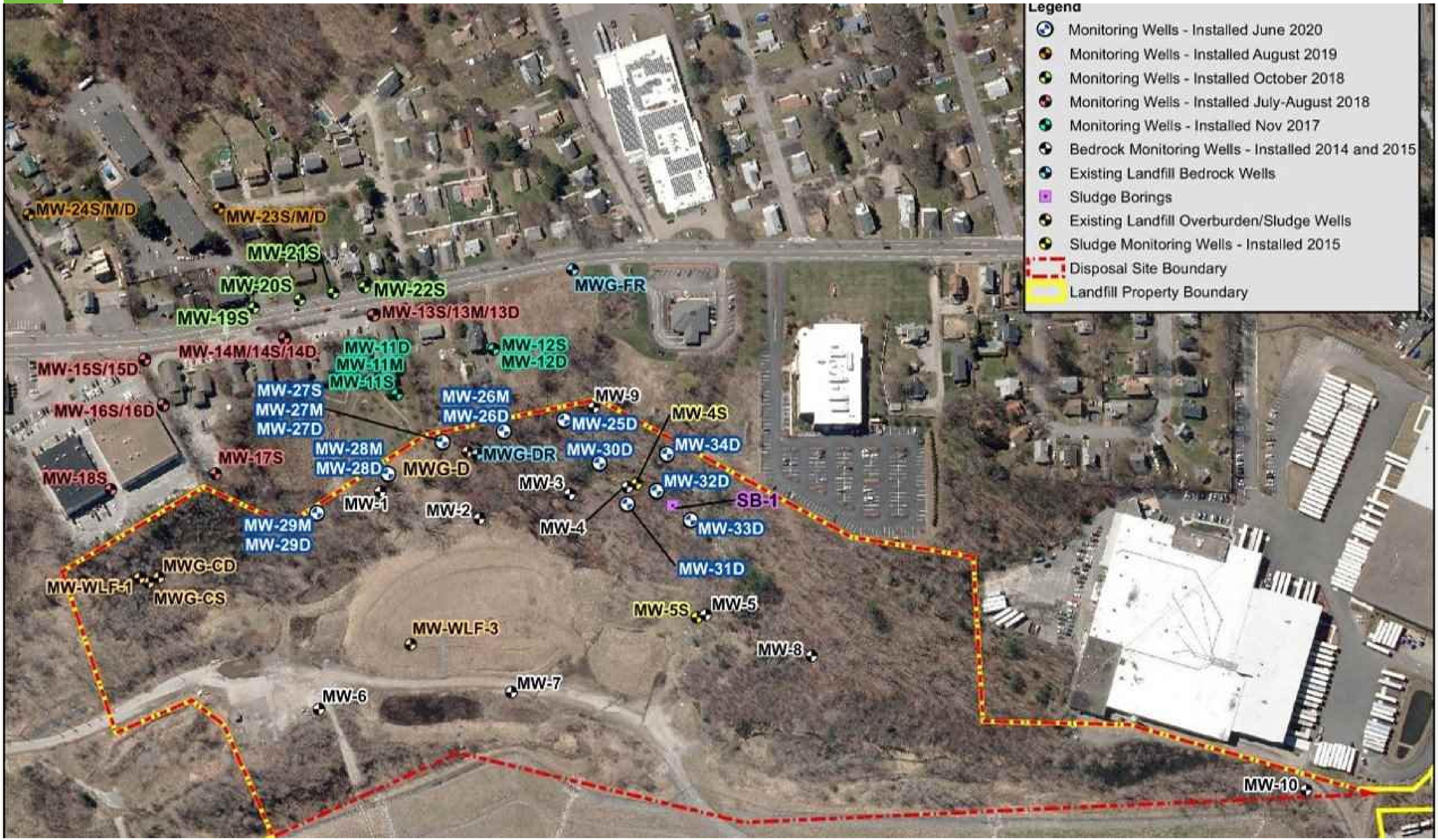
Well drilling

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

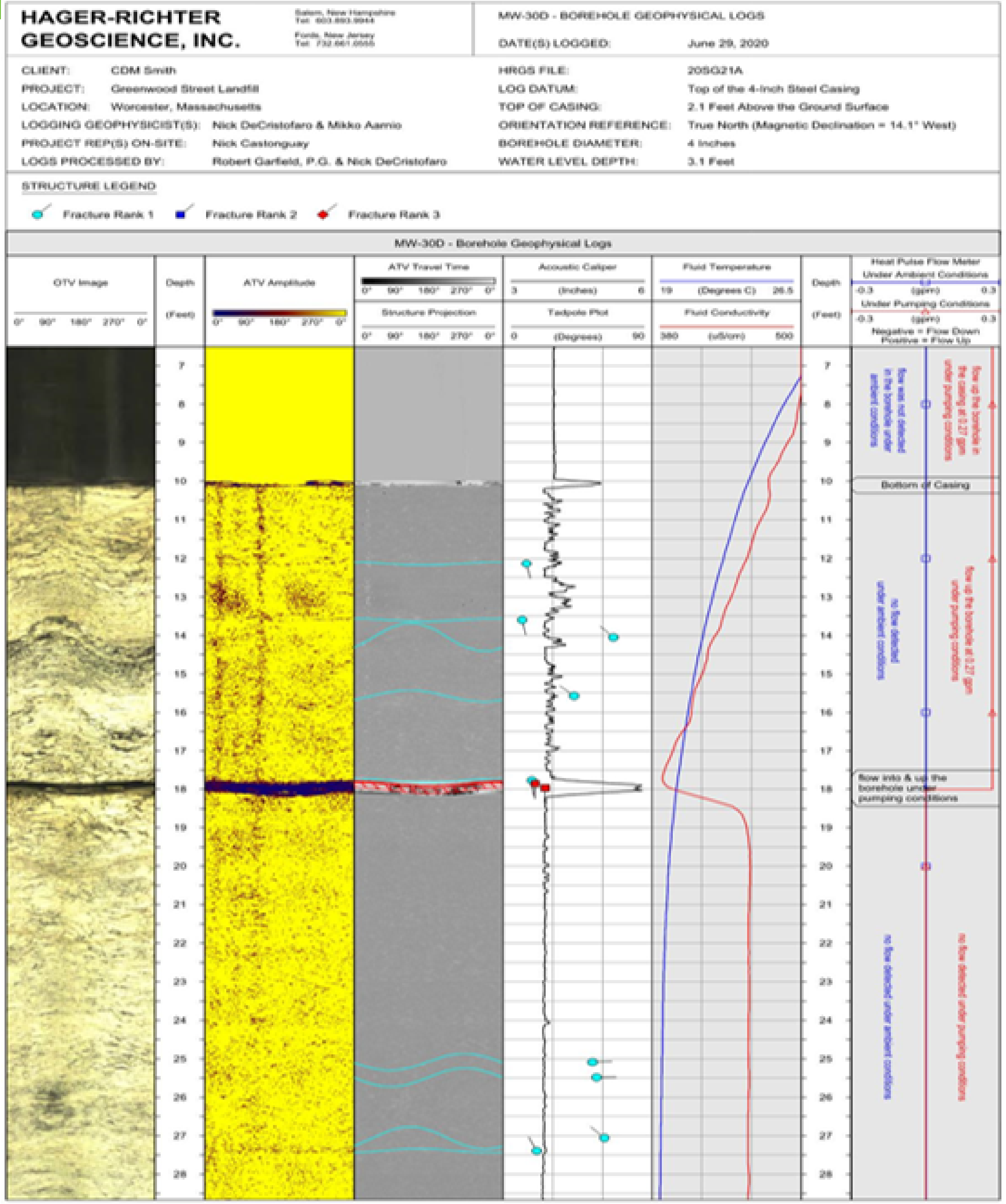


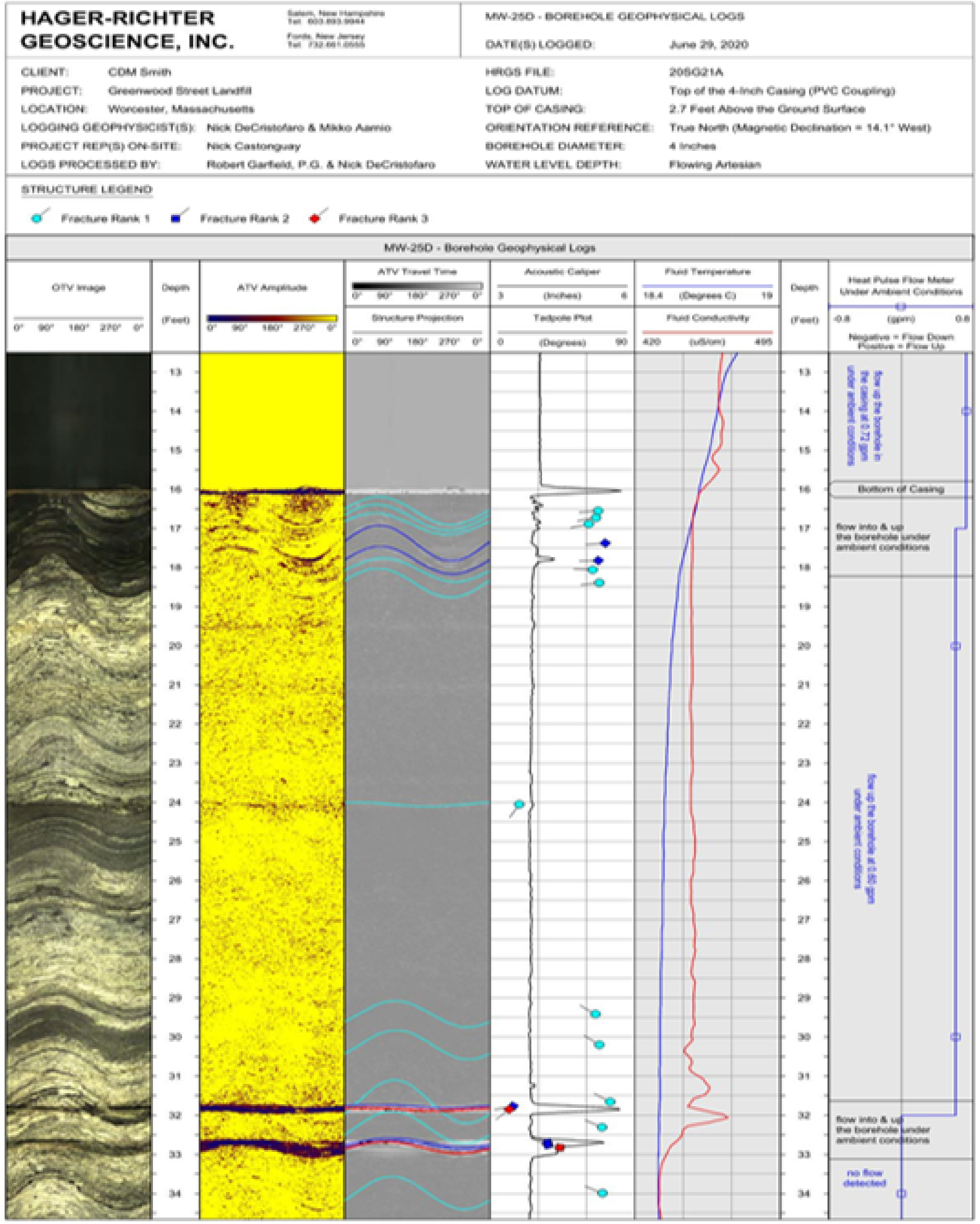
Well Network

Borehole Geophysics Results

- Depth and size of fractures
- Orientation of fractures
- Vertical flow of groundwater in the borehole
- Understand groundwater contaminant transport in bedrock
- Geophysical logs/results used to select packer testing and sampling locations

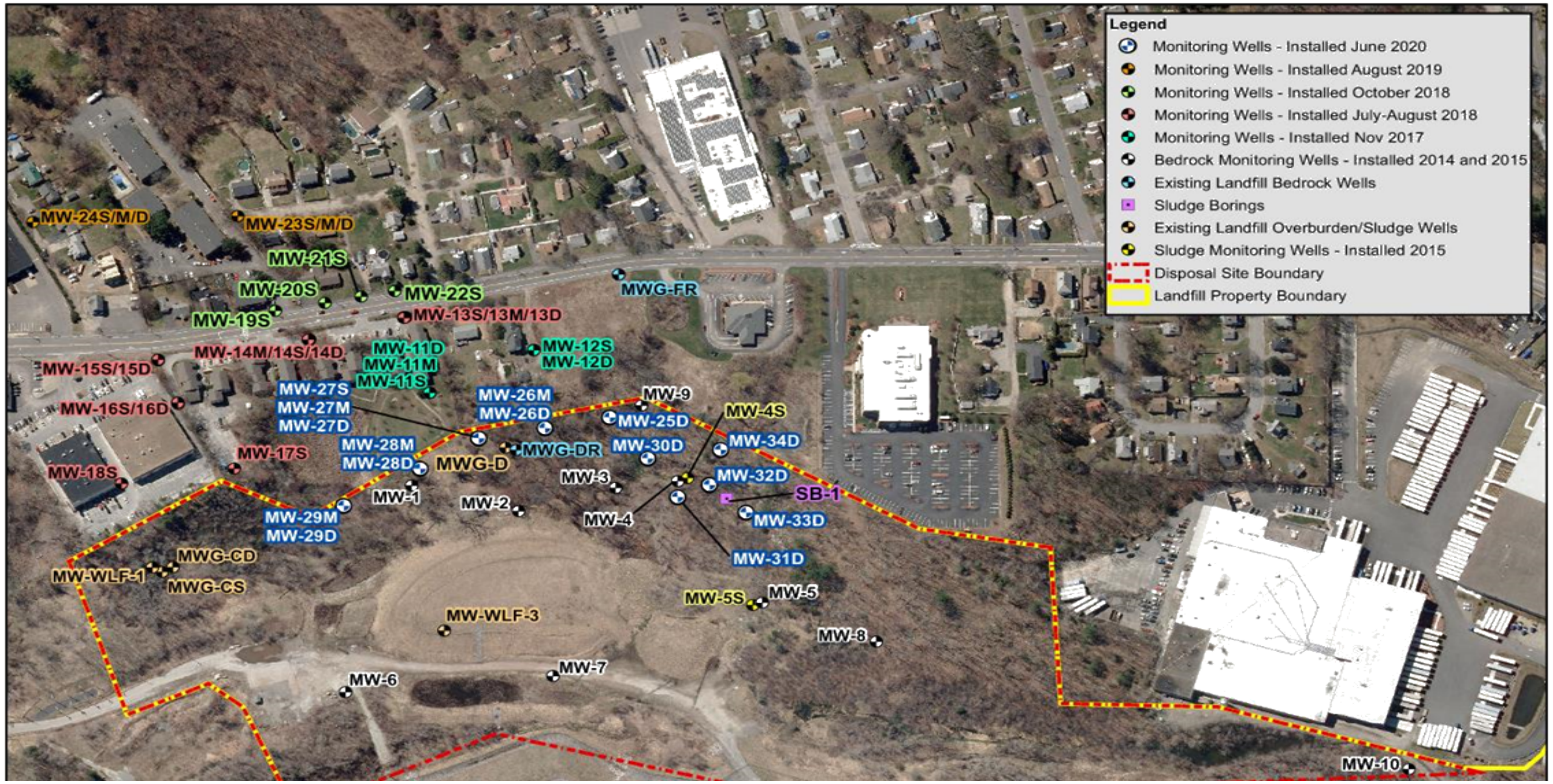
Borehole logging





Integrated Borehole Logs

Borehole Packer Testing

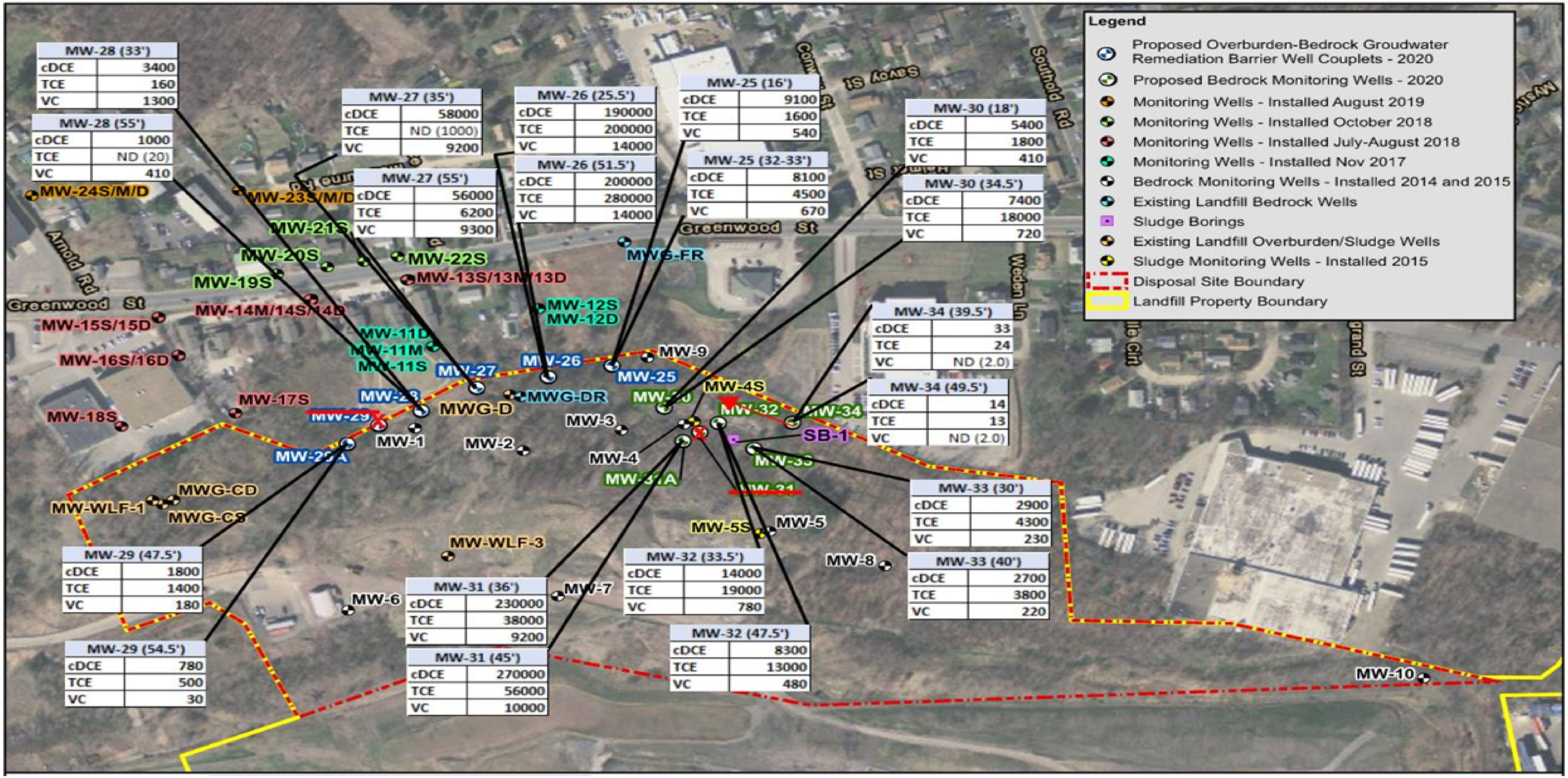


Site Layout

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

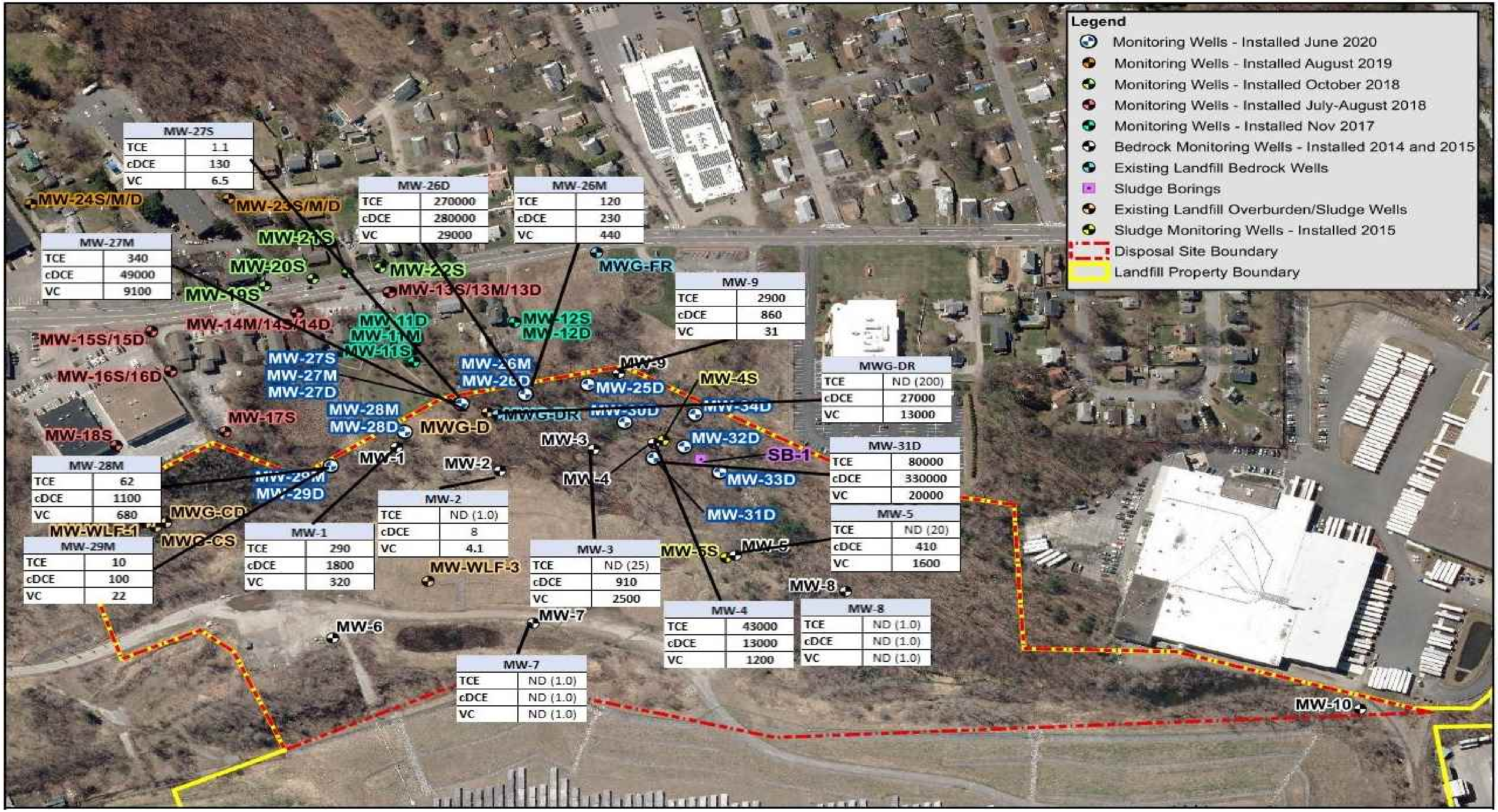
Transmissivity > 100 ft/day
Transmissivity 10-100 ft/day
Transmissivity <10 ft/day

Depth-Discrete VOC Results



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 DHC populations

Bench and Pilot Testing

Bench Scale Studies

- 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 lactate was selected for the full-scale remedy

Event	Test Condition ID	Location	PCE µg/L	TCE µg/L	cis-1,2-DCE µg/L	trans-1,2-DCE µg/L	Vinyl Chloride 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

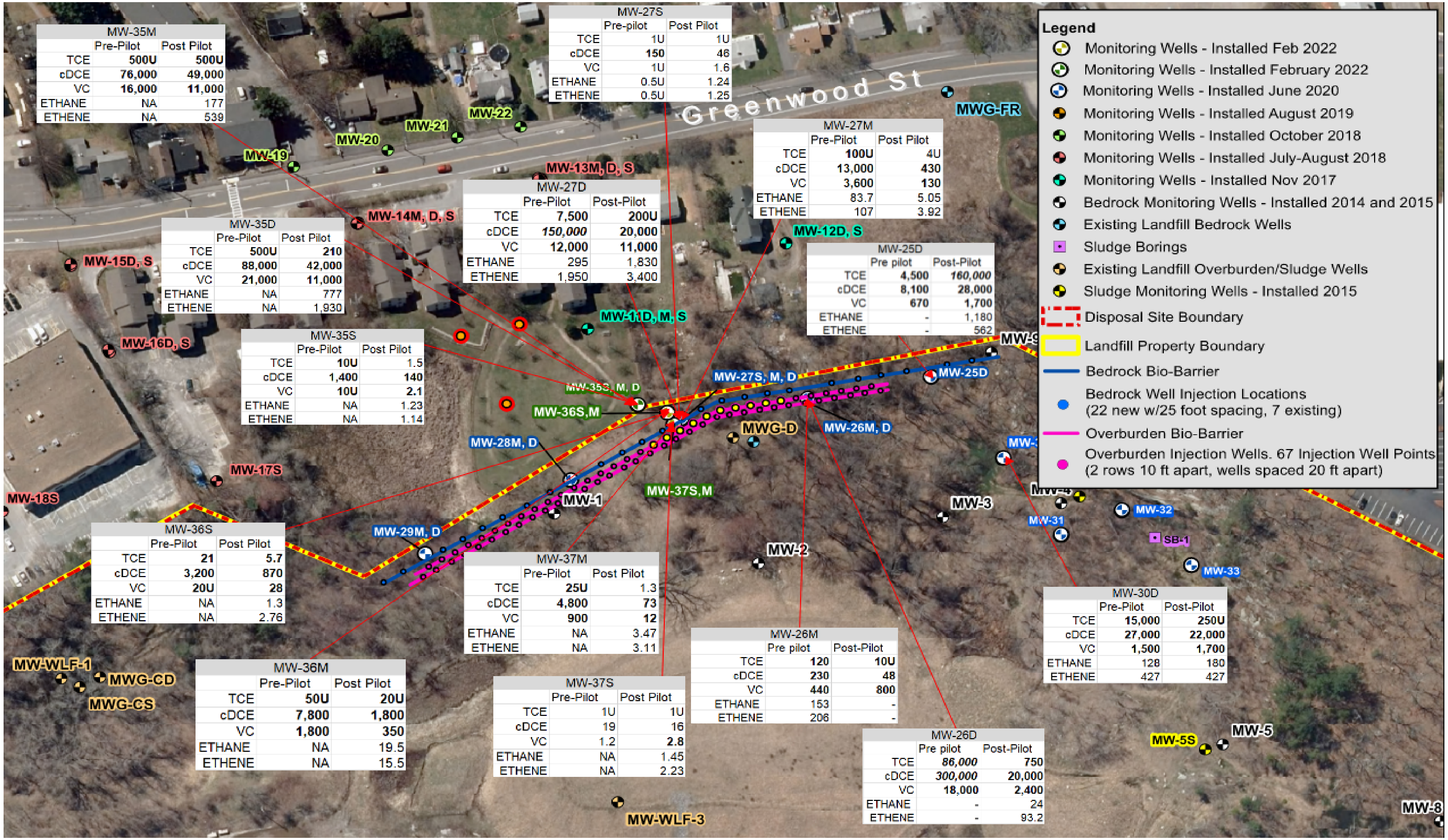
Overburden: amendment distribution beyond 10 feet achieved with acceptable injection rates

Bedrock: amendment distribution achieved along barrier orientation beyond 15 feet in all fractures tested except one

Limited sampling for geochemistry, redox parameters, and VOCs indicates onset of dechlorination

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

Pilot Testing Results



MW-35M	Pre-Pilot	Post Pilot
TCE	500U	500U
cDCE	76,000	49,000
VC	16,000	11,000
ETHANE	NA	177
ETHENE	NA	539

MW-27S	Pre-pilot	Post Pilot
TCE	1U	1U
cDCE	150	46
VC	1U	1.6
ETHANE	0.5U	1.24
ETHENE	0.5U	1.25

MW-27M	Pre-Pilot	Post Pilot
TCE	100U	4U
cDCE	13,000	430
VC	3,600	130
ETHANE	83.7	5.05
ETHENE	107	3.92

MW-27D	Pre-Pilot	Post-Pilot
TCE	7,500	200U
cDCE	*150,000*	20,000
VC	12,000	11,000
ETHANE	295	1,830
ETHENE	1,950	3,400

MW-35D	Pre-Pilot	Post Pilot
TCE	500U	210
cDCE	88,000	42,000
VC	21,000	11,000
ETHANE	NA	777
ETHENE	NA	1,930

MW-25D	Pre pilot	Post-Pilot
TCE	4,500	*160,000*
cDCE	8,100	28,000
VC	670	1,700
ETHANE	-	1,180
ETHENE	-	562

MW-35S	Pre-Pilot	Post Pilot
TCE	10U	1.5
cDCE	1,400	140
VC	10U	2.1
ETHANE	NA	1.23
ETHENE	NA	1.14

MW-36S	Pre-Pilot	Post Pilot
TCE	21	5.7
cDCE	3,200	870
VC	20U	28
ETHANE	NA	1.3
ETHENE	NA	2.76

MW-37M	Pre-Pilot	Post Pilot
TCE	25U	1.3
cDCE	4,800	73
VC	900	12
ETHANE	NA	3.47
ETHENE	NA	3.11

MW-26M	Pre pilot	Post-Pilot
TCE	120	10U
cDCE	230	48
VC	440	800
ETHANE	153	-
ETHENE	206	-

MW-30D	Pre-Pilot	Post-Pilot
TCE	15,000	250U
cDCE	27,000	22,000
VC	1,500	1,700
ETHANE	128	180
ETHENE	427	427

MW-36M	Pre-Pilot	Post Pilot
TCE	50U	20U
cDCE	7,800	1,800
VC	1,800	350
ETHANE	NA	19.5
ETHENE	NA	15.5

MW-37S	Pre-Pilot	Post Pilot
TCE	1U	1U
cDCE	19	16
VC	1.2	2.8
ETHANE	NA	1.45
ETHENE	NA	2.23

MW-26D	Pre pilot	Post-Pilot
TCE	*86,000*	750
cDCE	*300,000*	20,000
VC	18,000	2,400
ETHANE	-	24
ETHENE	-	93.2

Pilot Results

Final Remediation Barrier Design

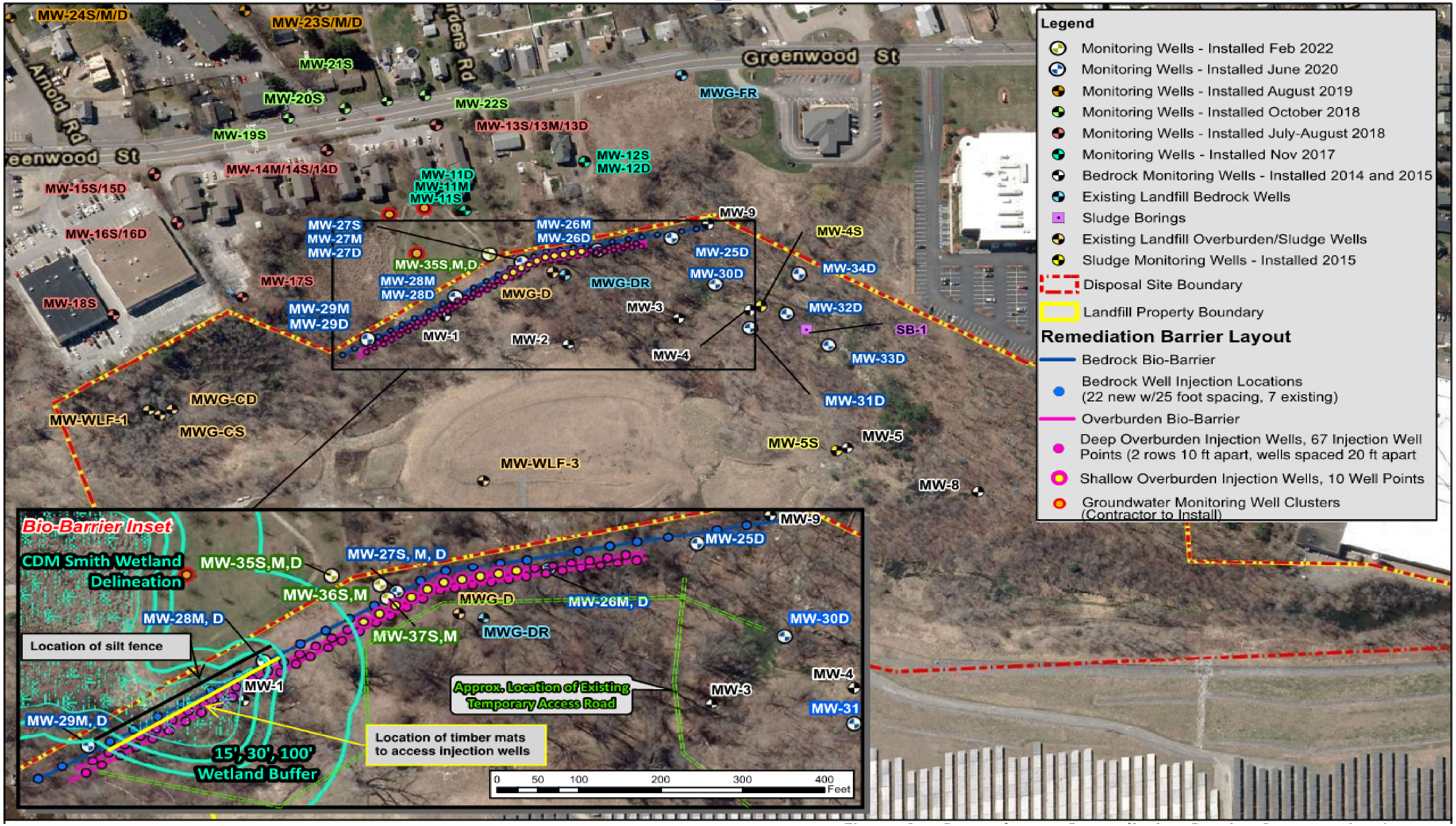
Remediation Barrier Design

- **Bedrock**
  - 29 bedrock boreholes installed 25 feet apart along property boundary to maximum depth of 70 feet
  - Geophysical logging to characterize fractures
  - Hydraulic fracture injection of EVO and ZVI into existing fractures
  - Follow-on injection of EVO and lactation with bioaugmentation

Remediation Barrier Design

- **Overburden**
  - 67 overburden injection wells (10 nested completions) installed on 10-foot centers to the top of bedrock (maximum depth of 30 feet)
  - Injection of EVO and lactation with bioaugmentation

Remediation Barrier Design



Biobarrier Details

Conclusions and Next Steps

Implemented several innovative technologies and approaches for pre-design characterization

Bench scale testing demonstrated feasibility of in situ biological/chemical reduction

Pilot testing demonstrated amendment delivery methods

Completion of all three components led to robust final design

Next steps: remediation barrier construction later in 2023, followed by potential source remediation

Thank You!

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