Remediating Bedrock:
What Once Was Impossible Is Now Routine.
Three Case Studies

September 26, 2024

Science Advisory Board for Contaminated Sites in BC

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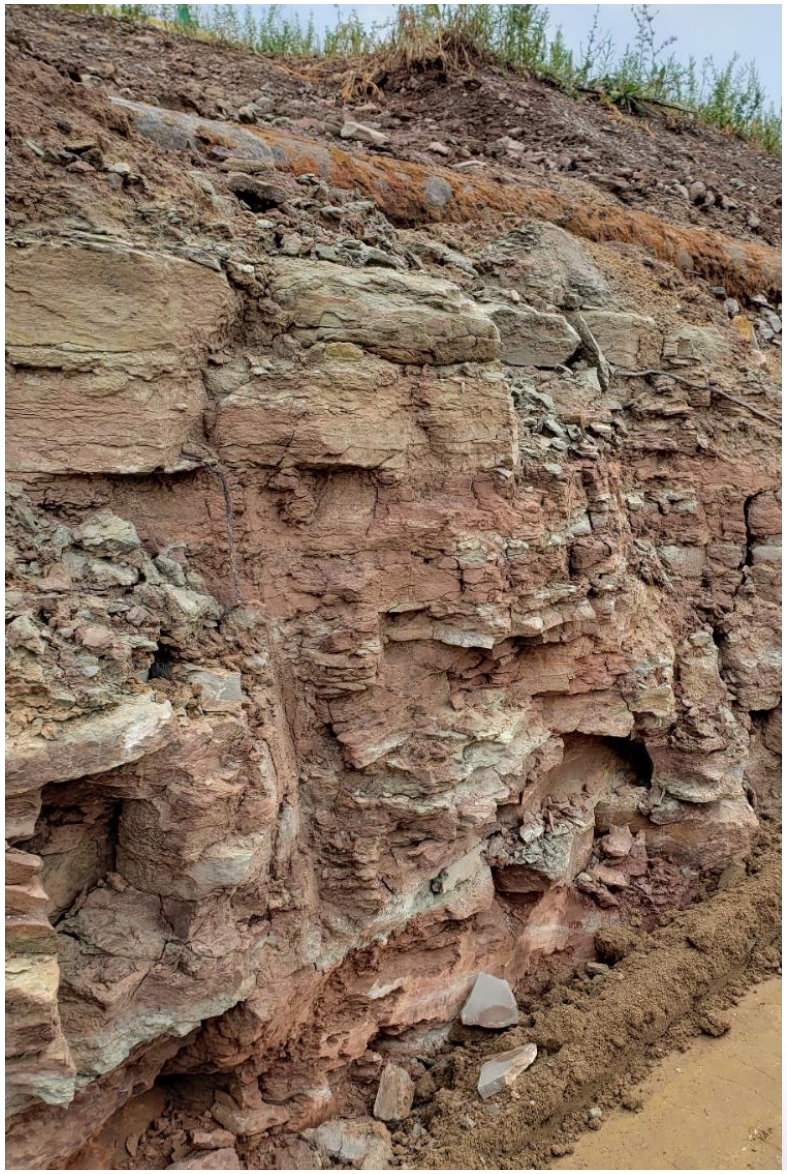
VEI Contracting Inc.



Presentation Overview

- Bedrock Remediation Difficulties
  - Why is it so difficult?
- Three Case Studies
  - Bedrock and PHCs (including LNAPL)
  - Bedrock and Metals (Hex Chrome)
  - Bedrock and Chlorinated Solvents
- Take Aways / Lessons Learned
- Questions

Presenter

- **Eric Cowan B.A.S., C.E.T.**
- Project Manager, Vertex Environmental Inc.
- B.A.S. University of Guelph. Graduate Certificate Environmental Engineering Conestoga College

Vertex Environmental Inc.

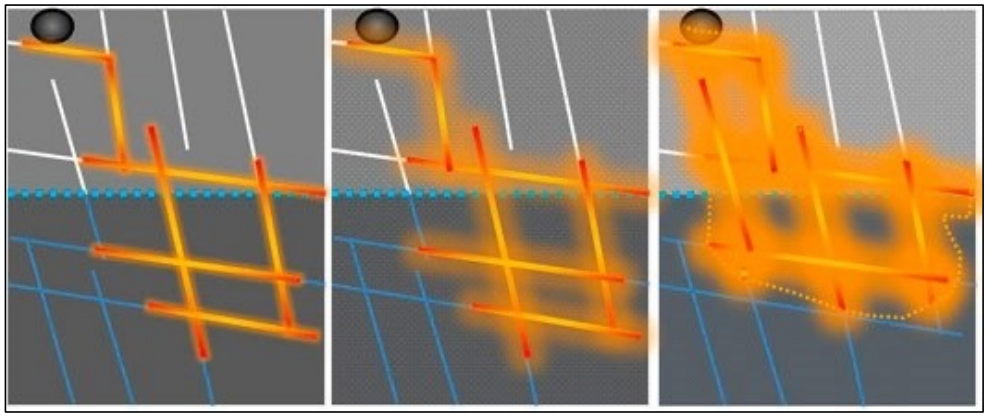
- Founded in 2003
- Bruce Tunnicliffe, M.A.Sc., P.Eng.
- Specialized Environmental Remediation Contractor (in-situ, ex-situ, systems, HRSC)

Bedrock Remediation Difficulties

Bedrock Remediation Difficulties

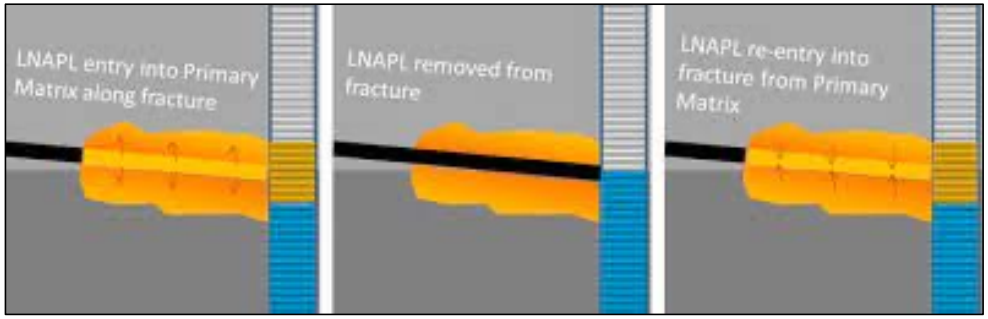
Why So Challenging?

- Fracture Network
  - Can be complex, variable fracture planes
  - Thus contaminant distribution also complex
- Secondary Porosity
  - Contamination “soaks” into rock, difficult to get out
  - Back diffusion
- Hard to Access / Expensive to Access
  - Easy for contaminant to enter fractures
  - Costly to access, must manage overburden
- Plume Length
  - Thin but long fractures = large plume
- Groundwater Flow Velocity
  - Can be fast compared to porous media



Source: ITRC

Early Time → Late Time



Source: ITRC

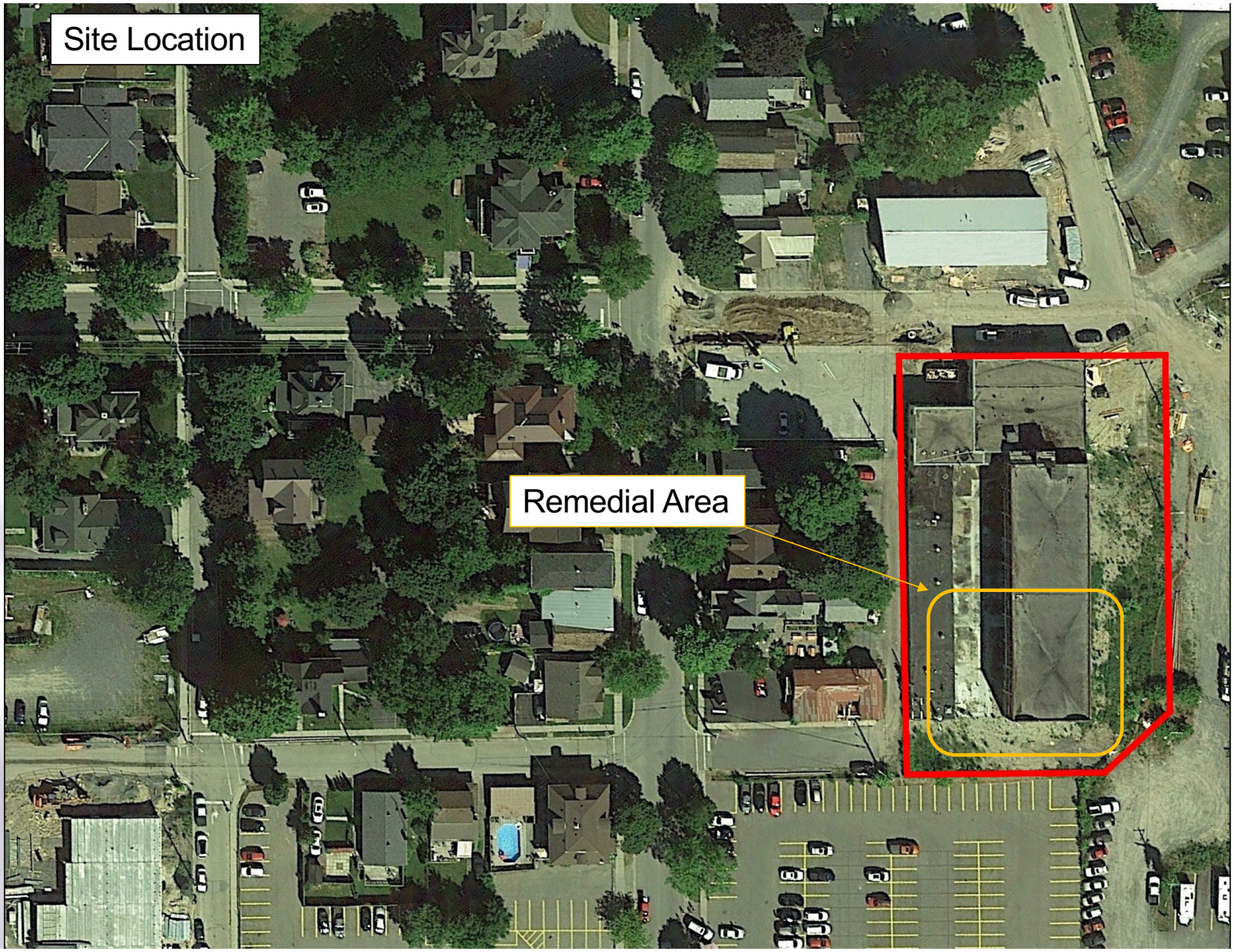
$$V = \frac{K \times i}{n}$$

Bedrock Case Study #1

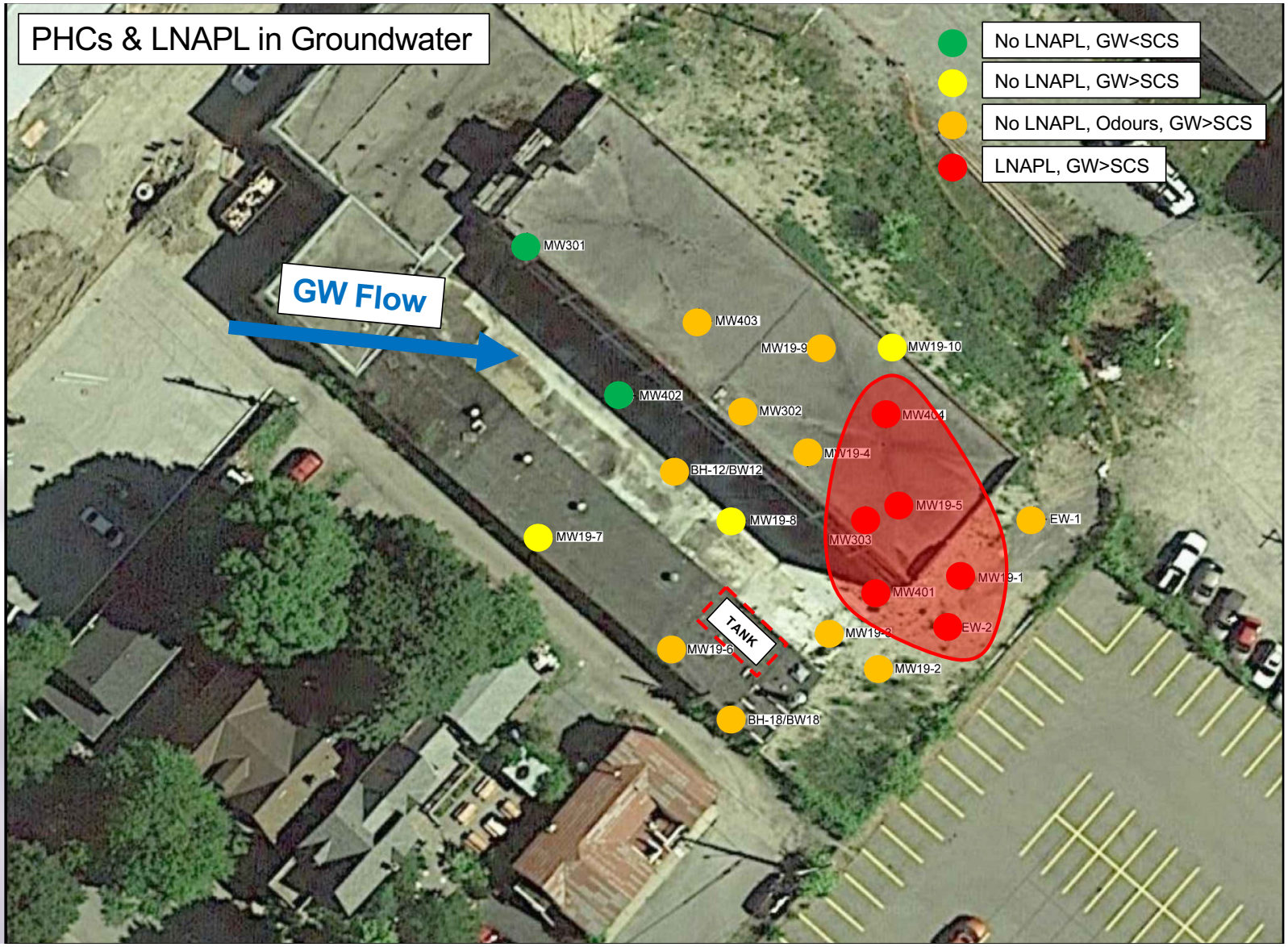
Bedrock and PHCs/LNAPL

Background – The Situation

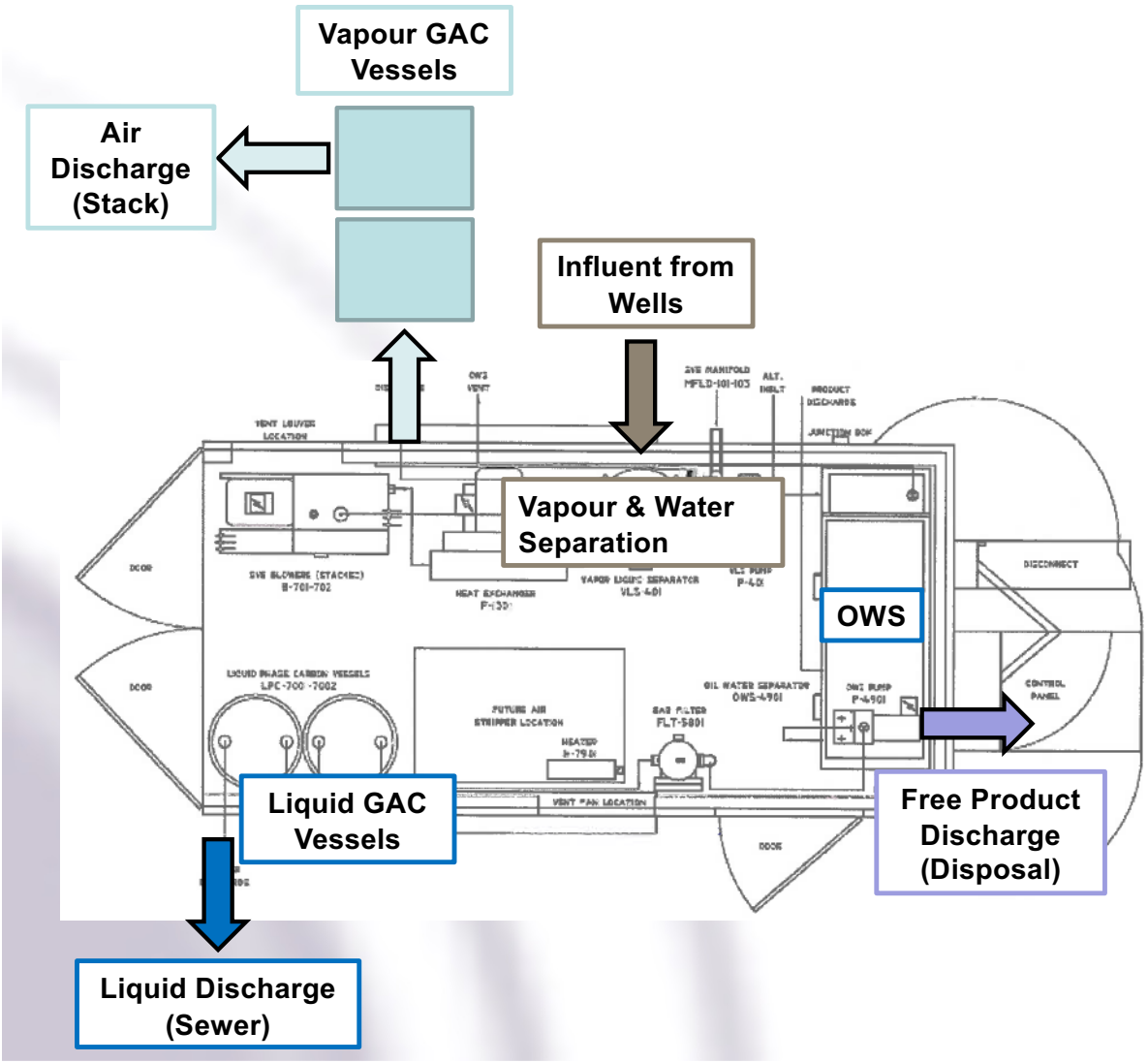
- Historical industrial operations:
  - Leaky fuel tank
  - PHCs and LNAPL primarily in bedrock groundwater
- Future redevelopment planned:
  - Residential redevelopment
  - RA and RSC process underway
  - Remediation required to address free product (LNAPL)
- Staged remedial approach:
  - Source Removal = Decommission fuel tank & removal of impacted soil
  - MPE System = Direct LNAPL removal
  - In-Situ Injection = Polishing step to address residual/remaining PHCs & LNAPL

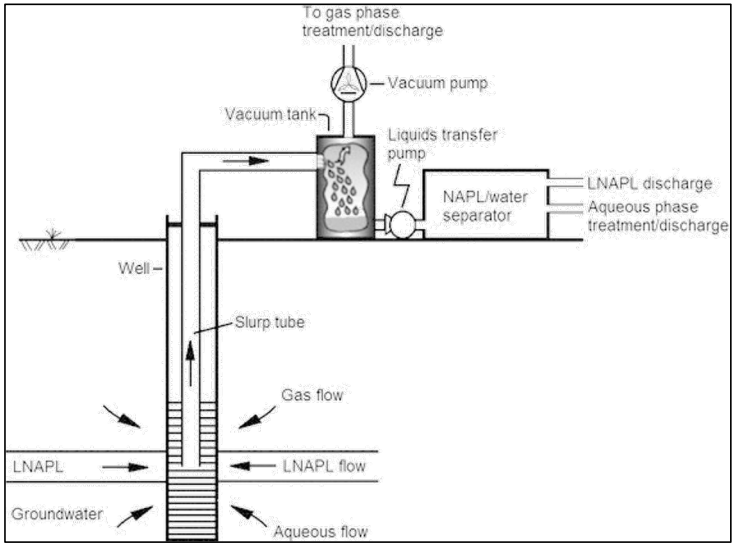

Site Location
Remedial Area

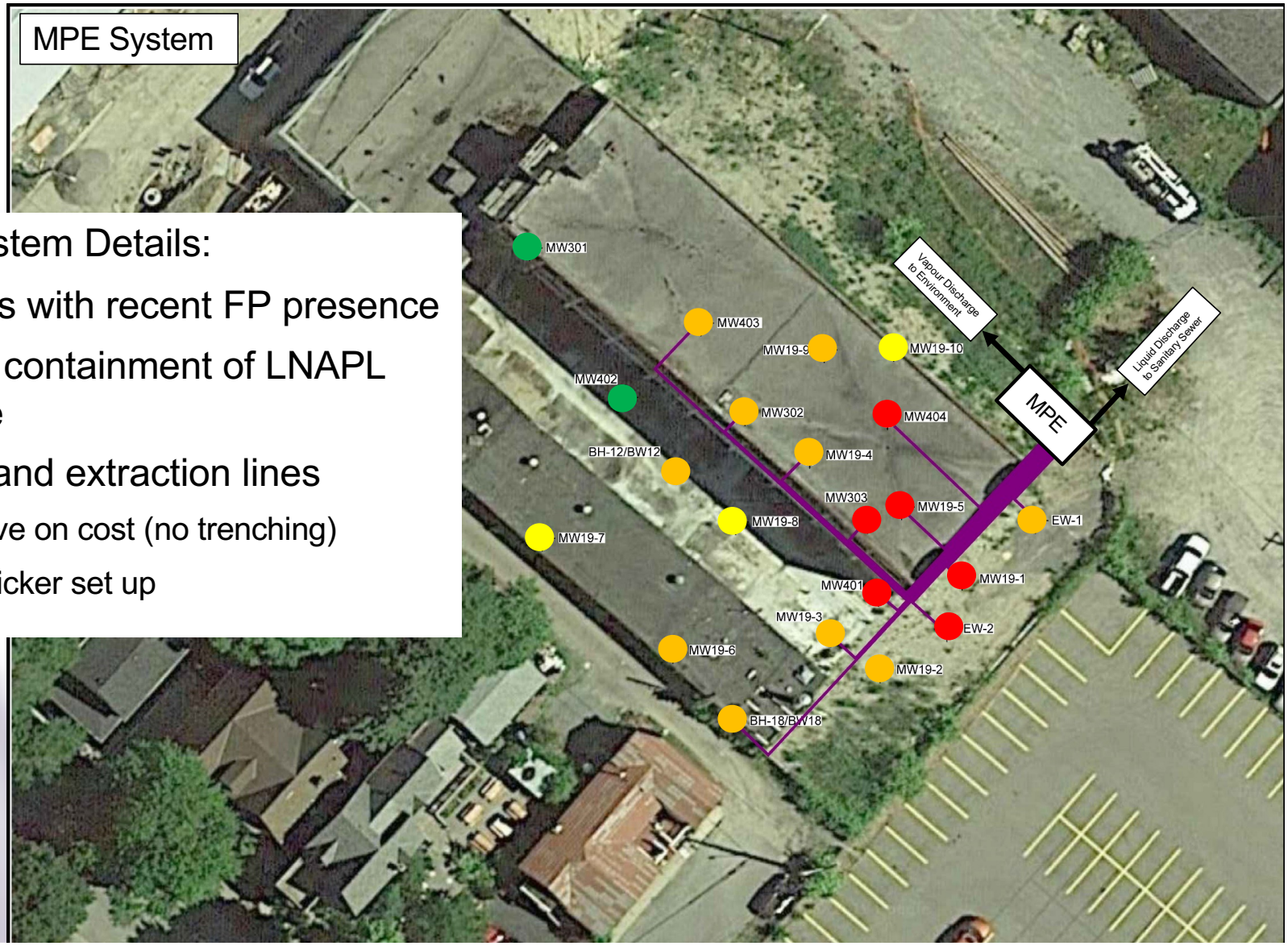
The Source


PHCs & LNAPL in Groundwater
No LNAPL, GW<SCS
No LNAPL, GW>SCS
No LNAPL, Odours, GW>SCS
LNAPL, GW>SCS
GW Flow
MW301
MW403
MW19-9
MW19-10
MW402
MW302
MW404
MW19-4
BH-12/BW12
MW19-5
MW19-8
EW-1
MW19-7
MW303
MW19-1
MW401
TANK
EW-2
MW19-3
MW19-6
MW19-2
BH-18/BW18

Multi-Phase Extraction (MPE) System


Vapour GAC Vessels
Air Discharge (Stack)
Influent from Wells
Vapour & Water Separation
OWS
Liquid GAC Vessels
Free Product Discharge (Disposal)
Liquid Discharge (Sewer)

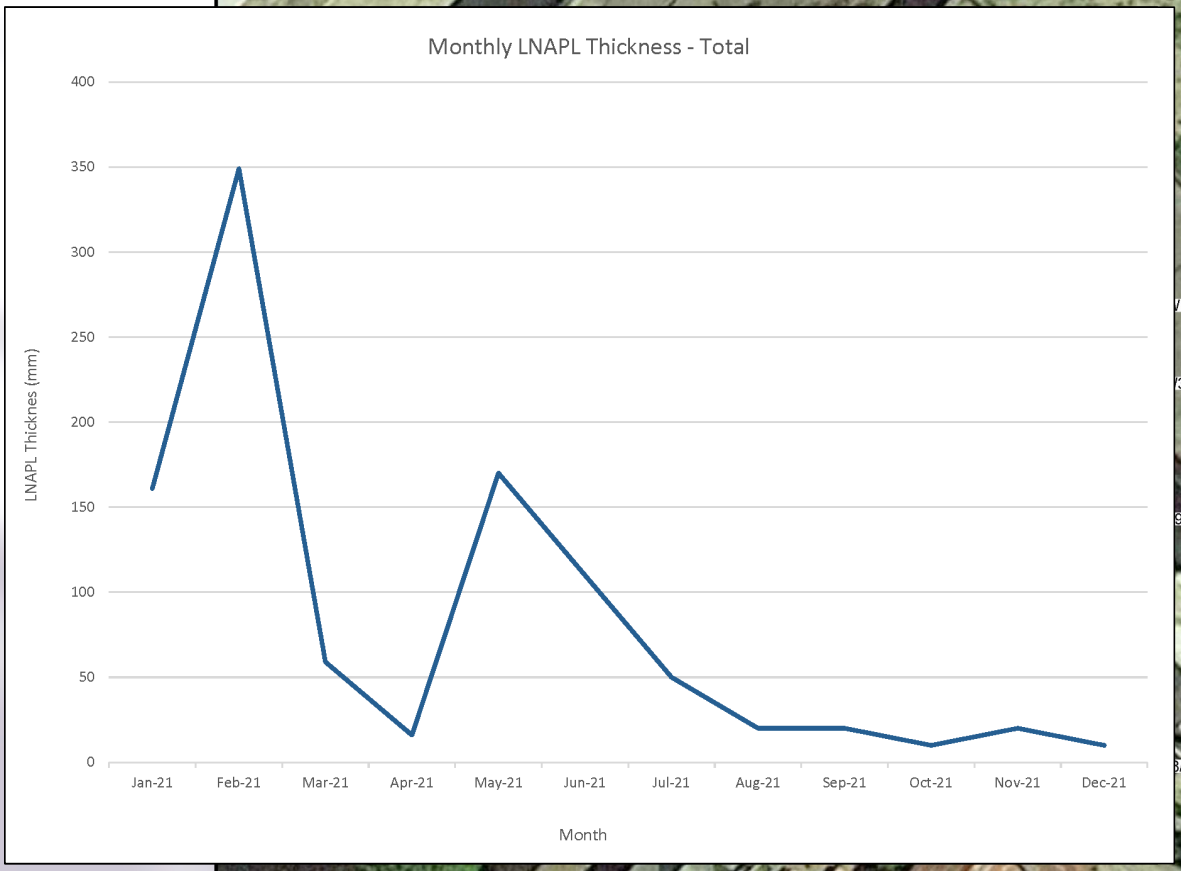

To gas phase treatment/discharge
Vacuum pump
Vacuum tank
Liquids transfer pump
NAPL/water separator
LNAPL discharge
Aqueous phase treatment/discharge
Well
Slurp tube
Gas flow
LNAPL
LNAPL flow
Groundwater
Aqueous flow



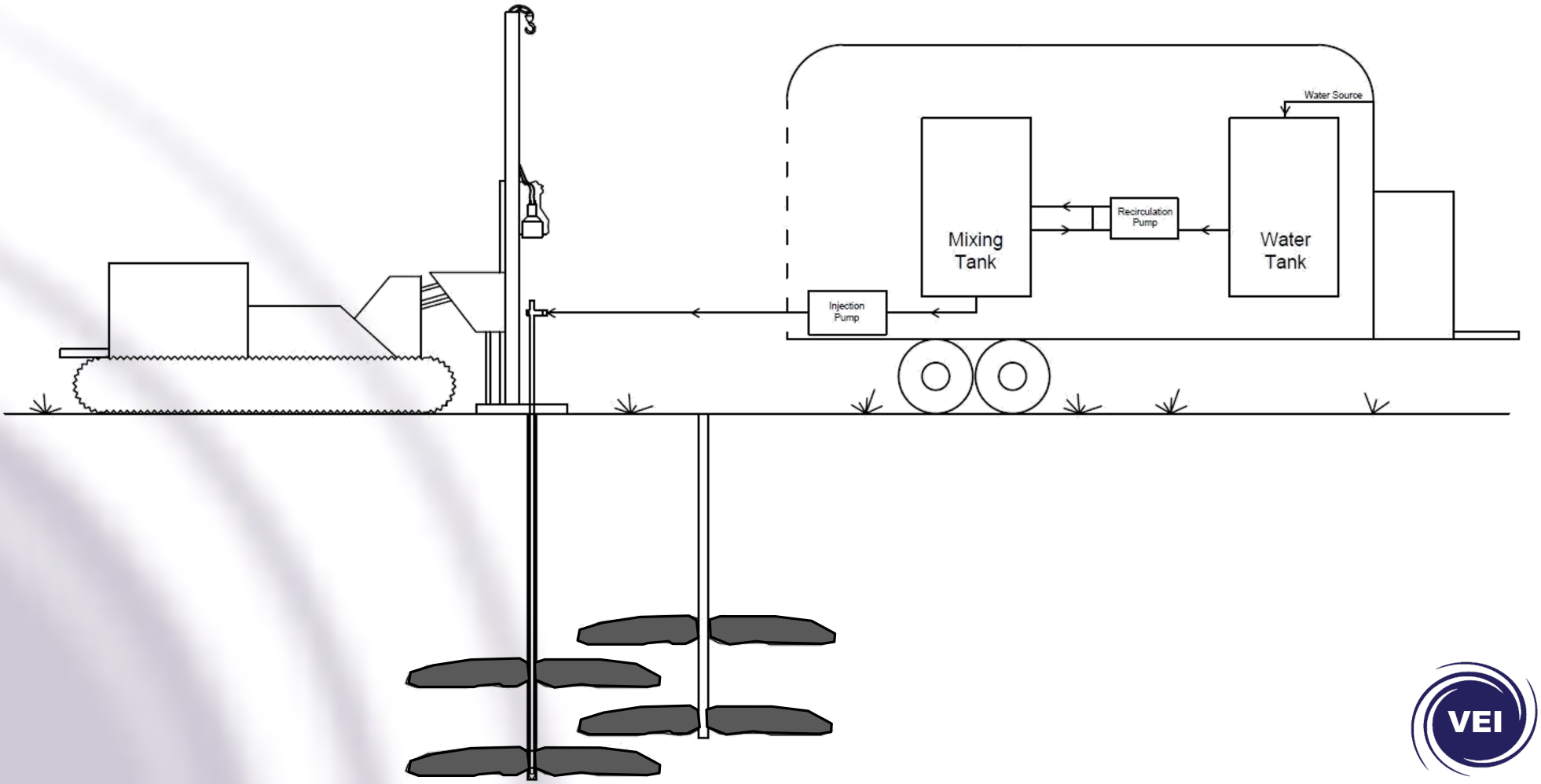
MPE System Details:

- 6 wells with recent FP presence
- Good containment of LNAPL plume
- Overland extraction lines
  - Save on cost (no trenching)
  - Quicker set up

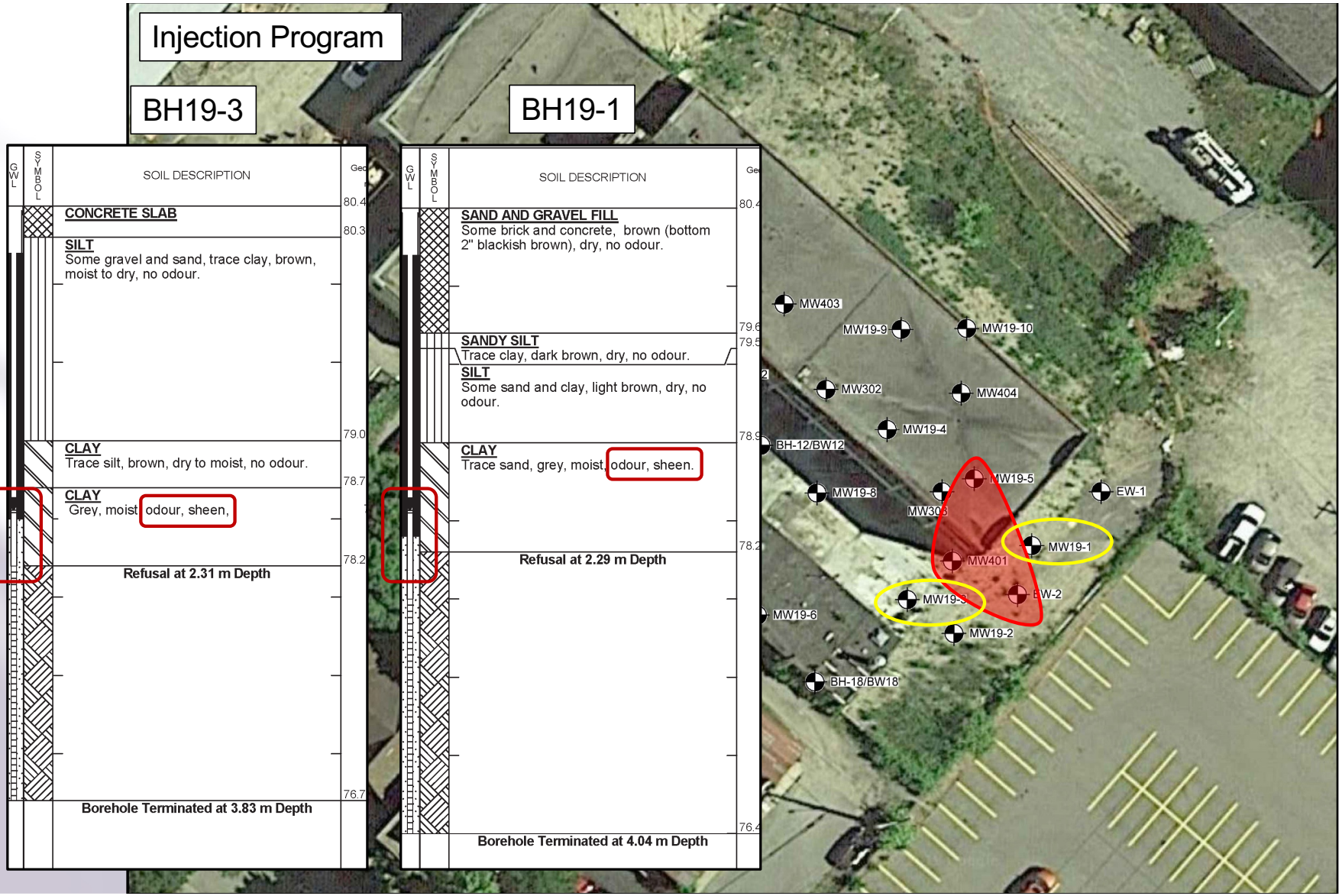
MPE System Results



Injection Program - Carbon Based Amendment

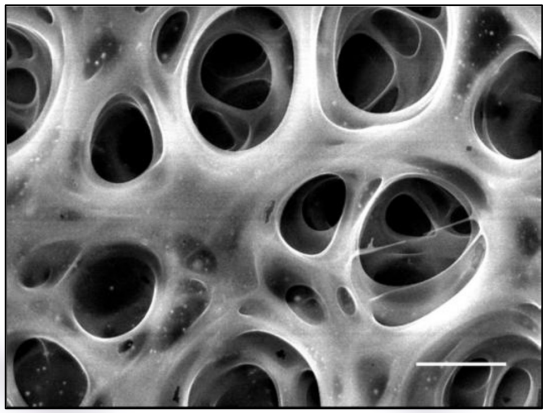


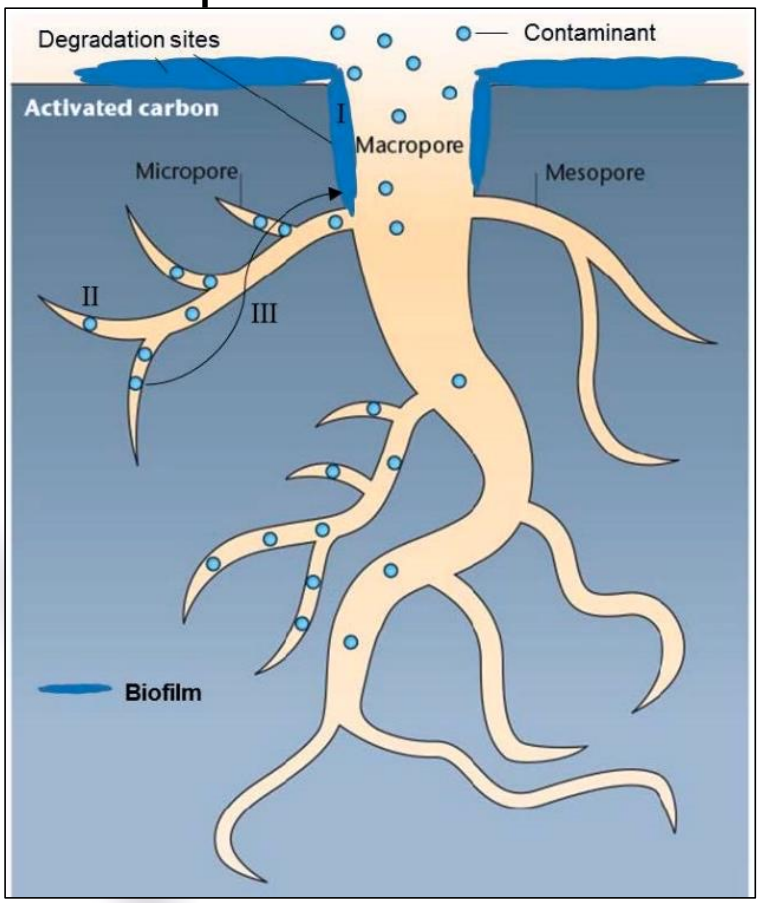
Injection Program

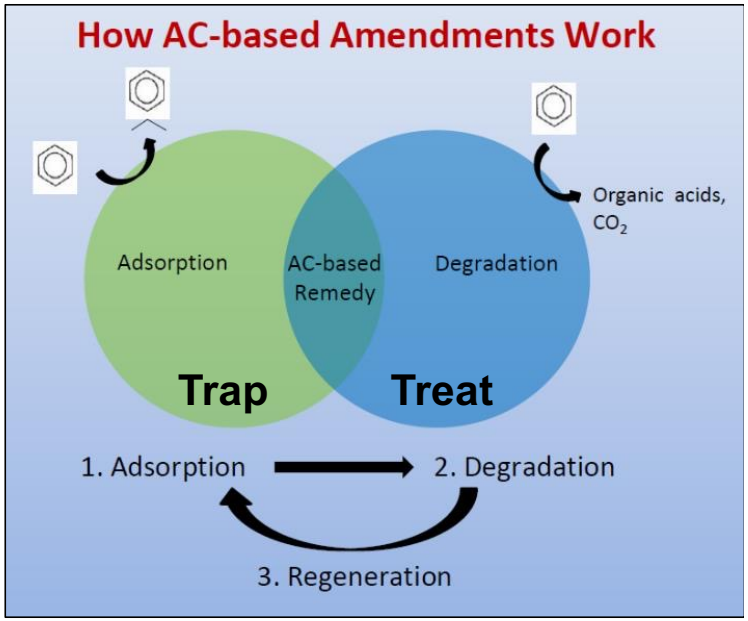



GeoTAP™ (Pre-Drill) Method

Trap & Treat® BOS 200+®



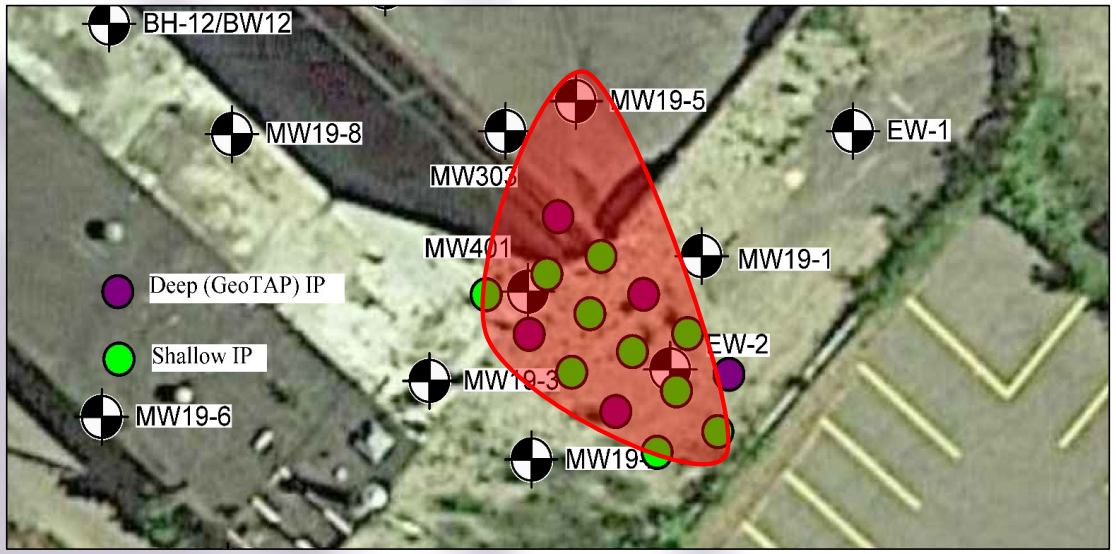




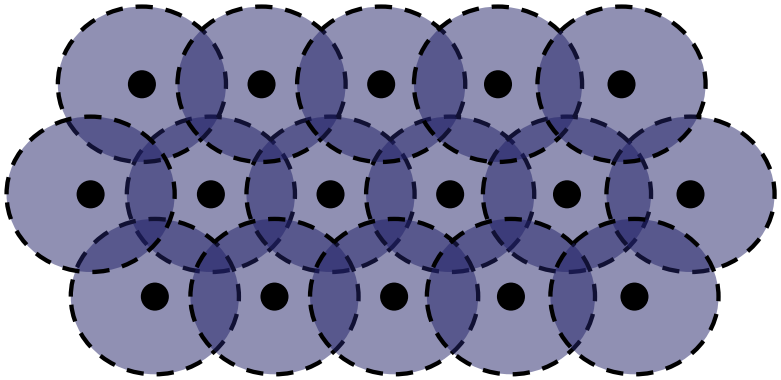
BOS 200+® incorporates activated carbon (AC), nutrients (complex carbohydrates & amino acids), and microbes to synergistically degrade contaminants while renewing the AC platform

Injection Summary

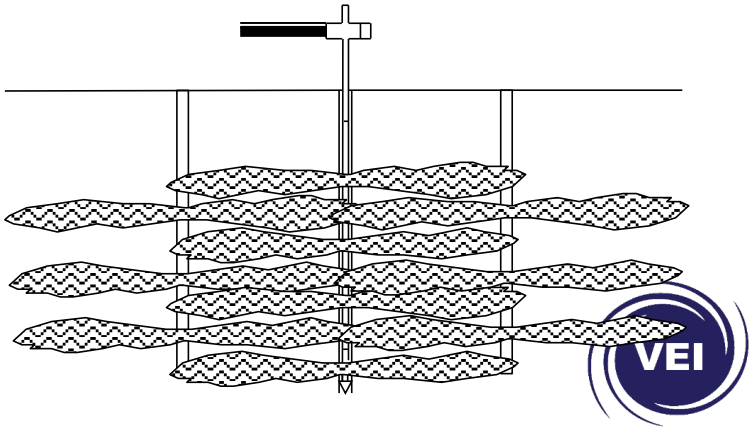
- Completed over 2 days
- 5 bedrock GeoTAP™ injection points (IPs)
- 10 overburden direct-push IPs
- 15 IPs in total to target “Hot Spot” area
- Injected 2,200 kg BOS 200+® in 4,000 L



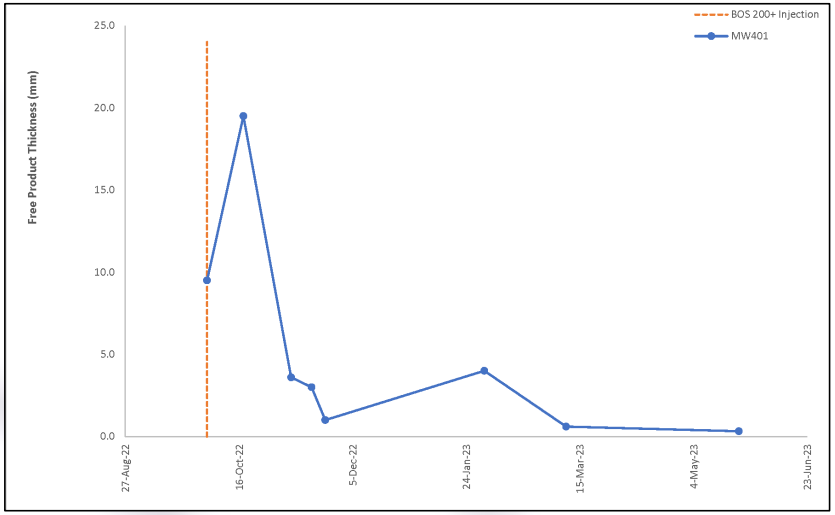
Plan View



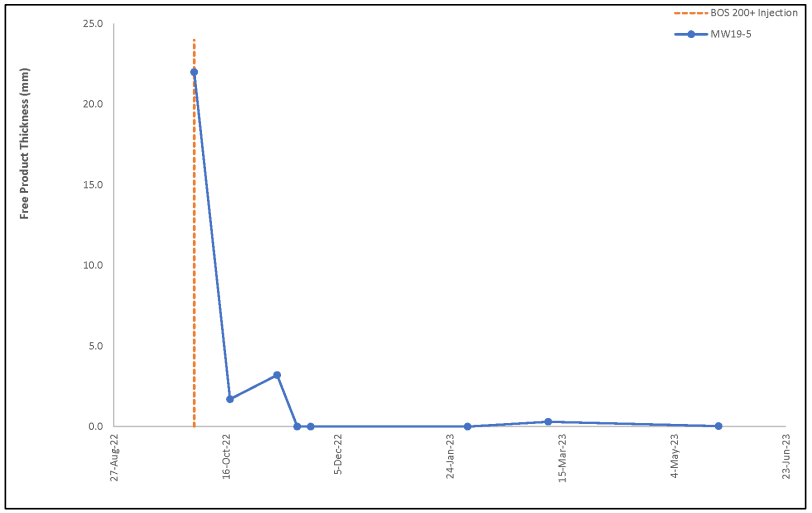
Profile View



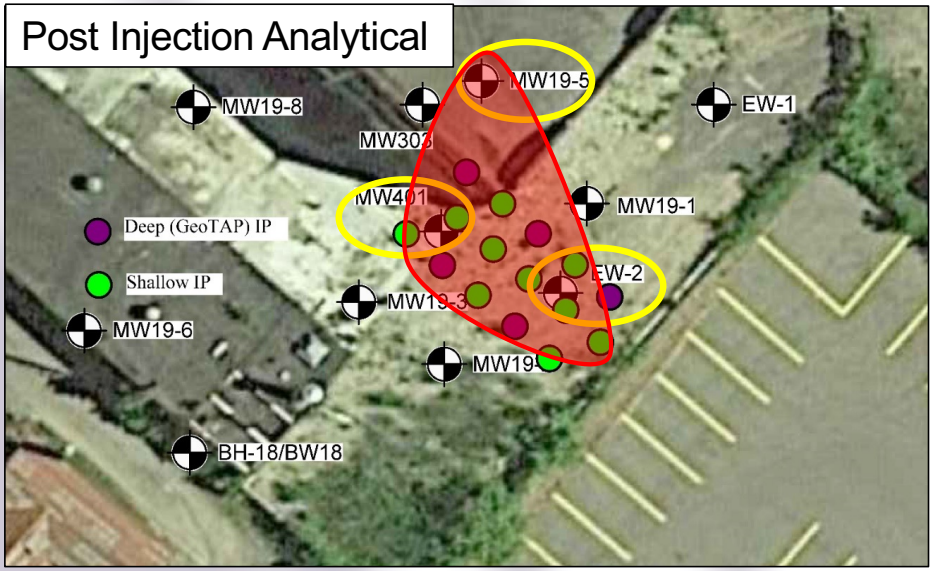
MW401



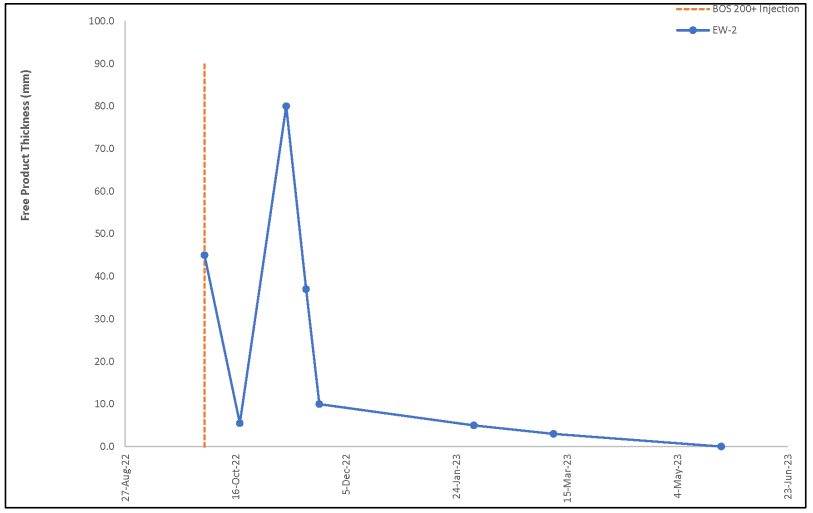
MW19-5



Post Injection Analytical



EW-2



Case Study Wrap-Up

Remediation of Bedrock with LNAPL:

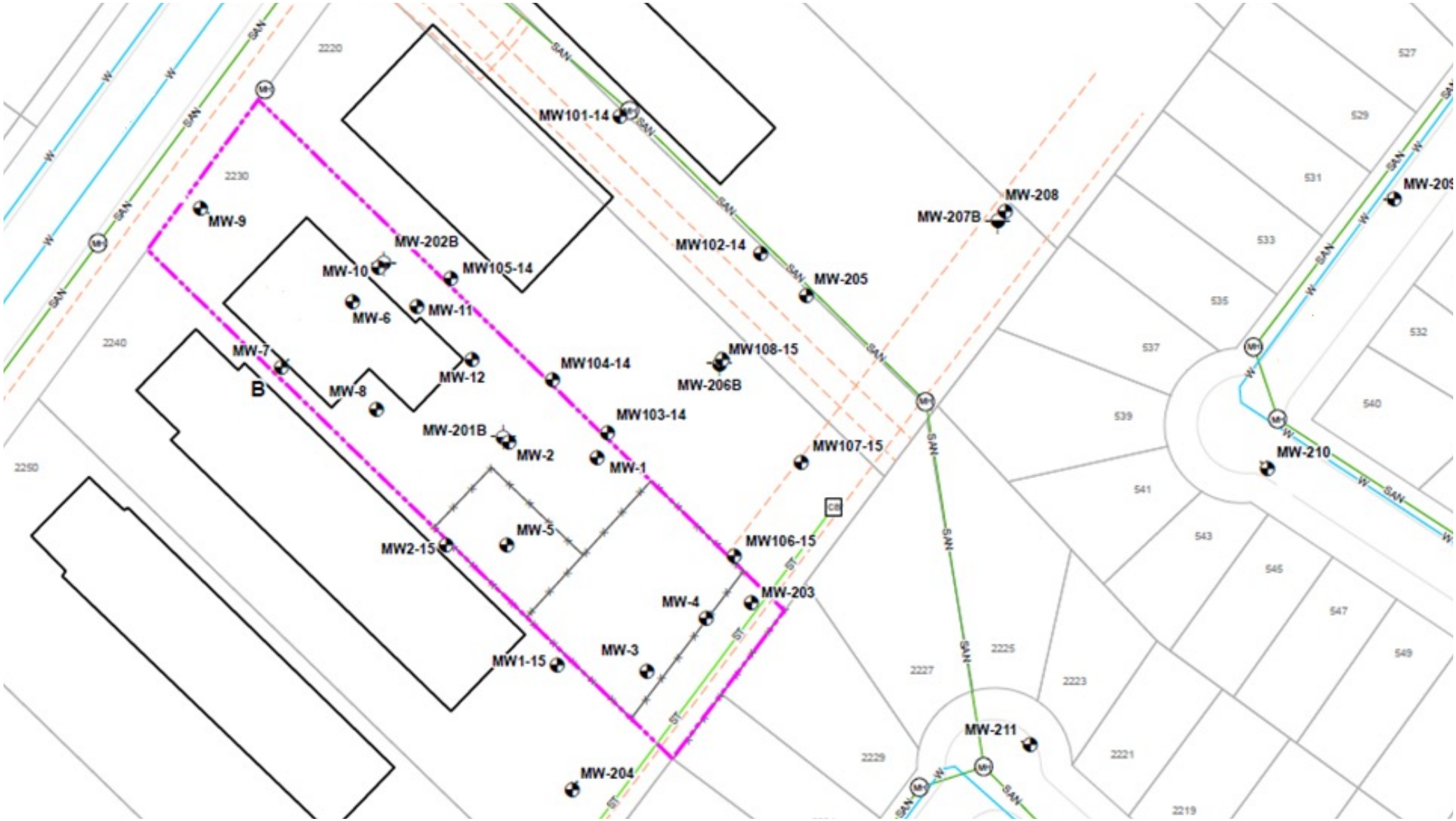
- UST Removal:
  - Source removal of leaky UST
- MPE System:
  - Implemented for a period of 12 months
  - Removal of majority (~75 %) of the LNAPL volume
- Trap and Treat® BOS 200+® Injection:
  - Implemented GeoTAP™ method to allow in-situ injection into fractured bedrock and overburden bedrock interface
  - Amendment selected to handle LNAPL and control migration and back diffusion of PHCs
  - Sustained reduction in LNAPL

Bedrock Case Study #2

Bedrock and Heavy Metals (Hex Chrome)

Background – The Situation

- Chromium plating facility:
  - Underground tanks containing chromium plating solution
  - Tanks leaked
  - Historical spills
- Neighbour completed Phase II ESA
- Chrome contamination
  - Hexavalent chromium
  - Total chromium
- Bench and Pilot Scale testing completed
  - Full-scale being implemented now

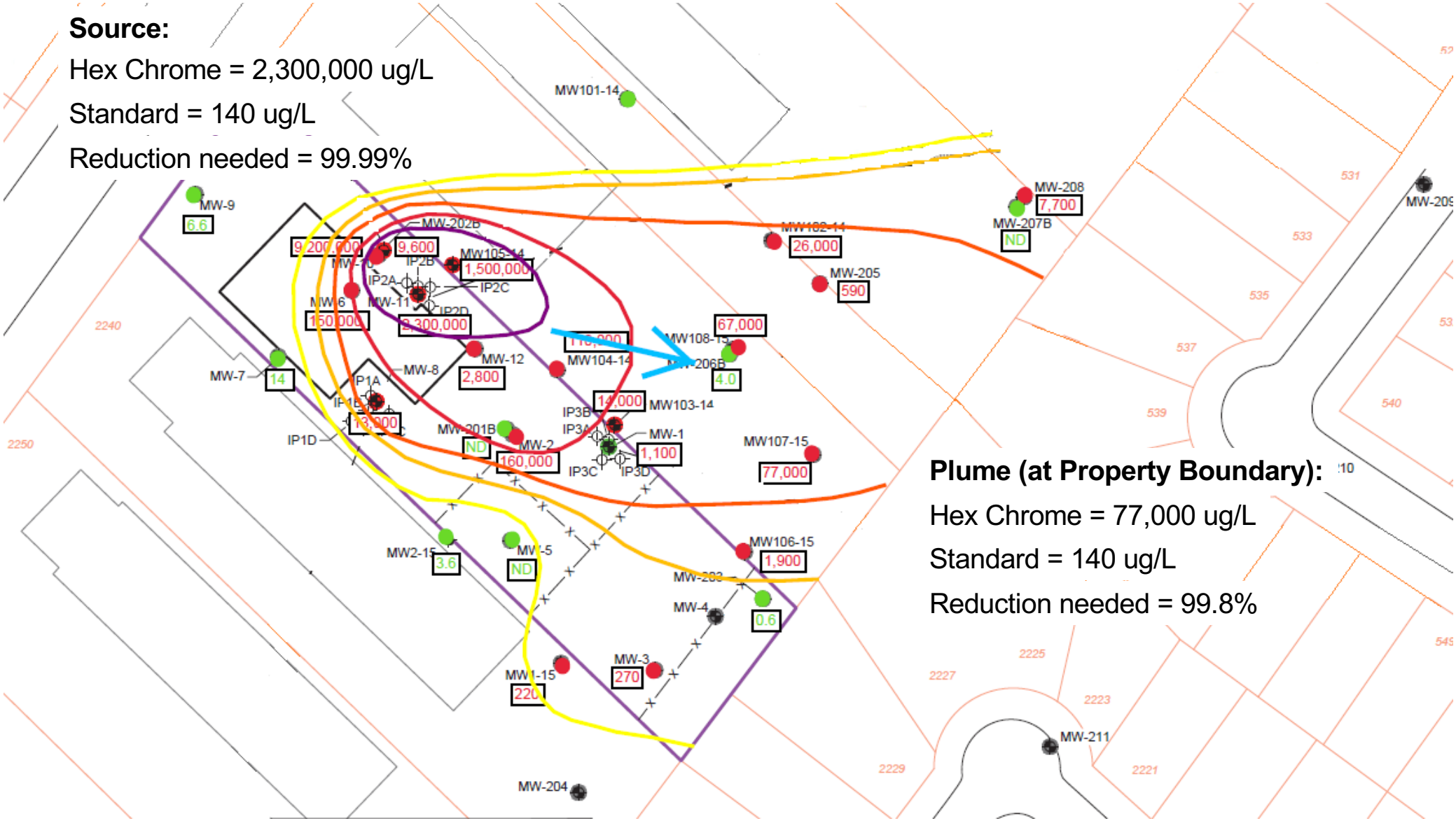

MW-9
MW-202B
MW-10
MW105-14
MW-6
MW-11
MW-7
MW-12
MW-8
B
MW101-14
MW102-14
MW-205
MW-207B
MW-208
MW104-14
MW108-15
MW-206B
MW103-14
MW-201B
MW-2
MW-1
MW107-15
MW-5
MW2-15
MW106-15
MW-203
MW-4
MW-3
MW1-15
MW-204
MW-211
MW-210
2220
2230
2240
2250
2227
2225
2223
2229
2221
2219
527
529
531
533
535
537
539
540
541
543
545
547
549
532
SAN
W
ST

Source:

Hex Chrome = 2,300,000 ug/L

Standard = 140 ug/L

Reduction needed = 99.99%



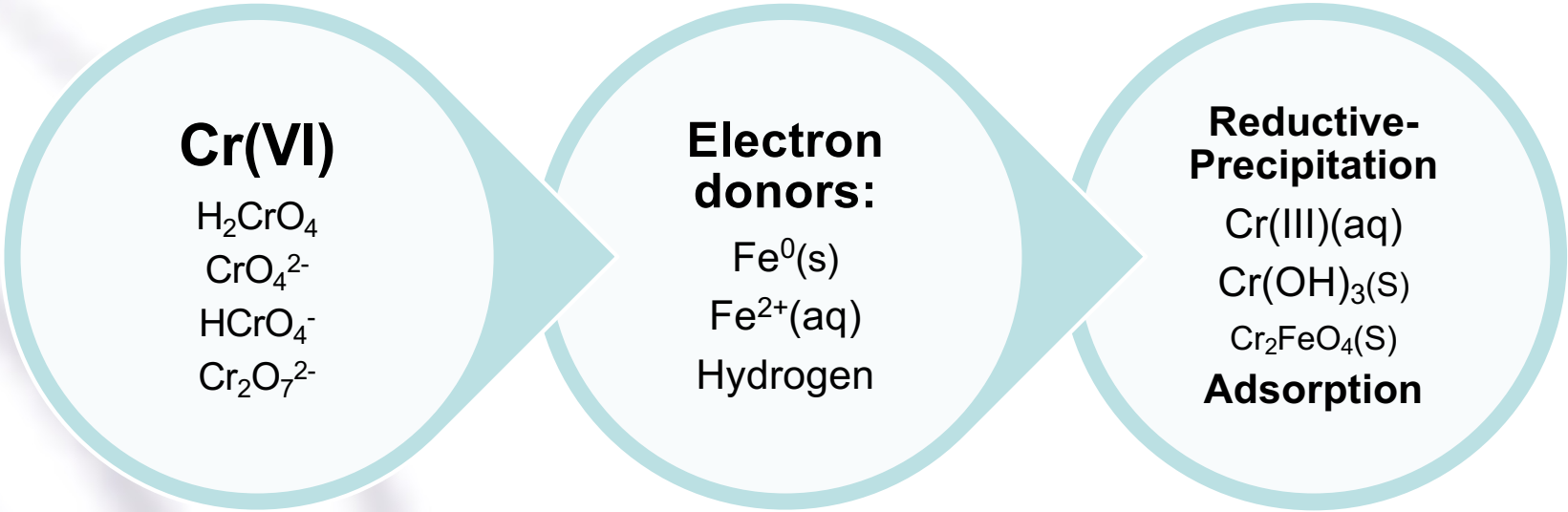
Plume (at Property Boundary):

Hex Chrome = 77,000 ug/L

Standard = 140 ug/L

Reduction needed = 99.8%

Removal from Groundwater – Dissolved to Solid Phase

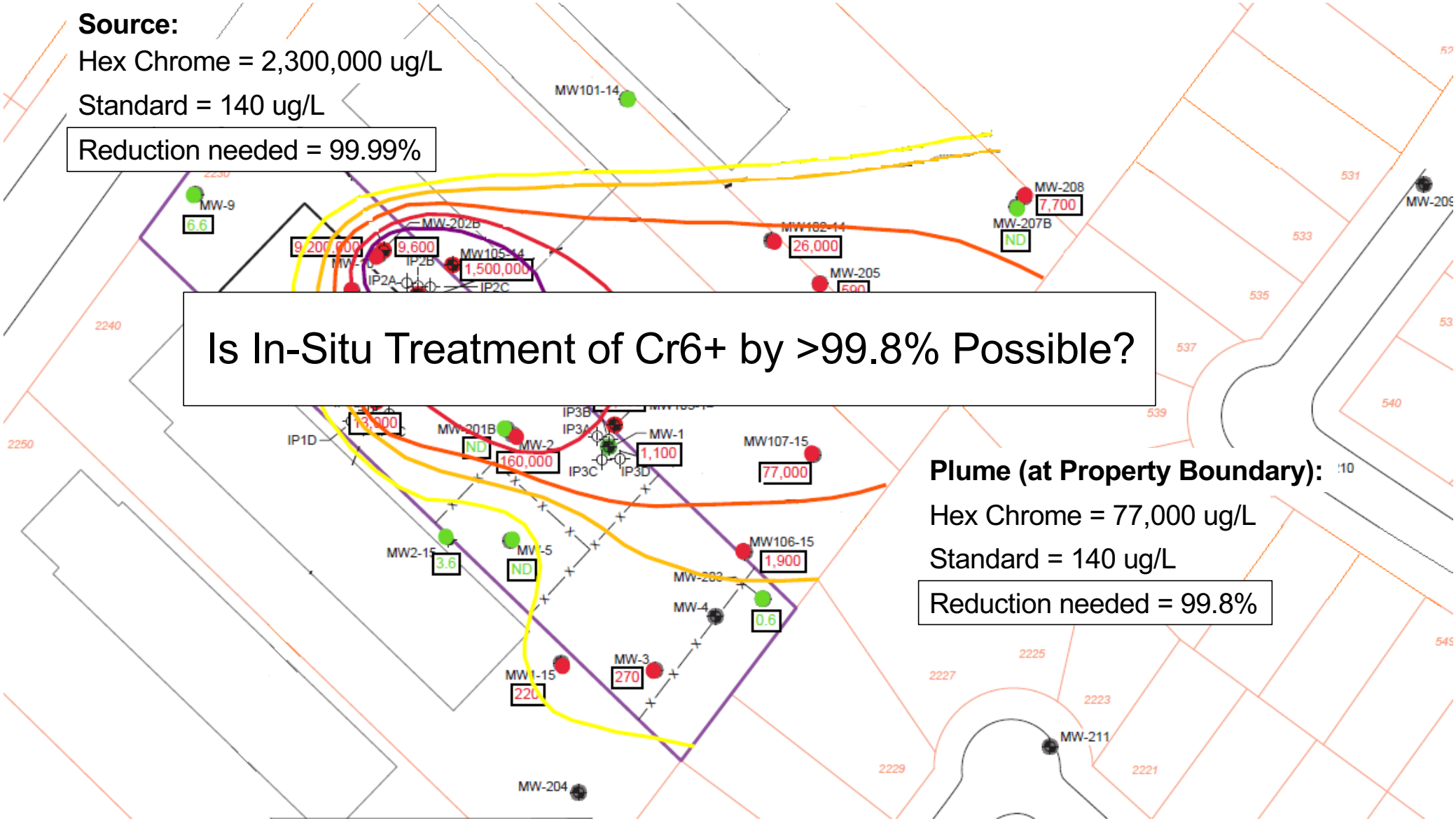


Source:

Hex Chrome = 2,300,000 ug/L

Standard = 140 ug/L

Reduction needed = 99.99%



Is In-Situ Treatment of Cr6+ by >99.8% Possible?

Plume (at Property Boundary):

Hex Chrome = 77,000 ug/L

Standard = 140 ug/L

Reduction needed = 99.8%

Bench-Scale Testing with Site Groundwater

Hex Chrome Case Study

Hex Chrome – Bench-Scale Testing

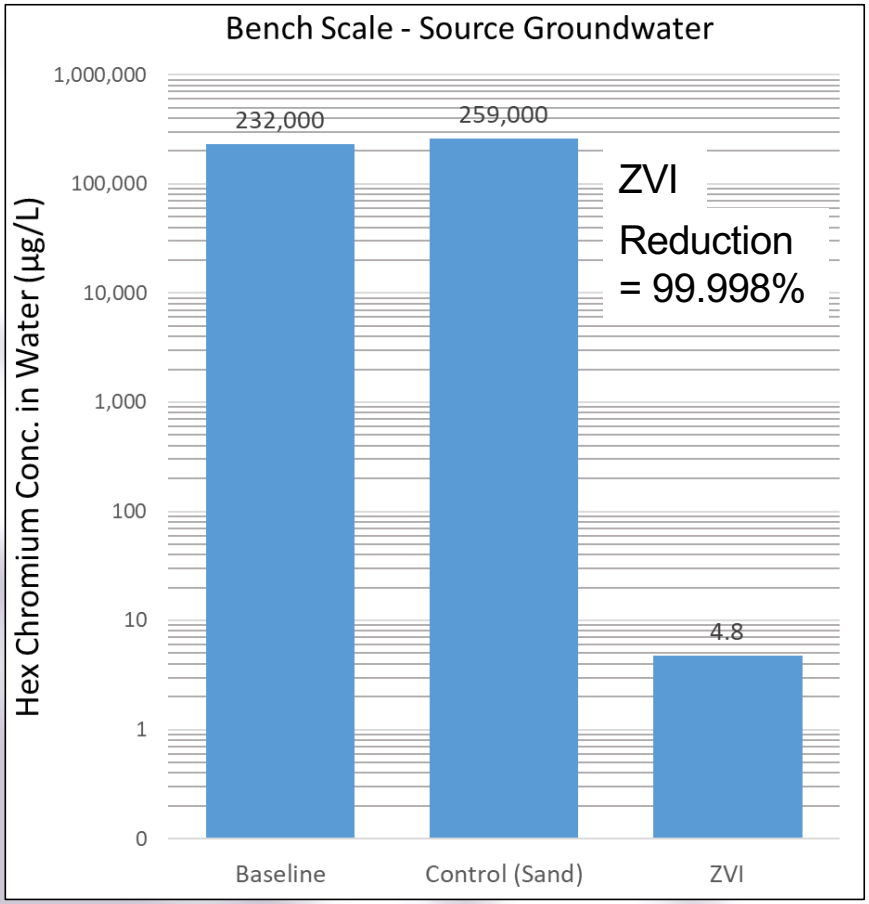
Remediation Amendments Tested

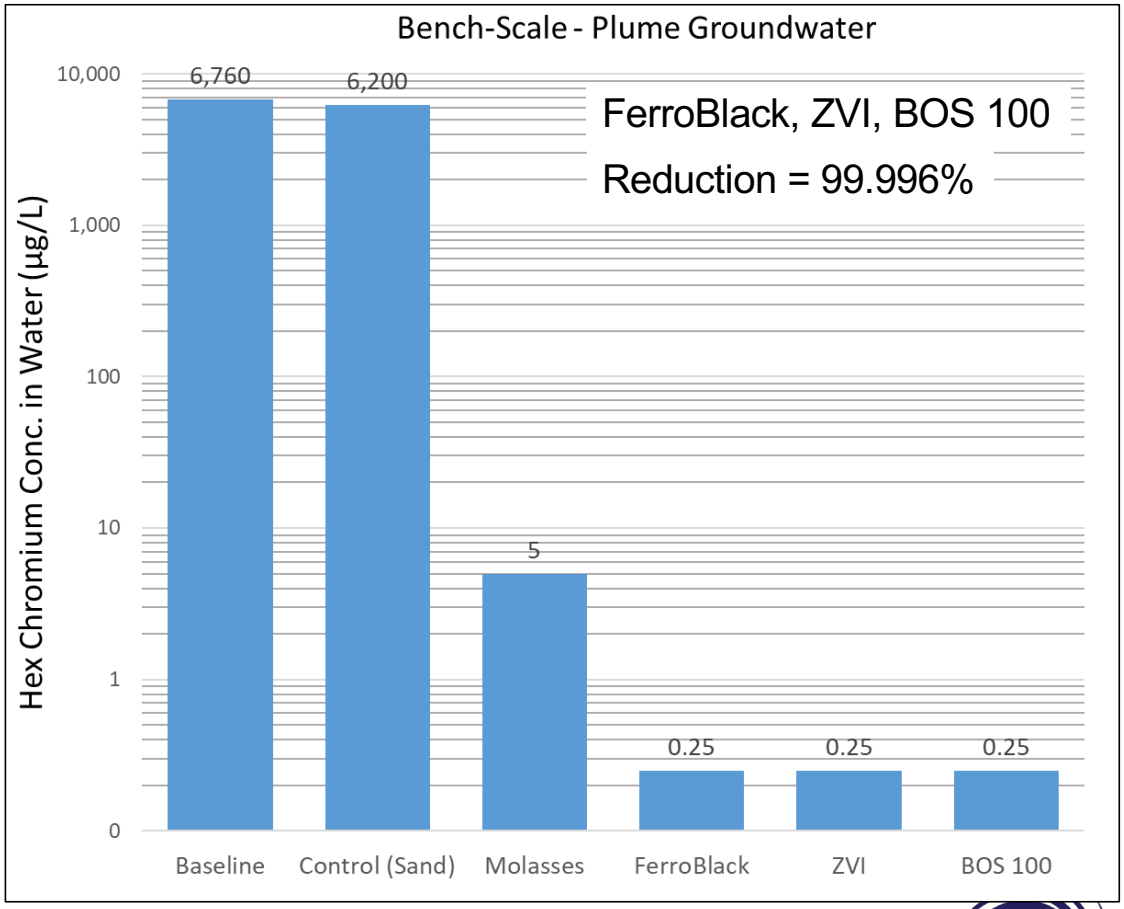
- Molasses
- FerroBlack®
- Zero Valent Iron (ZVI)
- Trap & Treat® BOS 100®

Method

- 1 L containers
- Silica sand and remedial amendment
- Groundwater added
- Placed in dark, let sit, sampled over time

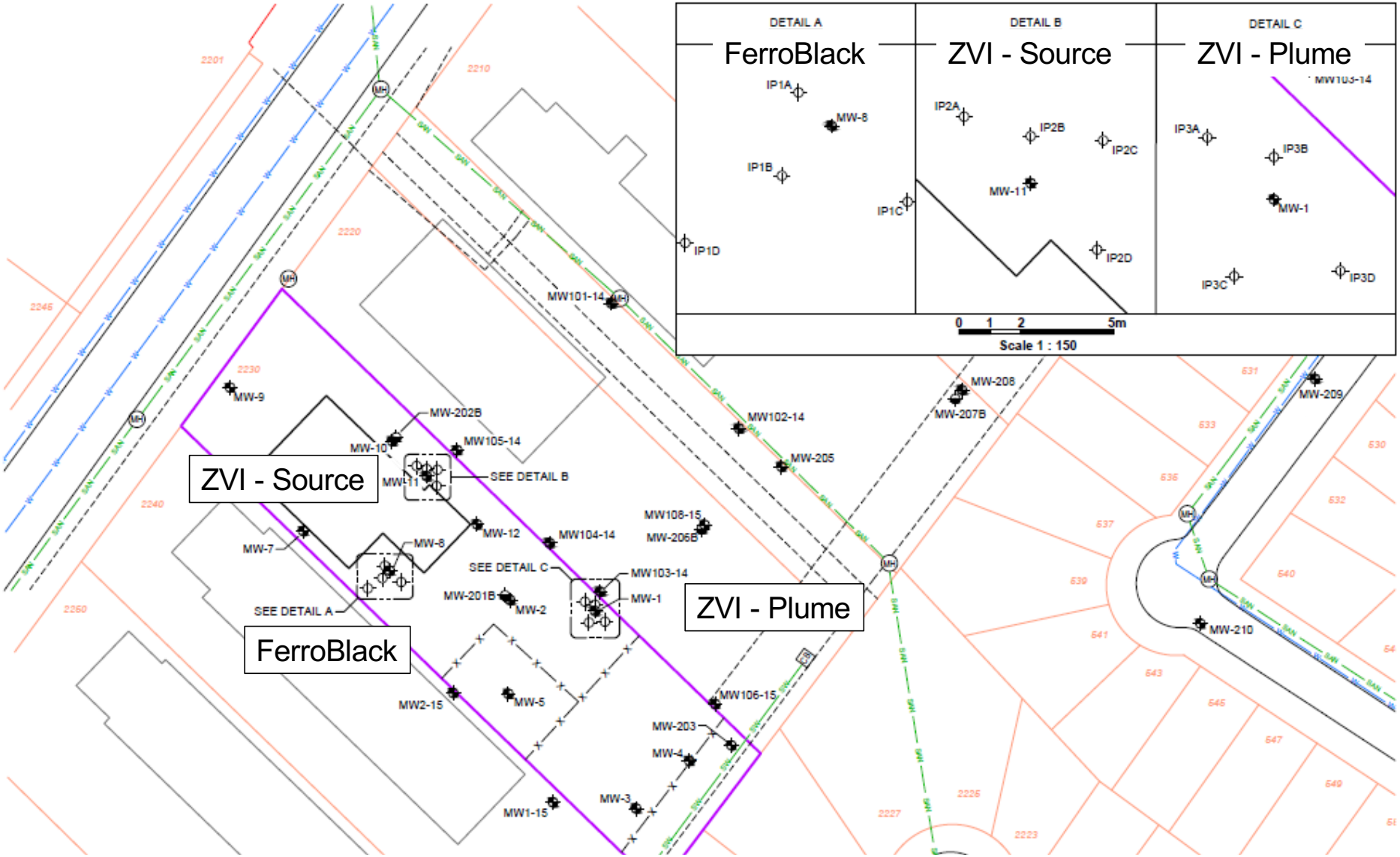
Bench-Scale Testing - Results

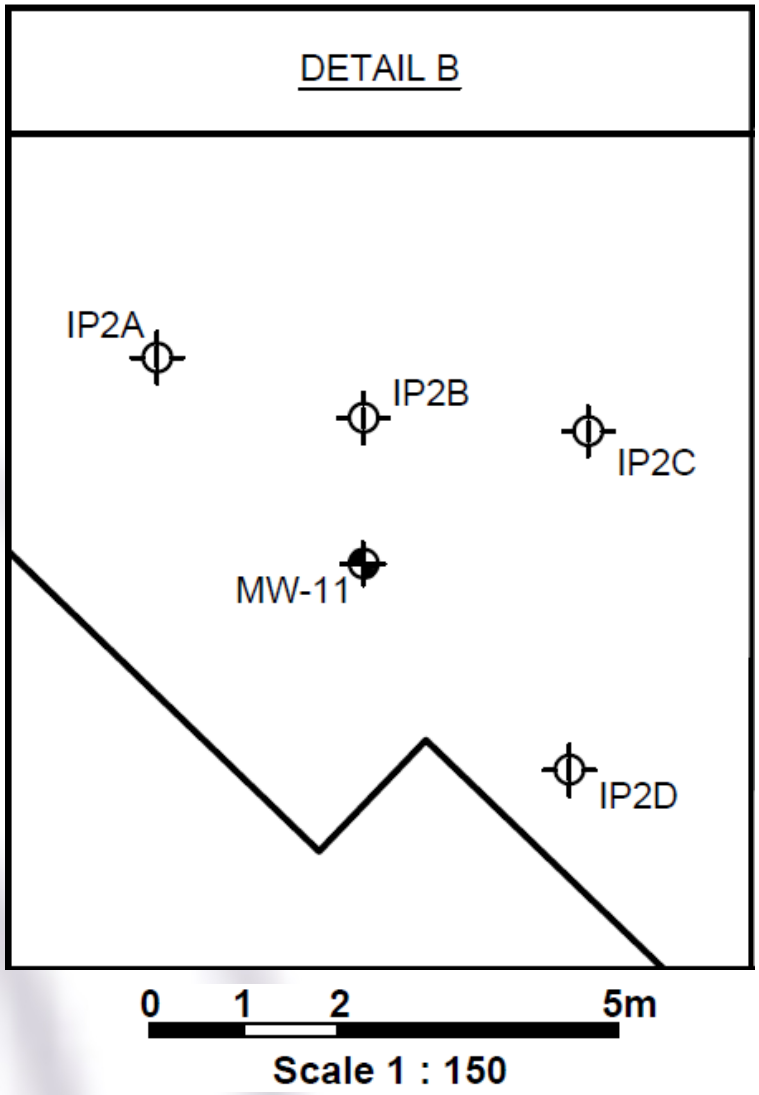




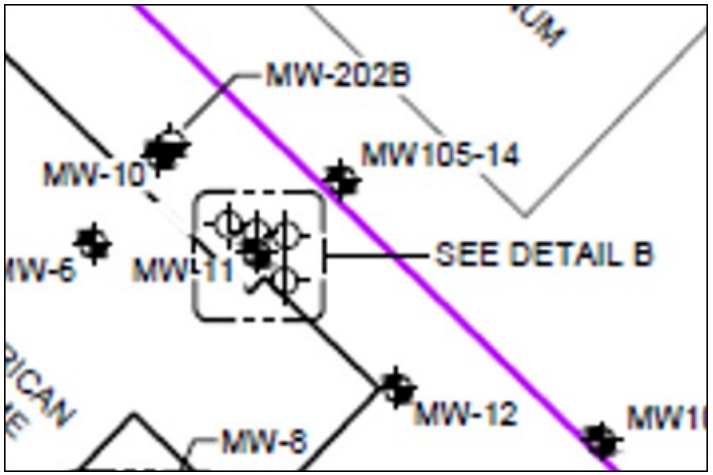
Pilot-Scale Testing on-Site

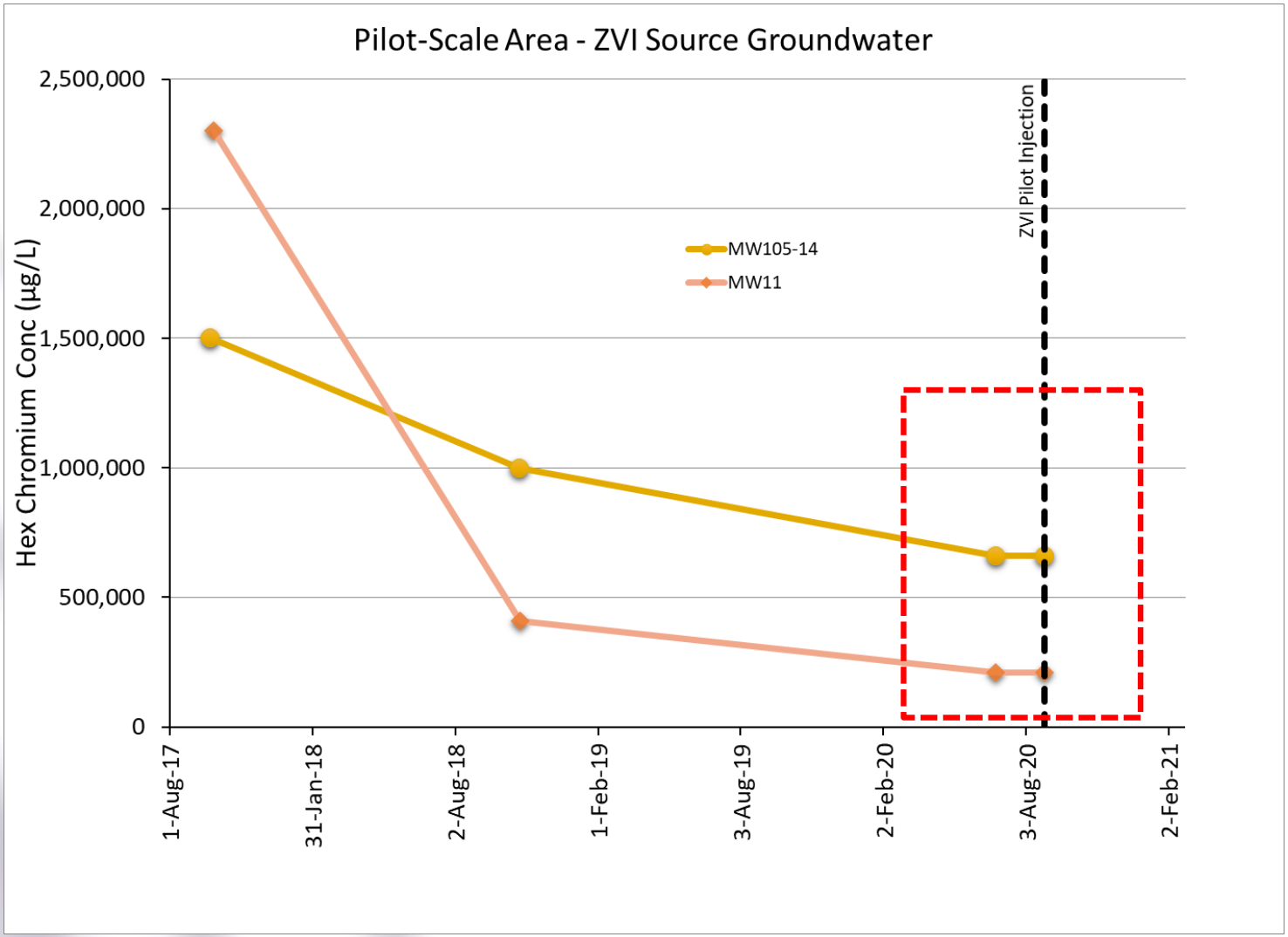
Hex Chrome Case Study

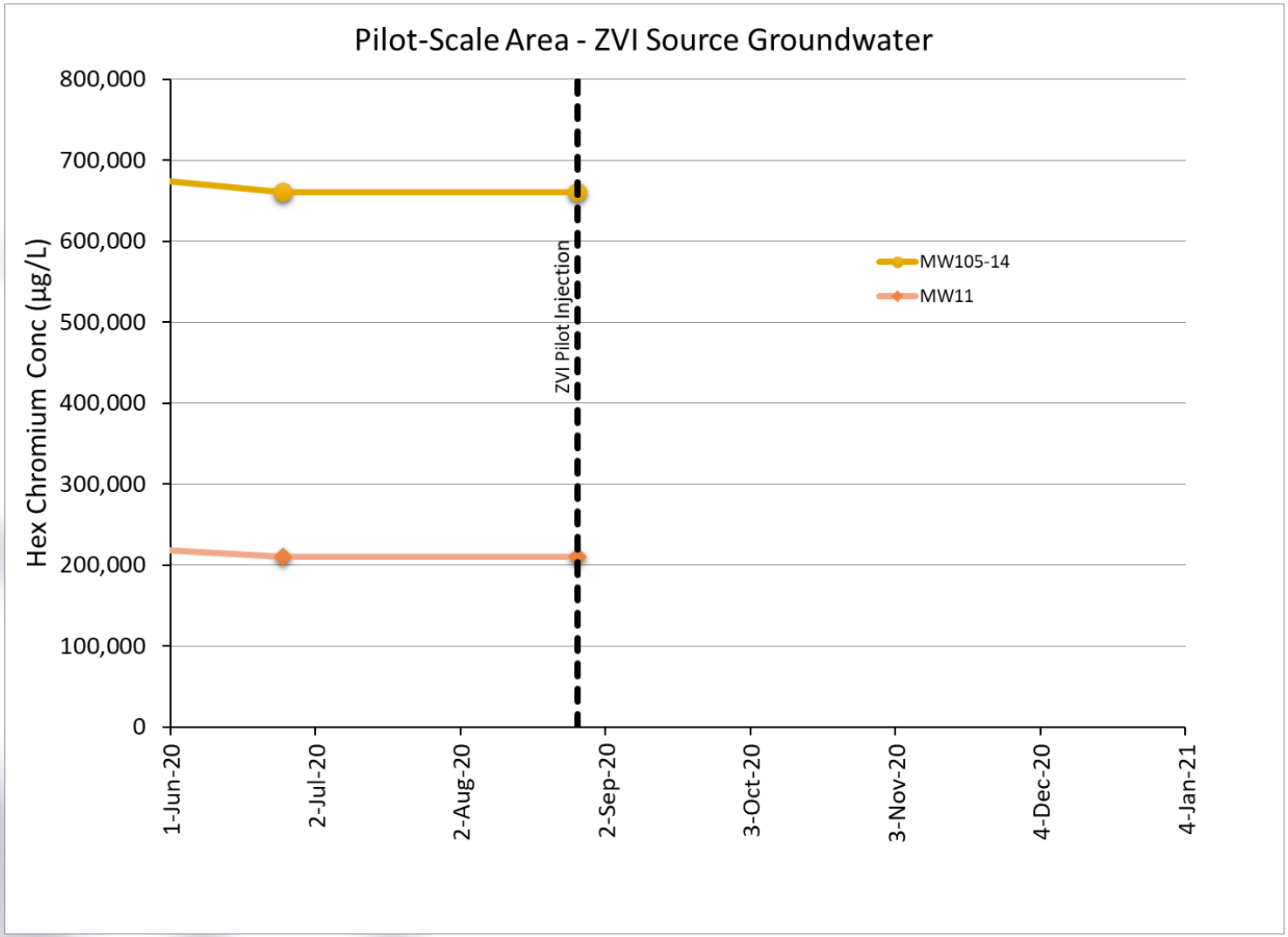

DETAIL A
FerroBlack
DETAIL B
ZVI - Source
DETAIL C
ZVI - Plume
IP1A
MW-8
IP1B
IP1C
IP1D
IP2A
IP2B
IP2C
MW-11
IP2D
IP3A
IP3B
MW-1
IP3C
IP3D
0 1 2 5m
Scale 1 : 150
ZVI - Source
ZVI - Plume
FerroBlack
MW-9
MW-202B
MW-10
MW105-14
MW-11
SEE DETAIL B
MW-7
MW-8
MW-12
MW104-14
MW108-15
MW-206B
SEE DETAIL C
MW103-14
MW-201B
MW-2
MW-1
SEE DETAIL A
MW2-15
MW-5
MW106-15
MW-203
MW-4
MW-3
MW1-15
MW101-14
MW102-14
MW-205
MW-208
MW-207B
MW-209
MW-210

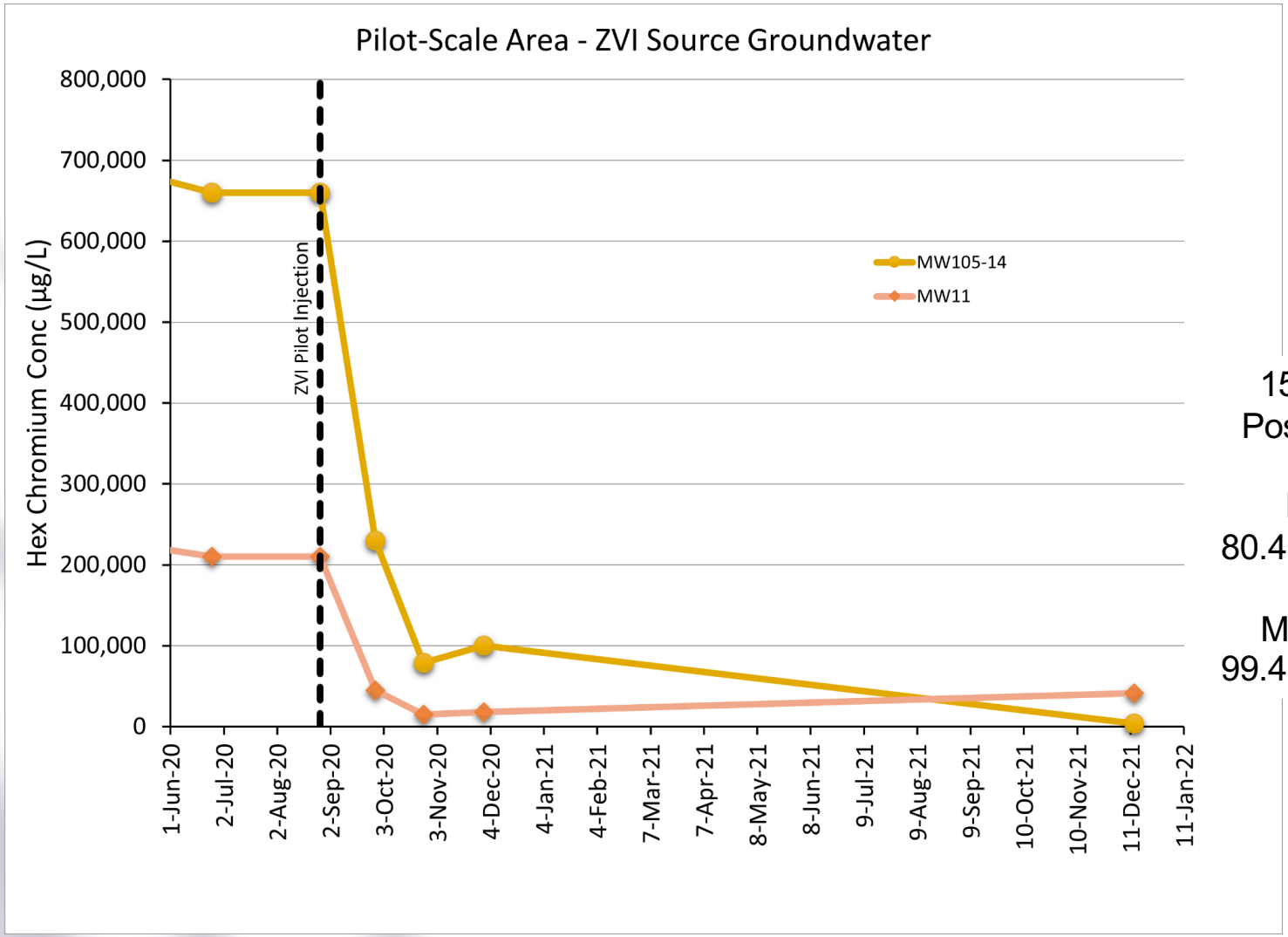

DETAIL B
IP2A
IP2B
IP2C
MW-11
IP2D
0
1
2
5m
Scale 1 : 150

ZVI - Source


MW-202B
MW-10
MW105-14
SEE DETAIL B
MW-6
MW-11
MW-12
MW-8


Pilot-Scale Area - ZVI Source Groundwater
Hex Chromium Conc (µg/L)
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
1-Aug-17
31-Jan-18
2-Aug-18
1-Feb-19
3-Aug-19
2-Feb-20
3-Aug-20
2-Feb-21
ZVI Pilot Injection
MW105-14
MW11

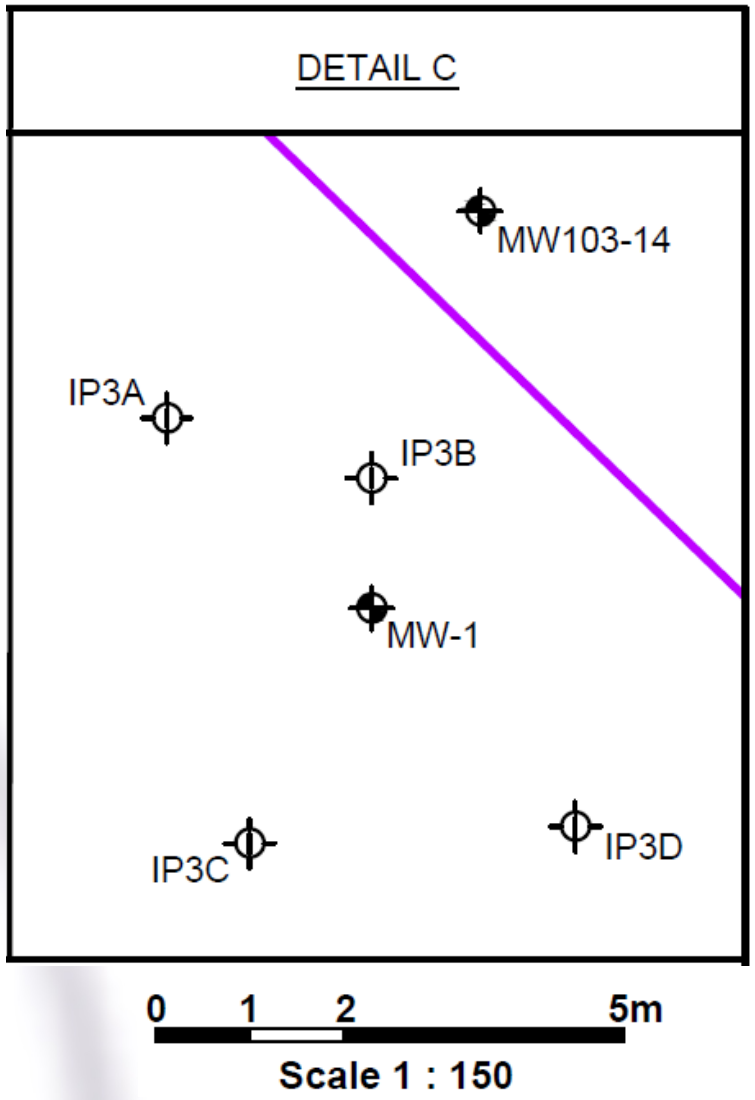

Pilot-Scale Area - ZVI Source Groundwater
Hex Chromium Conc (µg/L)
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
1-Jun-20
2-Jul-20
2-Aug-20
2-Sep-20
3-Oct-20
3-Nov-20
4-Dec-20
4-Jan-21
ZVI Pilot Injection
MW105-14
MW11



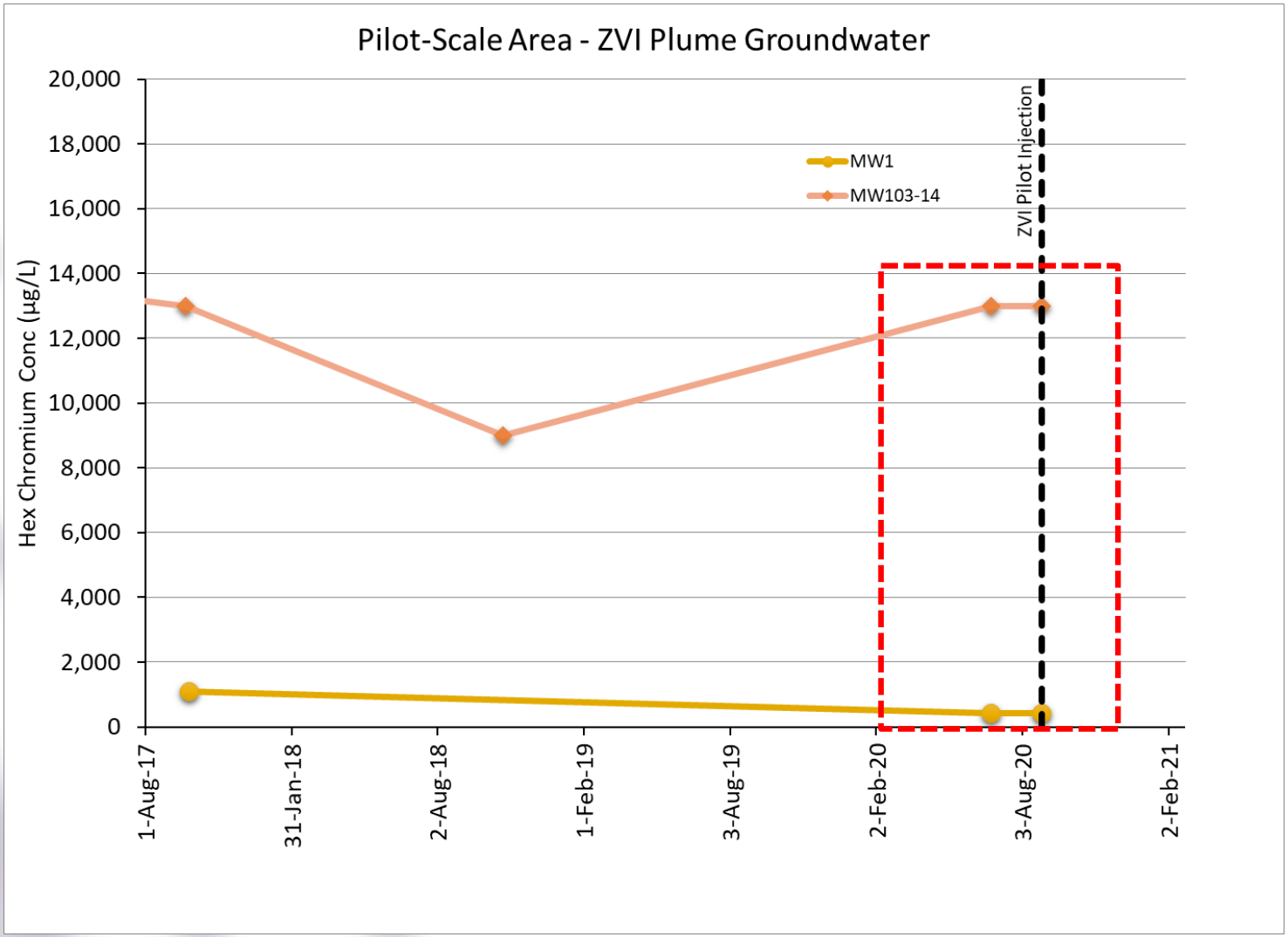
15 Months
Post Injection

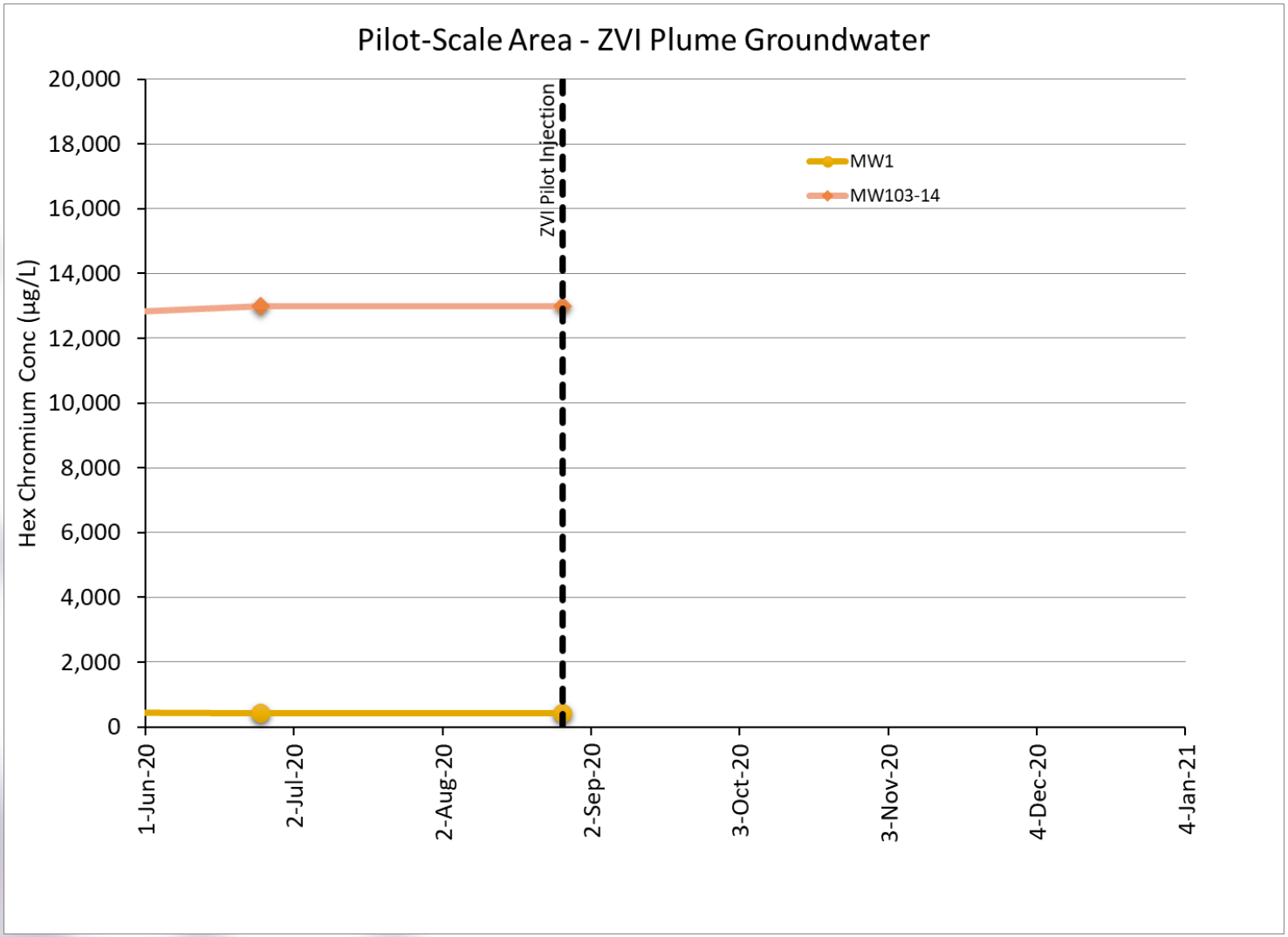
MW-11
80.4% reduction

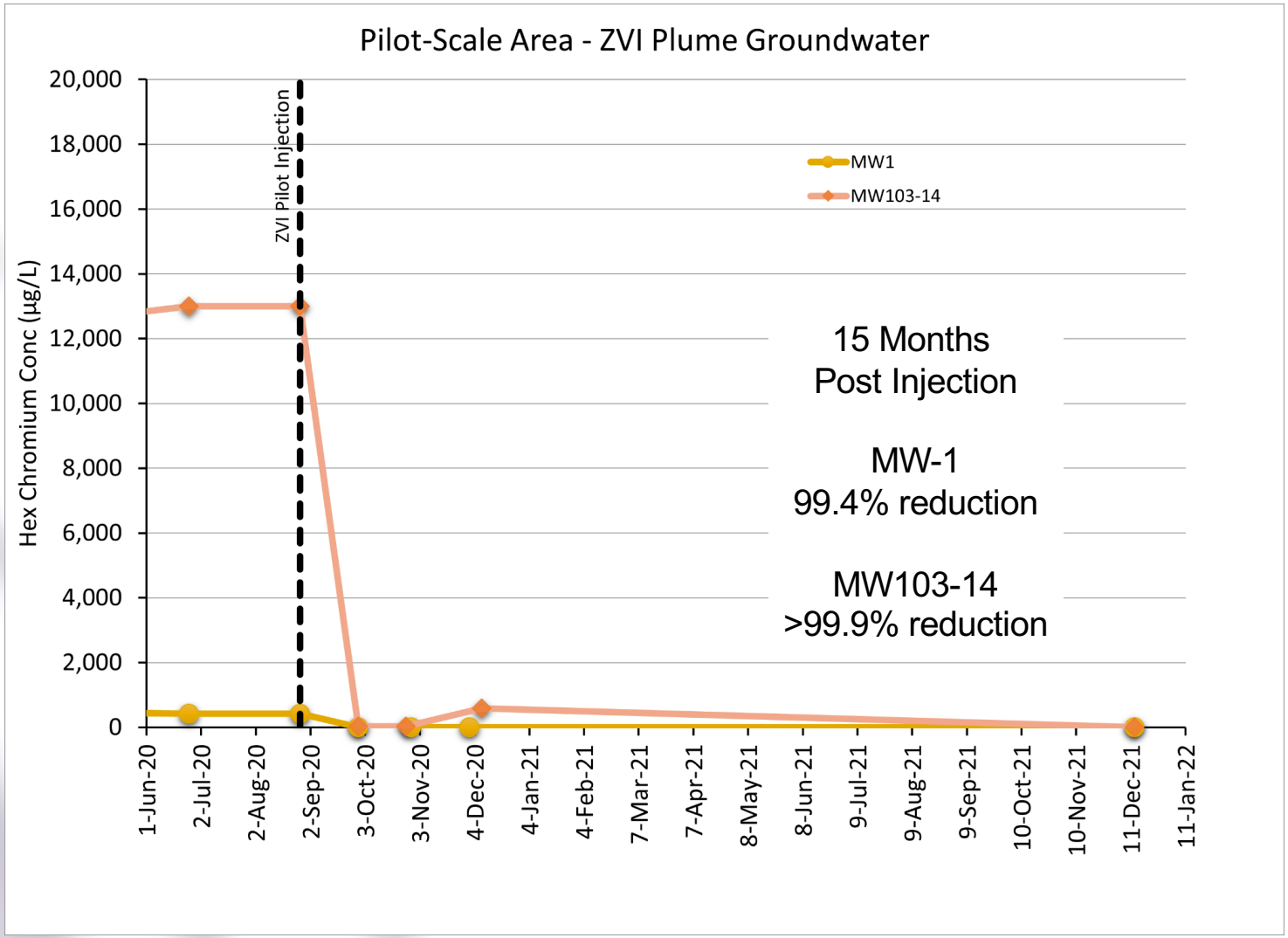
MW105-14
99.4% reduction



ZVI - Plume


Pilot-Scale Area - ZVI Plume Groundwater
Hex Chromium Conc (µg/L)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Aug-17
31-Jan-18
2-Aug-18
1-Feb-19
3-Aug-19
2-Feb-20
3-Aug-20
2-Feb-21
MW1
MW103-14
ZVI Pilot Injection


Pilot-Scale Area - ZVI Plume Groundwater
Hex Chromium Conc (µg/L)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
ZVI Pilot Injection
MW1
MW103-14
1-Jun-20
2-Jul-20
2-Aug-20
2-Sep-20
3-Oct-20
3-Nov-20
4-Dec-20
4-Jan-21

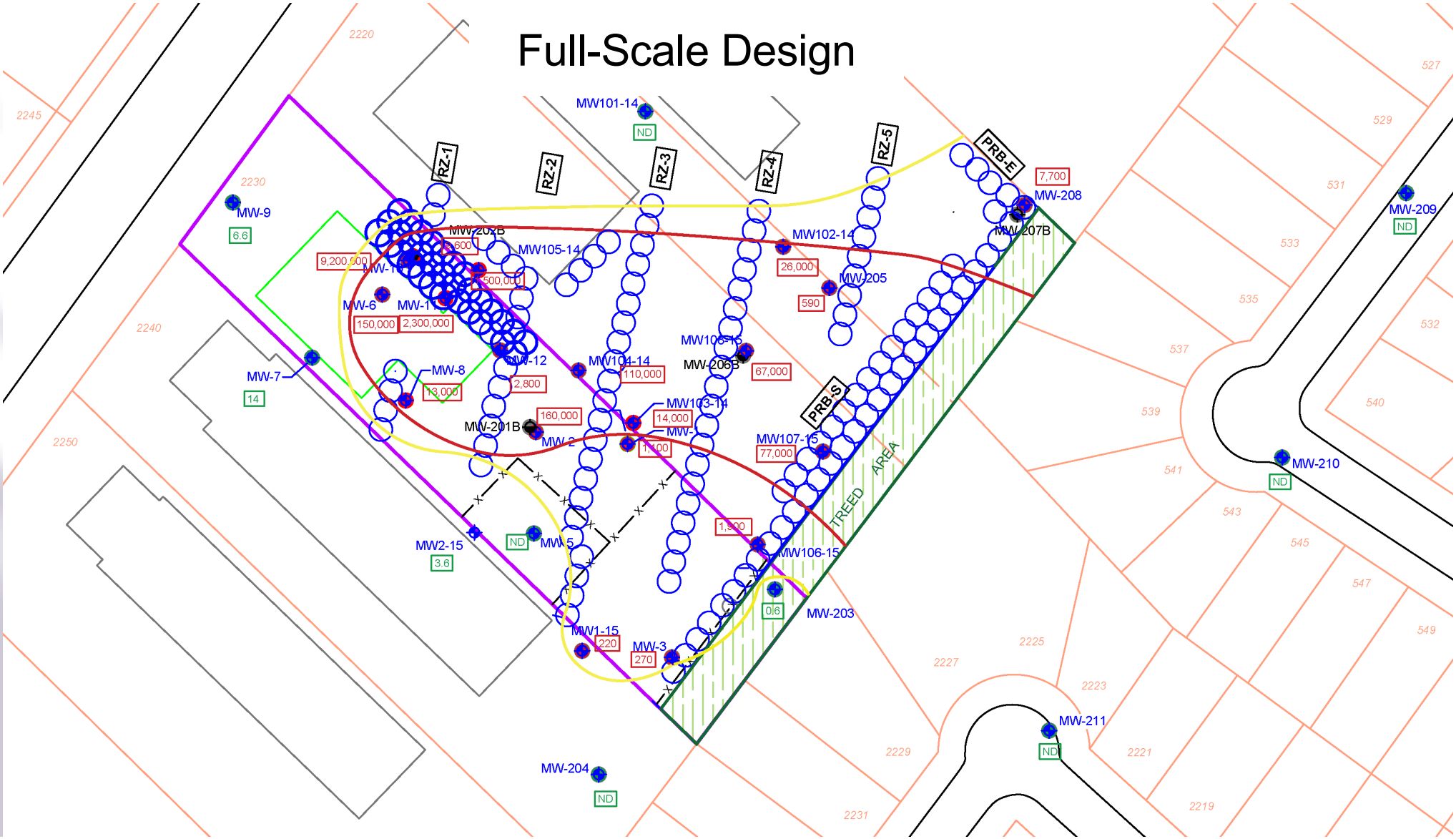

Pilot-Scale Area - ZVI Plume Groundwater
Hex Chromium Conc (µg/L)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
ZVI Pilot Injection
MW1
MW103-14
15 Months
Post Injection
MW-1
99.4% reduction
MW103-14
>99.9% reduction
1-Jun-20
2-Jul-20
2-Aug-20
2-Sep-20
3-Oct-20
3-Nov-20
4-Dec-20
4-Jan-21
4-Feb-21
7-Mar-21
7-Apr-21
8-May-21
8-Jun-21
9-Jul-21
9-Aug-21
9-Sep-21
10-Oct-21
10-Nov-21
11-Dec-21
11-Jan-22

Bedrock Case Study #2 Wrap-Up

Remediation of Bedrock with Heavy Metals (Hex Chrome):

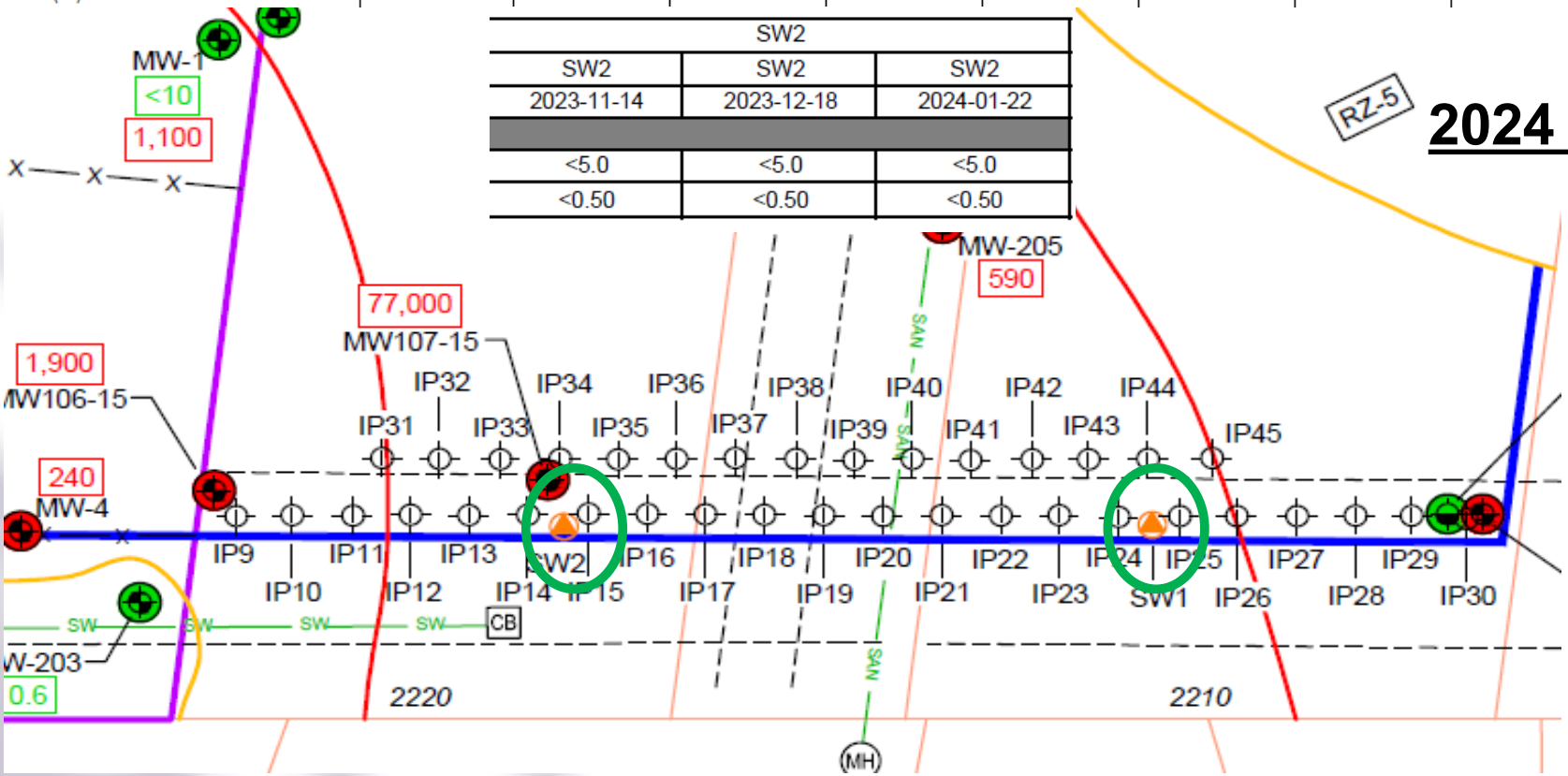
- Groundwater treatment is possible (in the field)
  - At bench-scale: >99.9%
  - At pilot-scale: ~80 to 90% (Source) & ~99% to 99.9% (Plume)
- ZVI is a feasible solution for both source and plume areas
- Full-scale commenced in 2022
  - Staged approach combining:
    - Downgradient property line PRB
    - Source area loading
    - Reactive zones in transects across plume

Full-Scale Design



Sample Location:	MECP[1] Table 3[2]	SW 1						
Sample ID:		SW 1	SW 1	DUP-1	SW 1	DUP-1	SW 1	DUP-1
Sampling Date (yyyy-mm-dd):		2023-02-02	2023-11-14	2023-11-14	2023-12-18	2023-12-18	2024-01-22	2024-01-22
Metals								
Chromium	810	<5.0	<5.0	<5.0	88	88	22	24
Chromium (VI)	140	<0.50	0.84	<0.50	79	54	6.3	7.5

SW2		
SW2	SW2	SW2
2023-11-14	2023-12-18	2024-01-22
<5.0	<5.0	<5.0
<0.50	<0.50	<0.50



2024 Update

Bedrock Case Study #3

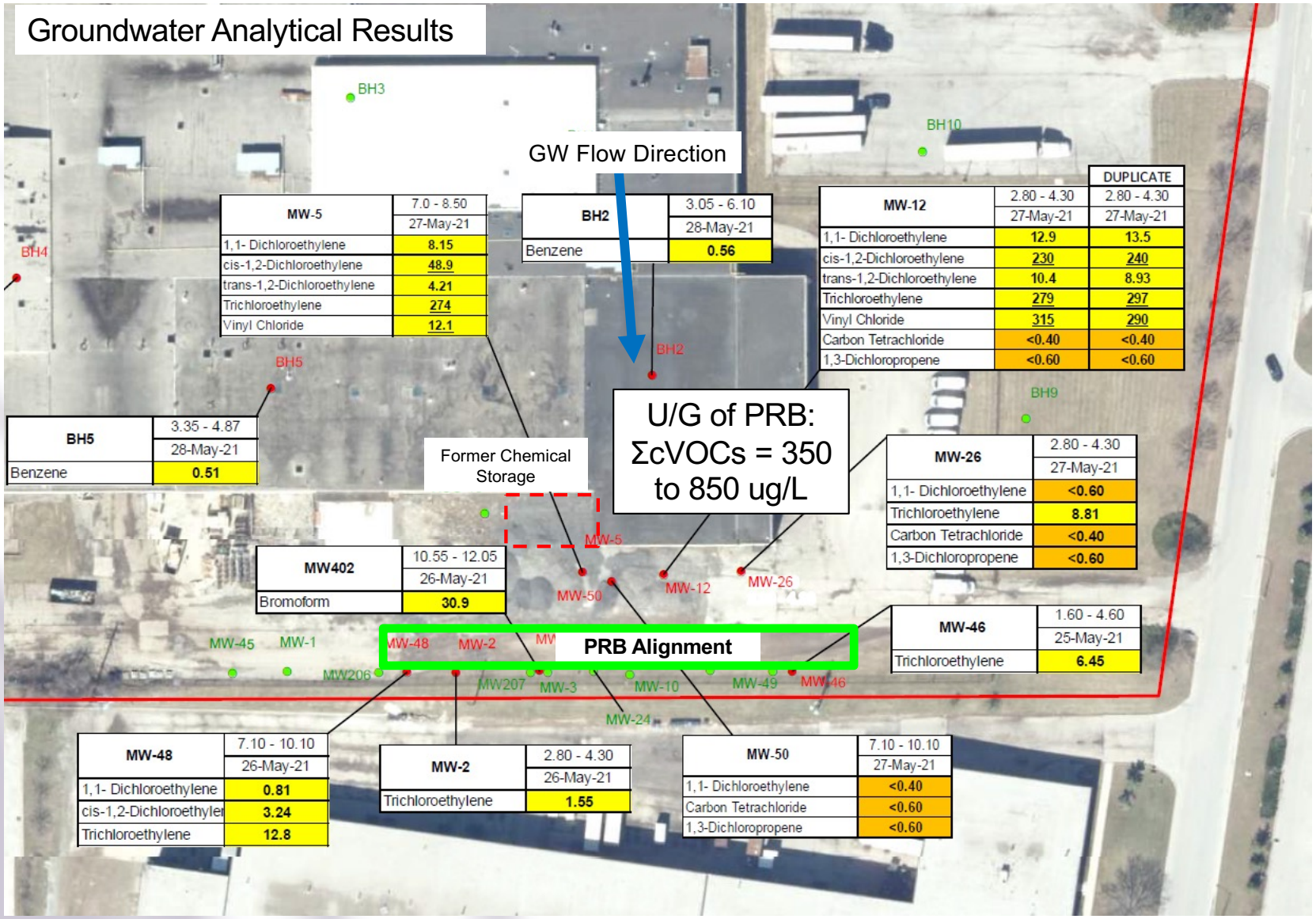
Bedrock and Chlorinated Solvents (cVOCs)

Background – The Situation

- Historical steel manufacturing operation:
  - Use of degreasing solvents
  - Improper chemical storage and historic spills
  - TCE, DCE isomers, & VC present in bedrock groundwater
- ISCO work completed (by others)
  - Historic permanganate injections
- Developer purchased
  - Industrial/commercial redevelopment
- Install PRB to manage off-site liability (by Vertex)


Site Location
200 m

Groundwater Analytical Results



MW-5	7.0 - 8.50
	27-May-21
1,1- Dichloroethylene	8.15
cis-1,2-Dichloroethylene	48.9
trans-1,2-Dichloroethylene	4.21
Trichloroethylene	274
Vinyl Chloride	12.1

BH2	3.05 - 6.10
	28-May-21
Benzene	0.56

MW-12	2.80 - 4.30	DUPLICATE
	27-May-21	2.80 - 4.30 27-May-21
1,1- Dichloroethylene	12.9	13.5
cis-1,2-Dichloroethylene	230	240
trans-1,2-Dichloroethylene	10.4	8.93
Trichloroethylene	279	297
Vinyl Chloride	315	290
Carbon Tetrachloride	<0.40	<0.40
1,3-Dichloropropene	<0.60	<0.60

BH5	3.35 - 4.87
	28-May-21
Benzene	0.51

MW-26	2.80 - 4.30
	27-May-21
1,1- Dichloroethylene	<0.60
Trichloroethylene	8.81
Carbon Tetrachloride	<0.40
1,3-Dichloropropene	<0.60

MW402	10.55 - 12.05
	26-May-21
Bromoform	30.9

MW-46	1.60 - 4.60
	25-May-21
Trichloroethylene	6.45

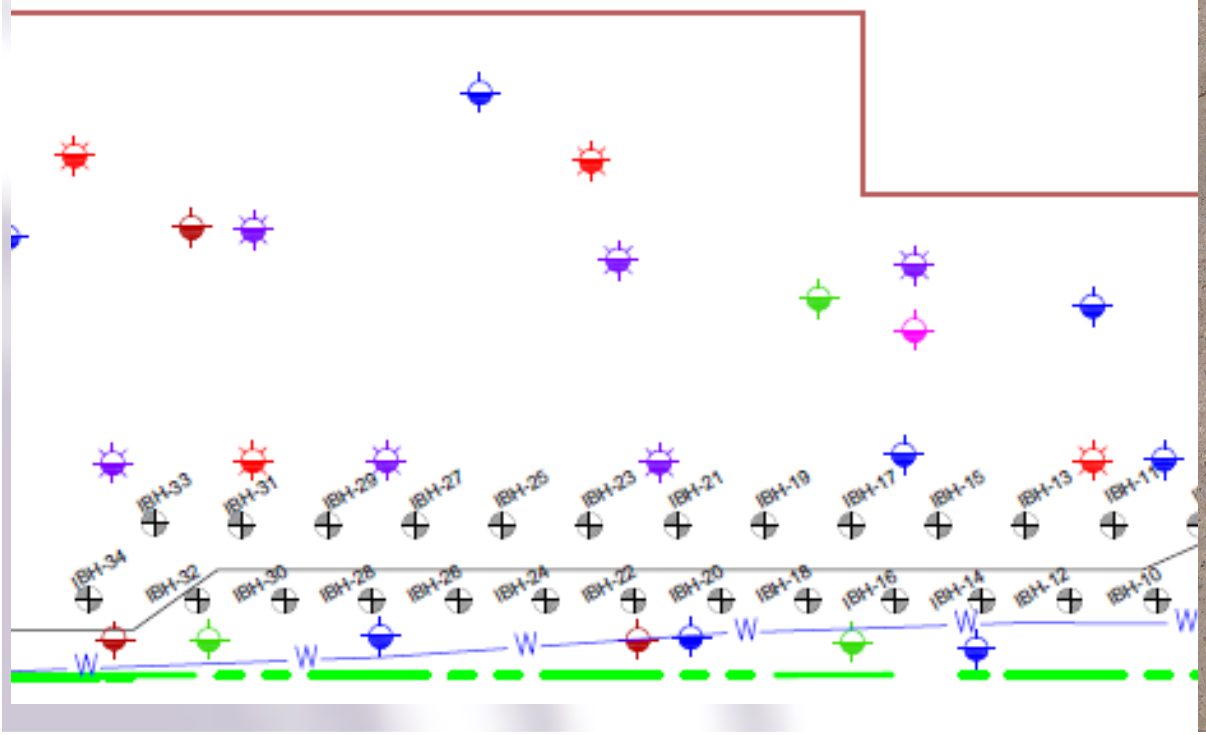
MW-48	7.10 - 10.10
	26-May-21
1,1- Dichloroethylene	0.81
cis-1,2-Dichloroethyler	3.24
Trichloroethylene	12.8

MW-2	2.80 - 4.30
	26-May-21
Trichloroethylene	1.55

MW-50	7.10 - 10.10
	27-May-21
1,1- Dichloroethylene	<0.40
Carbon Tetrachloride	<0.60
1,3-Dichloropropene	<0.60

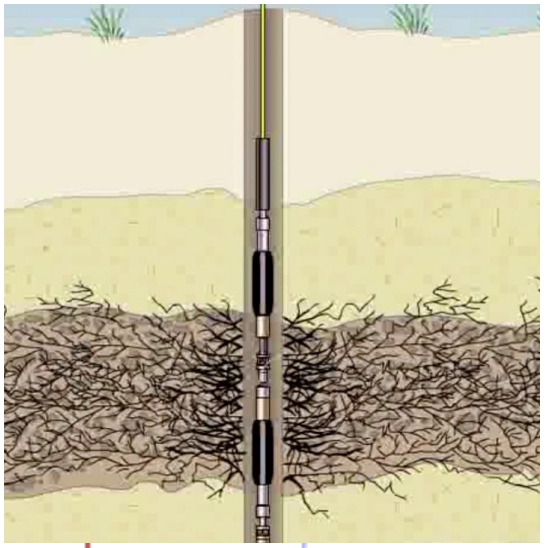
Injected PRB Installation:

- Install 34 injection boreholes (IBHs)
- PVC casing set to 3 mbgs
- Open borehole to 12 mbgs
- Straddle packer to inject BOS 100®

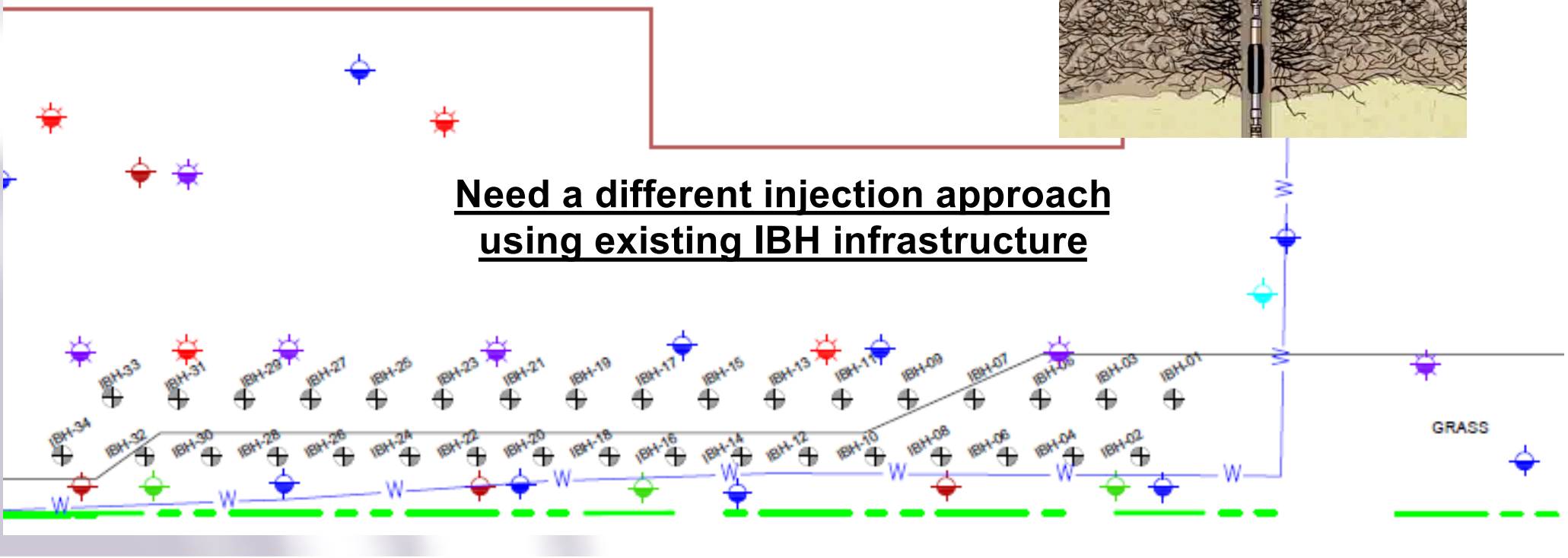


Injected PRB – Packer Diffculties:

- Shale bedrock highly weathered/fractured
- Resulted in frequent IBH cave-in / packers stuck
- Difficult to move packer up and down the IBH
- Lower injection production rate
- Proved not feasible = **Stratigraphy**



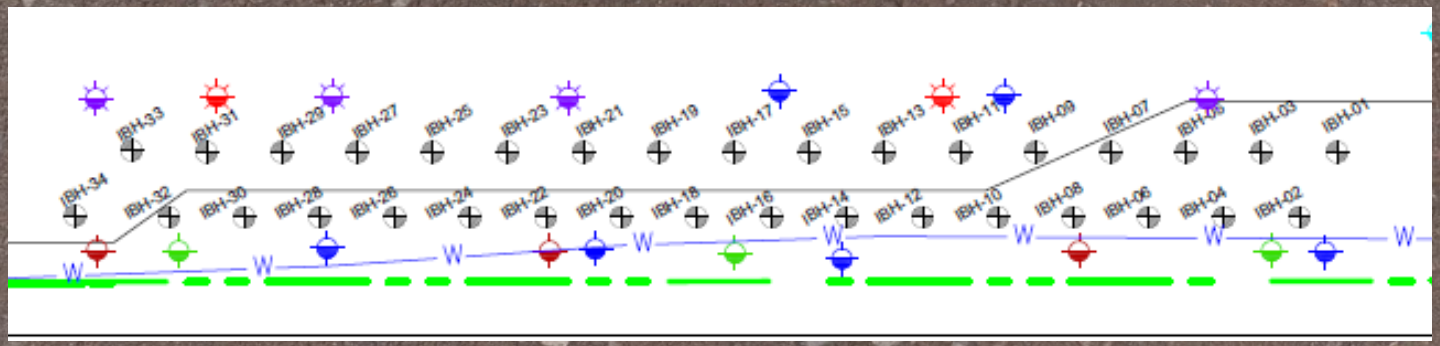
Need a different injection approach using existing IBH infrastructure



GeoTAP™ (Pre-Drill) Method

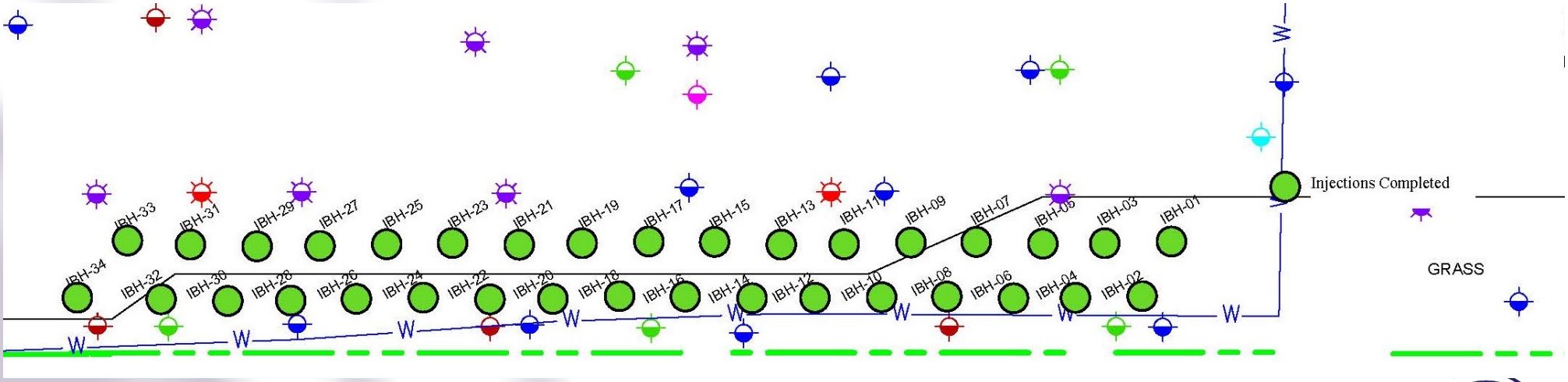
Methodology:

- Clear out any cave-in material in the IBHs using variety of methods including:
  - "Extract" material out with hydrovac
  - "Sample" material out with direct-push macro cores
  - "Flush" material out with air hammer tooling
- Backfill "cleared" IBH with bentonite chips and hydrate
- Allow 48 hours for bentonite seal to setup prior to injection

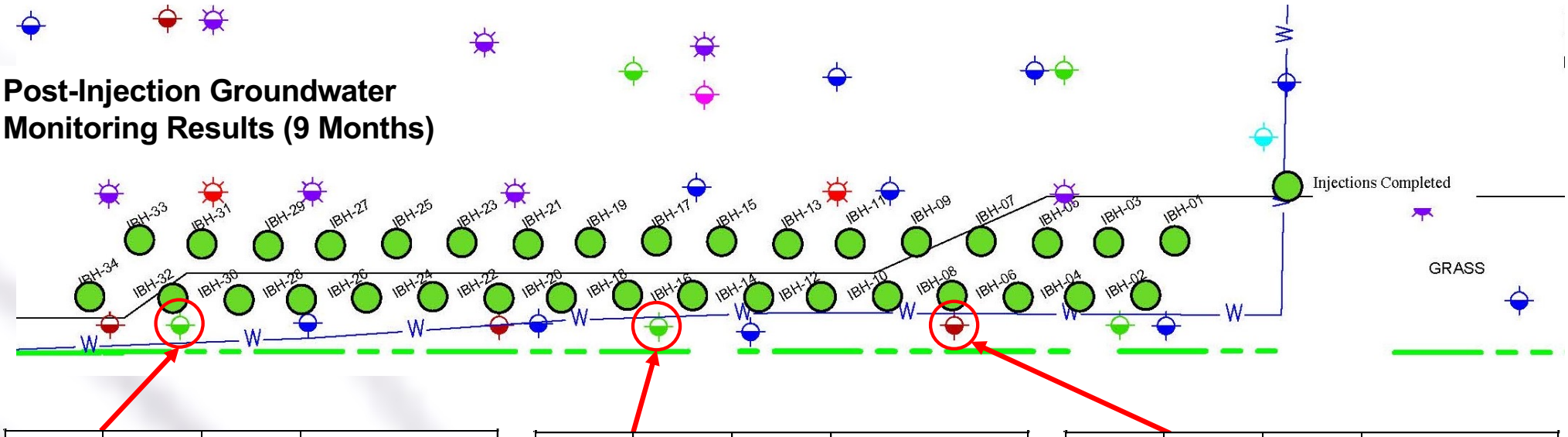


BOS 100® GeoTAP™ Injection:

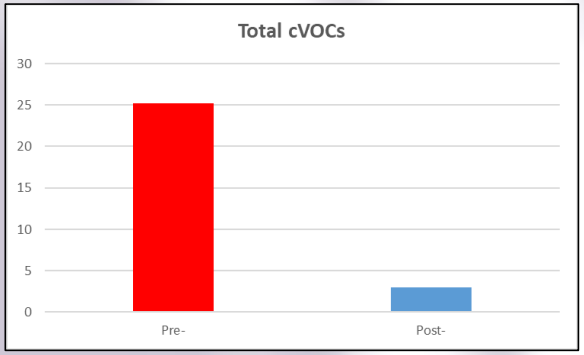
- IBHs successfully cleared and backfilled
- Bentonite backfill provided appropriate seal for injections
- Successfully injected a total of 87,000 L of BOS 100® as planned



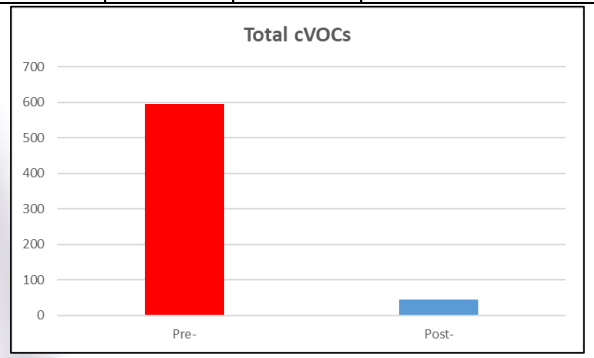
Post-Injection Groundwater Monitoring Results (9 Months)



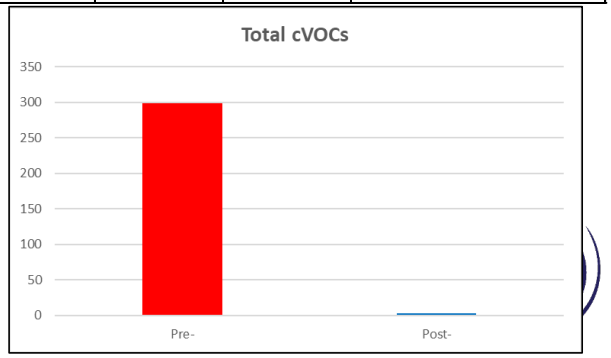
Parameter (ug/L)	2021	2023	Percent Change	
TCE	14	1.05	93%	Reduction
Cis-1,2-DCE	4.2	0.97	77%	Reduction
VC	5.7	1.0	83%	Reduction



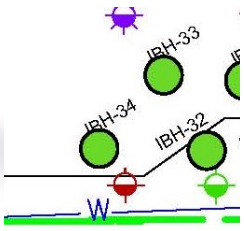
Parameter (ug/L)	2017-2019 Average	2023	Percent Change	
TCE	365	30	92%	Reduction
Cis-1,2-DCE	180	9.1	95%	Reduction
VC	51	6	88%	Reduction

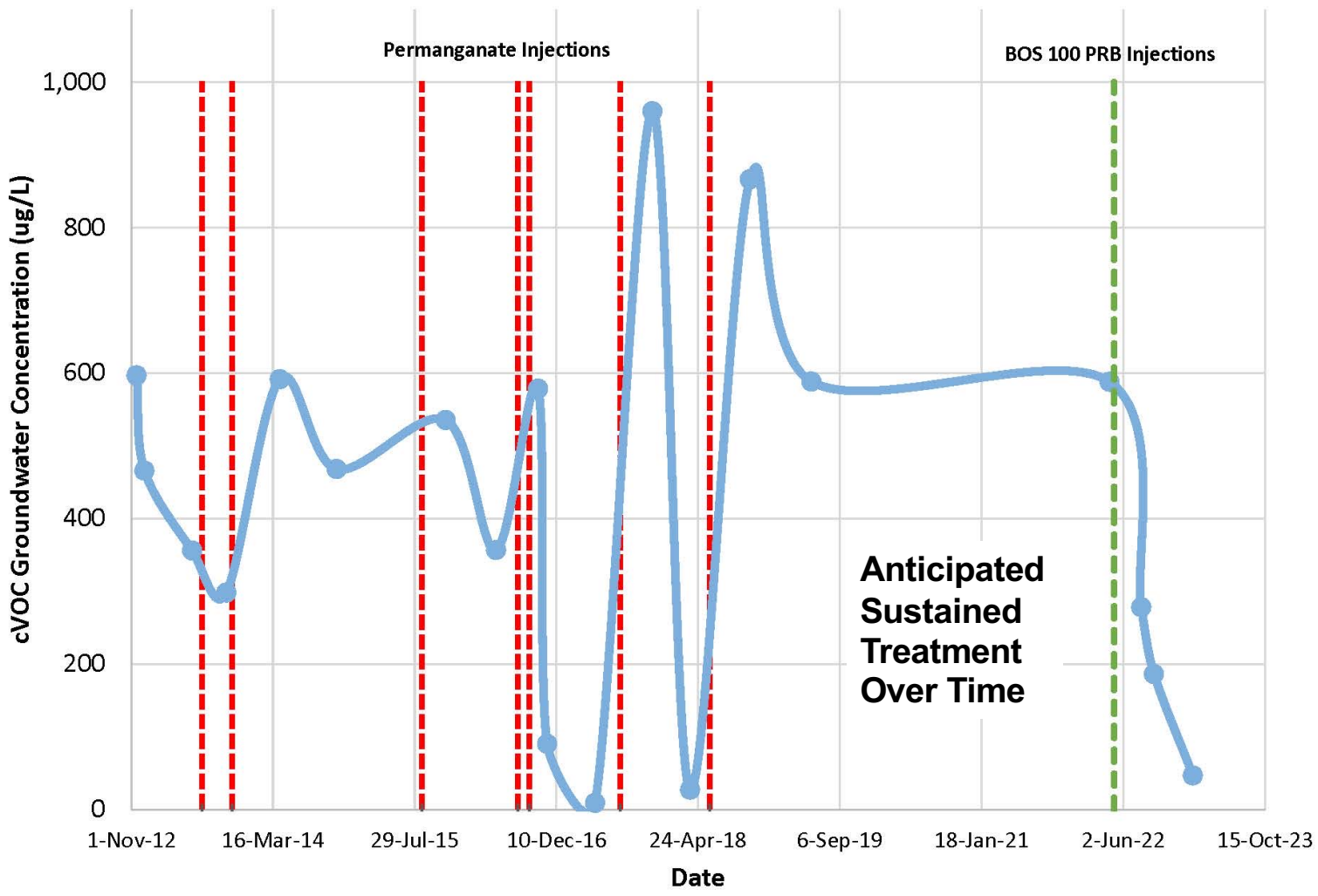


Parameter (ug/L)	2017	2023	Percent Change	
TCE	200	<0.2	100%	Reduction
Cis-1,2-DCE	37	<0.20	100%	Reduction
VC	56	<0.17	100%	Reduction



Historic
Monitorir
Over Tim





Completed

GRASS

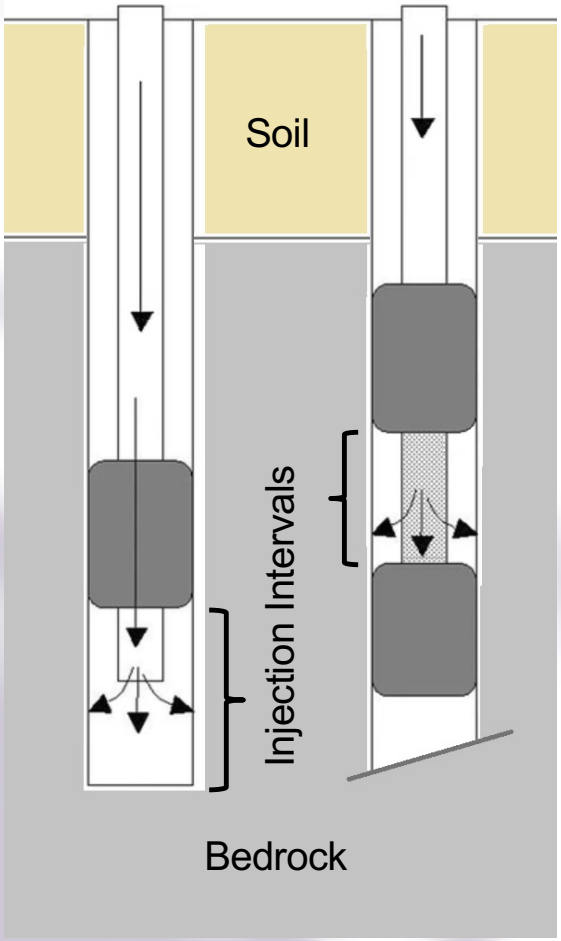
Bedrock Case Study #3 Wrap-Up

Remediation of Bedrock with Chlorinated Solvents:

- Original Open Borehole / Straddle Packer Injection Proposed
  - Friable shale bedrock, lots of cave-ins
  - Packers getting stuck, very slow production rates
  - Approach considered not feasible due to stratigraphy
- Adapted Injection Method
  - Implemented alternative GeoTAP™ method
  - Utilized existing open bedrock boreholes, cleared out & backfilled for subsequent direct push injection
- Trap and Treat® BOS 100® injection
  - Designed to control migration and back diffusion of cVOCs
  - Created a long-lasting PRB in difficult stratigraphy

Take Aways / Lessons Learned

Take Aways / Lessons Learned



Performing Bedrock Remediation:

- Address Source/NAPL by aggressive means
  - Excavation & MPE (Case Study #1)
- Back diffusion
  - Use a persistent / particulate remedial amendment that can overcome back diffusion:
    - Trap and Treat® (Case Study #1 and #3)
    - Zero Valent Iron (Case Study #2)
- Difficult stratigraphy
  - Adapt to site-specific conditions using appropriate bedrock injection technology and methods
- In-situ injections approaches can work
  - With proper remedial design, persistent amendments, proper drilling and injection techniques

Bedrock Remediation: What once was considered Impossible is now Routine!

Questions?

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