Complex Bedrock Remediation Case Study:
Dissolved Heavy Metals In-Situ Using Multiple Approaches

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RemTech

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VEI Contracting Inc.

Presentation Overview

- Bedrock Remediation Difficulties
  - Why is it so difficult?
- Case Study
  - Bench-Scale (2018/19)
  - Pilot-Scale (2020)
  - Full-Scale (2023)
- Take Aways
- Questions

Bruce @ UW, 1998

Bruce Tunnicliffe, P.Eng.

- University of Waterloo
  - Masters: Fractured Rock
- Founded Vertex in 2003
- Rebranded to VEI Contracting Inc. in 2024

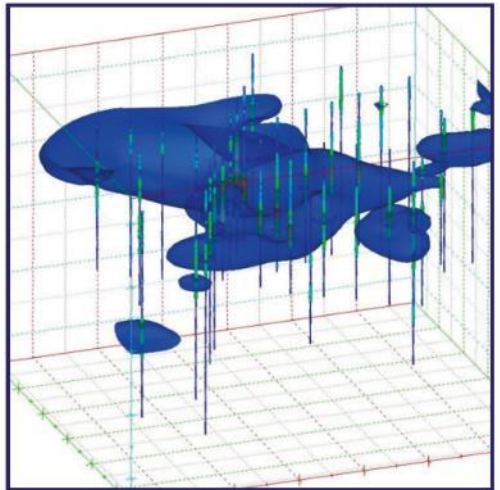
VEI Contracting Inc (formerly Vertex Environmental Inc.)

In-Situ Remediation

Ex-Situ Remediation

High Resolution Characterization

Treatment Systems



Remedial Design

Bench-Scale Testing

Vertex

- Specialized Contractor
- Works coast to coast

Bedrock Remediation Difficulties

The Difficulty with Bedrock Remediation

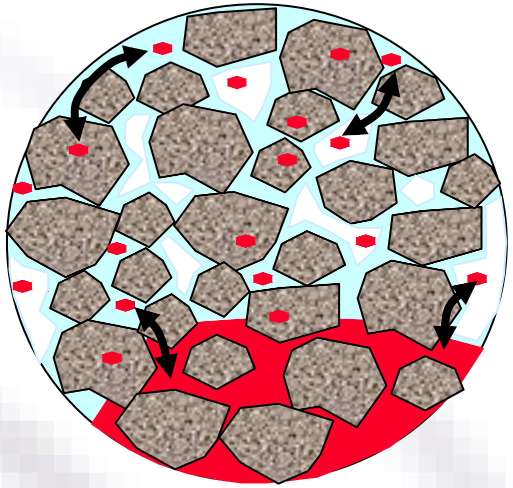
In 2013, the US Department of Defence (DoD) environmental research arm SERDP wrote:

"One of DoD's **most challenging** environmental restoration issues is determining how to deal with **contaminants** that have **seeped into the fractures in bedrock** and are a continuing source of groundwater contamination."

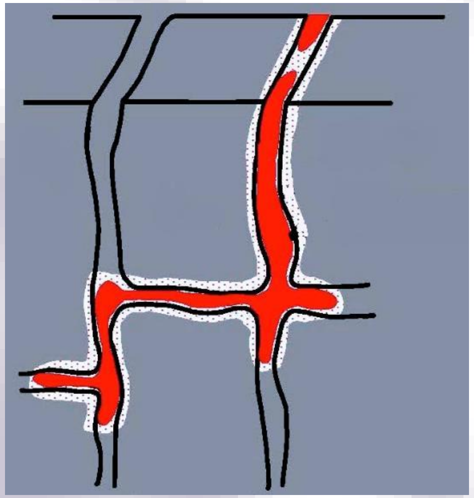
The U.S. Geological Survey noted:

"…remedial action is delayed or stymied by **the complexity of contaminated fractured-rock aquifers**"

The Difficulty with Bedrock Remediation



Porous Media
Porosity = 30%



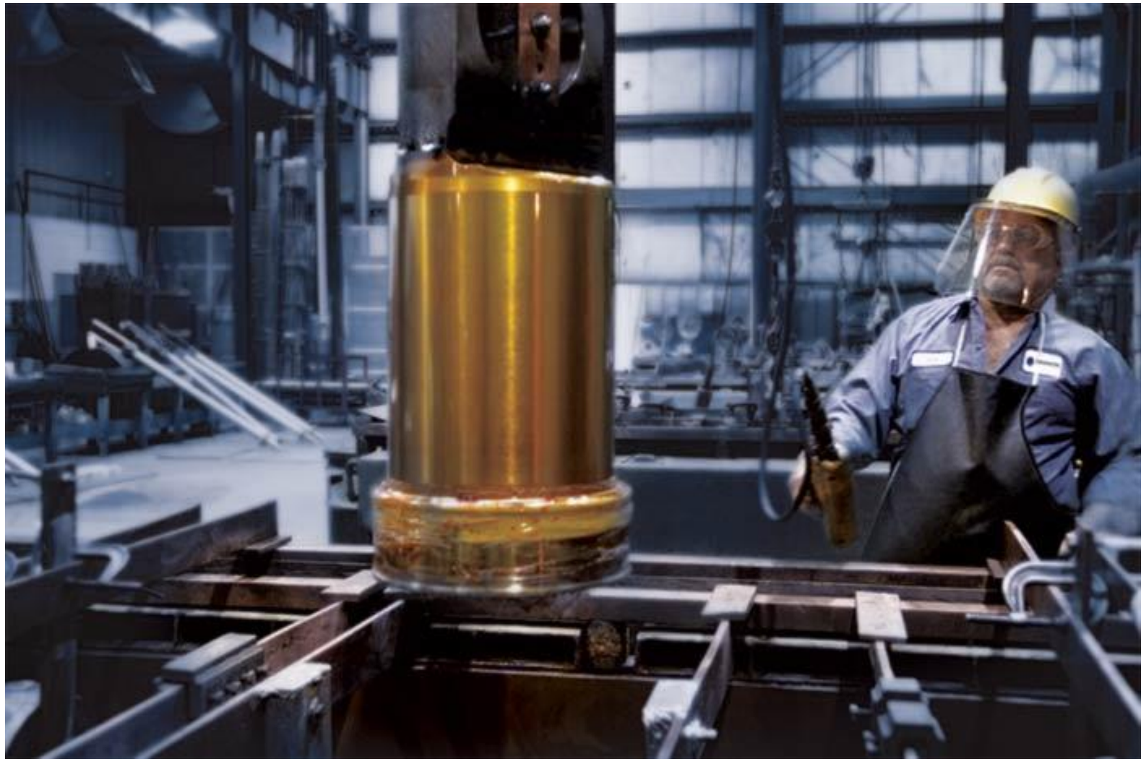
Fractured Rock
Porosity = 1 to 10%

Why So Challenging?

- Fracture Network
  - Can be complex
  - Thus Contaminant Distribution also complex
- Secondary Porosity
  - Contamination “soaks” into rock, difficult to get out
- Hard to Access / Expensive to Access
  - Easy for contaminant to enter fractures
  - Costly to access with remediation infrastructure
- Plume Length
  - Thin but Long Fractures = Large Plume
- Groundwater Flow Velocity
  - Can be fast compared to Porous Media

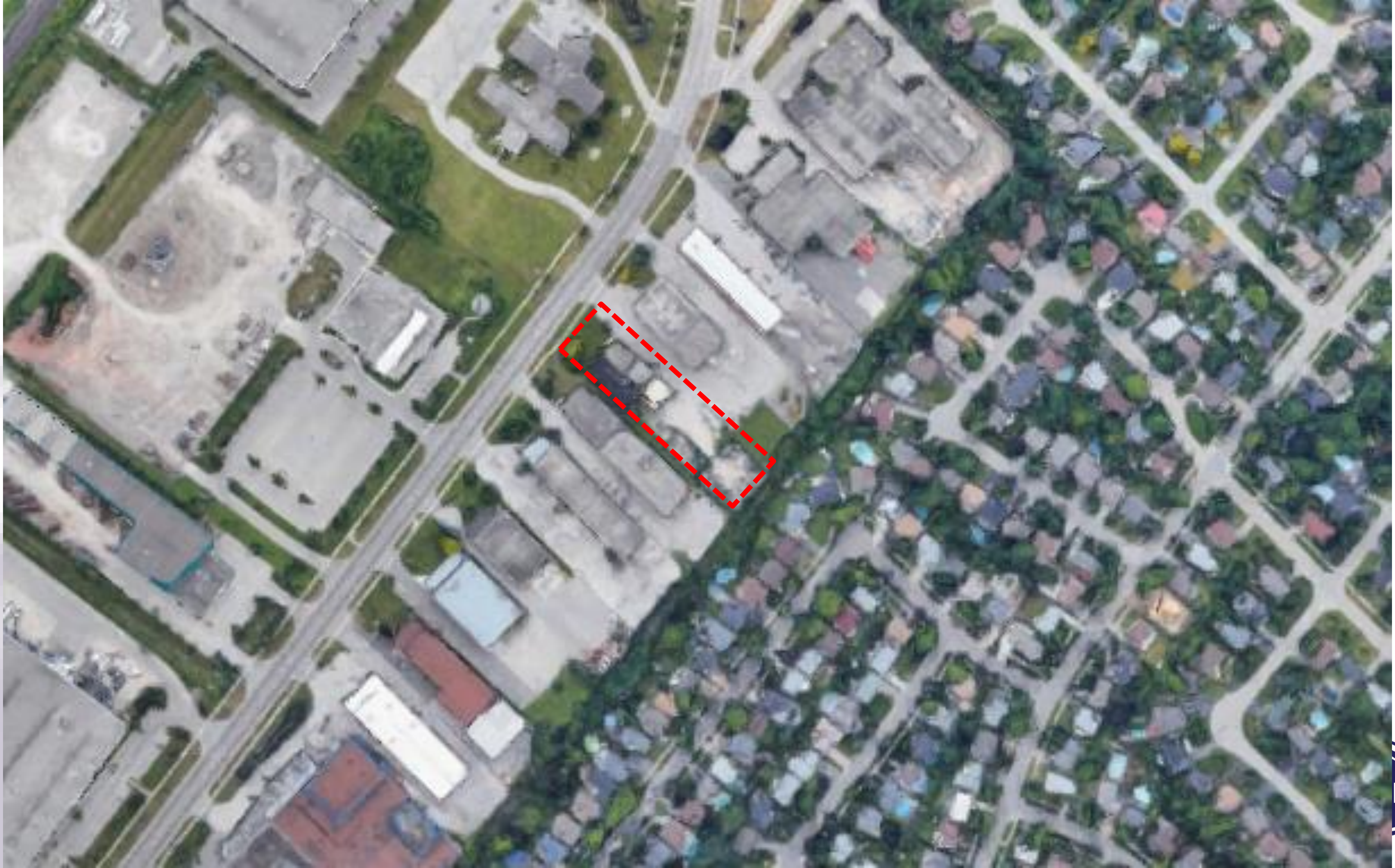
Case Study – Background

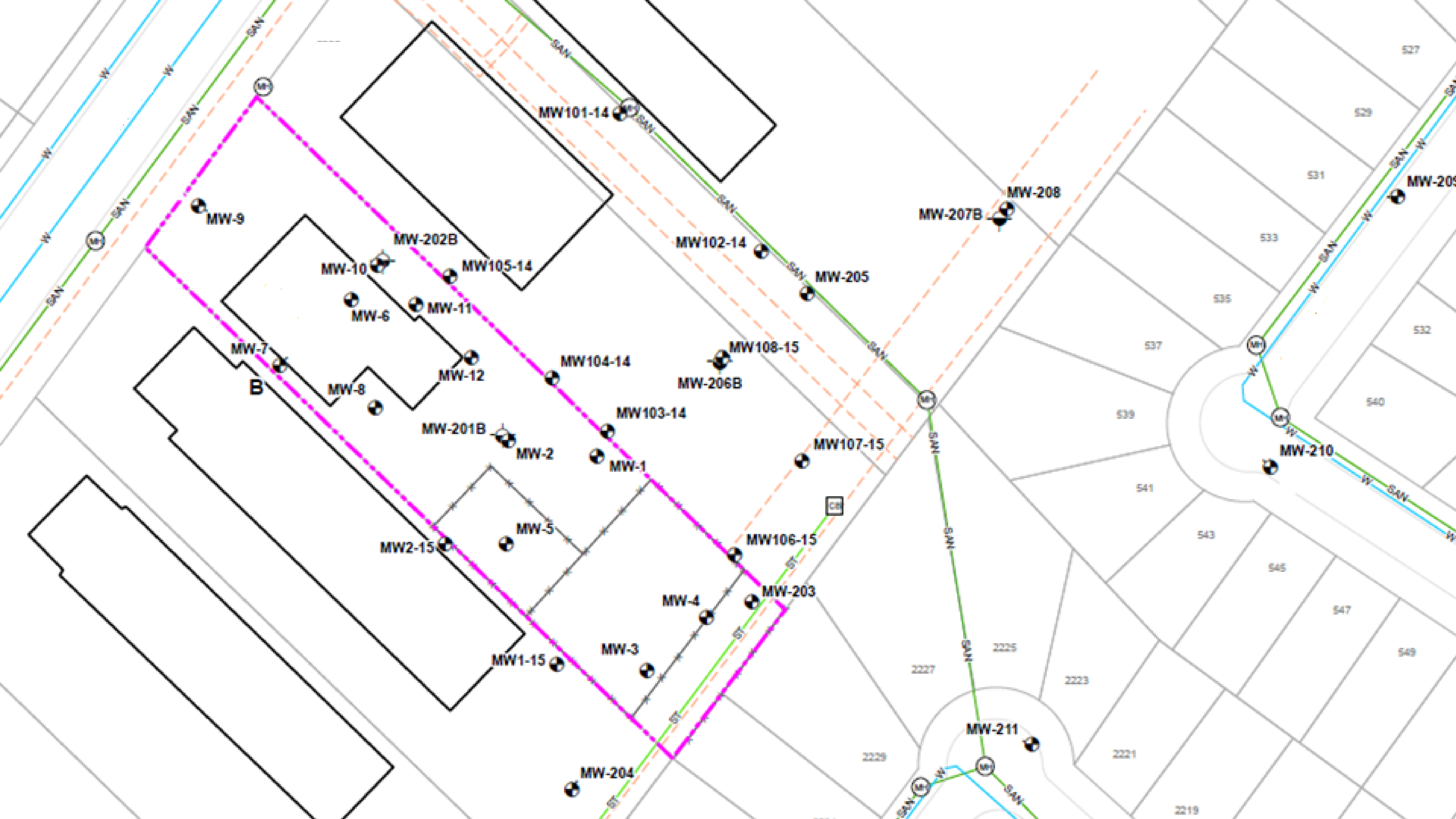
- Chromium plating facility:
  - Underground tanks containing chromium plating solution
  - Tanks leaked, historical spills
- Neighbour completed Phase II ESA
  - Now everyone is suing everyone else
- Chrome contamination
  - Hexavalent chromium
  - Total chromium
- Client Situation
  - The client had very little money
  - The work was done in stages
- Bench, Pilot, Full-Scale Work



Project Time Line

- Bench-Scale Testing:
  - 2018 to 2019
  - Using site groundwater and various amendments
- Pilot-Scale Testing
  - 2020
  - On-site testing of the best performing amendments
- Full-Scale
  - 2023
  - Injection infrastructure installation
  - Additional groundwater sampling completed
  - Injection of a Permeable Reactive Barrier (PRB) completed





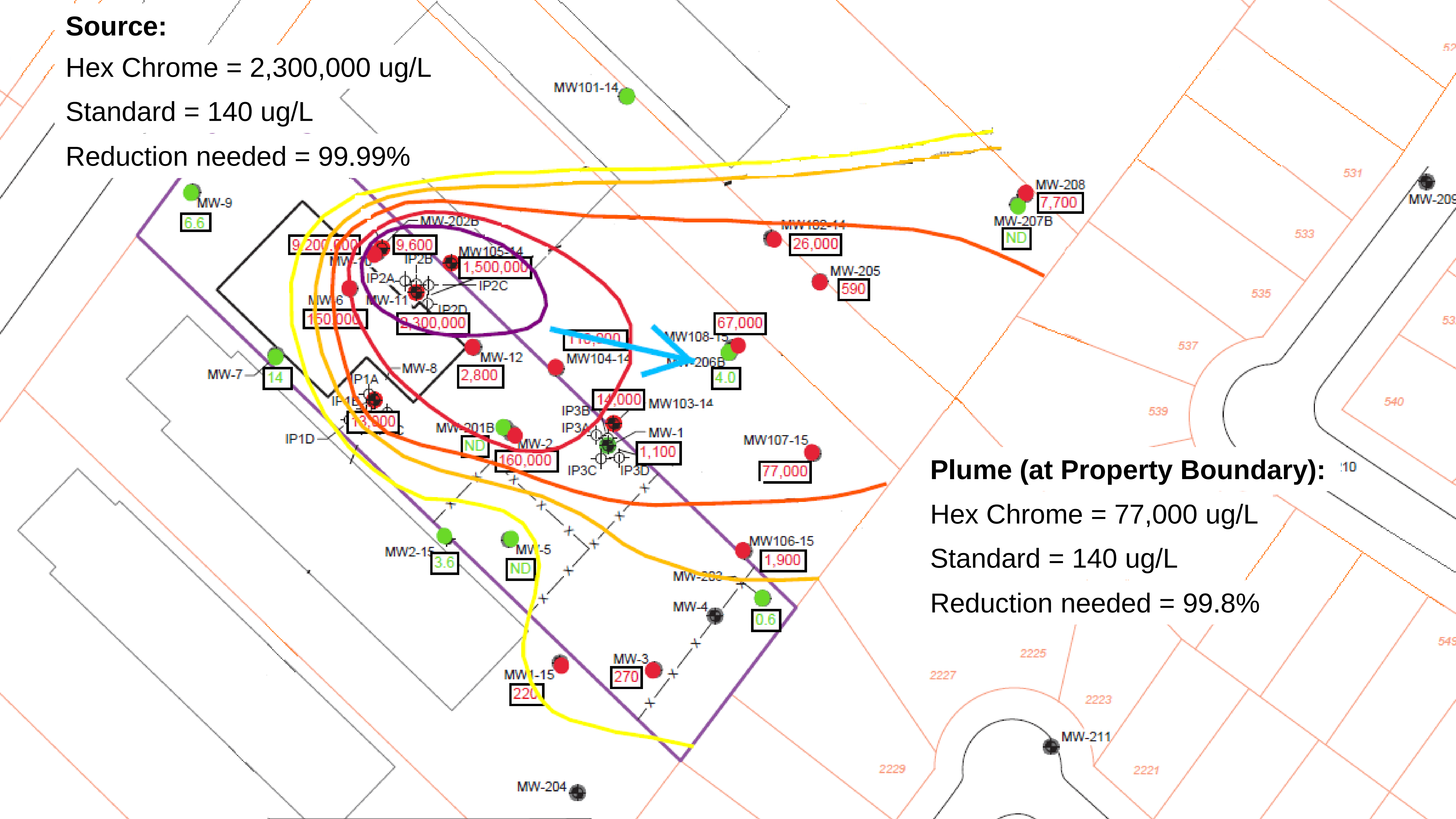
MW101-14
MW-9
MW-202B
MW-10
MW105-14
MW-6
MW-11
MW-7
MW-12
B
MW-8
MW104-14
MW102-14
MW-205
MW-207B
MW-208
MW108-15
MW-206B
MW103-14
MW-201B
MW-2
MW-1
MW107-15
MW-210
MW-5
MW2-15
MW106-15
MW-4
MW-203
MW-3
MW1-15
MW-211
MW-204
CB
SAN
W
ST
MH
527
529
531
533
535
537
539
541
543
545
547
549
532
540
2225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

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%

SUBSURFACE PROFILE				SAMPLE						
Depth (ft)	Depth (m)	Symbol	Description	Depth/Elev (m)	Sample ID	Analysed Y,N	Sample Type	Vapour ppm (0 250 500)	LEL % (0 50 100)	Backfill details
			Ground Surface	61.99						
0	0		**SAND (Fill)** Brown, medium to coarse grained, some gravel, trace silt, damp	0.00	MW-1-0.3	Y				
1										
2			**CLAY; Silty** Reddish brown, some sand, trace gravel, moist							
3	1				MW-1-1.2	Y				
4										
5										
6										
7	2				MW-1-2.1	Y				
			WEATHERED SHALE Red	59.86 2.13						
8										
9										
10	3									
11										
12										


Source
Source

Removal from Groundwater – Dissolved to Solid Phase

Cr(VI)

H_2CrO_4

CrO_4^{2-}

$HCrO_4^{-}$

$Cr_2O_7^{2-}$

Electron donors:

Fe^0(s)

Fe^{2+}(aq)

Hydrogen

Reductive-Precipitation

Cr(III)(aq)

$Cr(OH)_3$(S)

Cr_2FeO_4(S)

Adsorption

Source:

Hex Chrome = 2,300,000 ug/L

Standard = 140 ug/L

Reduction needed = 99.99%

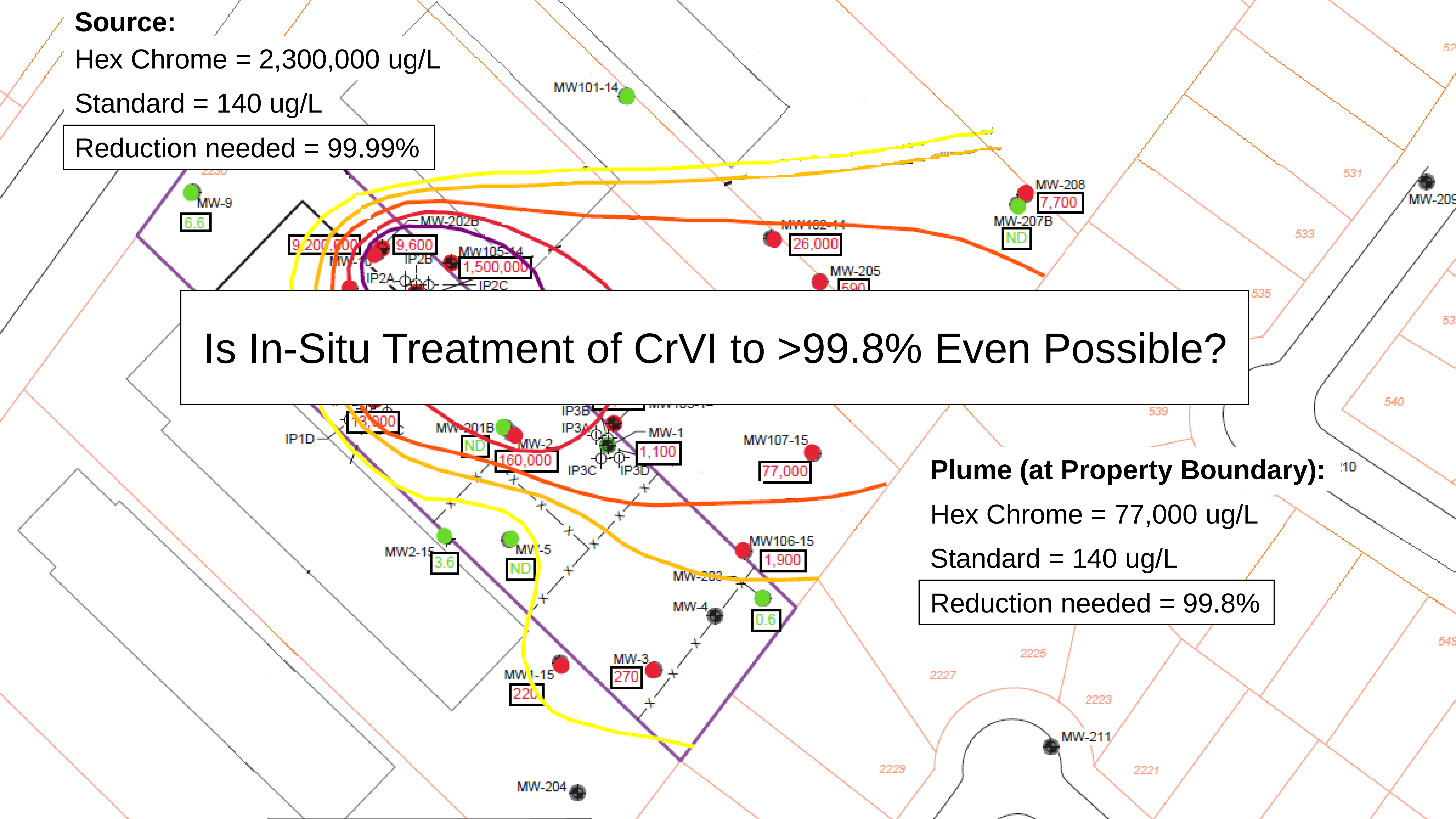
Is In-Situ Treatment of CrVI to >99.8% Even Possible?

Plume (at Property Boundary):

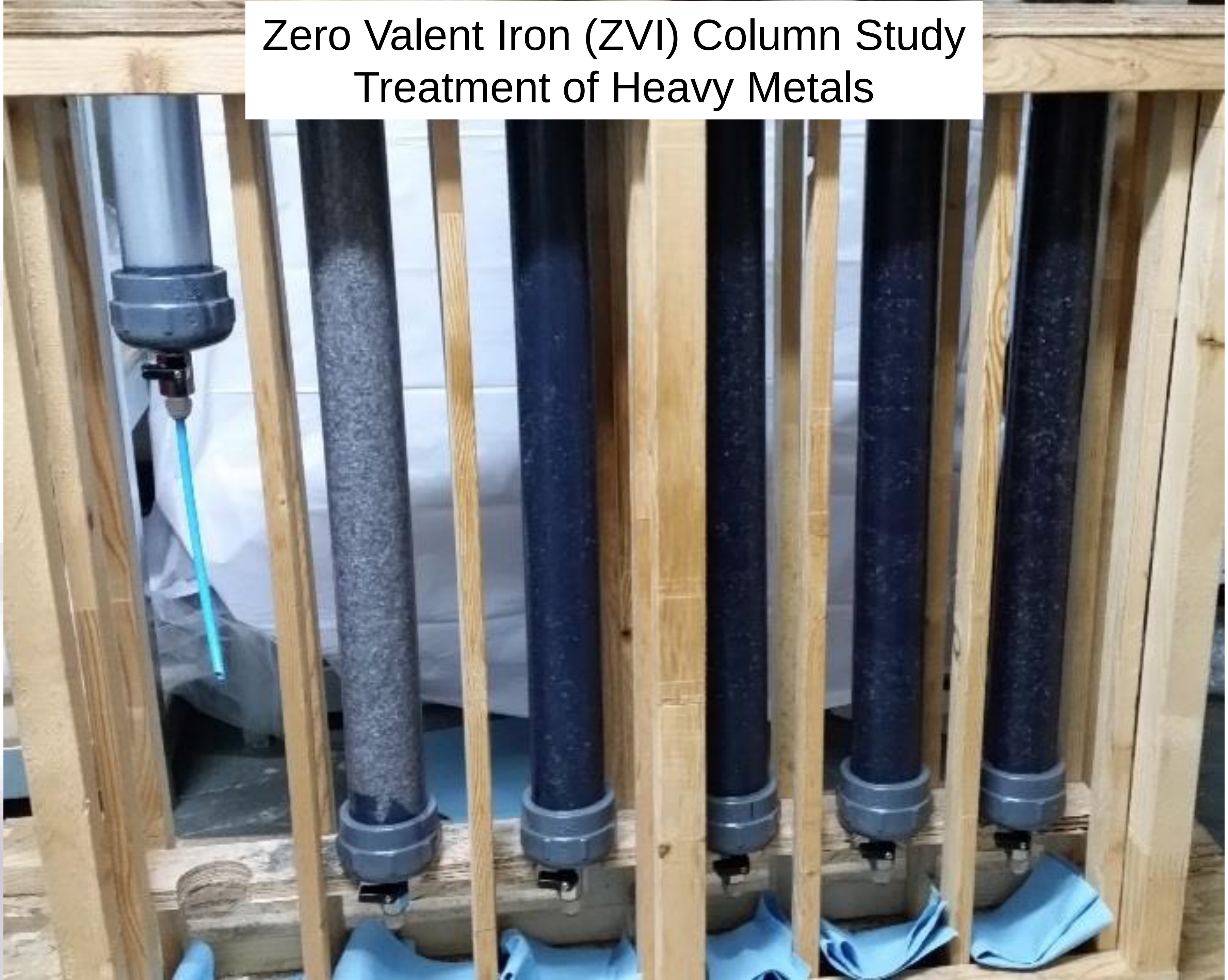
Hex Chrome = 77,000 ug/L

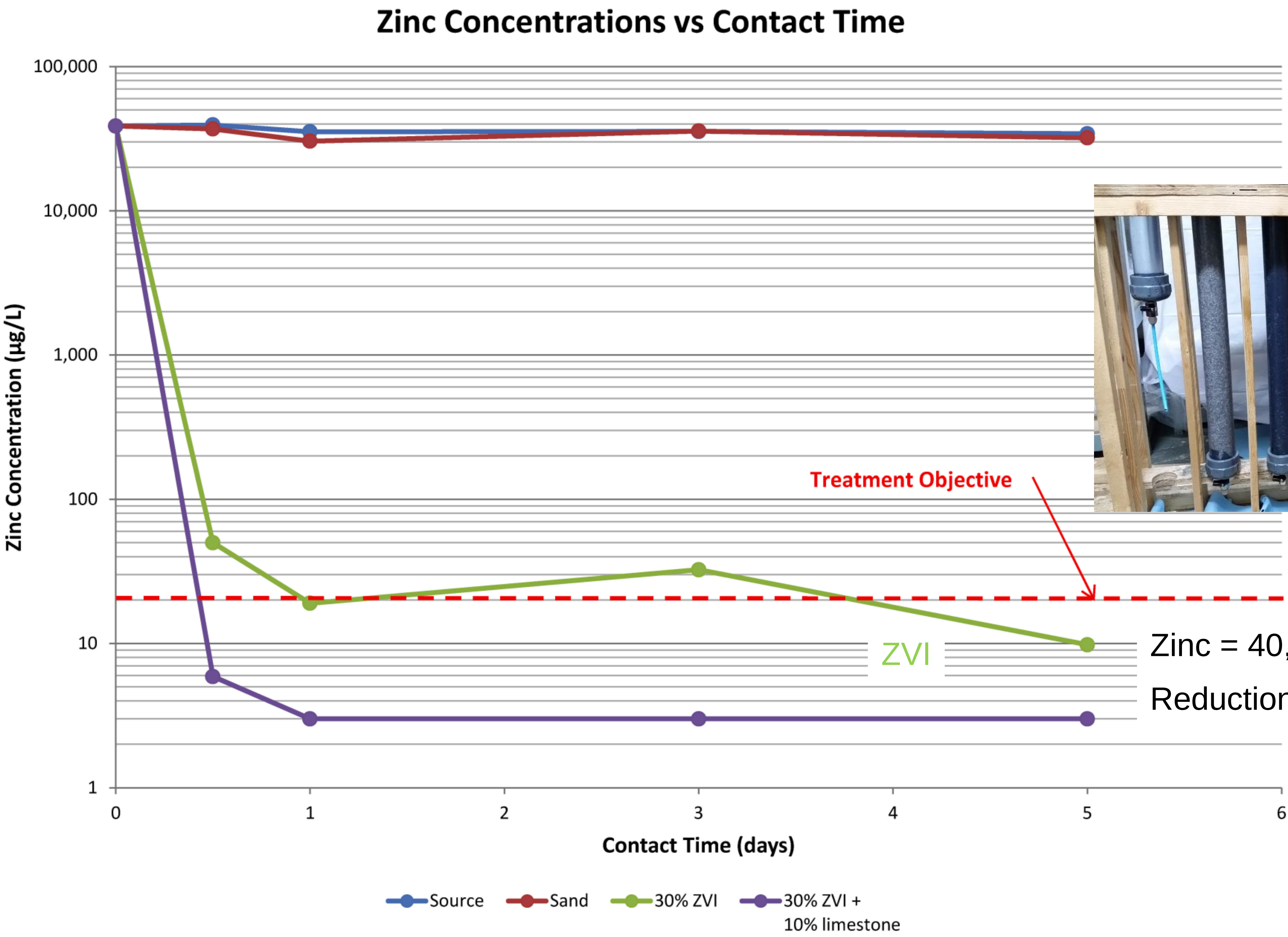
Standard = 140 ug/L

Reduction needed = 99.8%



Zero Valent Iron (ZVI) Column Study
Treatment of Heavy Metals





Zinc = 40,000 ug/L

Reduction = 99.98%

Bench-Scale Testing

Bench-Scale Testing

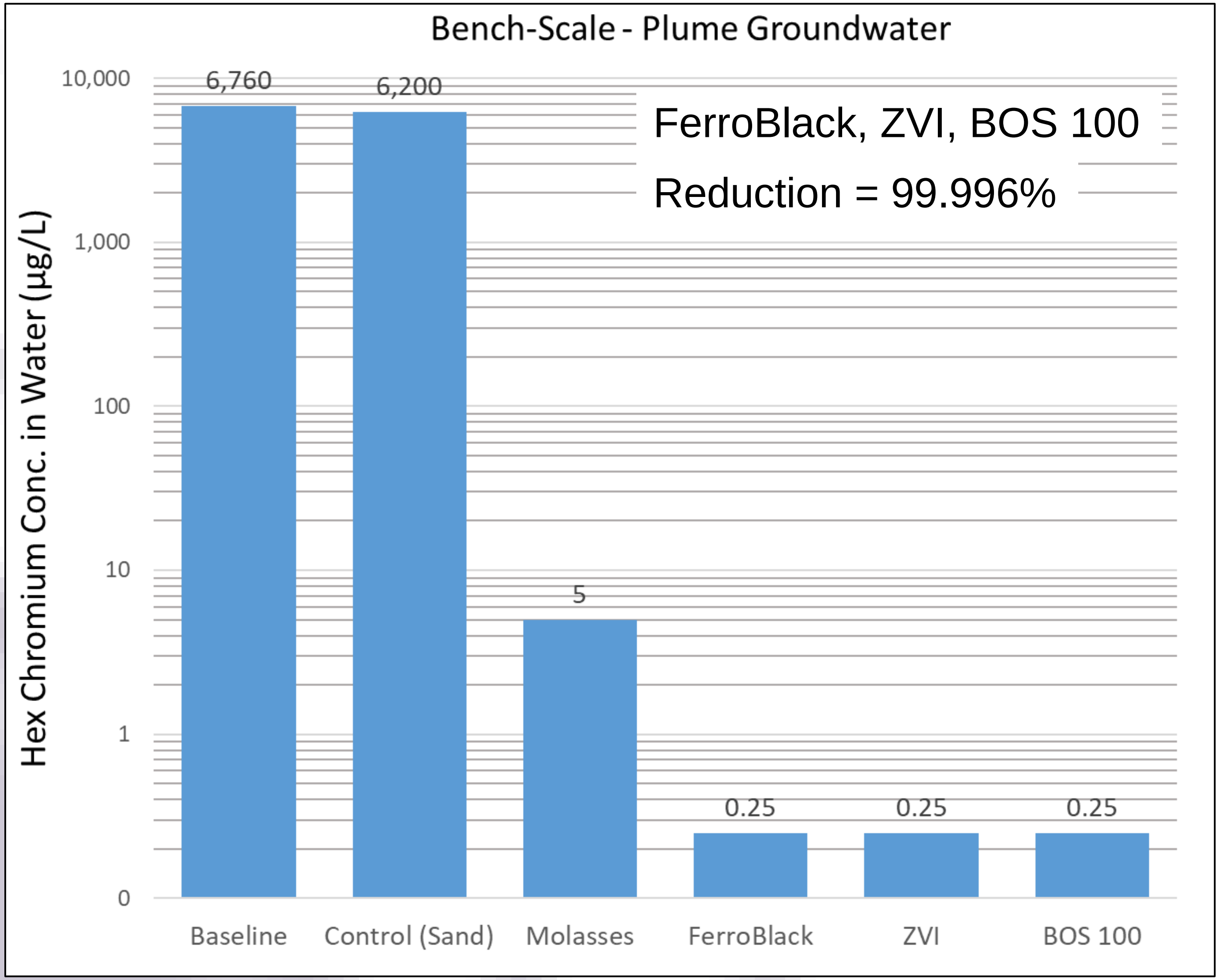
Remediation Amendments Tested

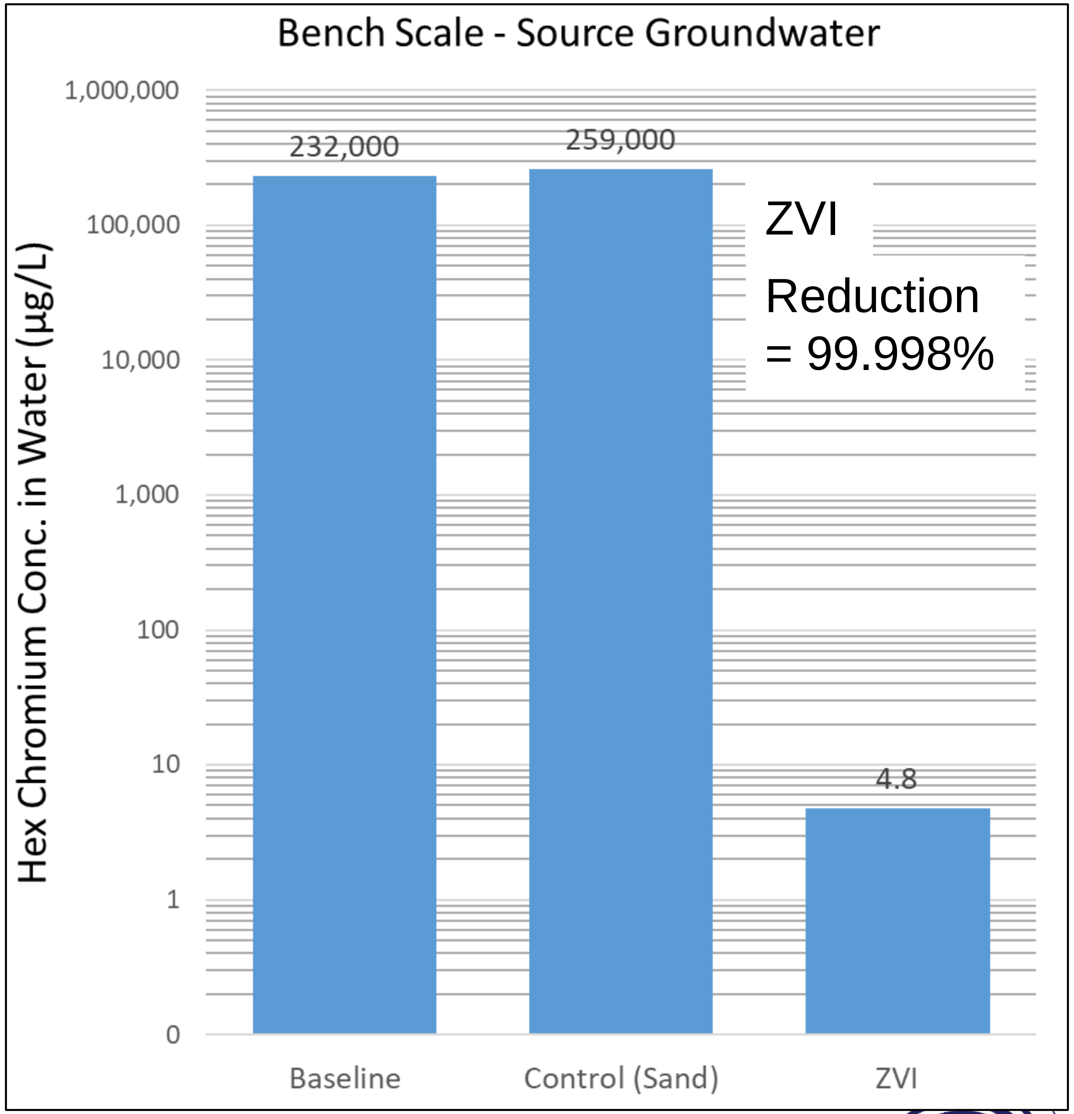
- Molasses
- FerroBlack®
- Zero Valent Iron (ZVI)
- Trap & Treat® BOS 100®

Method

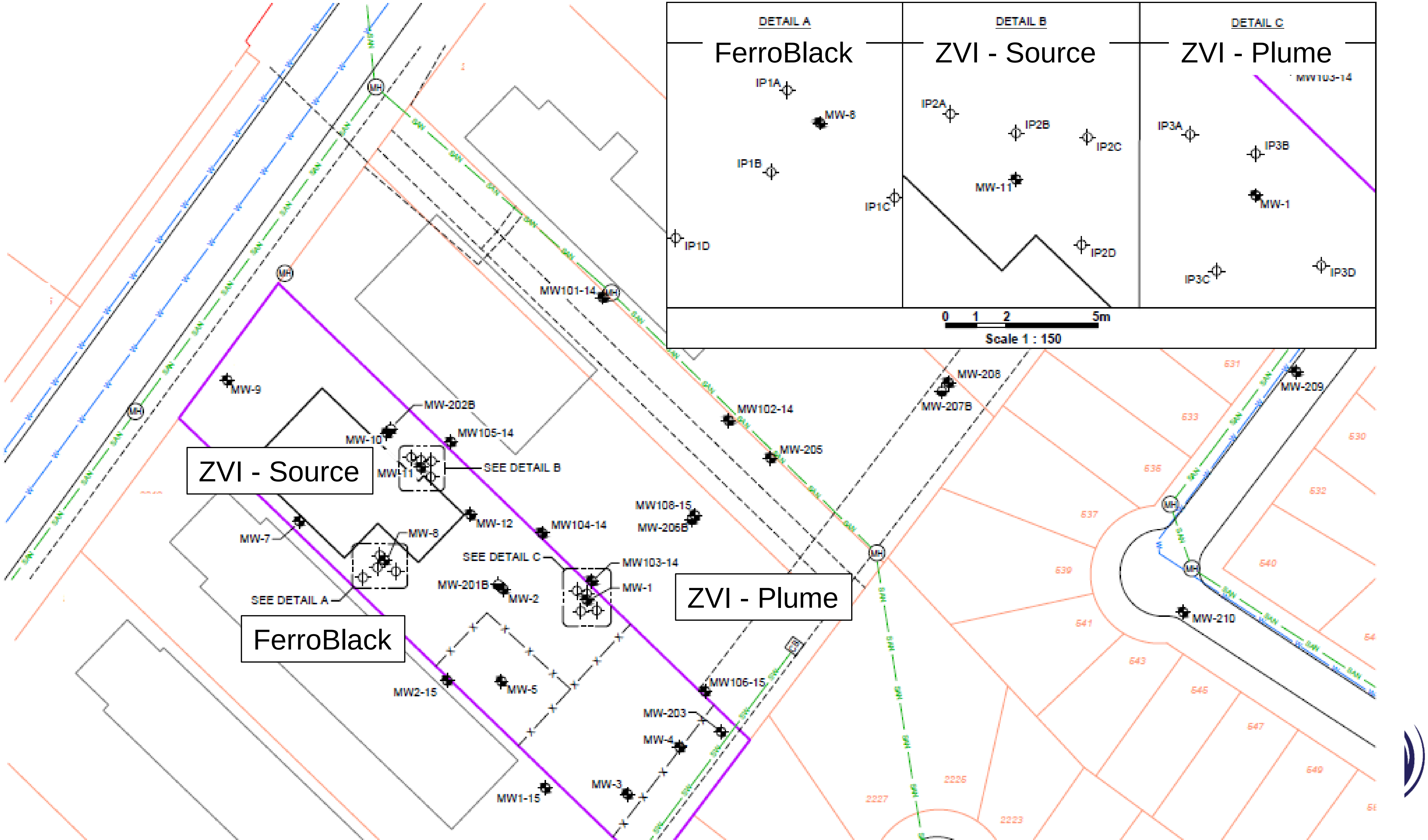
- 1 L containers
- Silica sand and remedial amendment
- Groundwater added
- Placed in dark, let sit, sampled over time

Bench-Scale Testing - Results



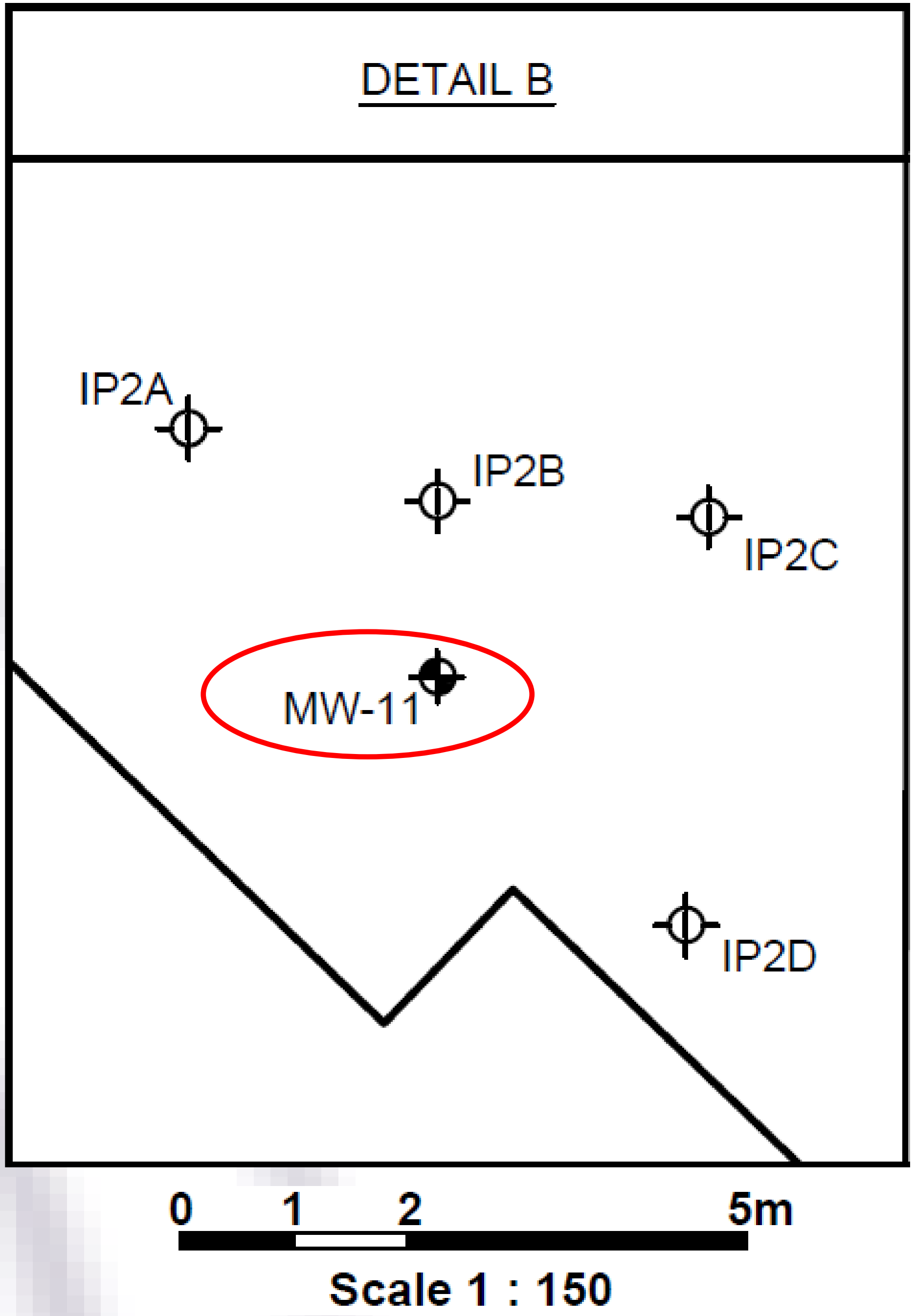


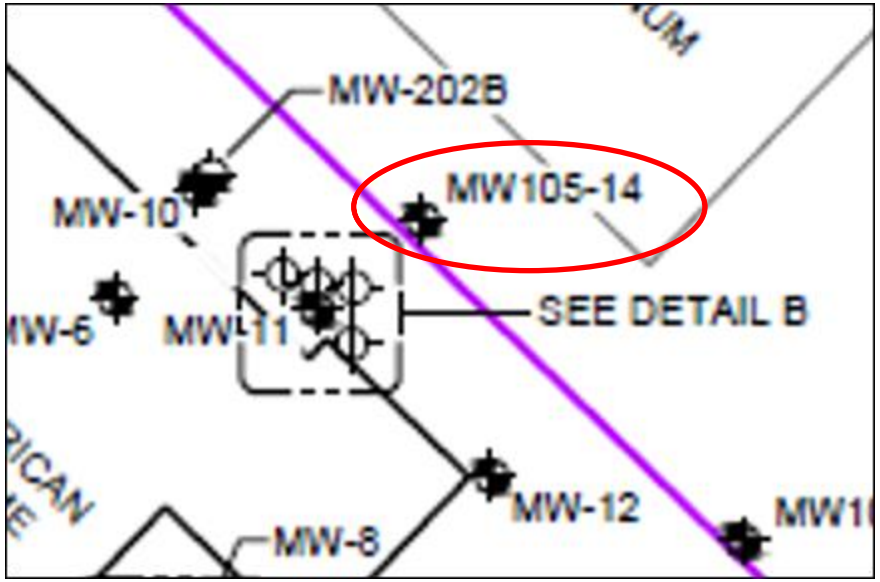
Pilot-Scale Testing

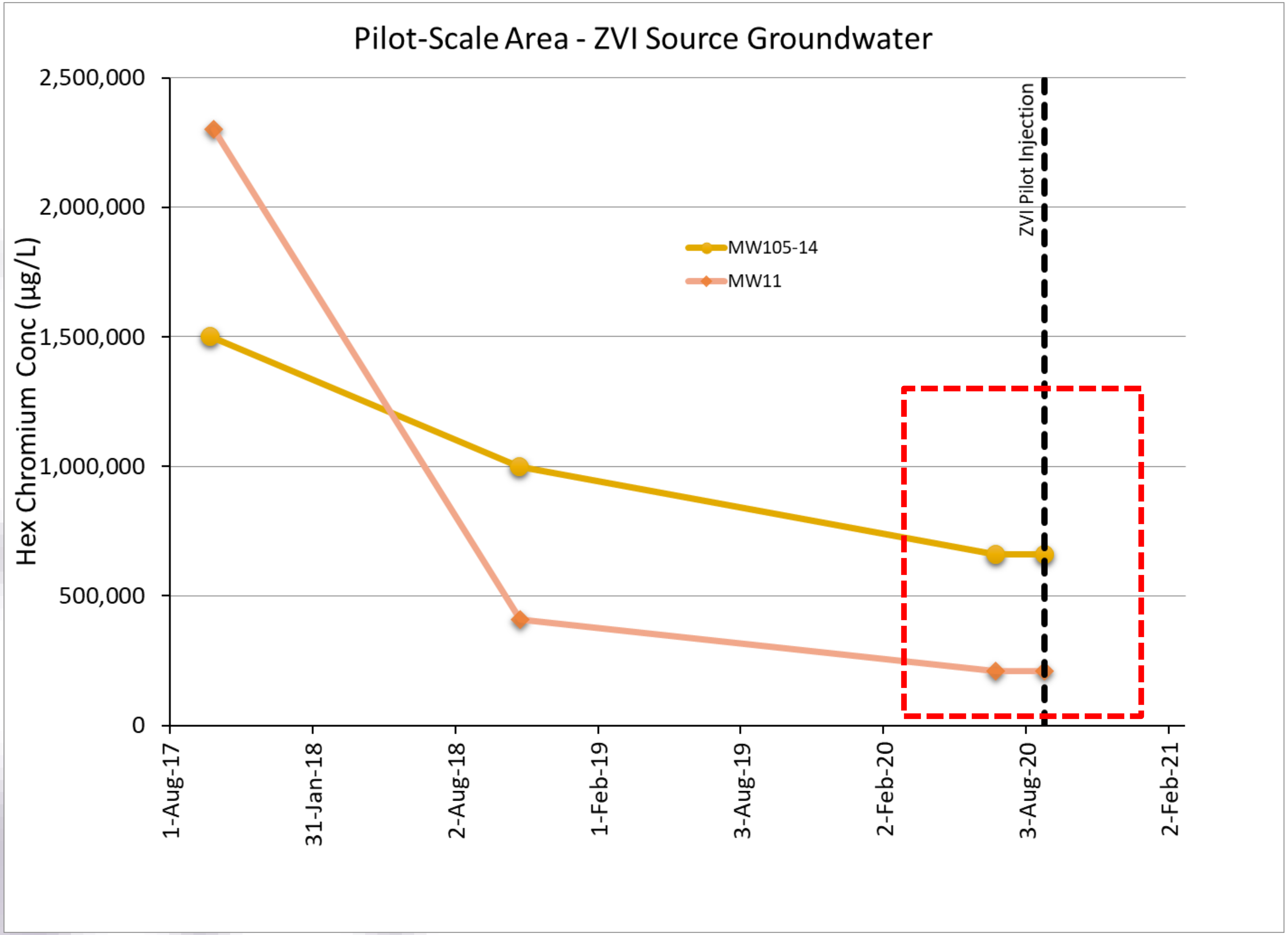


DETAIL A
FerroBlack
IP1A
MW-8
IP1B
IP1C
IP1D
DETAIL B
ZVI - Source
IP2A
IP2B
IP2C
MW-11
IP2D
DETAIL C
ZVI - Plume
IP3A
IP3B
MW-1
IP3C
IP3D
0 1 2 5m
Scale 1 : 150
MW-9
MW-202B
MW-10
MW105-14
ZVI - Source
MW-11
SEE DETAIL B
MW-12
MW104-14
MW-7
MW-8
SEE DETAIL C
MW103-14
SEE DETAIL A
MW-201B
MW-2
MW-1
FerroBlack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

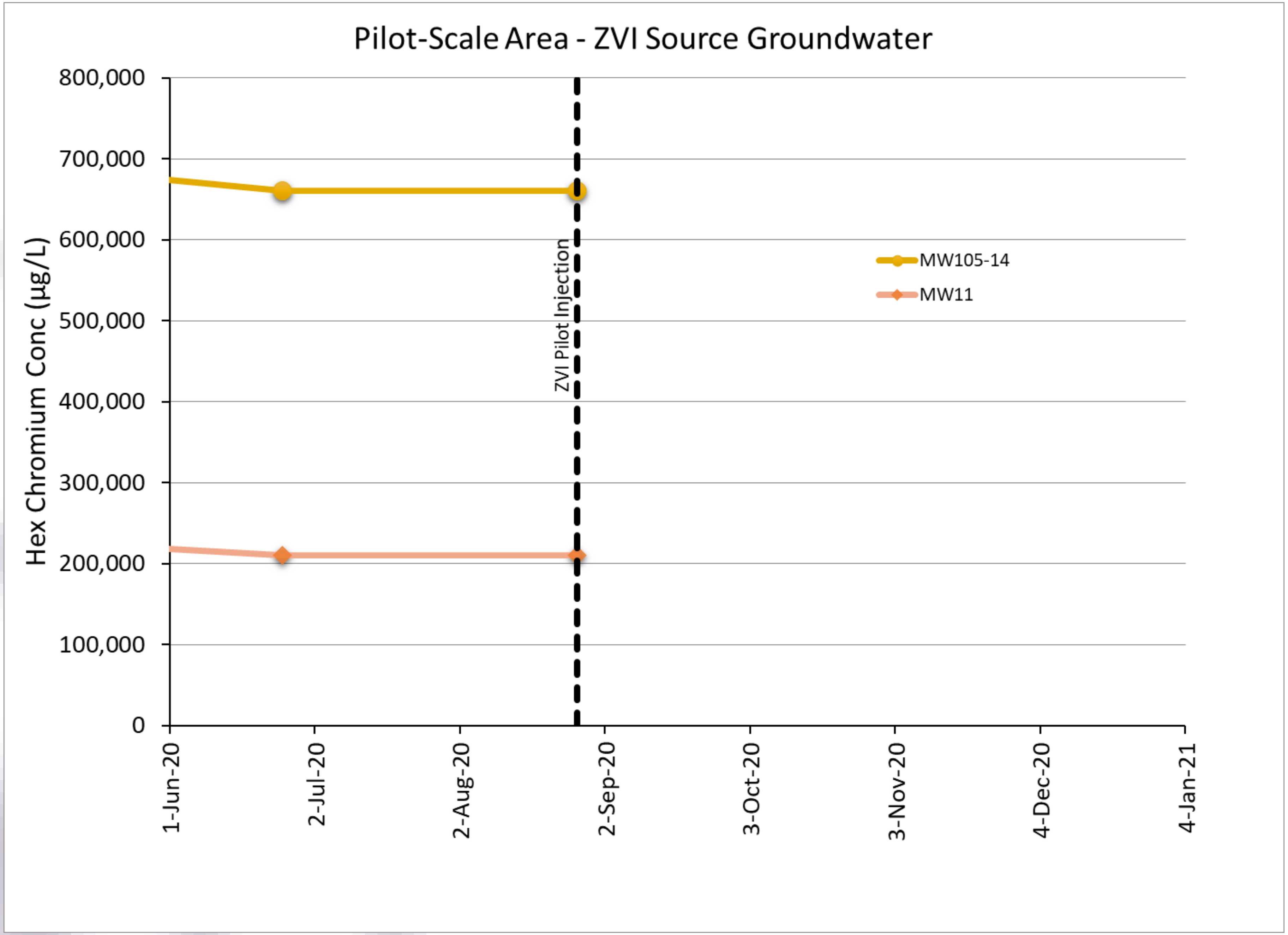
Pilot Layout
ZVI - Source



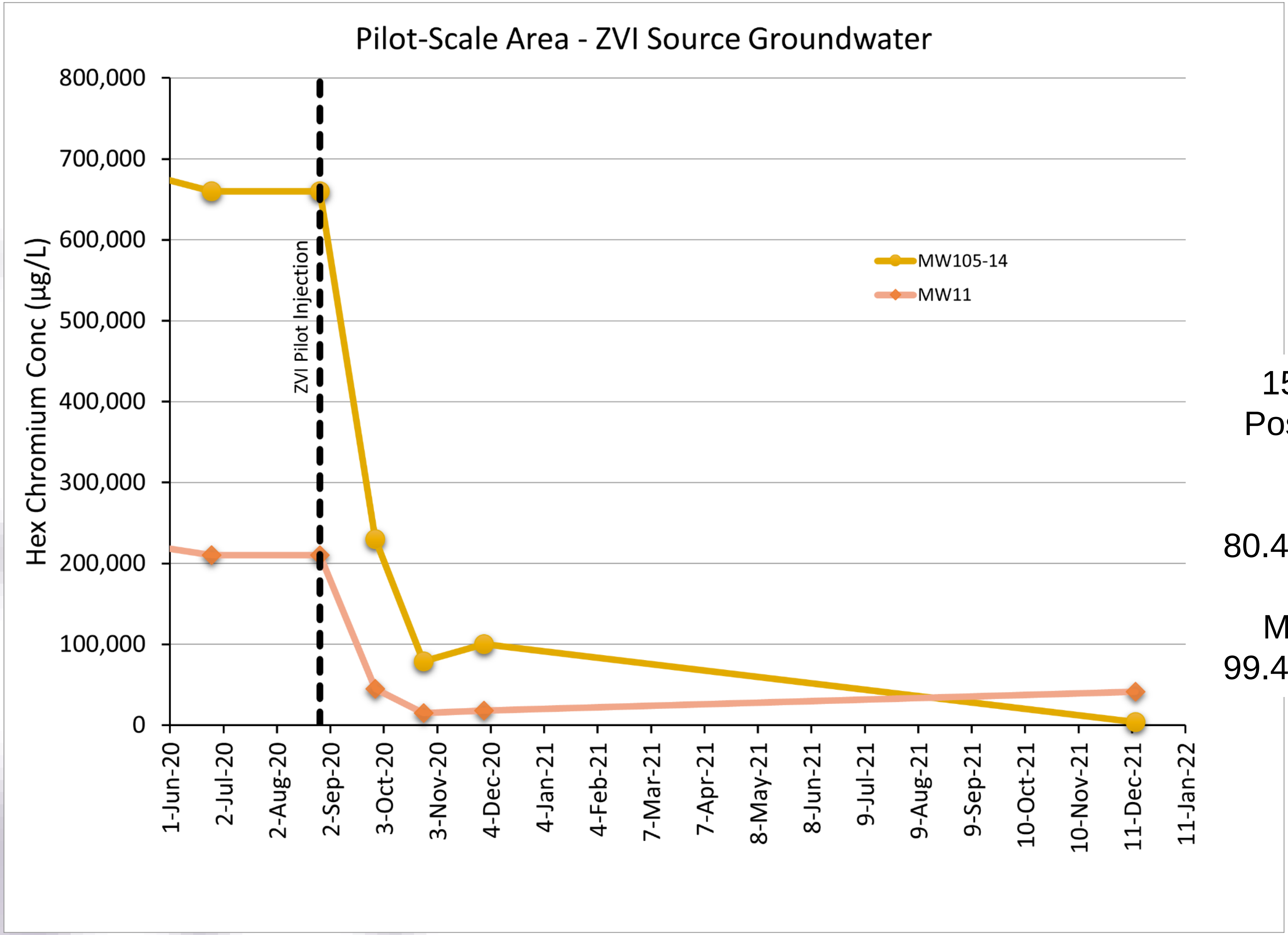




Pilot-Scale Area - ZVI Source Groundwater
Hex Chromium Conc (µg/L)
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
MW105-14
MW11
ZVI Pilot Injection
1-Aug-17
31-Jan-18
2-Aug-18
1-Feb-19
3-Aug-19
2-Feb-20
3-Aug-20
2-Feb-21



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

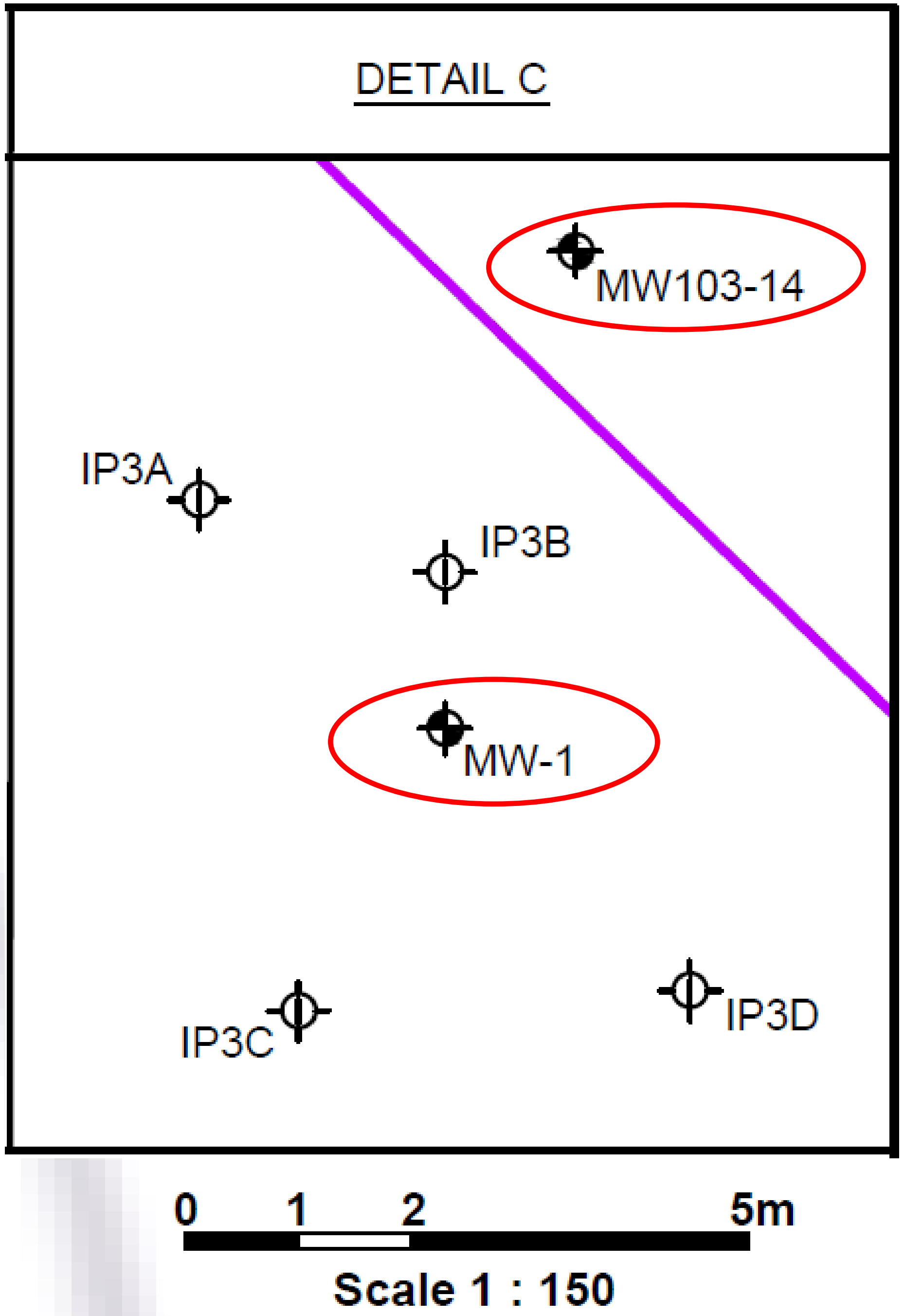


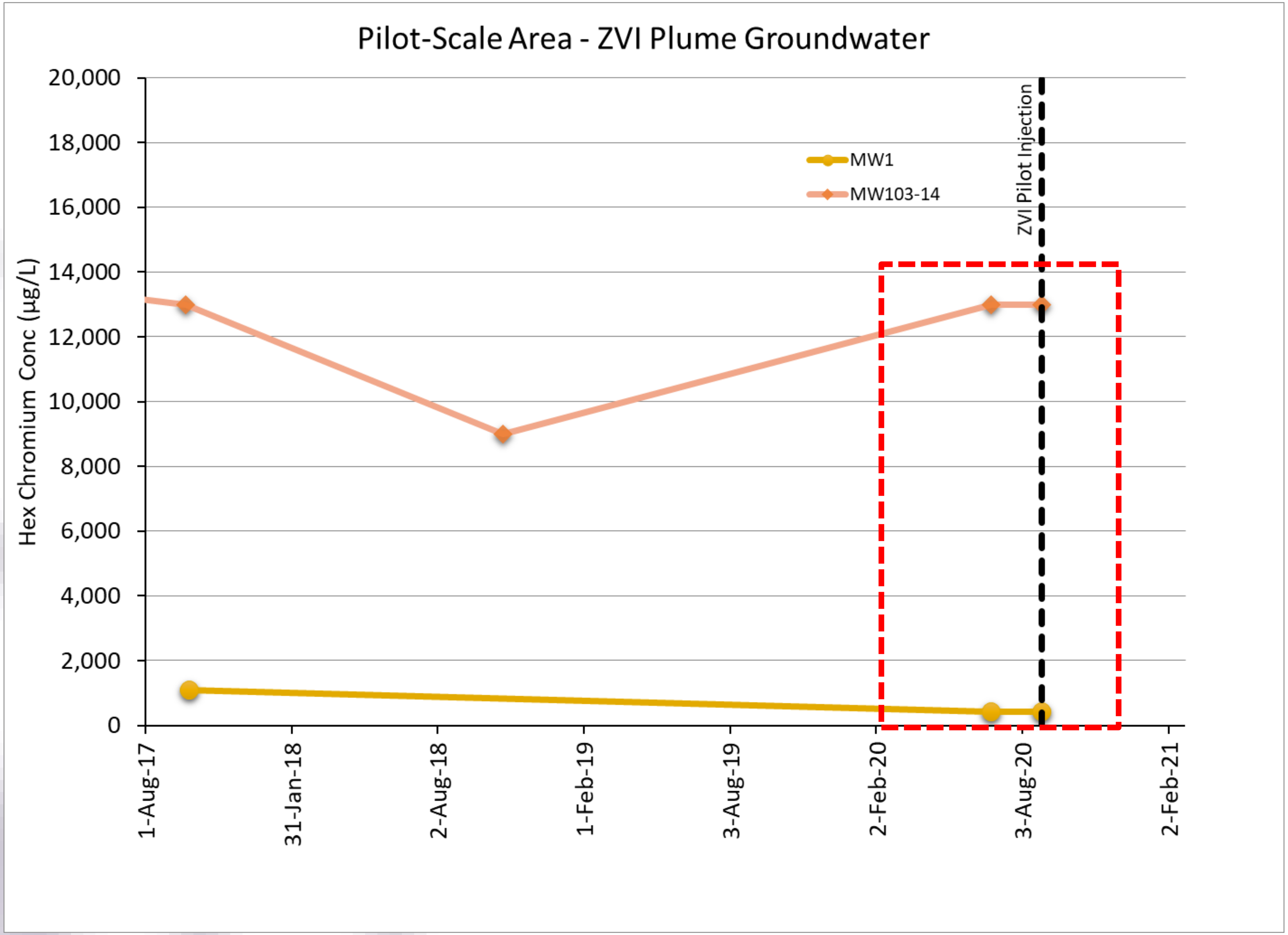
15 Months
Post Injection

MW-11
80.4% reduction

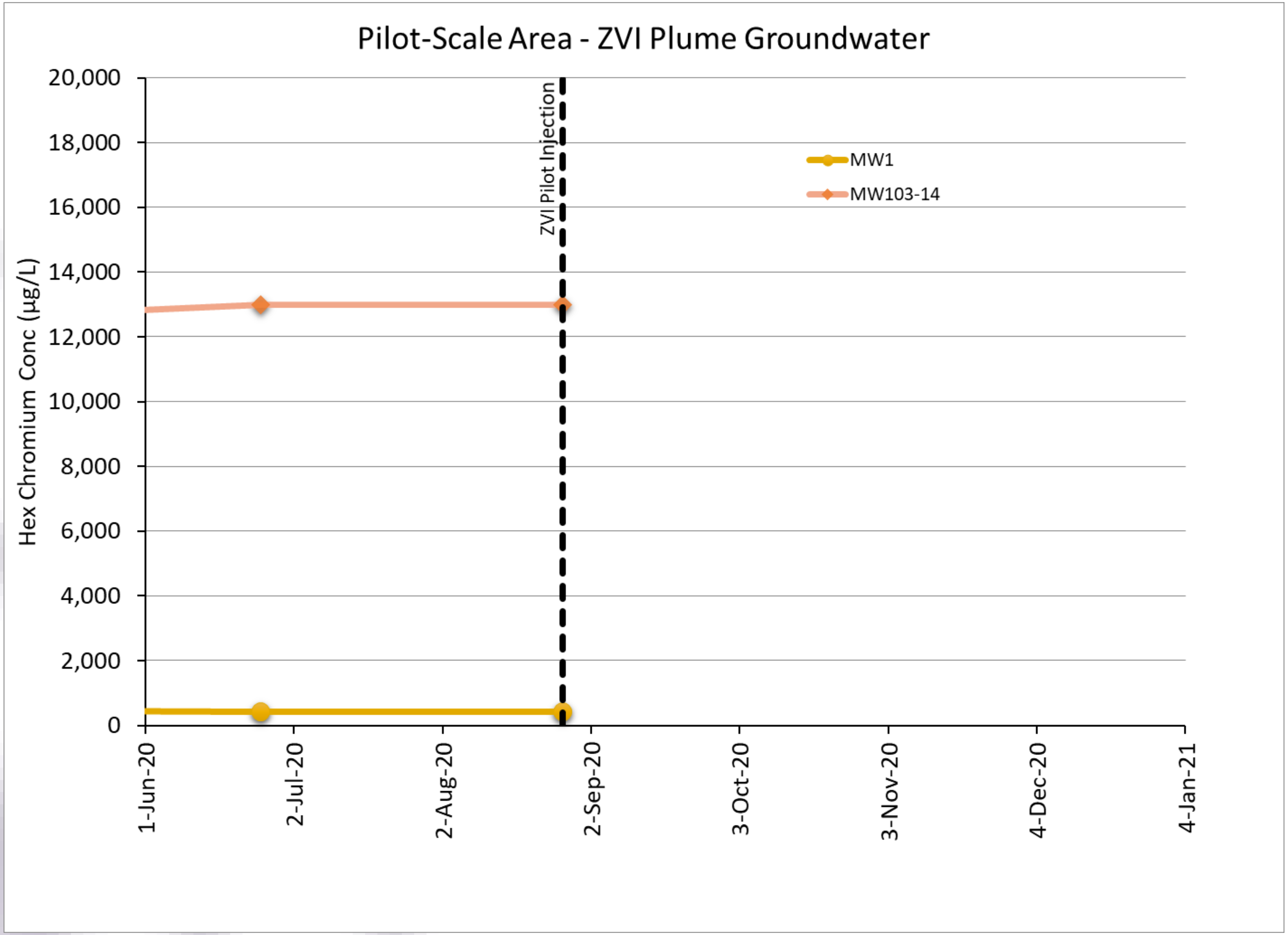
MW105-14
99.4% reduction

Pilot Layout
ZVI - Plume

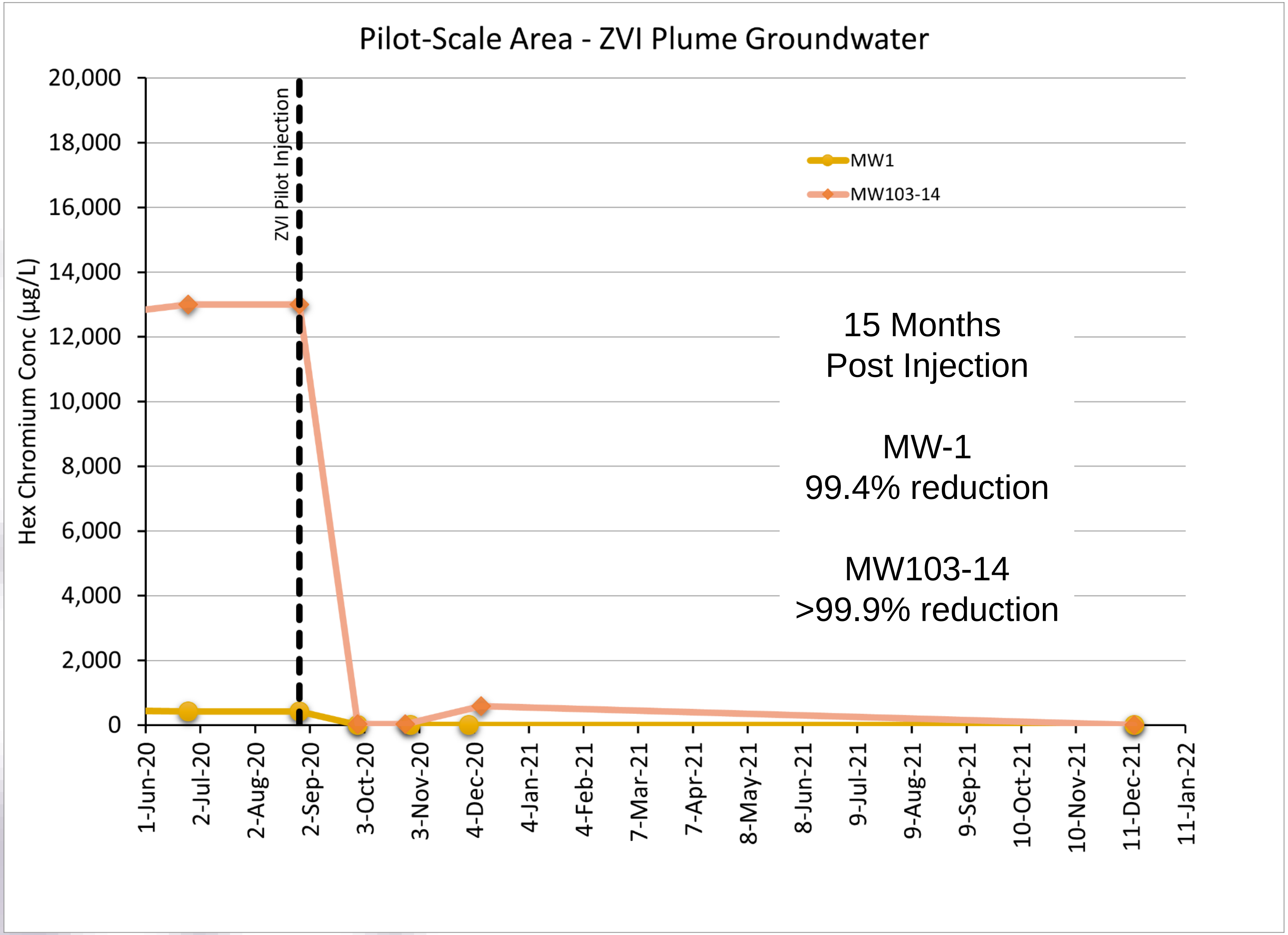




Pilot-Scale Area - ZVI Plume Groundwater
Hex Chromium Conc (µg/L)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
MW1
MW103-14
ZVI Pilot Injection
1-Aug-17
31-Jan-18
2-Aug-18
1-Feb-19
3-Aug-19
2-Feb-20
3-Aug-20
2-Feb-21



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
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

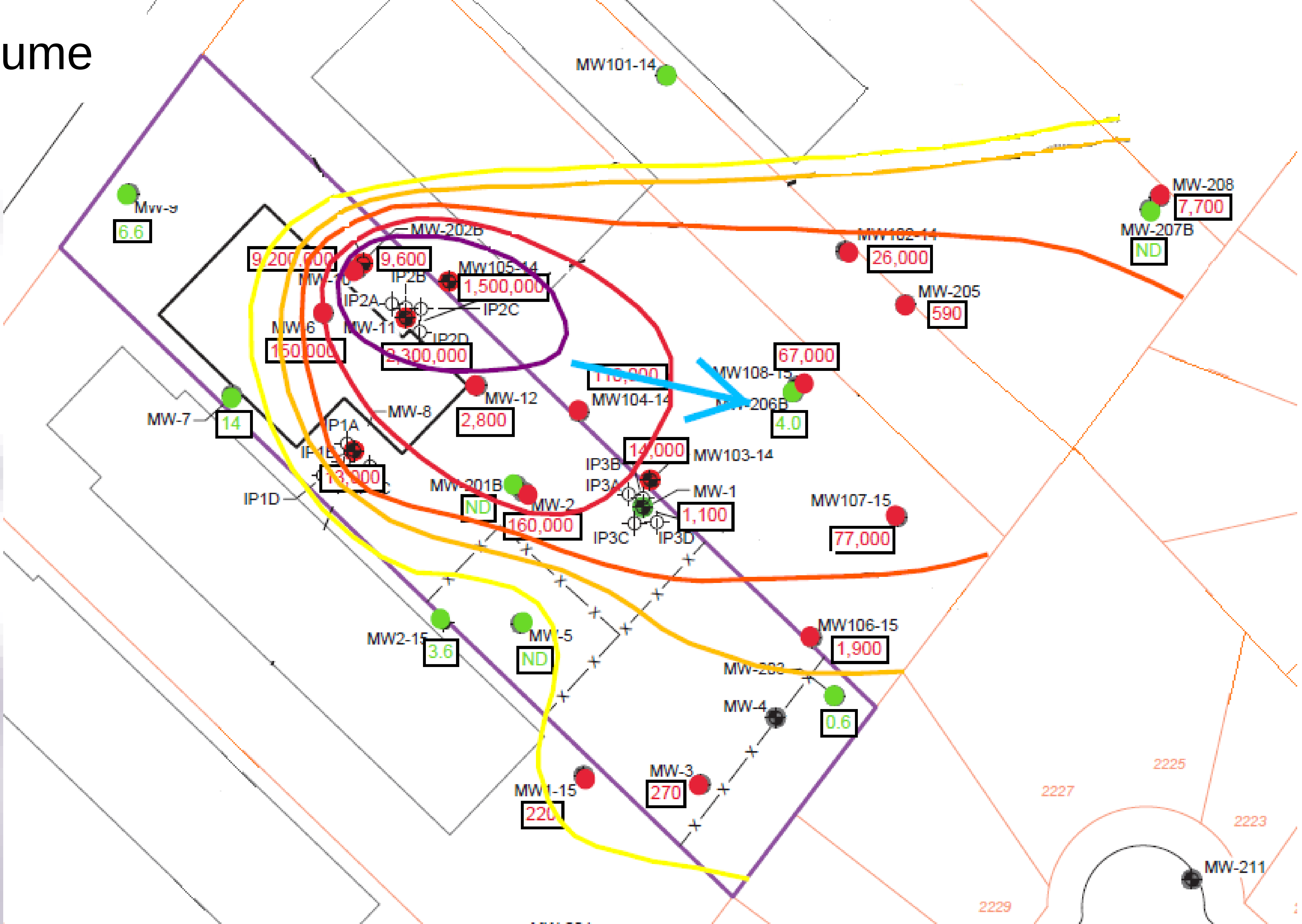
Full-Scale Remediation

Using Zero Valent Iron (ZVI)

Key Information Pertaining to Full-Scale

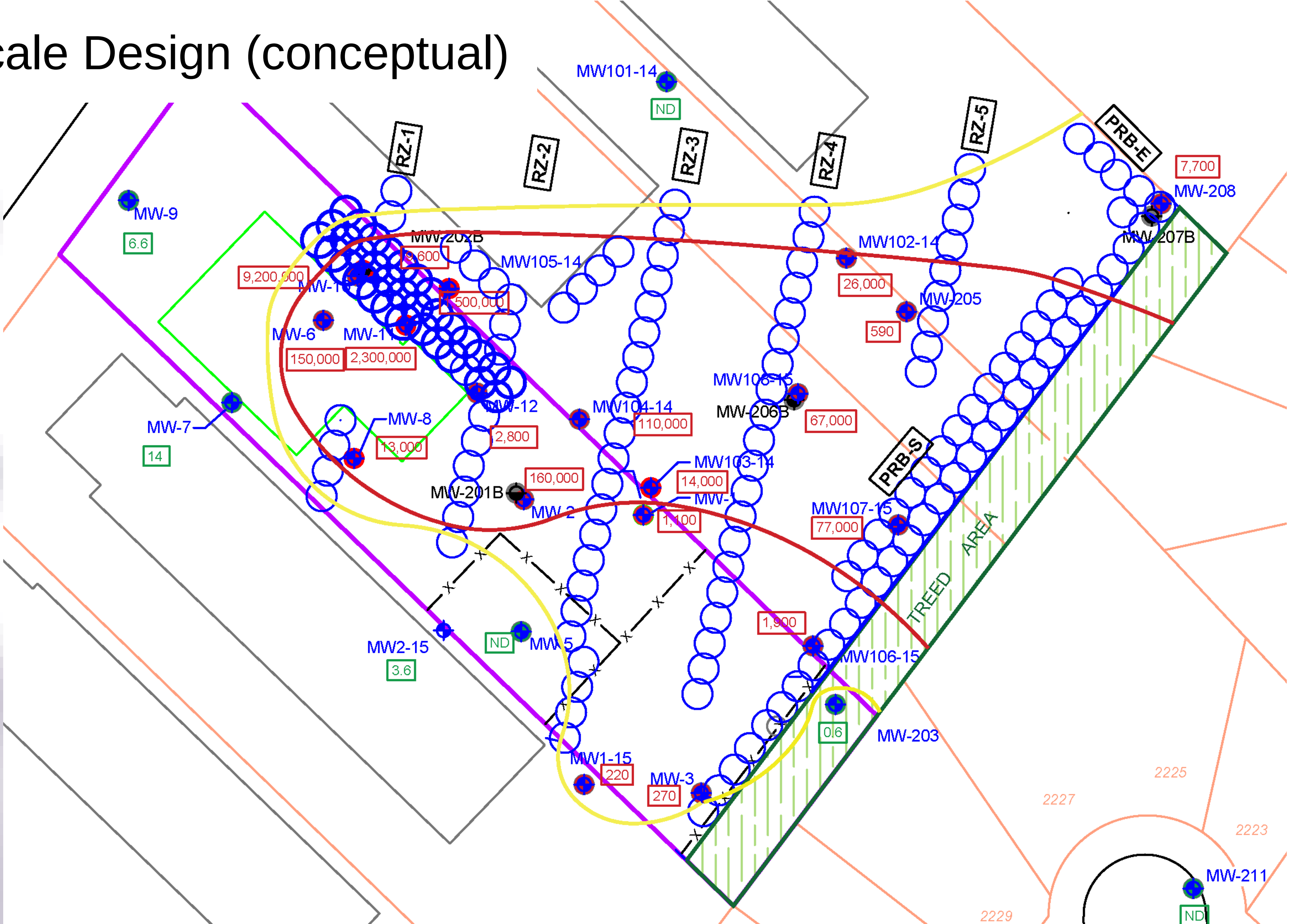
- The Client & Remedial Design
  - Client had very little cash
  - We could not tackle the entire plume at once
  - The work had to be staggered, to fit into the cash flow of the business
  - Use of Reactive Zones (RZs) and a Permeable Reactive Barrier (PRB)
    - PRB to stop continued migration downgradient (to residential properties)
- Full-Scale
  - Injection infrastructure installed first
  - Using this infrastructure additional groundwater sampling was completed
  - Then the PRB was installed
    - Method: Injection using a double packer system
    - Remedial Amendment: Zero Valent Iron slurry
    - Depth: into the plume in the bedrock between 4 m to 7 m bgs

The Plume

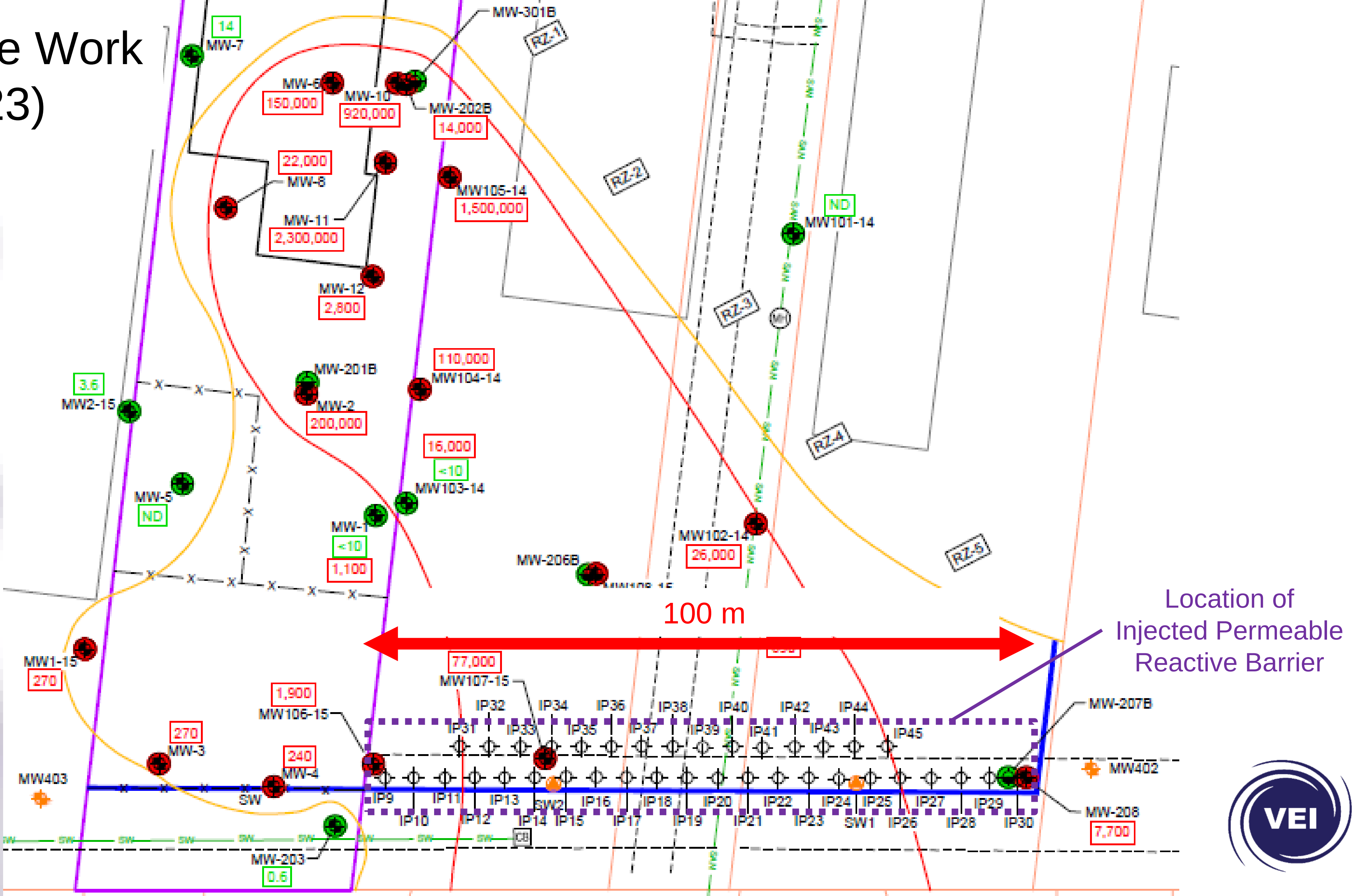


MW101-14
MW-208
7,700
MW-207B
ND
6.6
MW102-14
26,000
MW-202B
9,200,000
9,600
MW105-14
1,500,000
IP2B
IP2A
IP2C
IP2D
MW-205
590
MW-6
MW-11
150,000
2,300,000
67,000
MW108-15
MW-206B
4.0
MW-12
MW104-14
MW-7
14
MW-8
2,800
IP1A
14,000
MW103-14
13,000
IP3B
IP1D
MW-201B
MW-1
ND
MW-2
1,100
160,000
MW107-15
IP3C
IP3D
77,000
MW106-15
1,900
MW2-15
MW-5
3.6
ND
MW-4
0.6
MW-3
270
220
2225
2227
2223
2229
MW-211
VEI

Full-Scale Design (conceptual)



Full-Scale Work (2023)



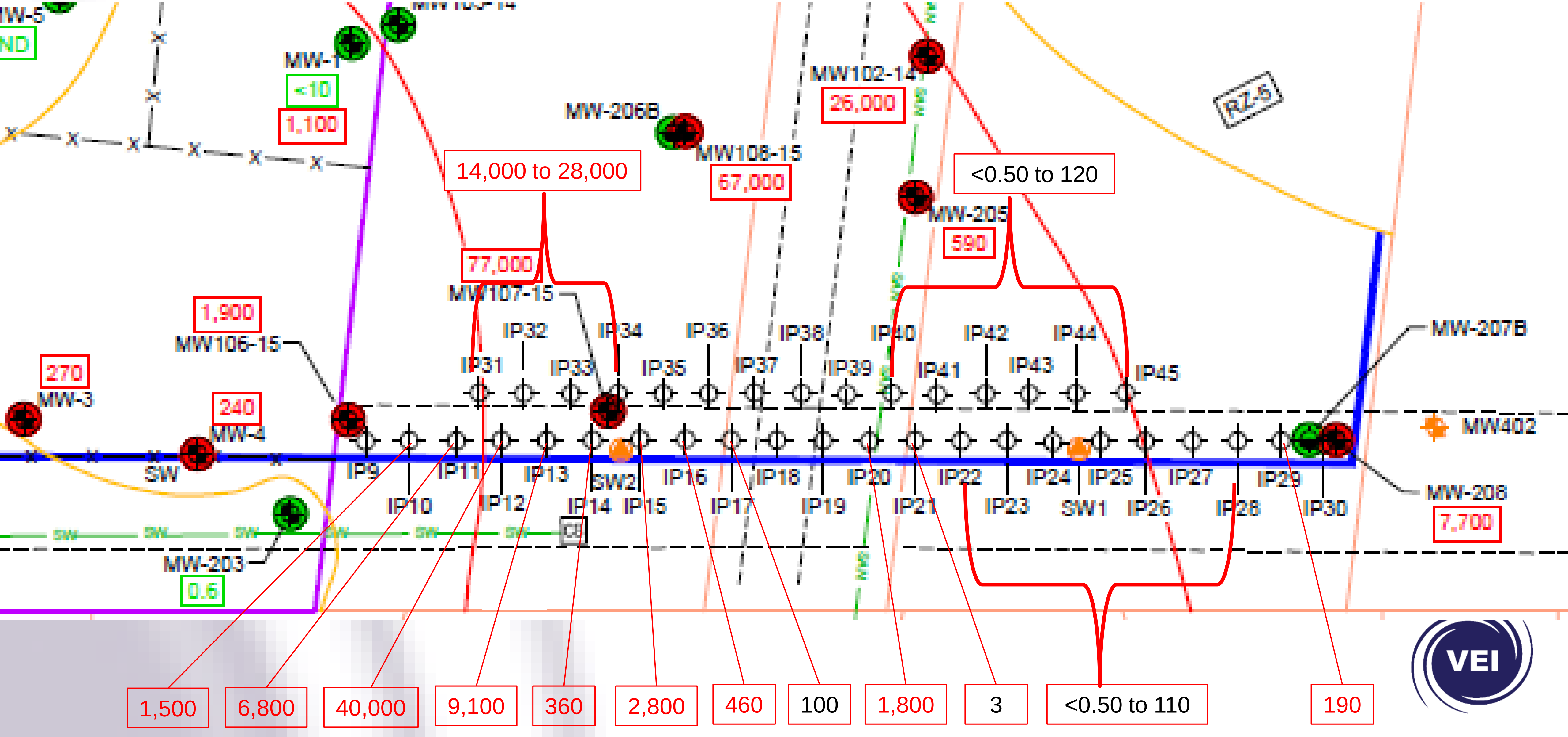
VEI


Genuine
Geoprobe
tex


Geoprobe
3230DT

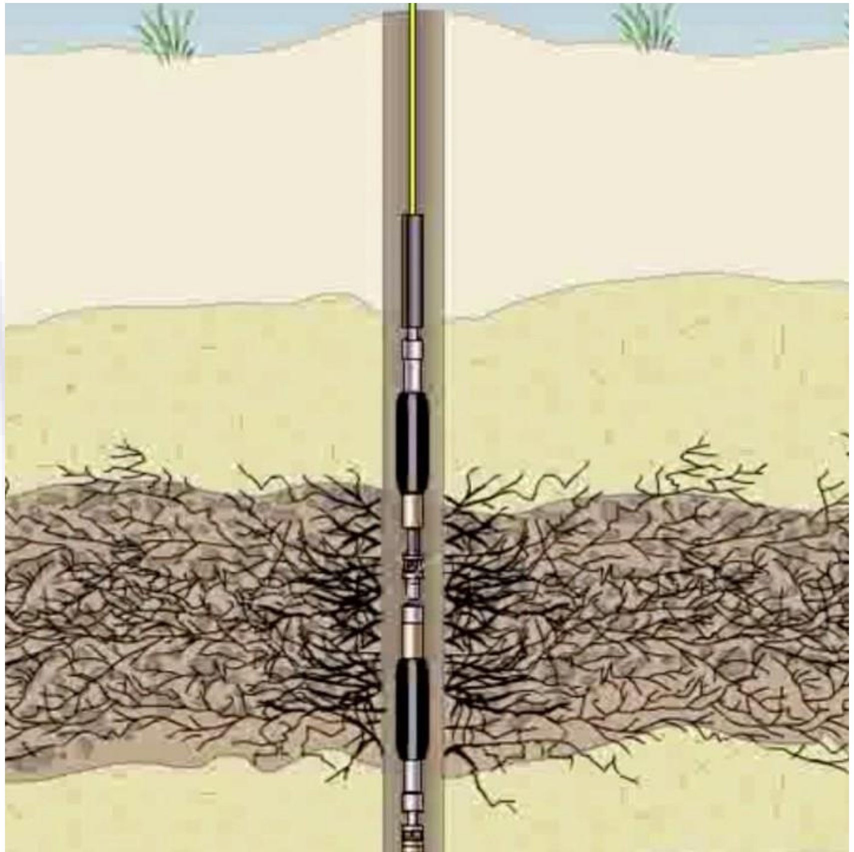
Using the Injection Boreholes (IBHs) to collect Groundwater data

Data – Hex Chrome (ug/L)
Standard = 140 ug/L



Injection Details:

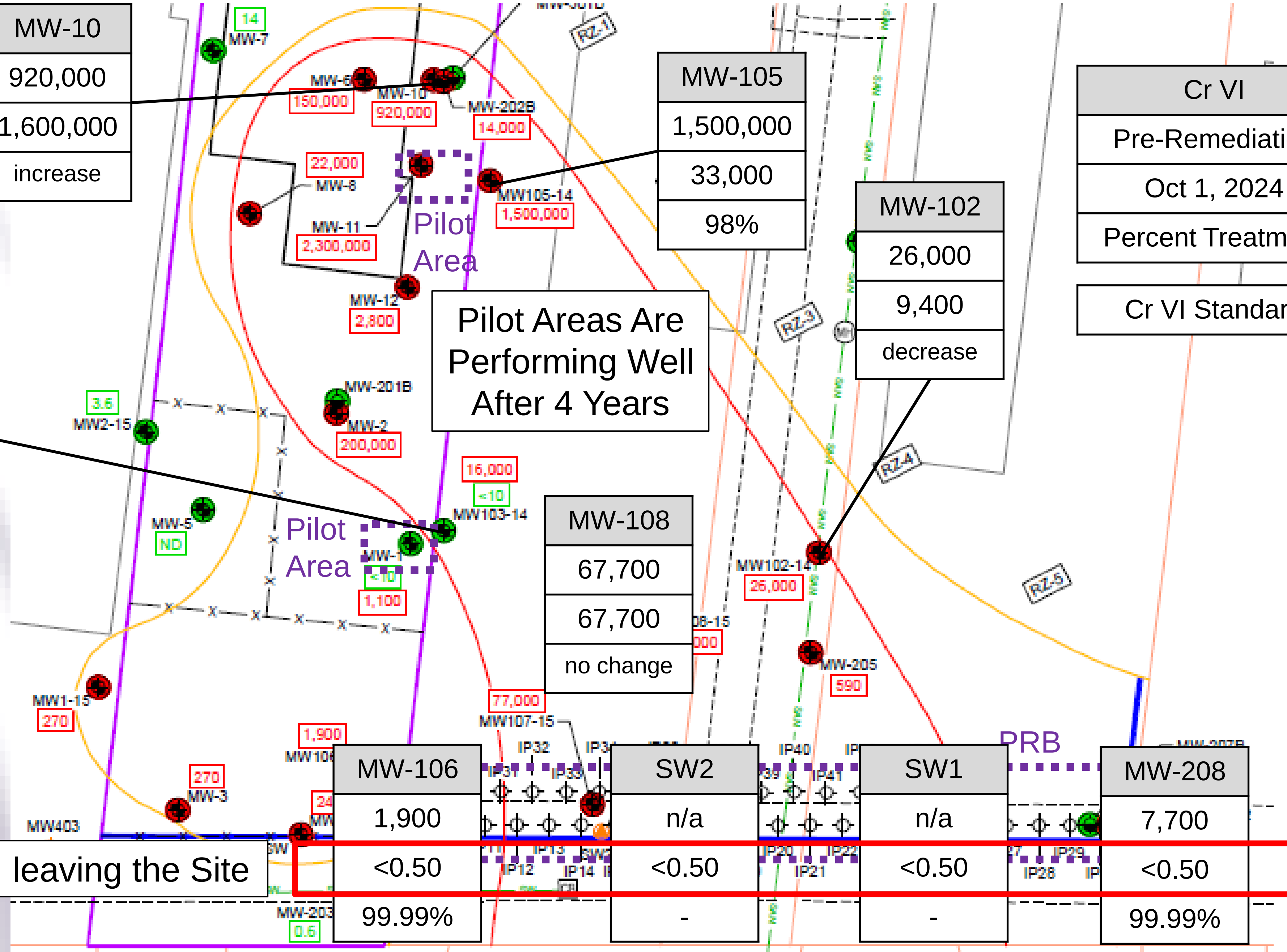
- Placed ZVI using packers
- Industrial dual packer system
- Custom deployment system
- 4 discrete vertical injection intervals



- ZVI slurry used
- 50% by wt
  - This is very concentrated
- Injections at 400 psi to 1,200 psi

Groundwater Results – 14 months after Injection

Sampled:
Oct 1, 2024



MW-10
920,000
1,600,000
increase

MW-105
1,500,000
33,000
98%

MW-102
26,000
9,400
decrease

Cr VI	MW107-5
Pre-Remediation	77,000 ug/L
Oct 1, 2024	76 ug/L
Percent Treatment	99.90%

Cr VI Standard	140 ug/L

MW-103
16,000
440
97%

Pilot Areas Are Performing Well After 4 Years

MW-108
67,700
67,700
no change

No Cr VI leaving the Site

MW-106	SW2	SW1	MW-208
1,900	n/a	n/a	7,700
<0.50	<0.50	<0.50	<0.50
99.99%	-	-	99.99%

Take Aways

- Groundwater treatment of heavy metals in bedrock is possible
  - At full-scale: 99.99% in PRB
- ZVI is a feasible amendment for both source and plume areas
  - Pilot Areas performing after 4 years
- Other Take Aways
  - Use injection infrastructure for additional GW data collection
  - Thin fractures necessitated 50% by wt ZVI injection slurry
  - ZVI can be effectively injected into bedrock
    - With proper design and execution

Questions?

Thank You for Your Time

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