Vertex Environmental Inc.

Remediating Bedrock:

What Once Was Impossible Is Now Possible.

Three Case Studies

October 14, 2021

RemTech

Bruce Tunnicliffe, M.A.Sc., P.Eng.

Outline

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

Bruce @ UW, 1998

Bruce Tunnicliffe, P.Eng.

- University of Waterloo
  - Masters: Fractured Rock
- Founded Vertex in 2003

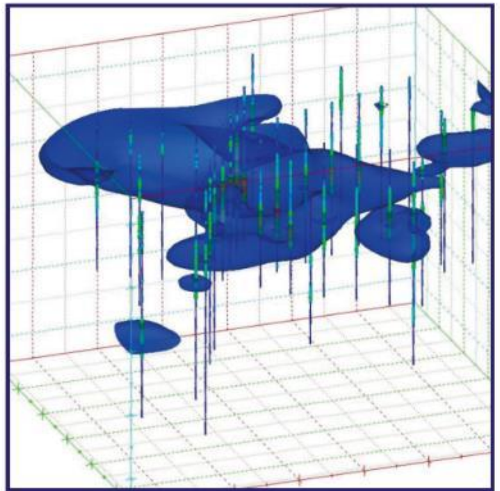
Vertex Environmental Inc.


In-Situ Remediation

Ex-Situ Remediation


High Resolution Characterization


Treatment Systems


Remedial Design

Bench-Scale Testing

Vertex

- Specialized Contractor
- Works coast to coast

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:

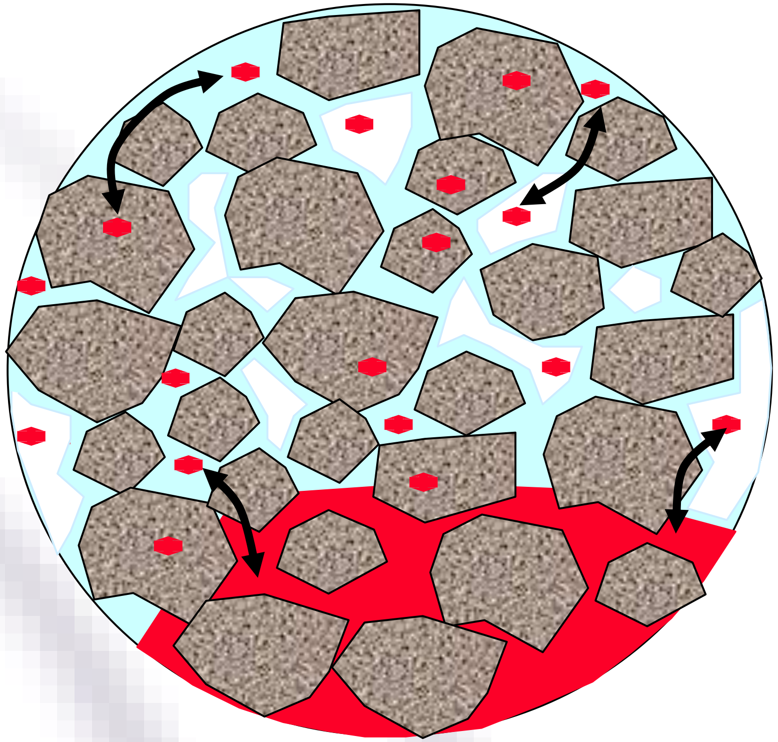
"…remedial action is delayed or stymied by **the complexity of contaminated fractured-rock aquifers**"

The Difficulty with Bedrock Remediation

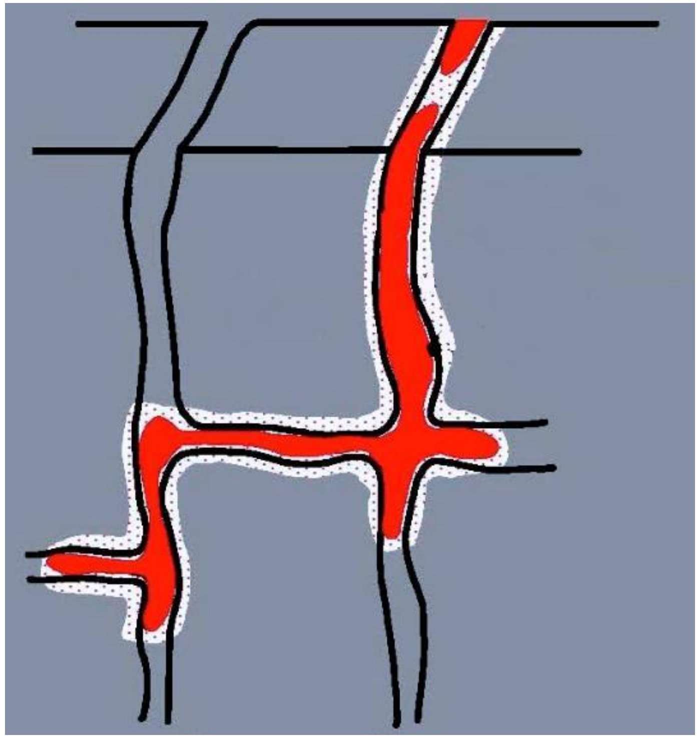
Why So Challenging?

- 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

The Difficulty with Bedrock Remediation

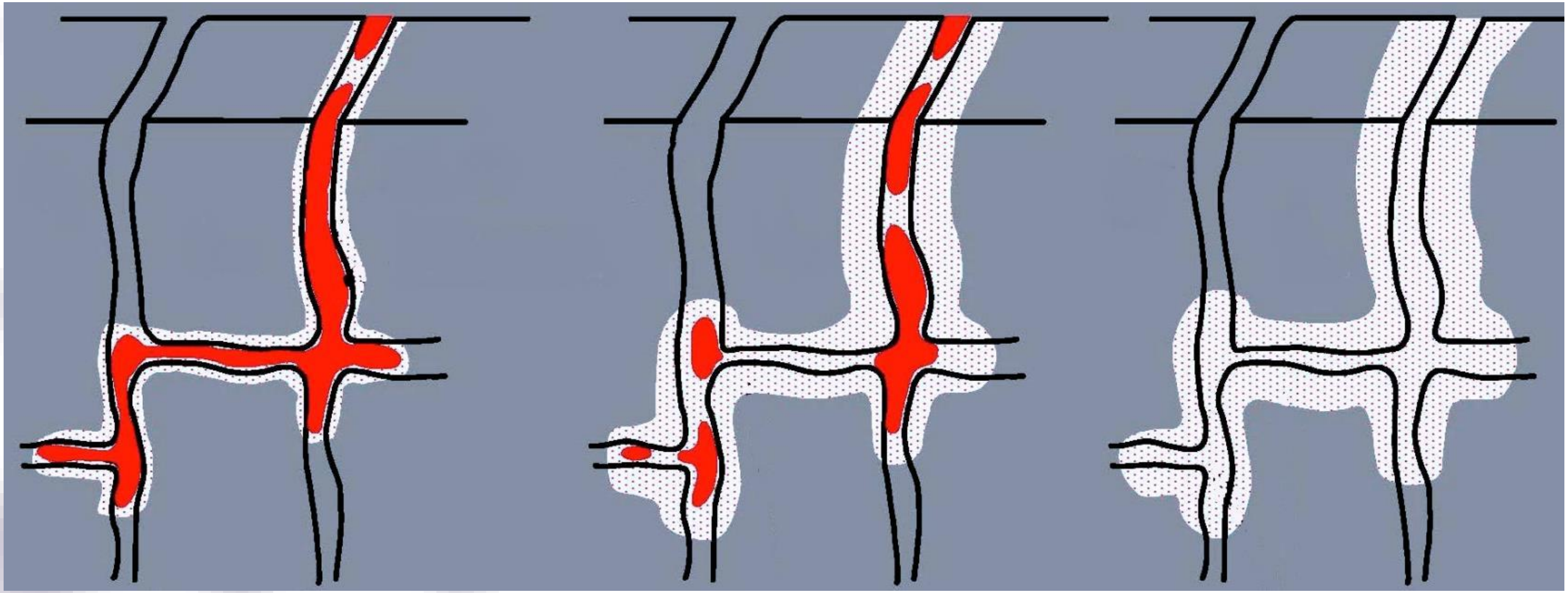


Porous Media
Porosity = 30%



Fractured Rock
Porosity = 1 to 10%

The Difficulty with Bedrock Remediation



Early Time

Intermediate Time

Late Time

Diffusion into the Rock Matrix

Back Diffusion – a Problem for Remediation

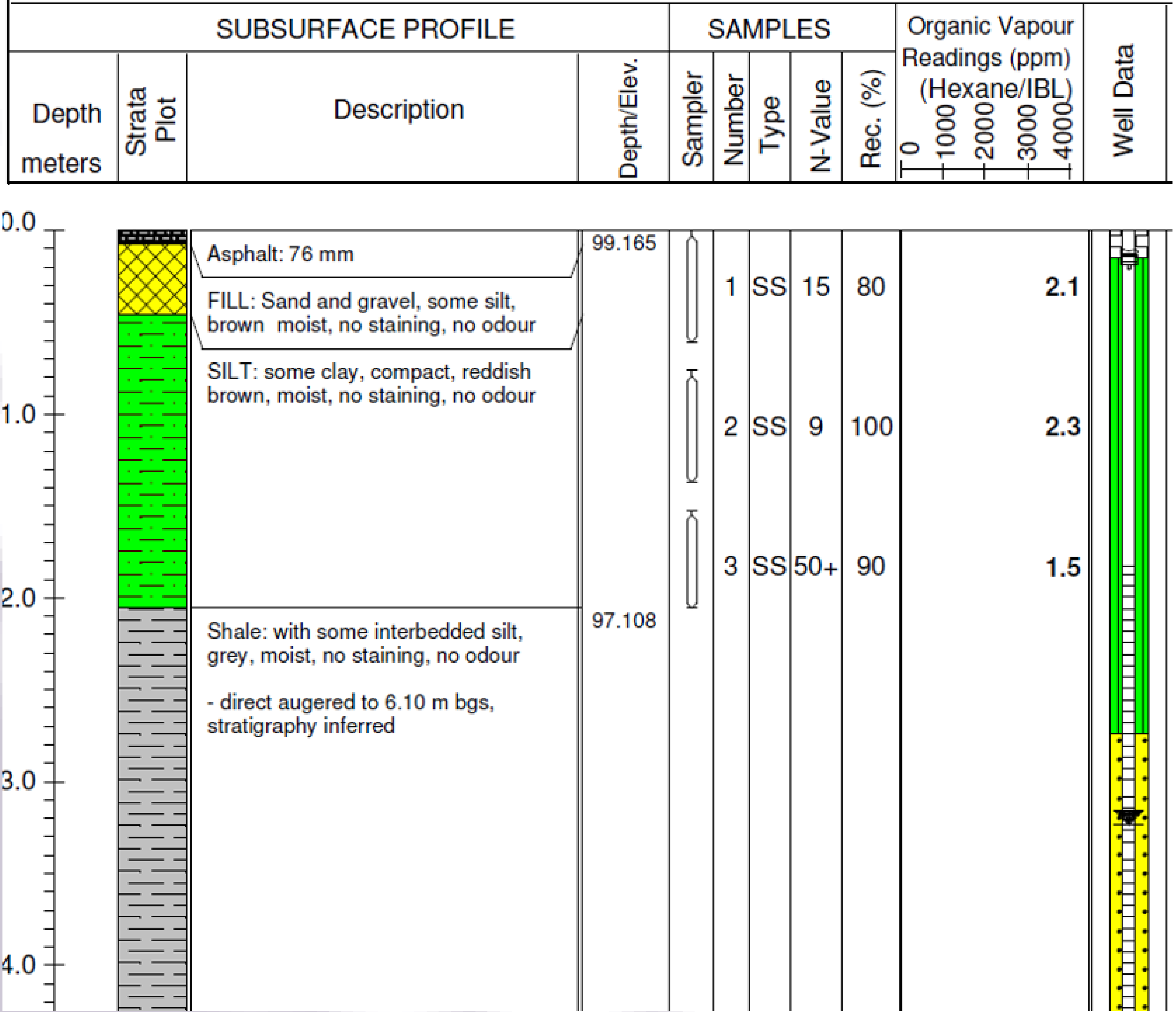
Bedrock Case Study #1

Bedrock and PHCs

Background – The Situation

- Confidential Site
- A former retail fuel outlet (RFO) with:
  - Underground storage tanks (USTs)
  - Dispenser-island, and,
  - Automotive service operations including motor oil changes
- Petroleum Hydrocarbon (PHC) contamination
  - LNAPL
  - Dissolved Phase
- ISCO (In-Situ Chemical Oxidation) work completed (by others):
  - Injections in each of: 2015, 2016, 2017
- Vertex on-site later:
  - 2019 to 2021

Monitoring Well Network

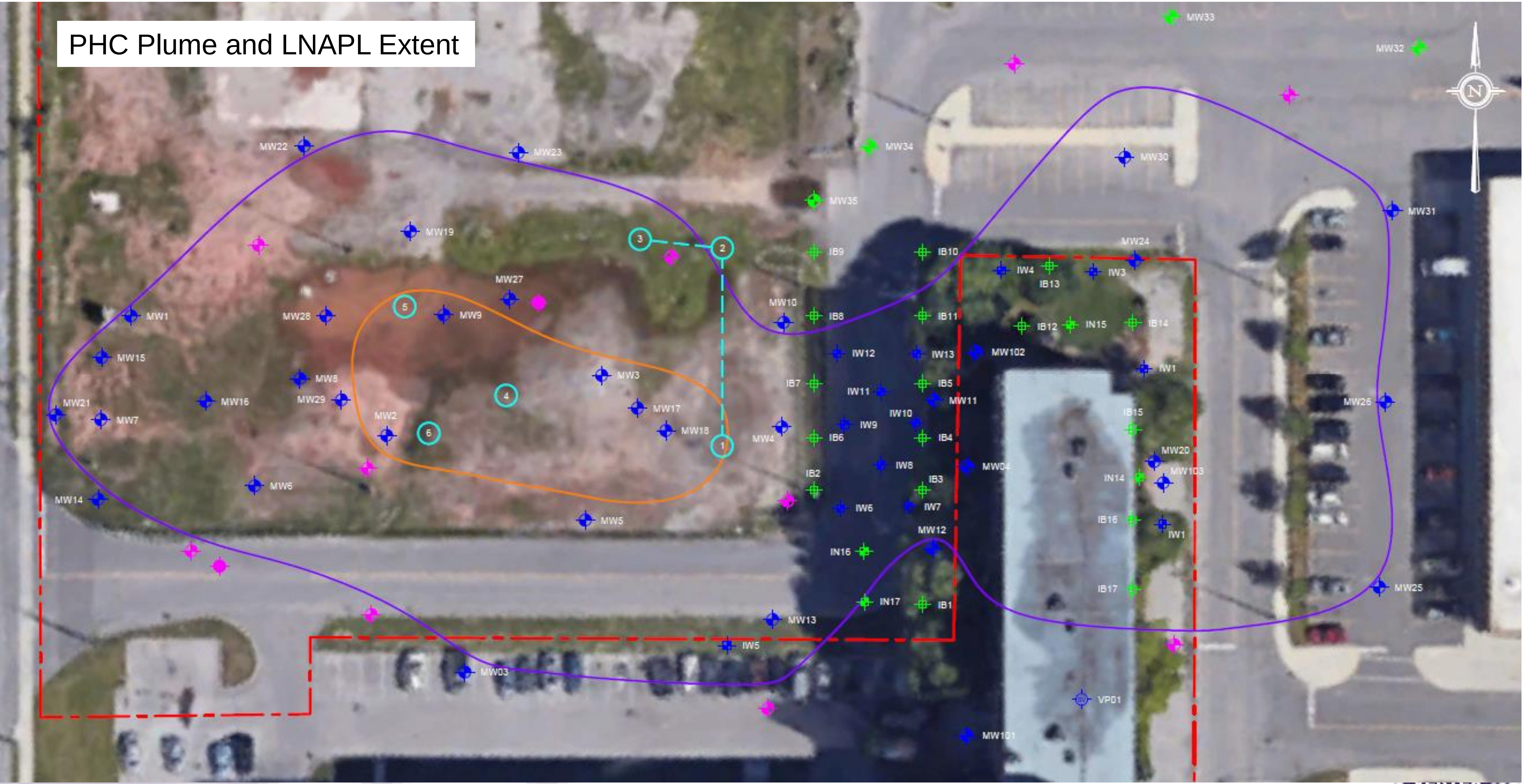


Description	Depth/Elev.
Asphalt: 76 mm	99.165
FILL: Sand and gravel, some silt, brown moist, no staining, no odour	
SILT: some clay, compact, reddish brown, moist, no staining, no odour	
Shale: with some interbedded silt, grey, moist, no staining, no odour - direct augered to 6.10 m bgs, stratigraphy inferred	97.108

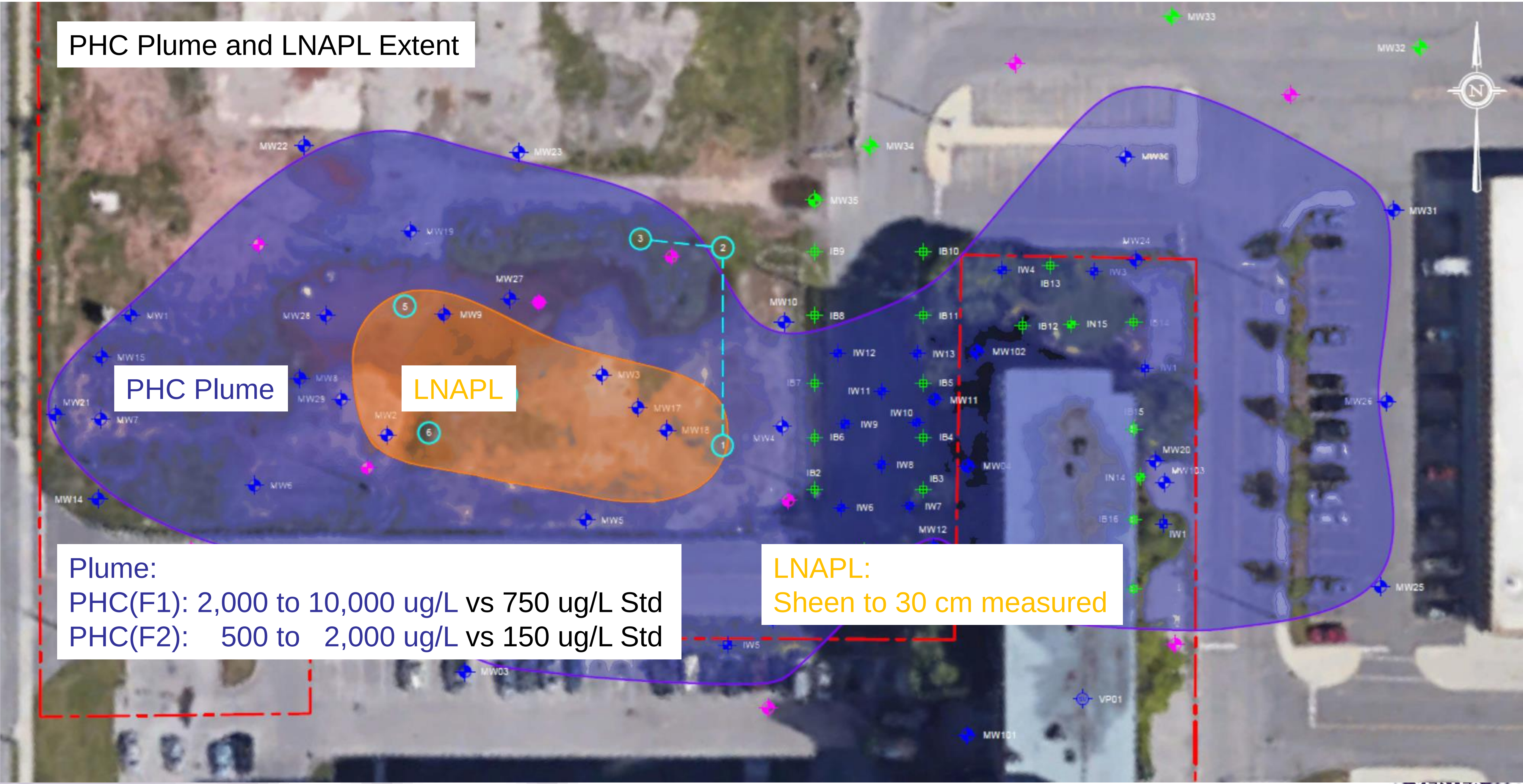
Number	Type	N-Value	Rec. (%)	Organic Vapour Readings (ppm) (Hexane/IBL)
1	SS	15	80	2.1
2	SS	9	100	2.3
3	SS	50+	90	1.5

Subsurface
1.0 to 3.0 m – depth to Bedrock
3.0 to 3.5 m – depth to Groundwater

PHC Plume and LNAPL Extent



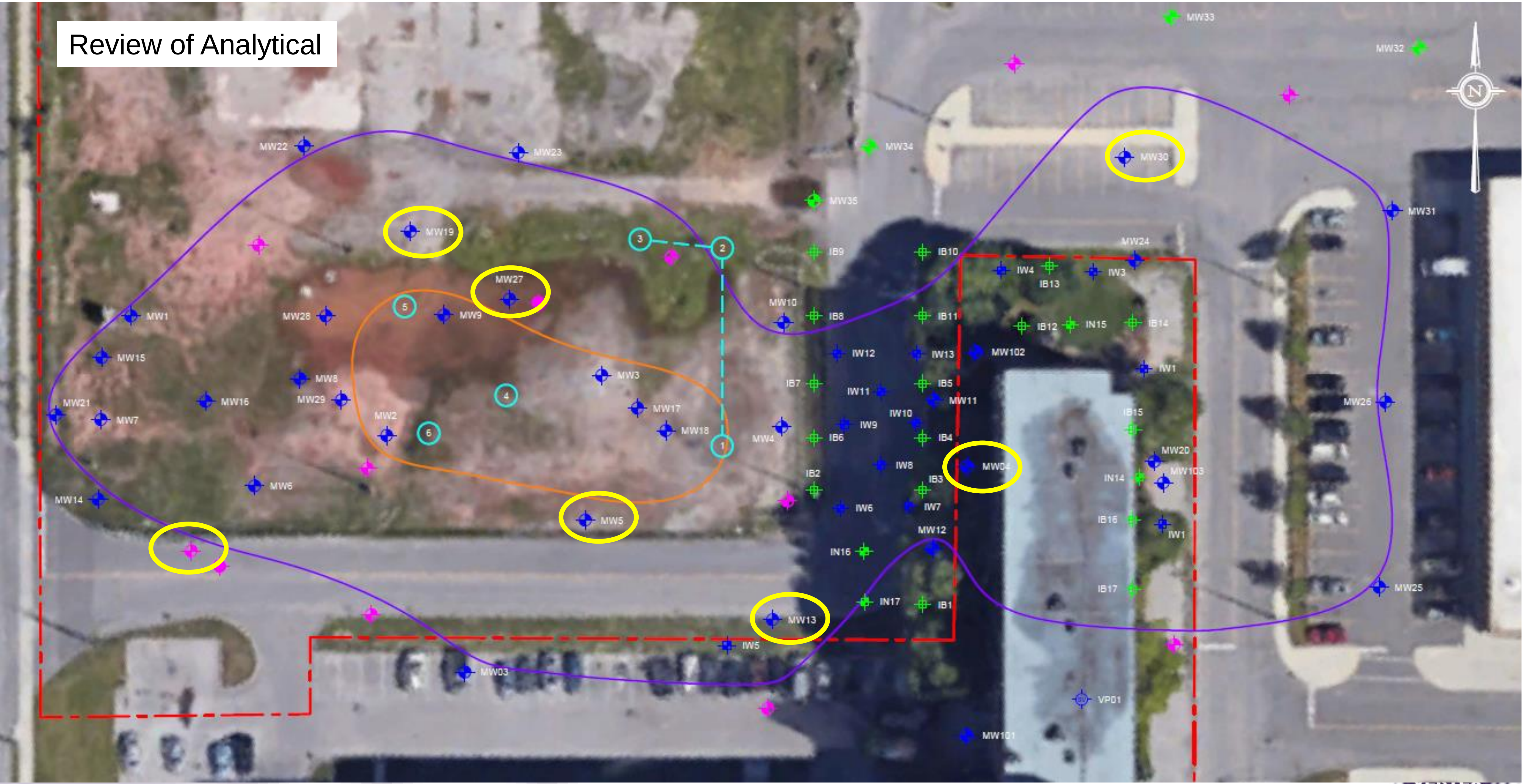
PHC Plume and LNAPL Extent

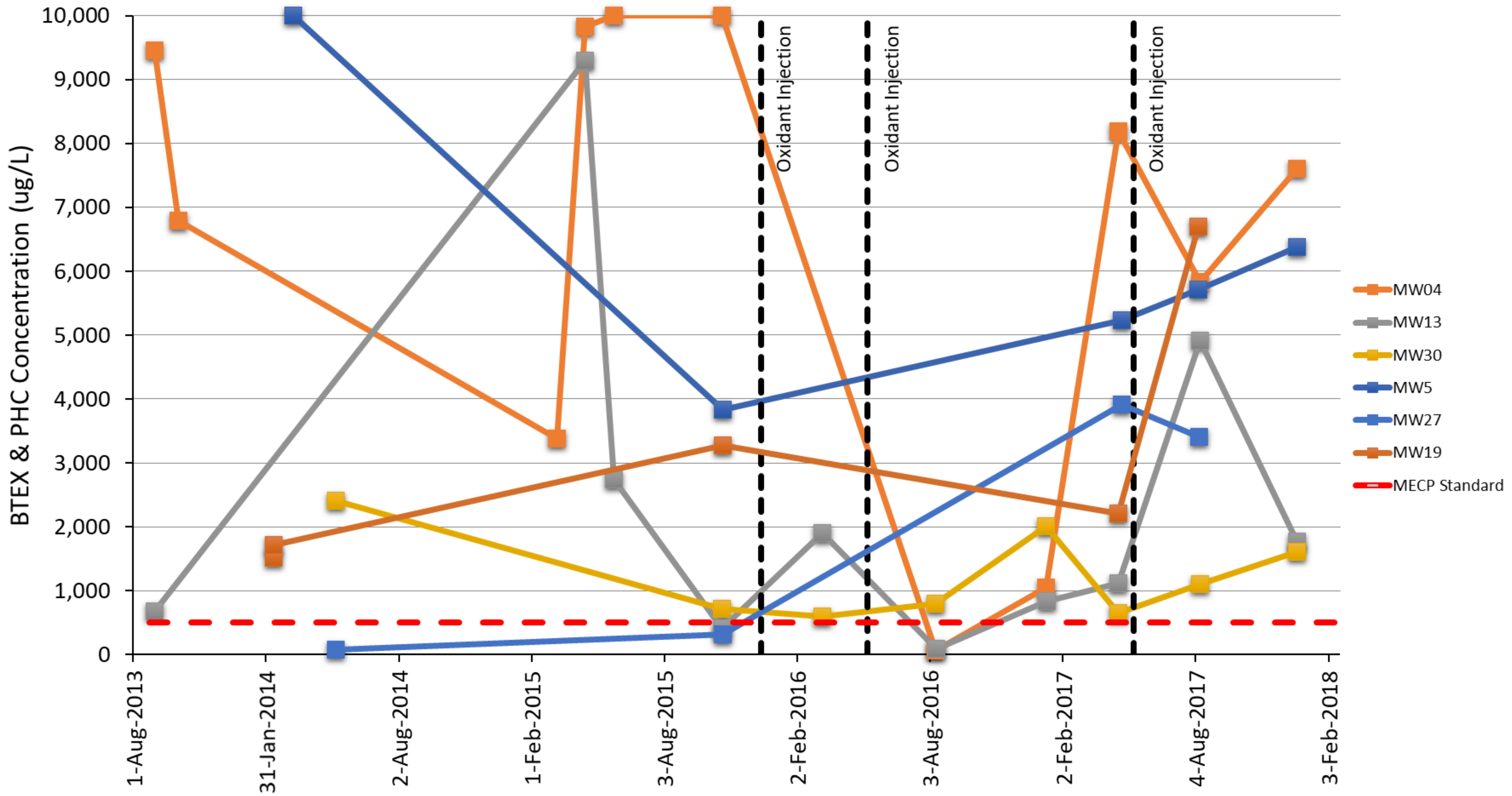


Plume:
PHC(F1): 2,000 to 10,000 ug/L vs 750 ug/L Std
PHC(F2): 500 to 2,000 ug/L vs 150 ug/L Std

LNAPL:
Sheen to 30 cm measured

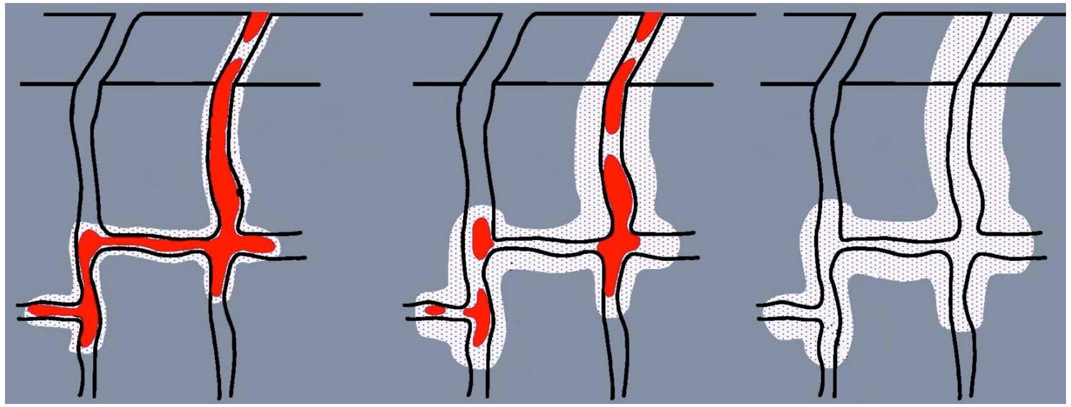
Review of Analytical



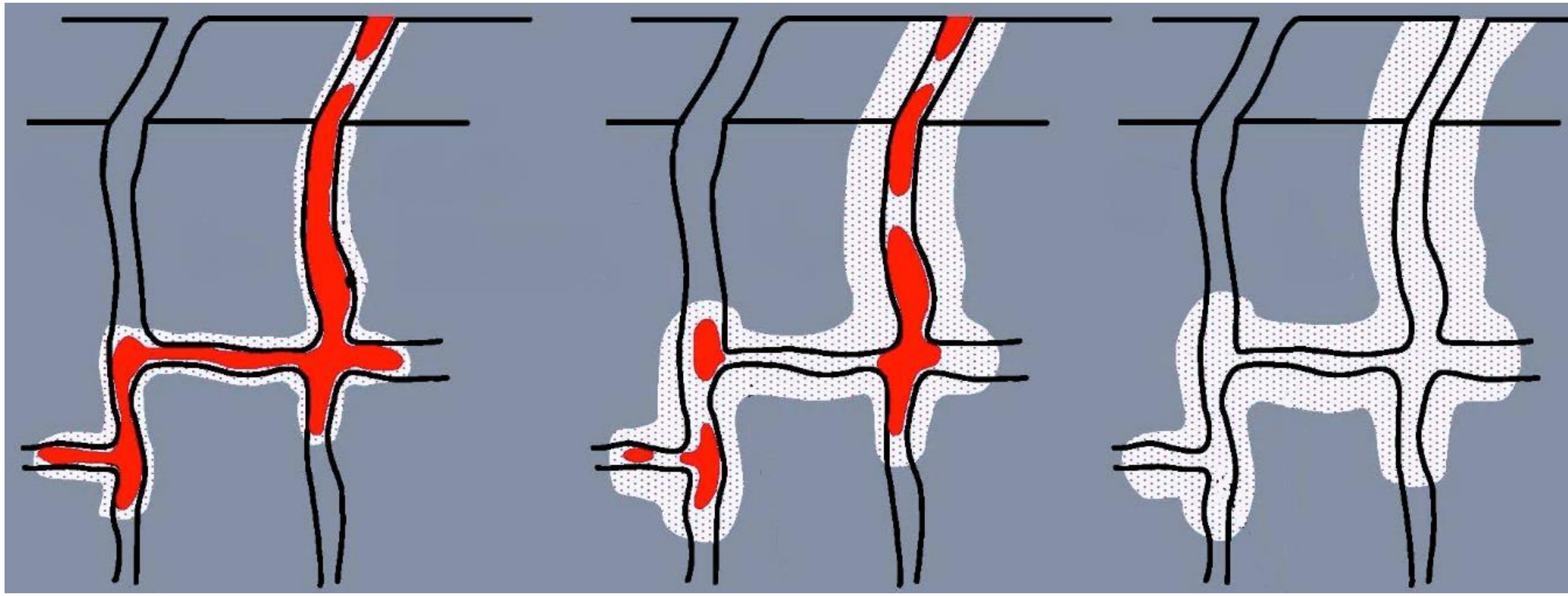

BTEX & PHC Concentration (ug/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1-Aug-2013
31-Jan-2014
2-Aug-2014
1-Feb-2015
3-Aug-2015
2-Feb-2016
3-Aug-2016
2-Feb-2017
4-Aug-2017
3-Feb-2018
Oxidant Injection
Oxidant Injection
Oxidant Injection
MW04
MW13
MW30
MW5
MW27
MW19
MECP Standard

The ISCO Years: 2015 to 2017

- After ISCO (In-Situ Chemical Oxidation)
  - LNAPL persisted
  - Significant PHC concentrations remained
- From the consultant’s report
  - “increases….are interpreted to be a result of the oxidative conditions **causing mobilization to groundwater of contaminants from within the soil/bedrock matrix**.”
- New consultant. With Vertex. 2019.



Focus of Remediation (Vertex in 2019)



Early Time

Intermediate Time

Late Time

LNAPL?

Don’t Fight It

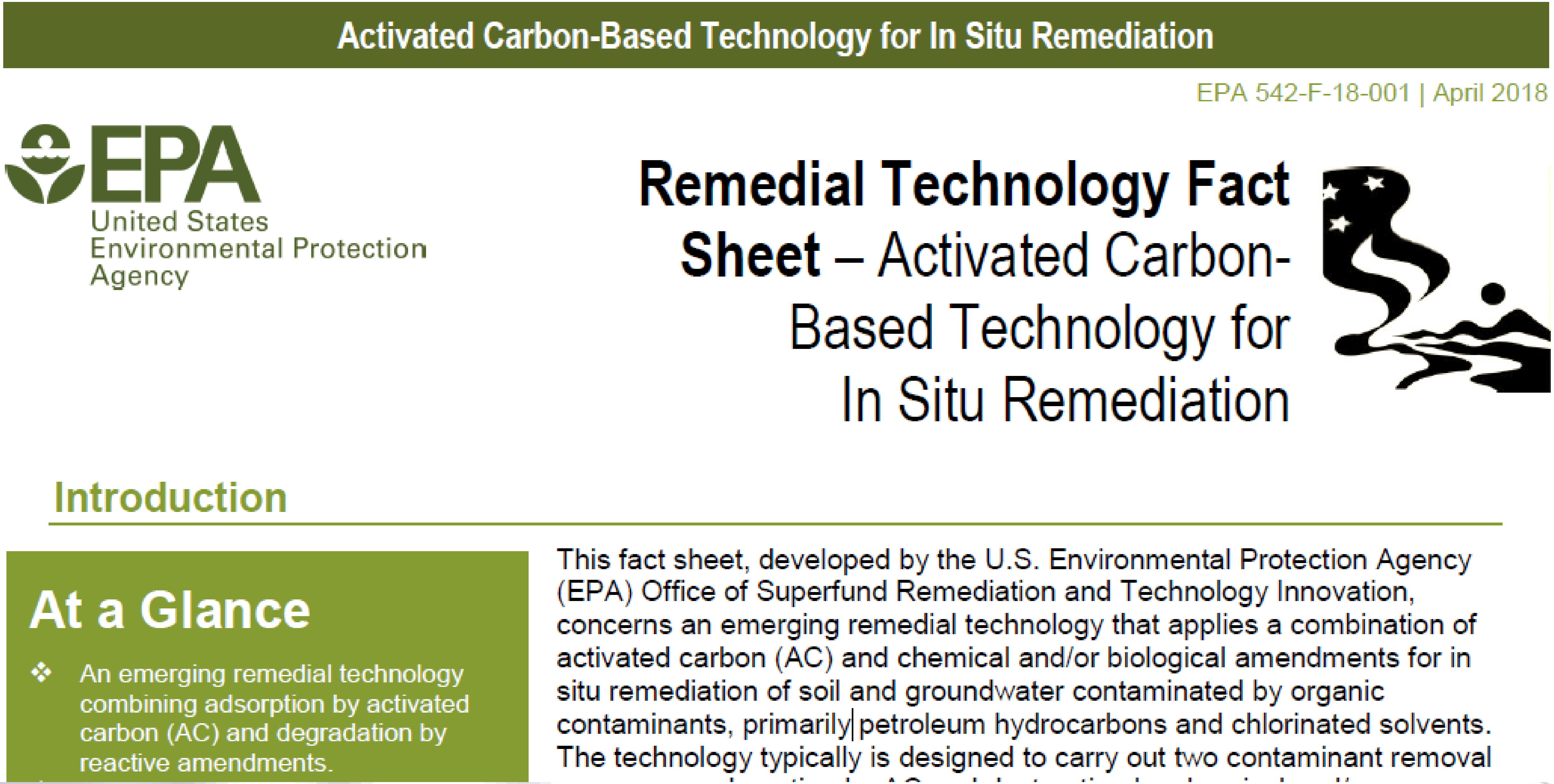
<u>Excavation</u>

Back Diffusion?

Don’t Fight It

<u>Trap and Treat</u>

Activated Carbon-based Approach



Activated Carbon-Based Technology for In Situ Remediation

EPA 542-F-18-001 | April 2018

EPA
United States
Environmental Protection
Agency

Remedial Technology Fact Sheet – Activated Carbon-Based Technology for In Situ Remediation

Introduction

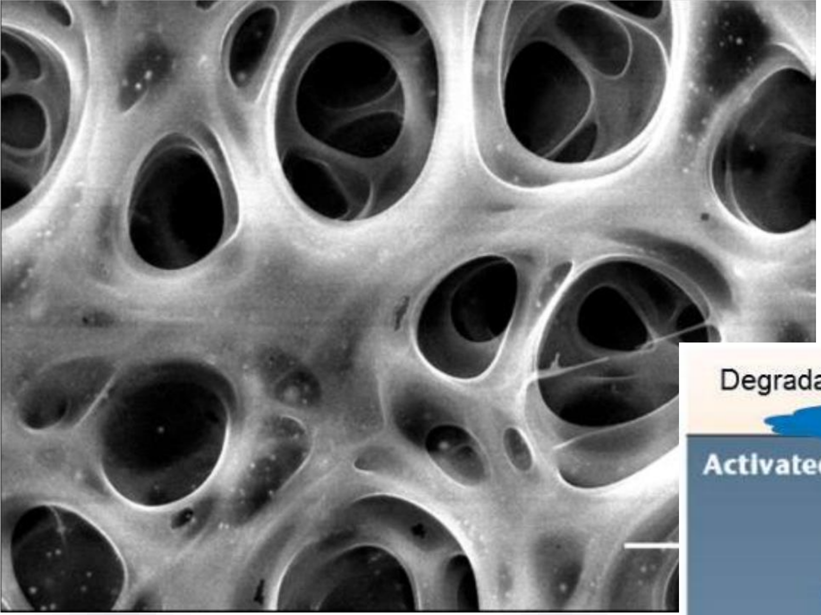
At a Glance

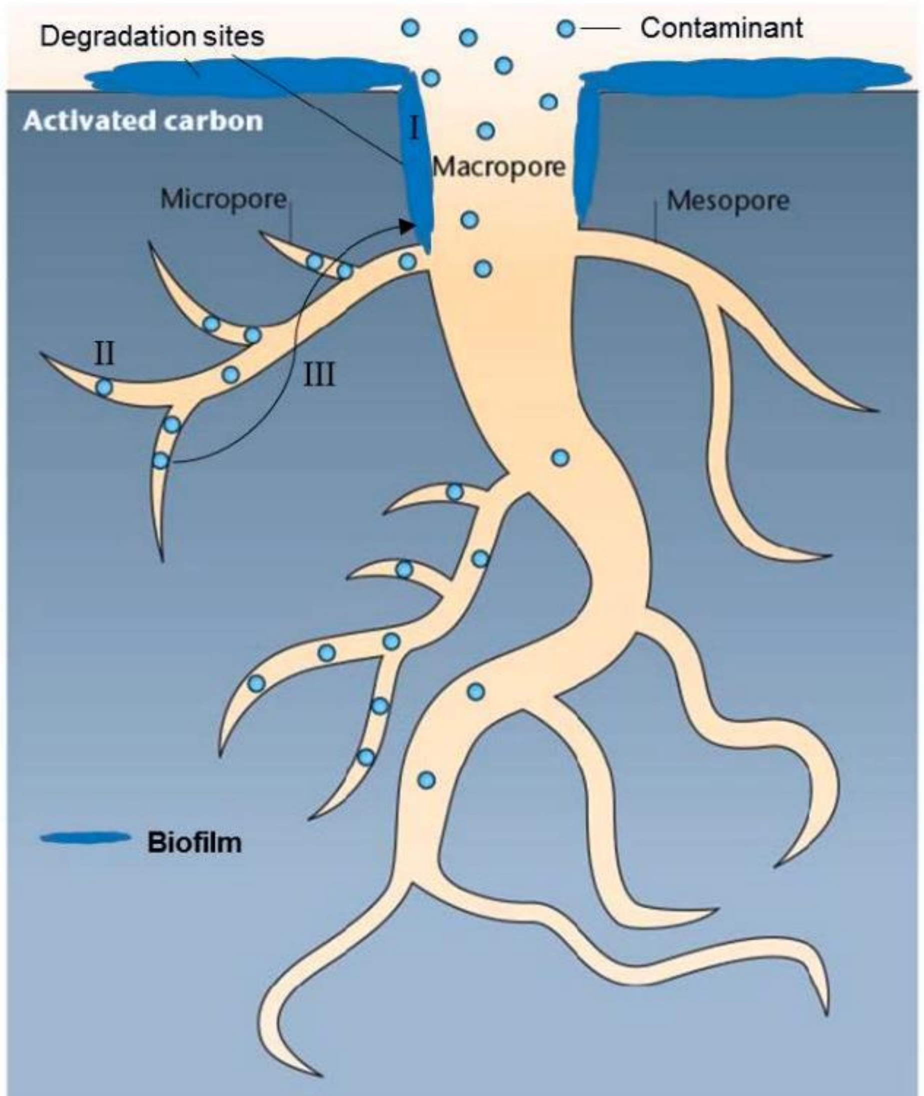
- An emerging remedial technology combining adsorption by activated carbon (AC) and degradation by reactive amendments.

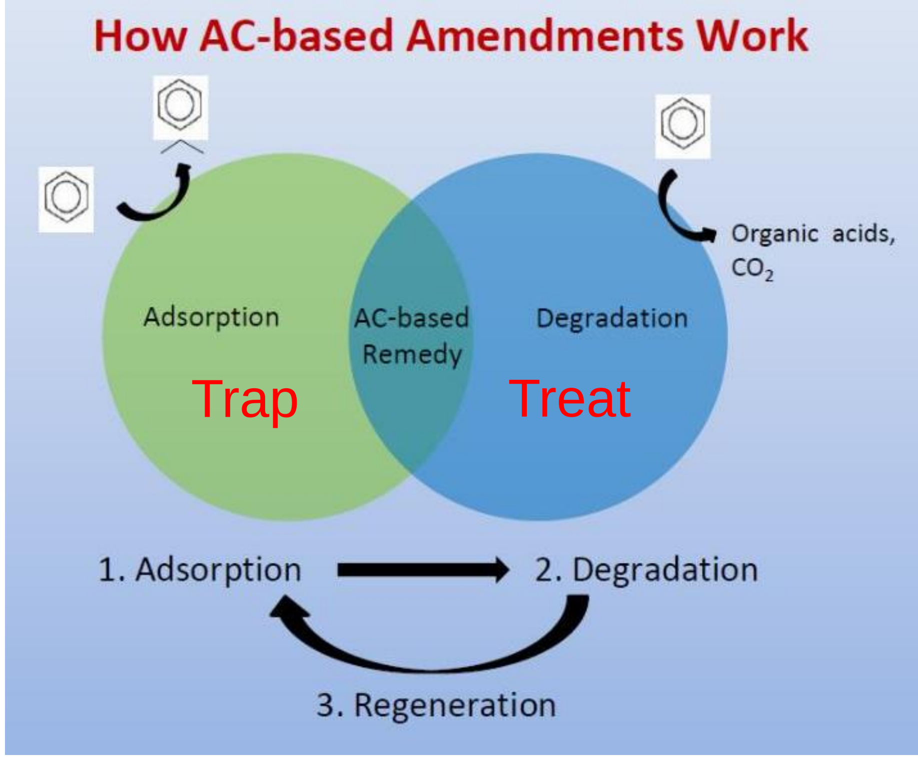
This fact sheet, developed by the U.S. Environmental Protection Agency (EPA) Office of Superfund Remediation and Technology Innovation, concerns an emerging remedial technology that applies a combination of activated carbon (AC) and chemical and/or biological amendments for in situ remediation of soil and groundwater contaminated by organic contaminants, primarily petroleum hydrocarbons and chlorinated solvents. The technology typically is designed to carry out two contaminant removal

VERTEX

Activated Carbon – For Groundwater Remediation

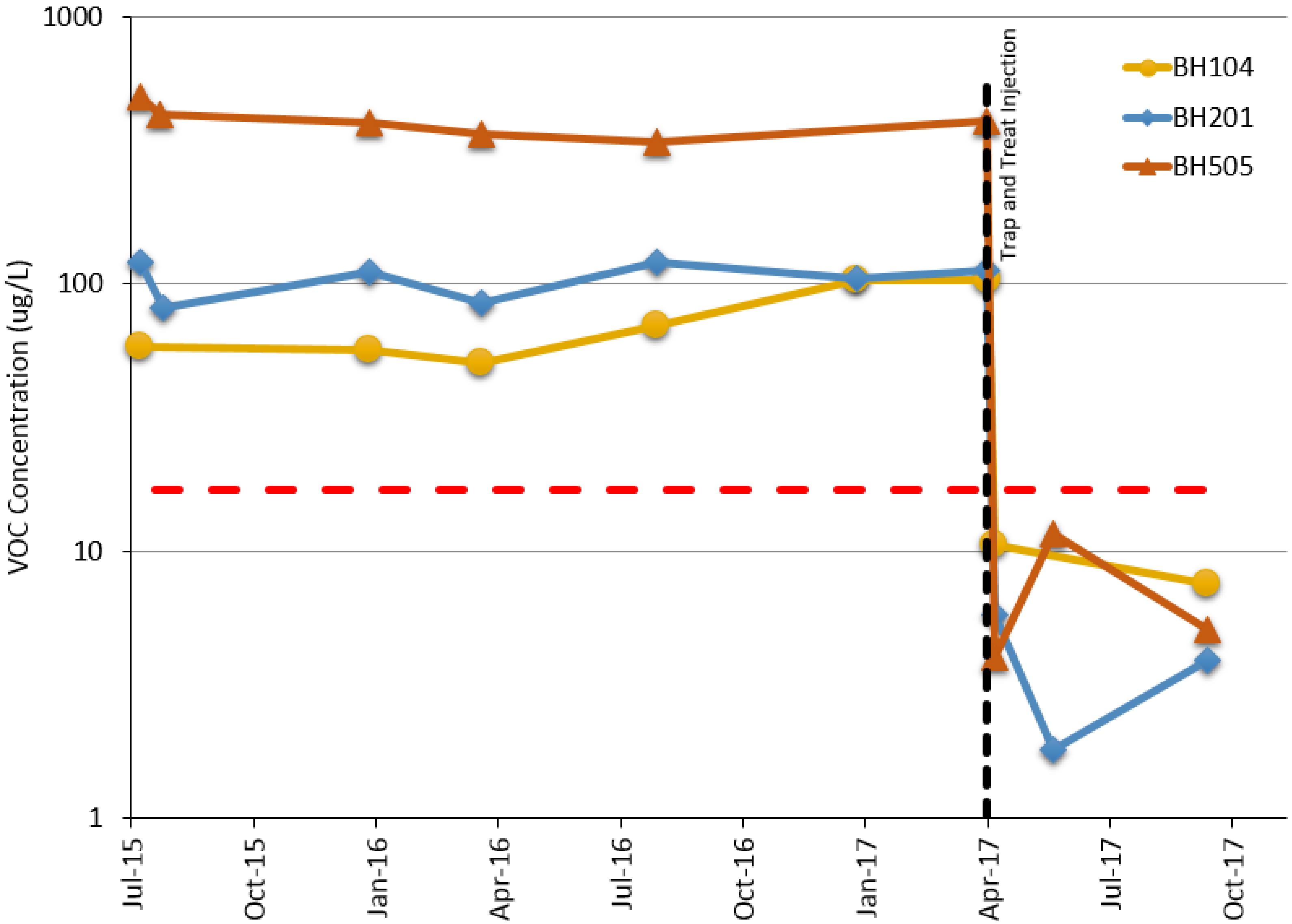






Trap and Treat
BOS200® - PHCs
BOS100® - cVOCs

Trap and Treat – Does It Work?

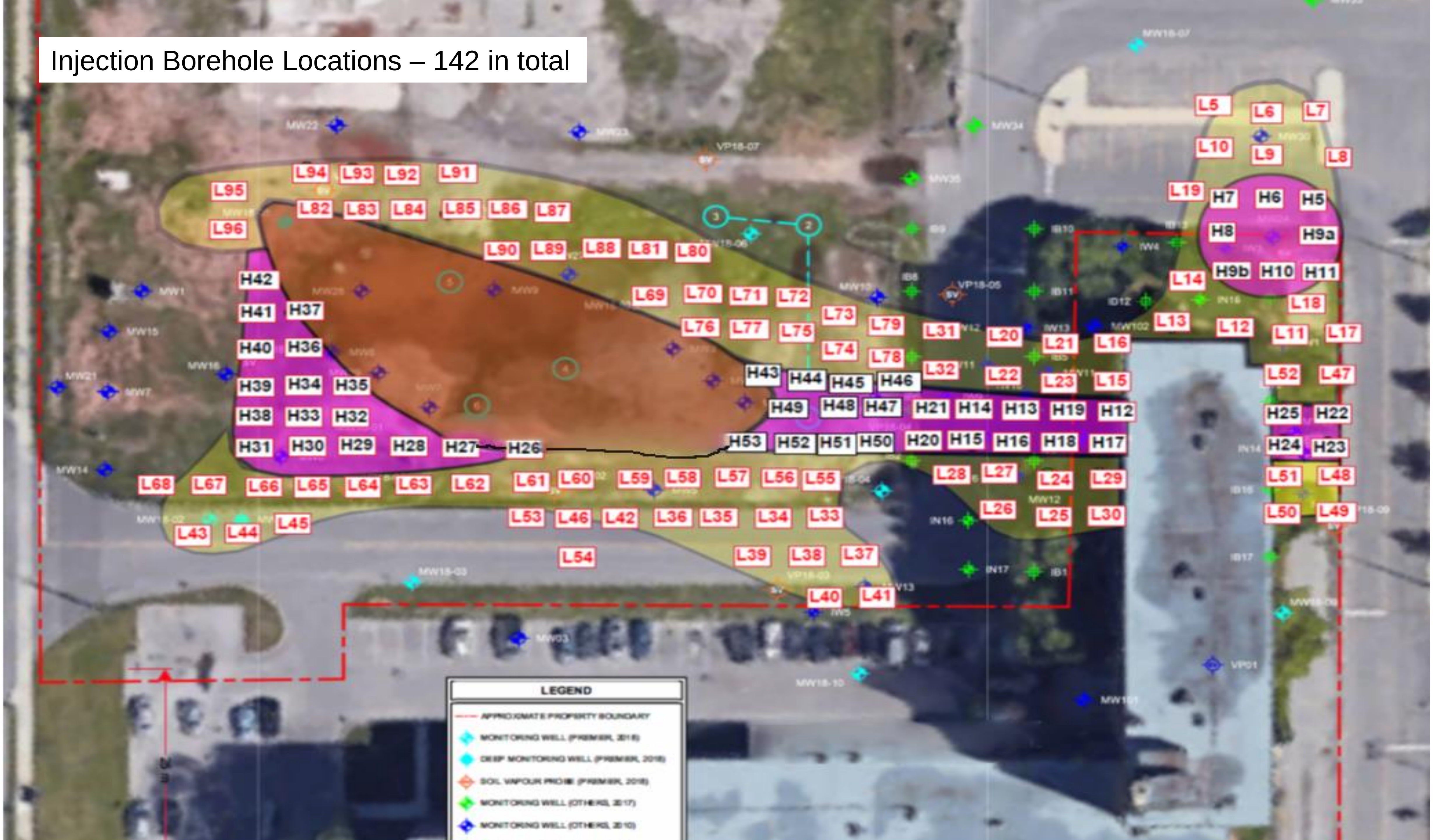


Excavation of LNAPL Area

Excavation of LNAPL Area

Injection Borehole Installation

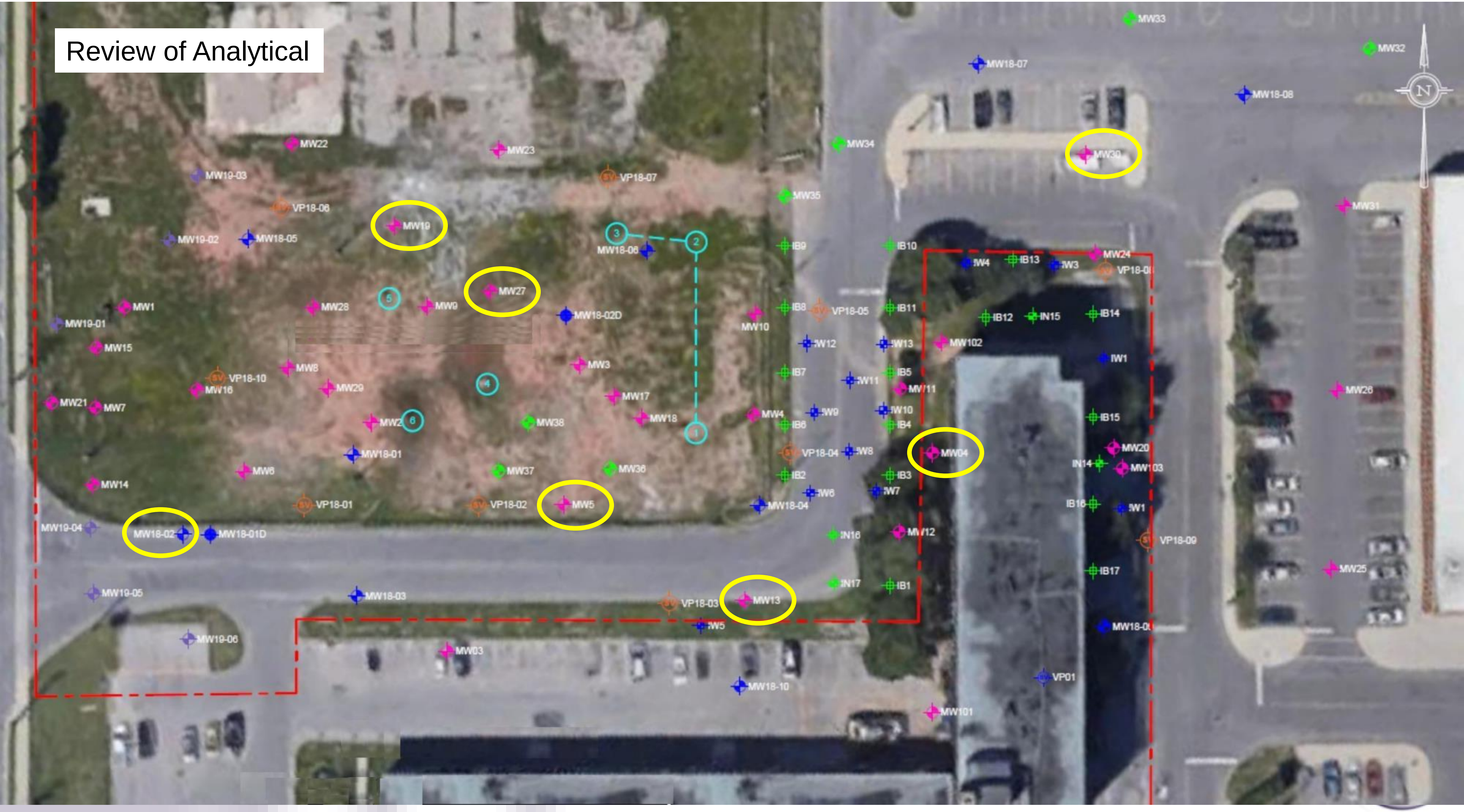
Injection Borehole Locations – 142 in total

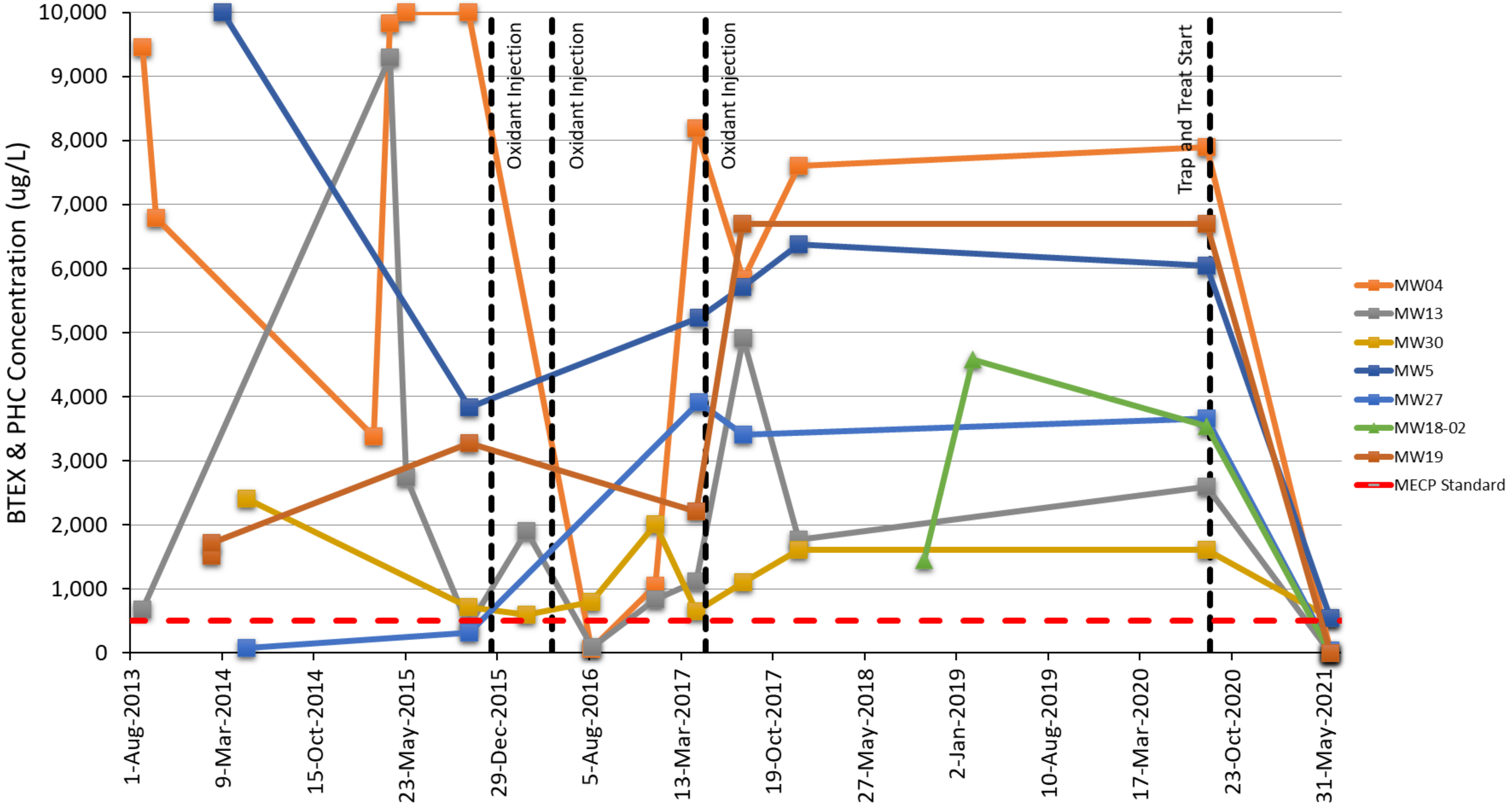


Trap and Treat Injection Completed (Fall 2019, Winter 2020)

Using a Packer System
146,000 L Injected

Review of Analytical

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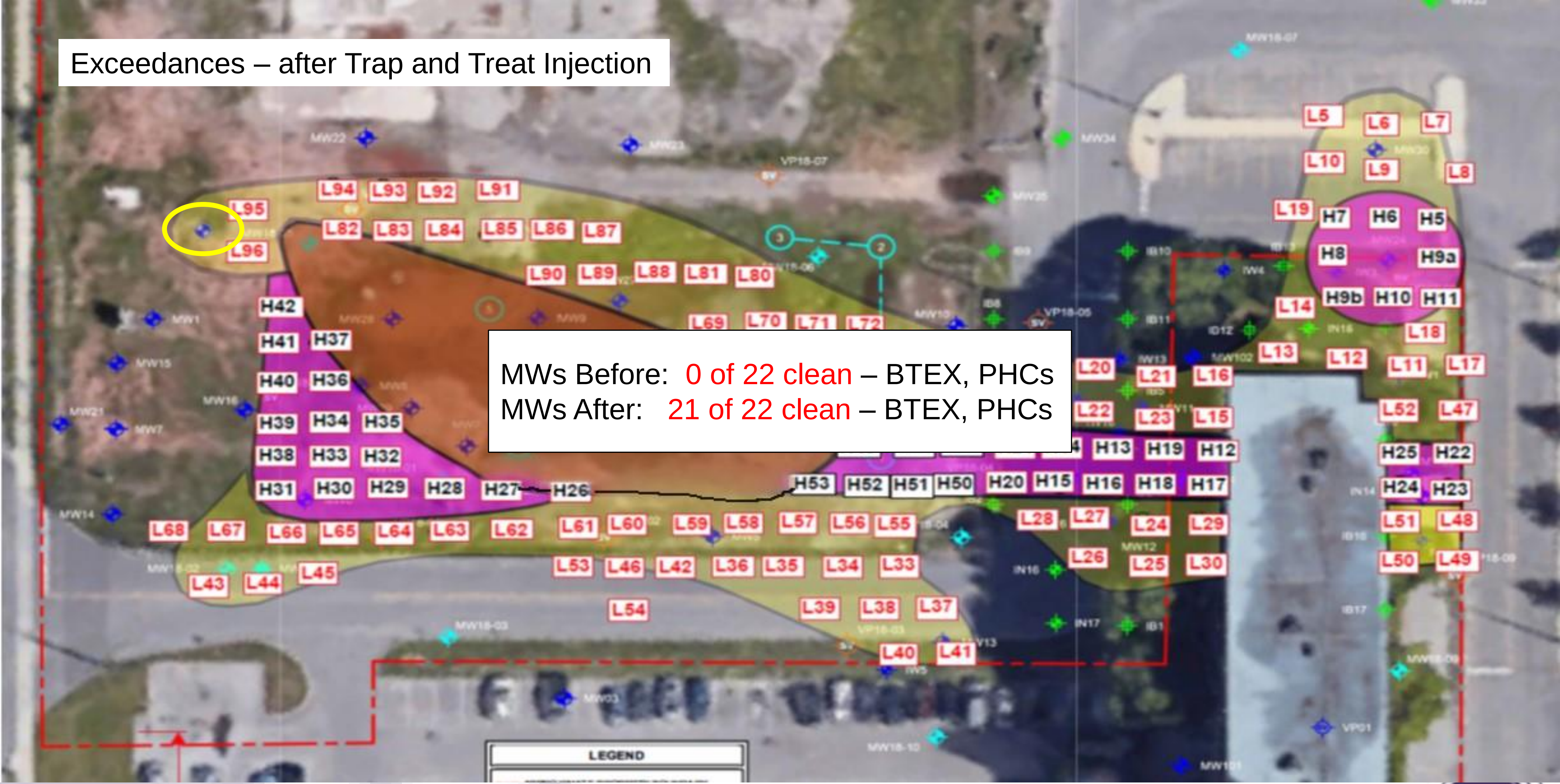
1,000
0
1-Aug-2013
9-Mar-2014
15-Oct-2014
23-May-2015
29-Dec-2015
5-Aug-2016
13-Mar-2017
19-Oct-2017
27-May-2018
2-Jan-2019
10-Aug-2019
17-Mar-2020
23-Oct-2020
31-May-2021
Oxidant Injection
Oxidant Injection
Oxidant Injection
Trap and Treat Start
MW04
MW13
MW30
MW5
MW27
MW18-02
MW19
MECP Standard

Exceedances – after Trap and Treat Injection



MWs Before: 0 of 22 clean – BTEX, PHCs

MWs After: 21 of 22 clean – BTEX, PHCs

Bedrock Case Study #1 Wrap-Up

Remediation of Bedrock with PHCs (including LNAPL):

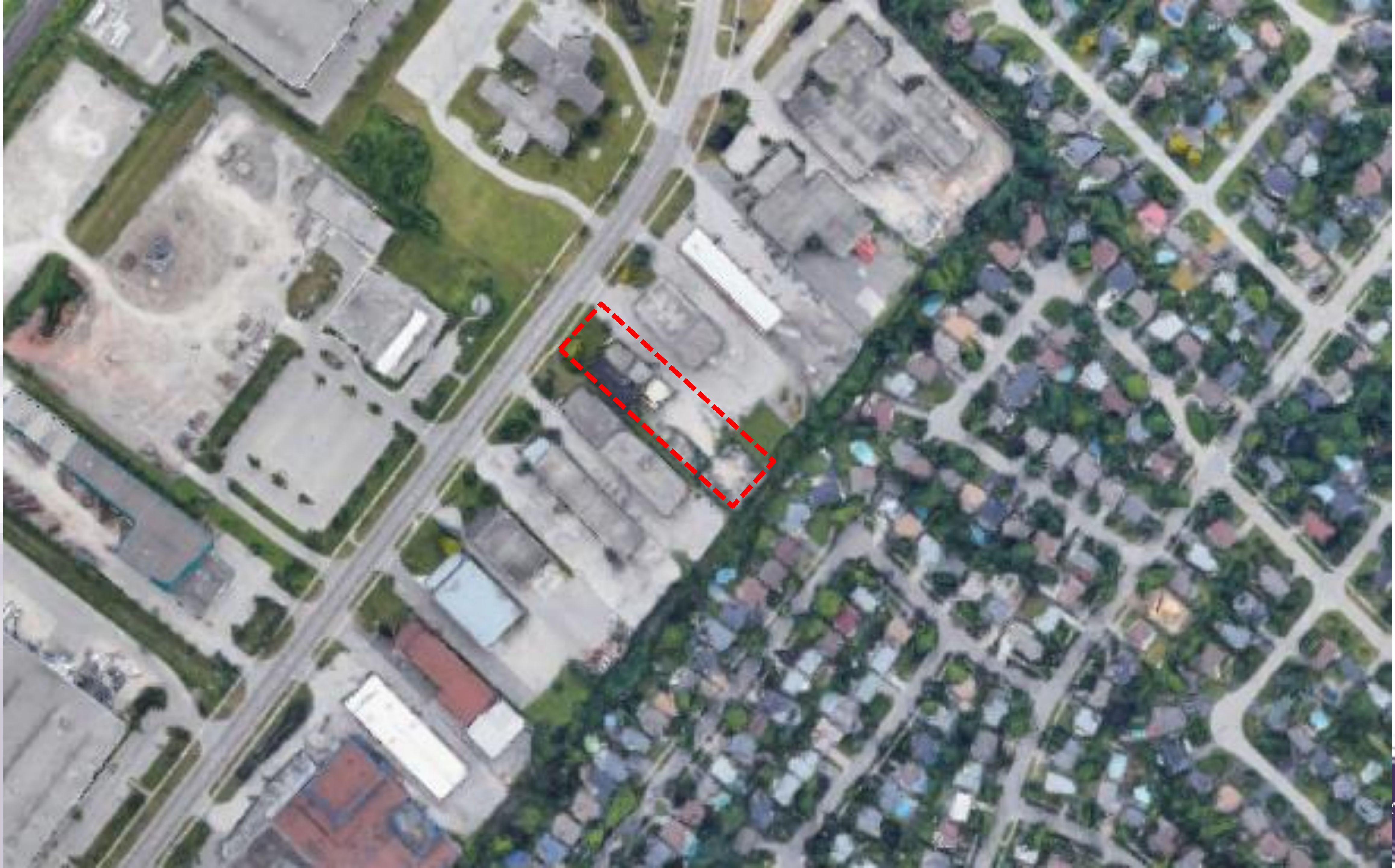
- ISCO should only be applied after careful consideration
  - ISCO has difficulty with LNAPL
  - ISCO has difficulty with bedrock secondary porosity
    - Back Diffusion
- Excavation (in 2020)
  - Direct removal of LNAPL
- Trap and Treat – BOS200® (2020 – 2021)
  - Adsorbes the PHC Plume
  - Treats the PHC Plume
  - Directly addresses Bedrock Back Diffusion
- Result (in 2021): Success
  - 21 of 22 MWs clean

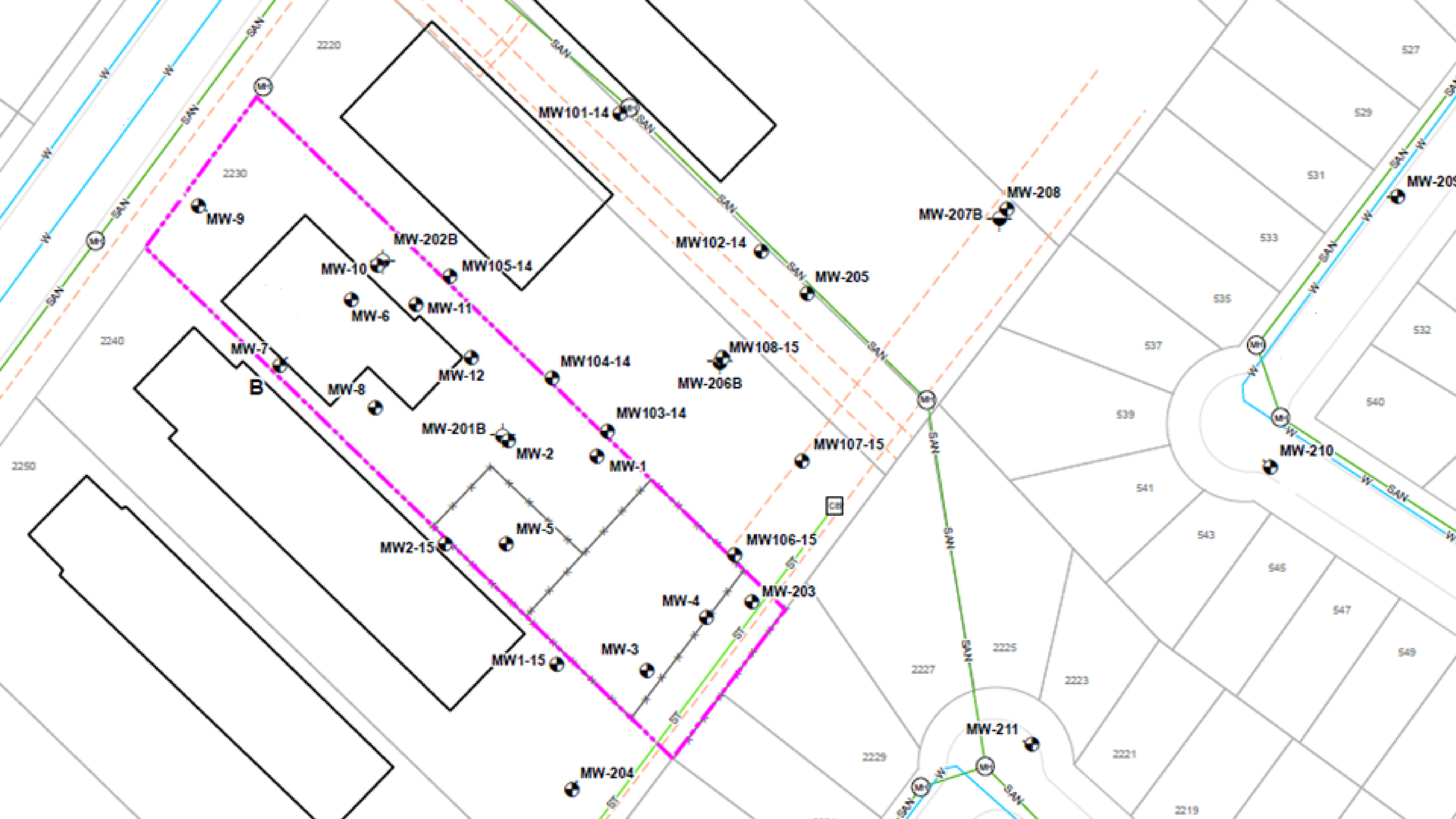
Bedrock Case Study #2

Bedrock and Heavy Metals (Hex Chrome)

Background – The Situation

- Confidential Site
- A hexavalent chromium plating facility:
  - Underground treatment tanks with the Hex Chrome liquid
  - Tanks leaked
  - And historical spills
- Neighbour does a Phase II ESA
- Chrome contamination
  - Hexavalent Chrome
  - Trivalent Chrome
- Bench and Pilot Scale testing completed
  - Full-scale being designed now

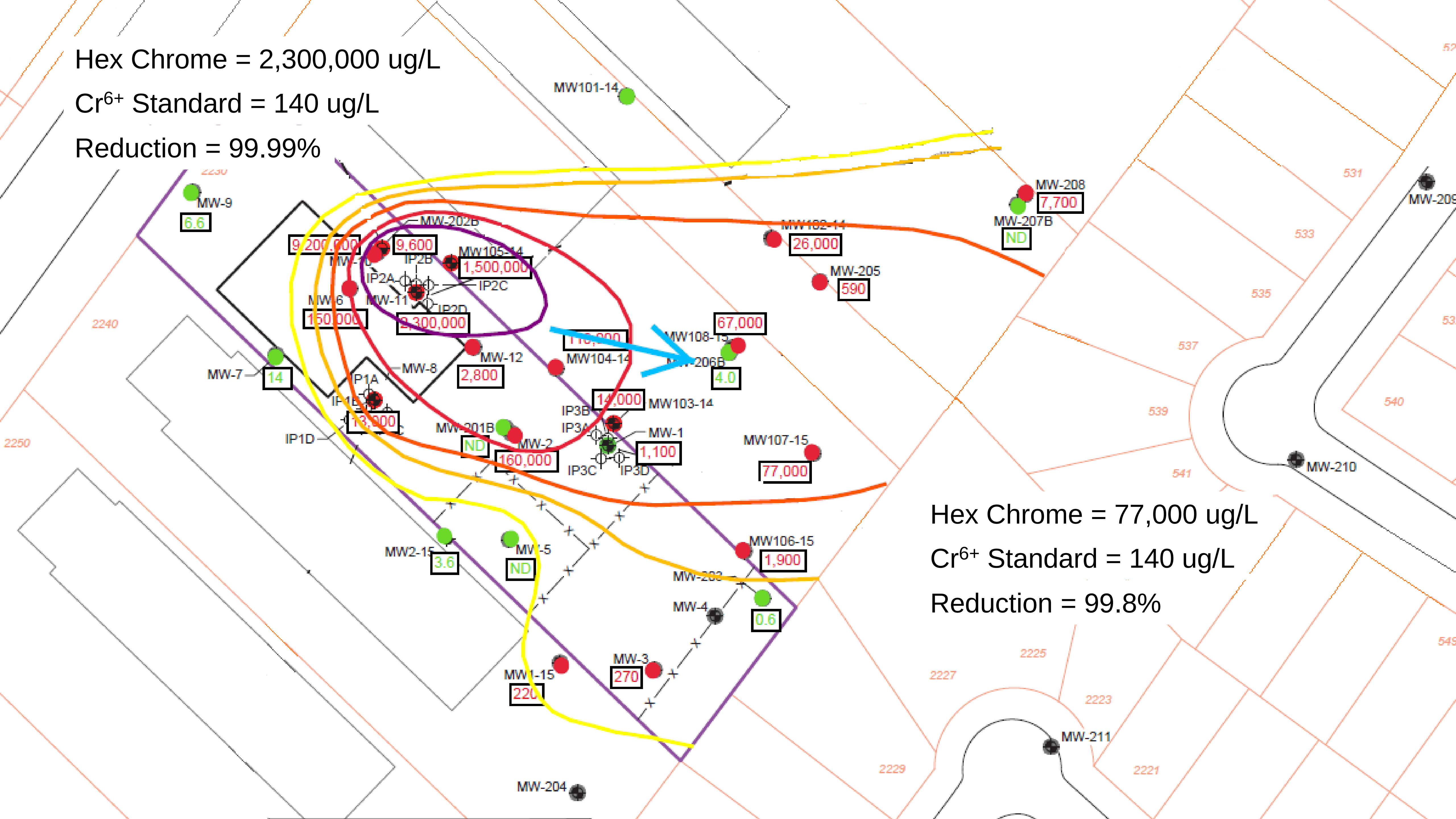



2220
2230
2240
2250
MW101-14
MW-9
MW-202B
MW-10
MW105-14
MW-6
MW-11
MW-7
MW-12
B
MW-8
MW104-14
MW102-14
MW-205
MW108-15
MW-206B
MW103-14
MW-201B
MW-2
MW-1
MW107-15
MW-5
MW2-15
MW106-15
MW-4
MW-203
MW-3
MW1-15
MW-204
MW-208
MW-207B
MW-20
MW-210
MW-211
CB
MH
SAN
W
ST
527
529
531
533
535
537
532
539
540
541
543
545
547
549
2225
2227
2223
2229
2221
2219

Hex Chrome = 2,300,000 ug/L

Cr^{6+} Standard = 140 ug/L

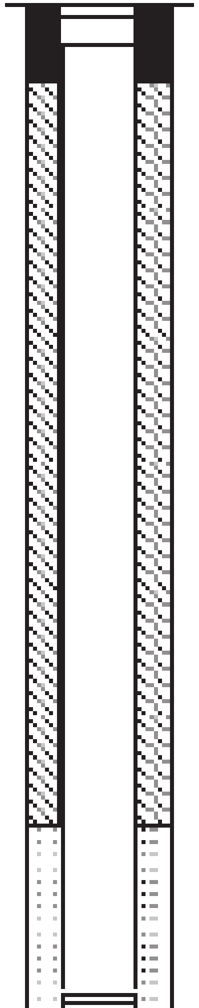
Reduction = 99.99%



Hex Chrome = 77,000 ug/L

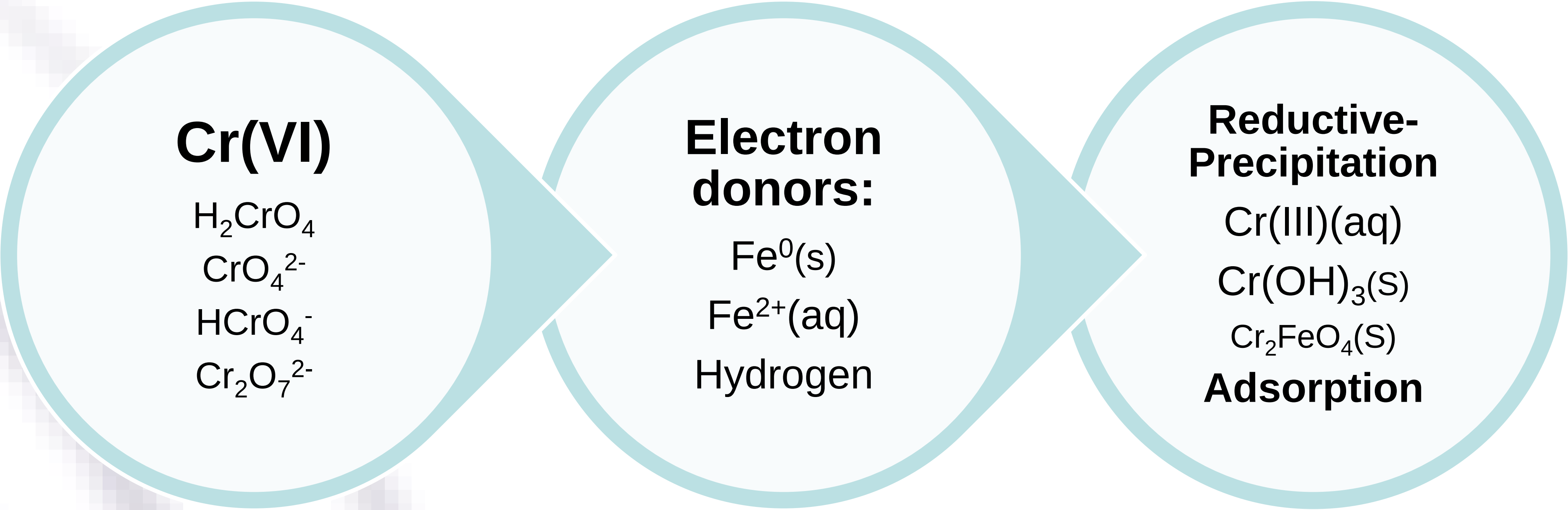
Cr^{6+} Standard = 140 ug/L

Reduction = 99.8%

SUBSURFACE PROFILE			SAMPLE						
Depth	Symbol	Description	Depth/Elev (m)	Sample ID	Analysed Y,N	Sample Type	Vapour ppm 0 250 500	LEL % 0 50 100	Backfill details
ft m		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 4 5				MW-1-1.2	Y				
6 2				MW-1-2.1	Y				
7 8 9 10 3 11 12		**WEATHERED SHALE** Red	59.86 2.13						


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

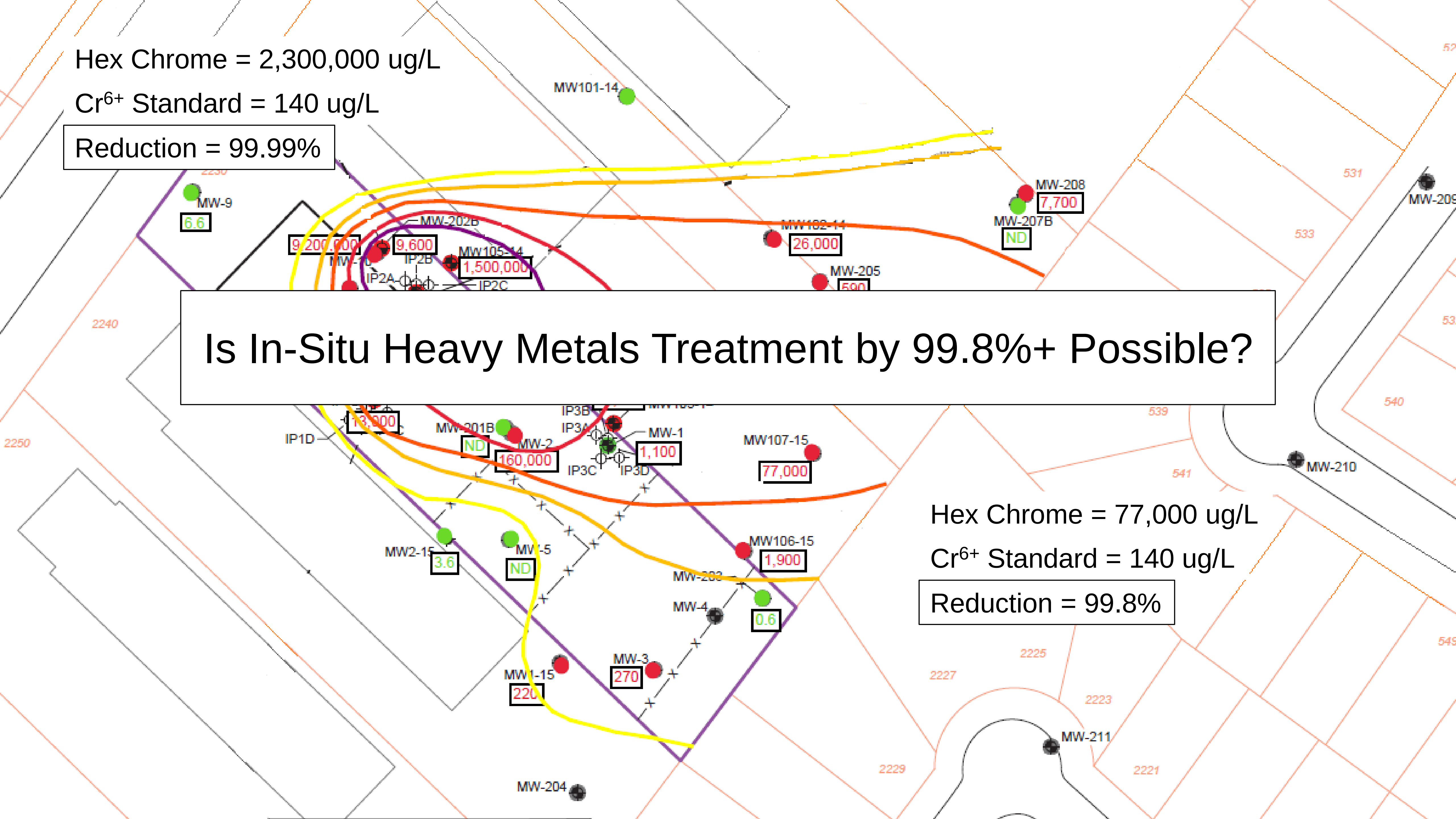
Cr(III)(aq)

$Cr(OH)_3$(S)

Cr_2FeO_4(S)

Adsorption

Is In-Situ Heavy Metals Treatment by 99.8%+ Possible?



Hex Chrome = 2,300,000 ug/L

Cr^{6+} Standard = 140 ug/L

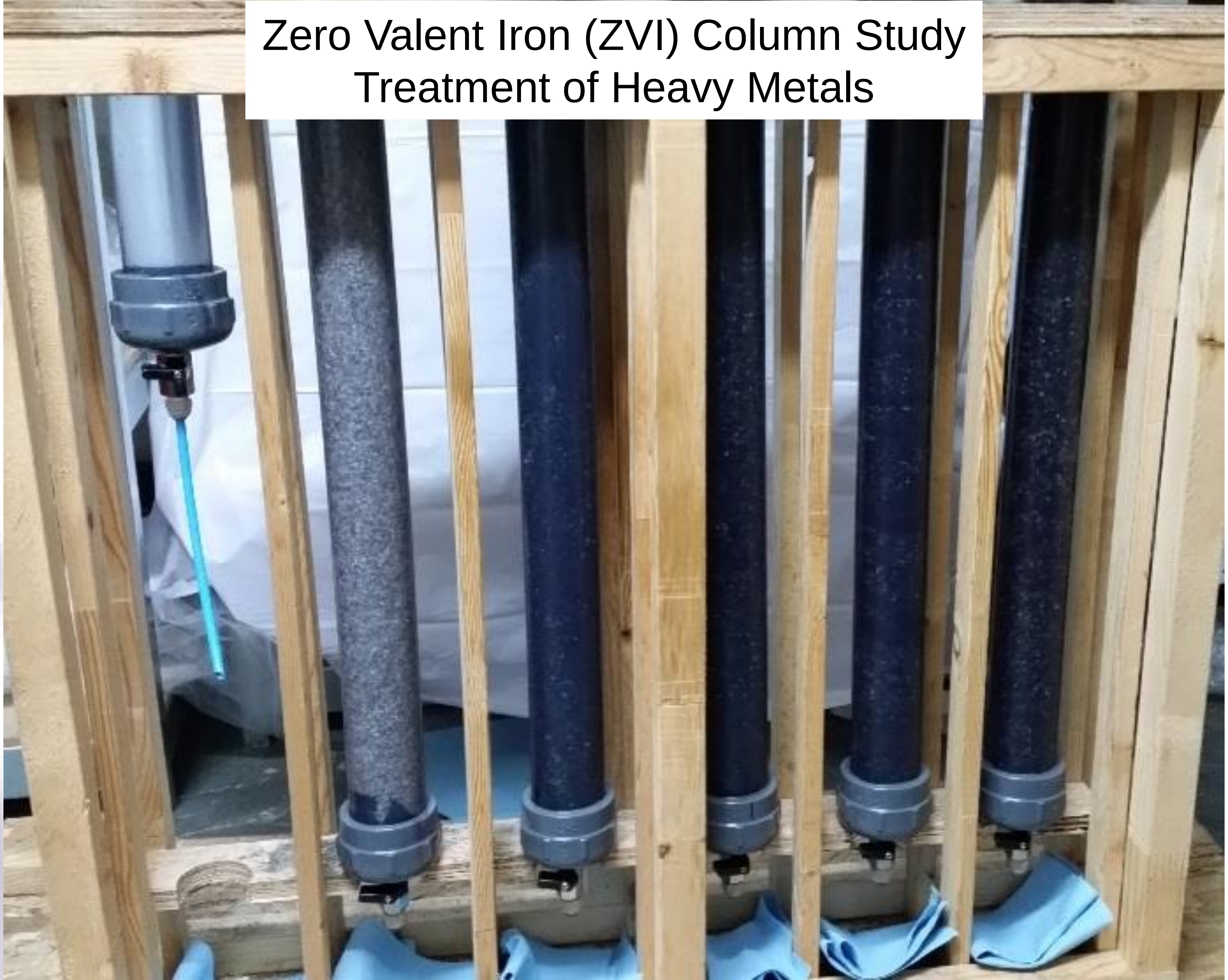
Reduction = 99.99%

Hex Chrome = 77,000 ug/L

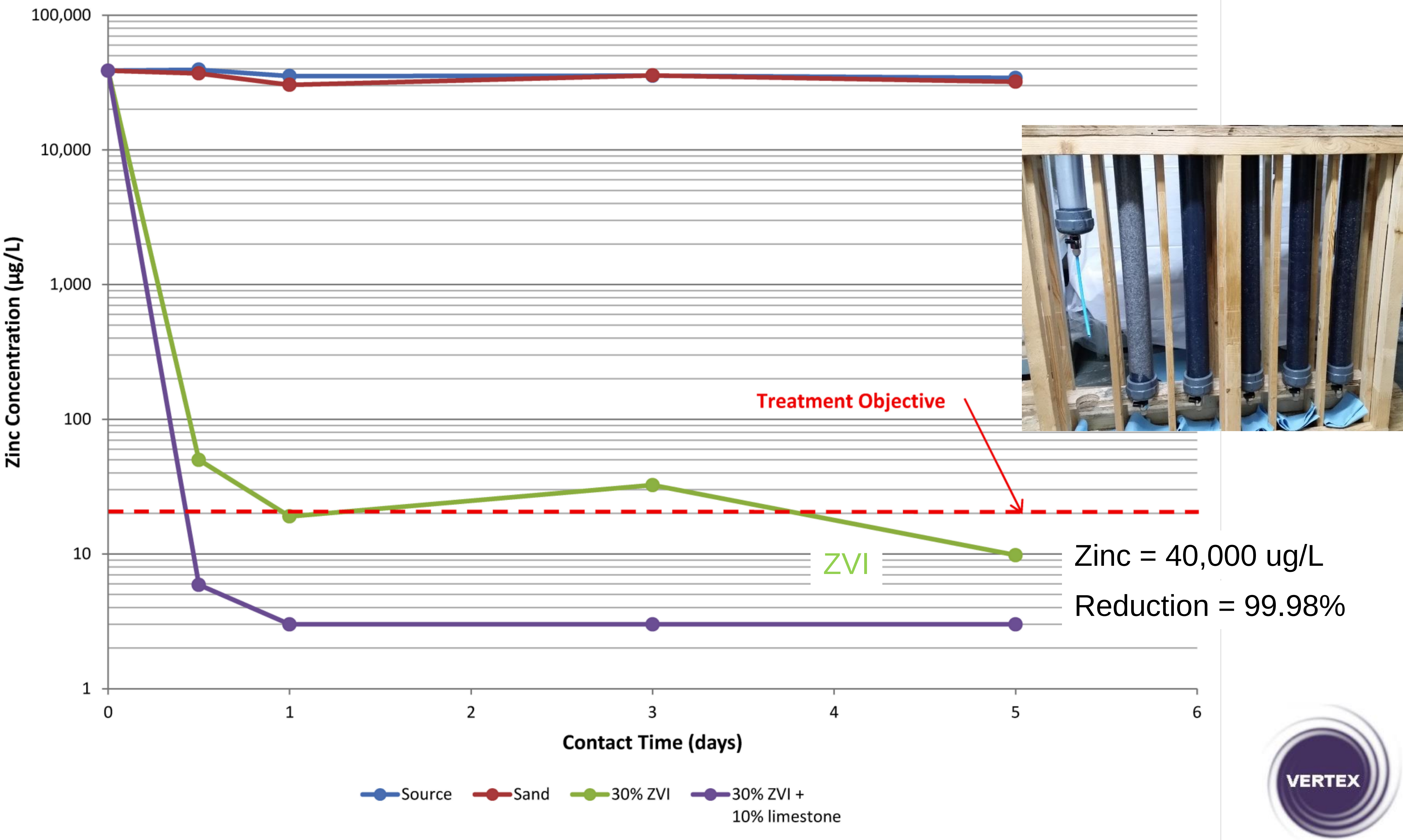
Cr^{6+} Standard = 140 ug/L

Reduction = 99.8%

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



Zinc Concentrations vs Contact Time



Zinc = 40,000 ug/L

Reduction = 99.98%

Bench-Scale Testing with Site Groundwater

Hex Chrome Case Study

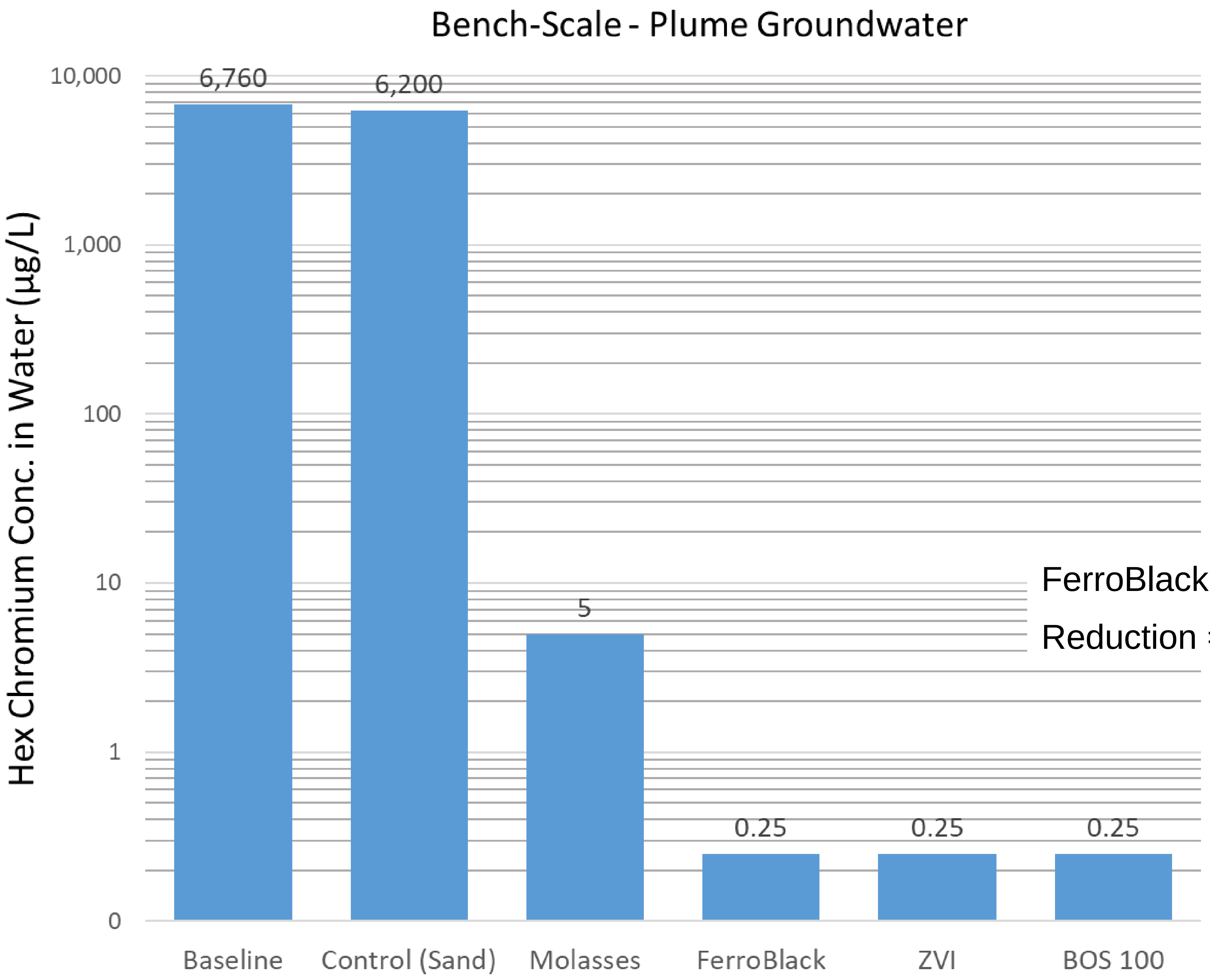
Hex Chrome – Bench-Scale Testing

Remediation Amendments Tested

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

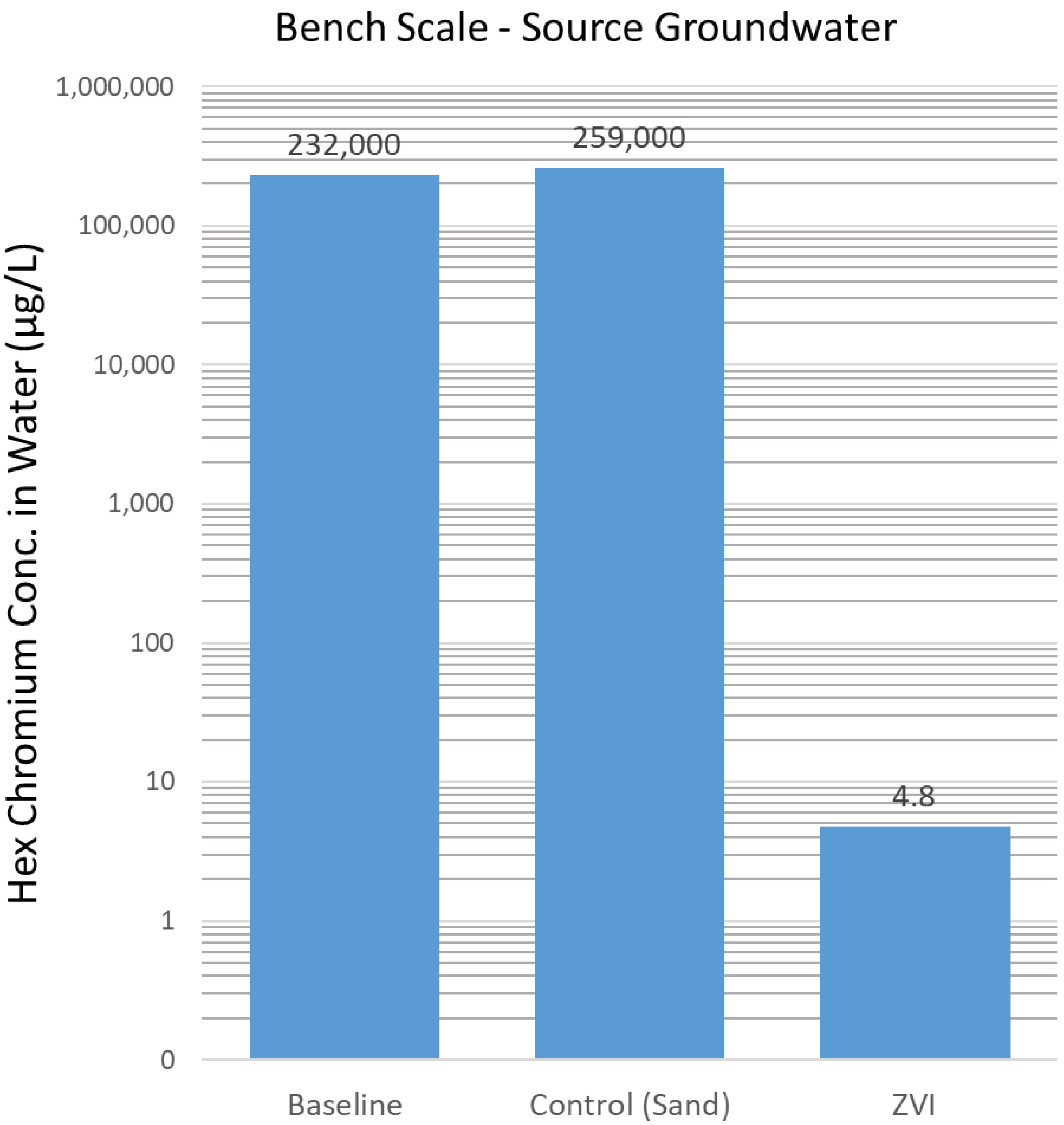
Method

- 1 L Containers
- Silica Sand and Remedial Amendment
- Groundwater Added
- Placed in Dark, let sit one week, sampled



FerroBlack, ZVI, BOS100

Reduction = 99.996%

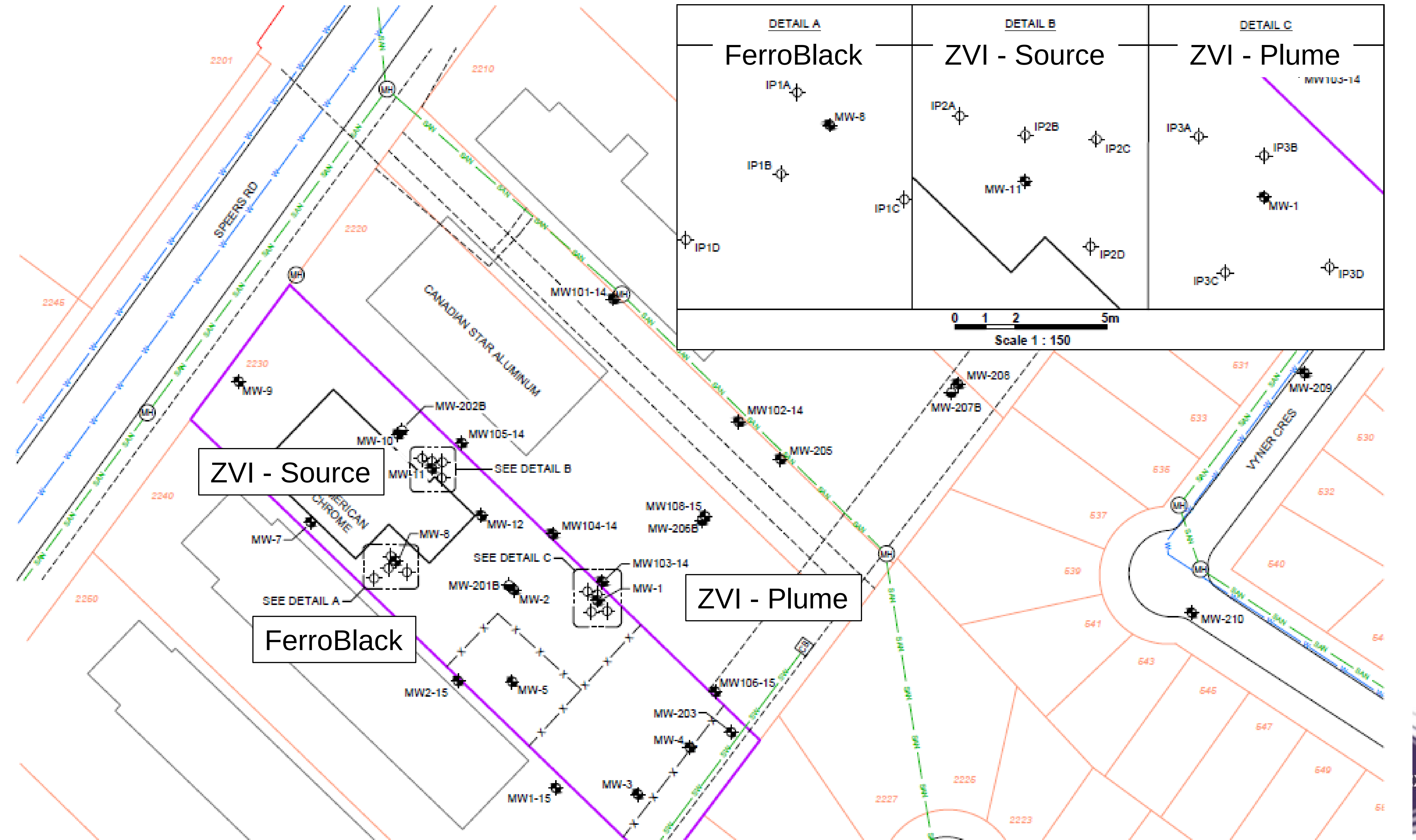


ZVI

Reduction = 99.998%

Pilot-Scale Testing on-Site

Hex Chrome Case Study



FerroBlack

ZVI - Source

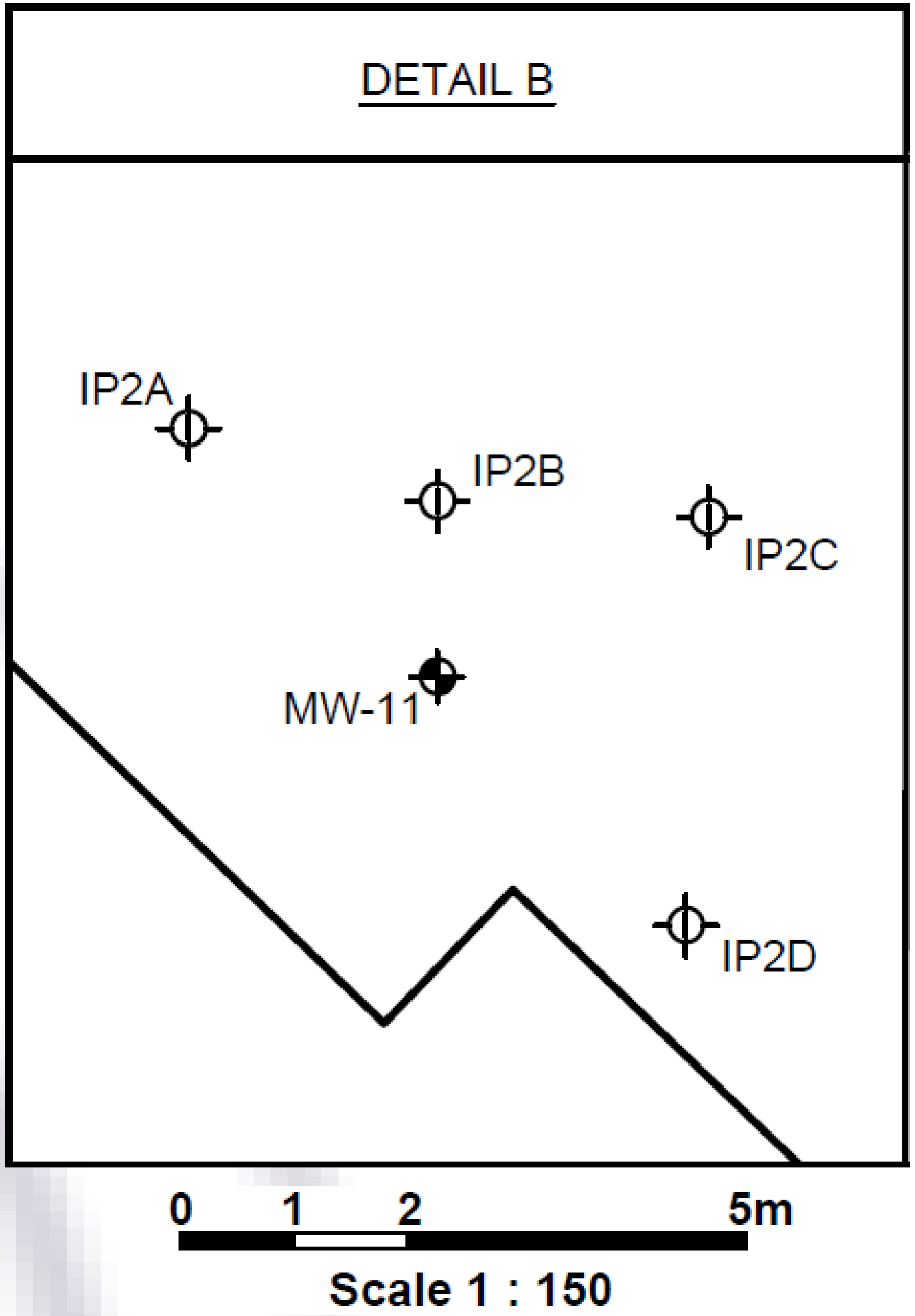
ZVI - Plume

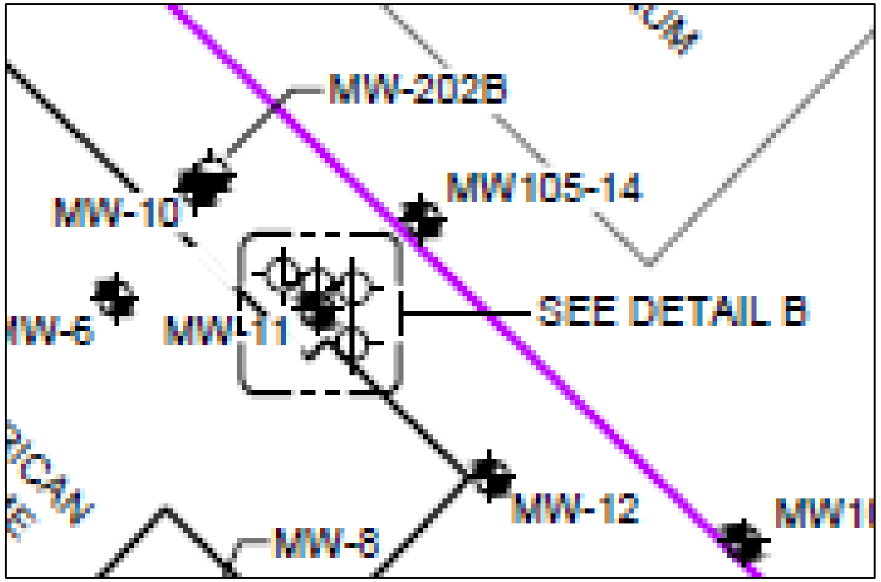
ZVI - Source

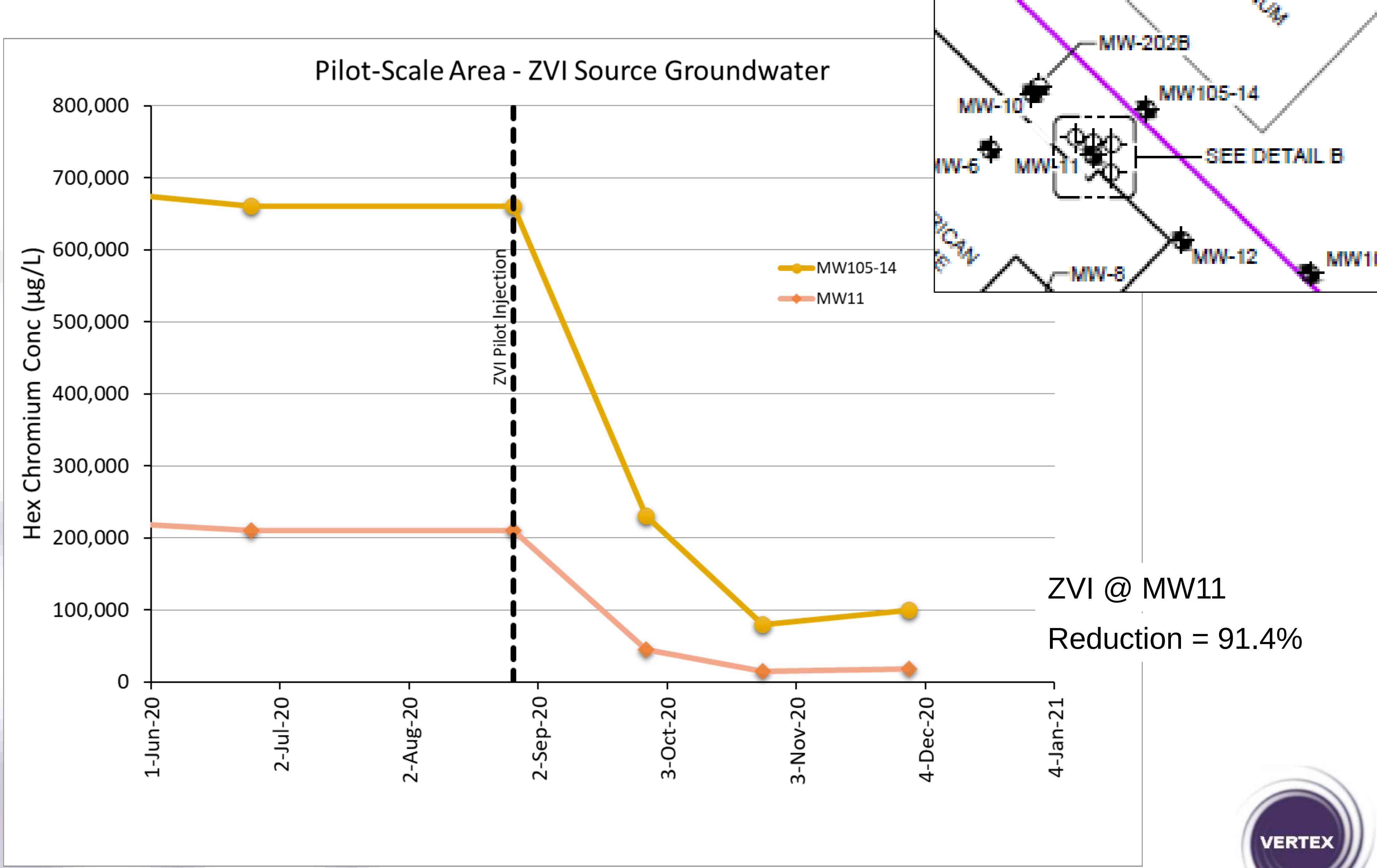
FerroBlack

ZVI - Plume

ZVI - Source


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

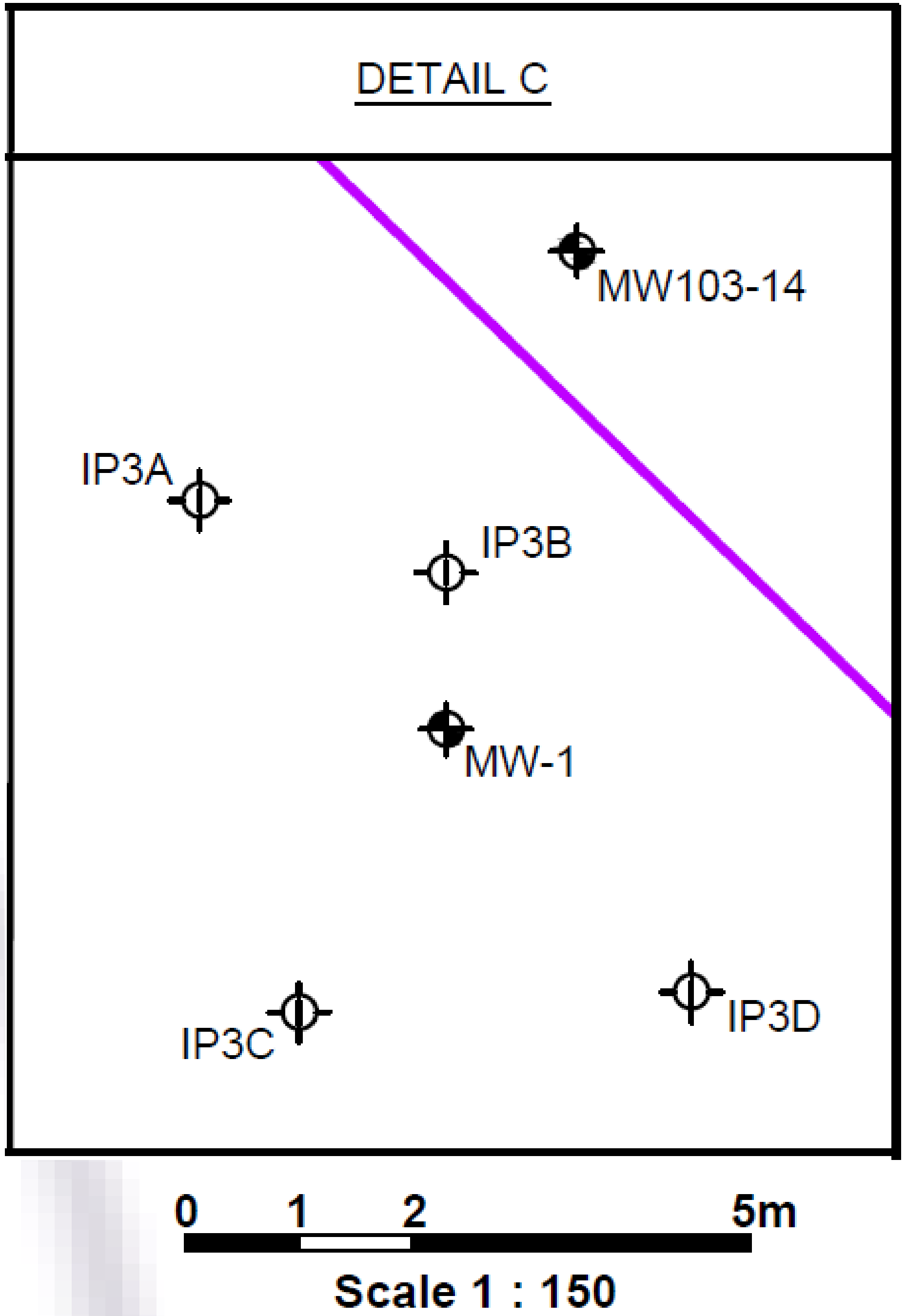

MW-202B
MW105-14
MW-10
IW-6
MW-11
SEE DETAIL B
MW-12
MW-8
MW1
RICAN

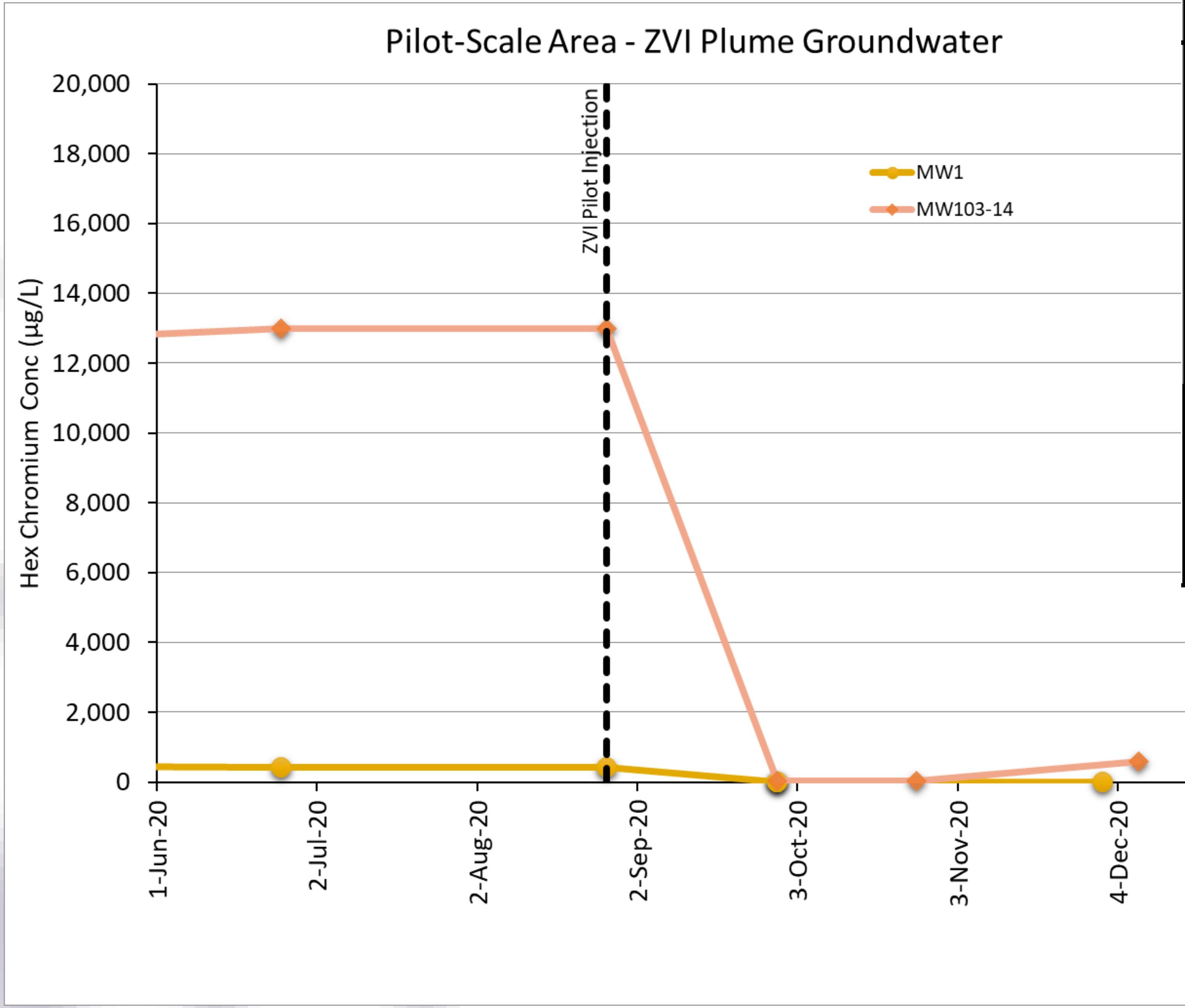


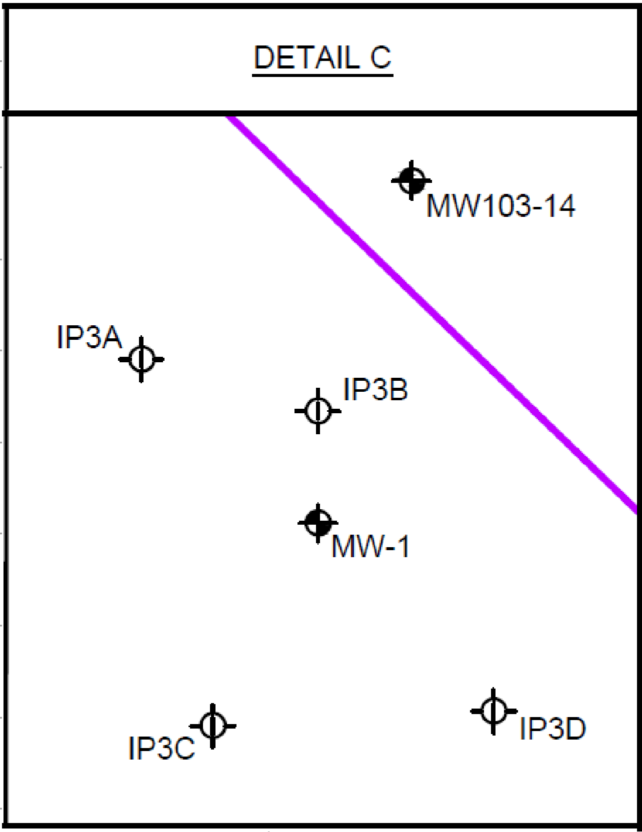
ZVI @ MW11

Reduction = 91.4%

ZVI - Plume







ZVI @ MW1

Reduction = 99.4%

ZVI @ MW103-14

Reduction = 96%

Bedrock Case Study #2 Wrap-Up

Remediation of Bedrock with Heavy Metals (Hex Chrome):

- Groundwater treatment is possible (in the field)
  - At Bench – >99.9%
  - At Pilot-Scale – 91% (Source) to 99.4% (Plume)
- Zero Valent Iron is a feasible solution
- Full-scale about to be implemented

Bedrock Case Study #3

Bedrock and Chlorinated Solvents (cVOCs)

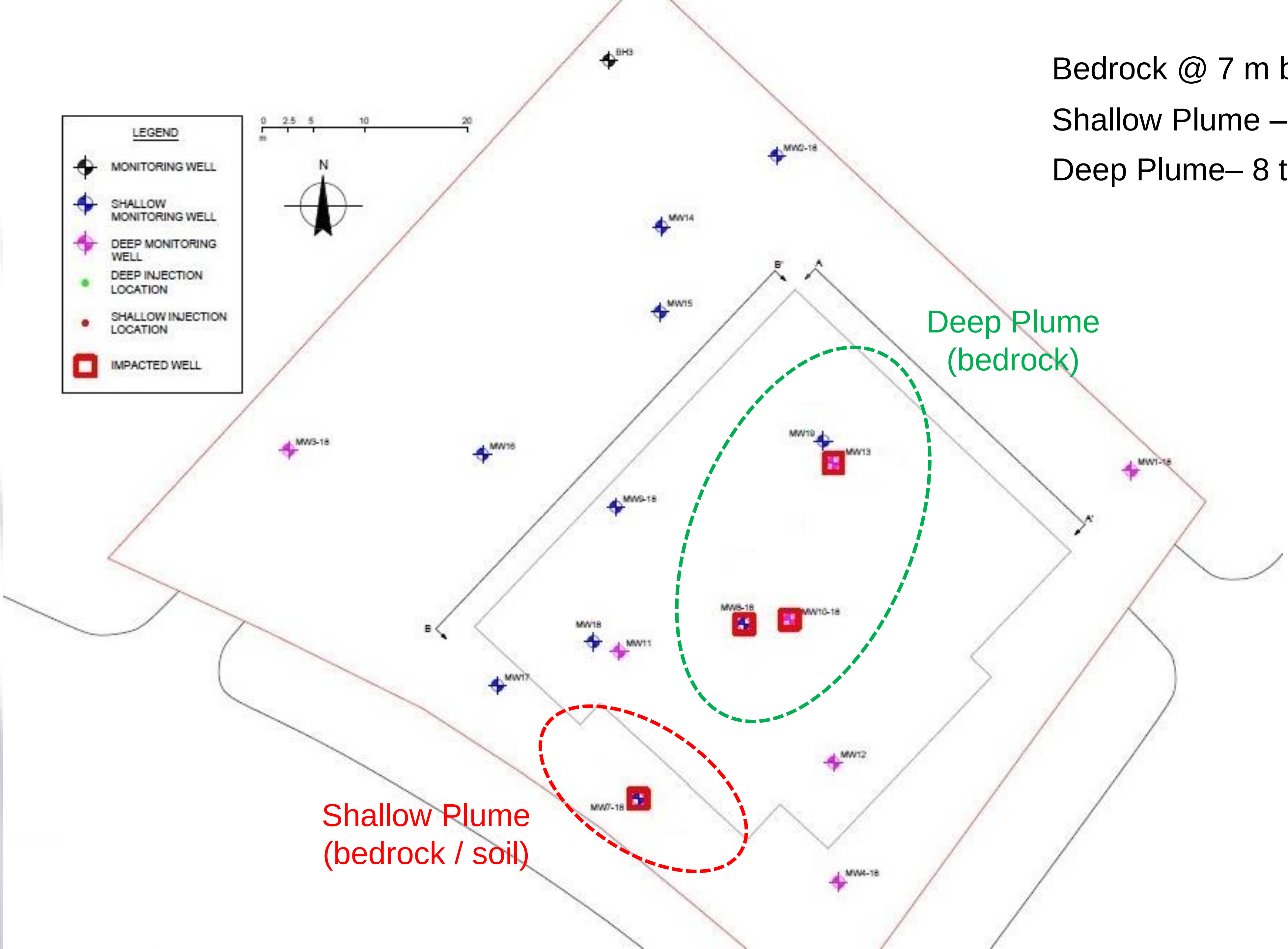
Background – The Situation

- Confidential Site
- Historical Commercial Operation:
  - Use of dry cleaning solvent – Tetrachloroethene (PCE)
- Developer purchased
  - Residential Redevelopment
- Had to be Fully Remediated
  - No Risk Assessment
- PCE Concentrations were low:
  - 40 ug/L vs 17 ug/L Standard
- Remediation:
  - Extraction (to pull the plume in, see if higher concentrations exist)
  - Injection (Shallow) – Trap and Treat BOS100®
  - Injection (Deep) – Powered Activated Carbon (PAC)

Bedrock @ 7 m bgs

Shallow Plume – 5 to 8 m

Deep Plume– 8 to 13.5 m



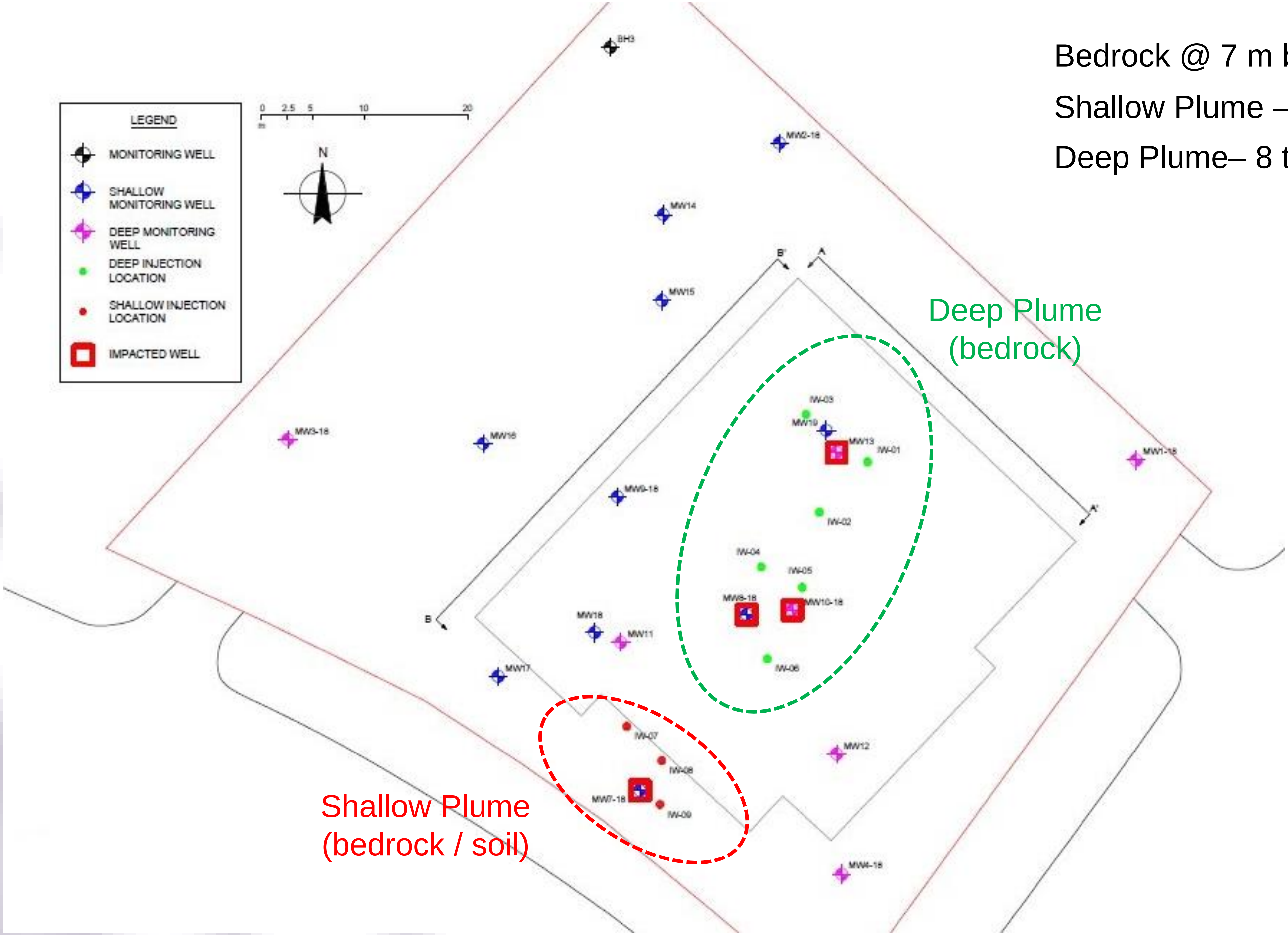
Deep Plume (bedrock)

Shallow Plume (bedrock / soil)

Bedrock @ 7 m bgs

Shallow Plume – 5 to 8 m

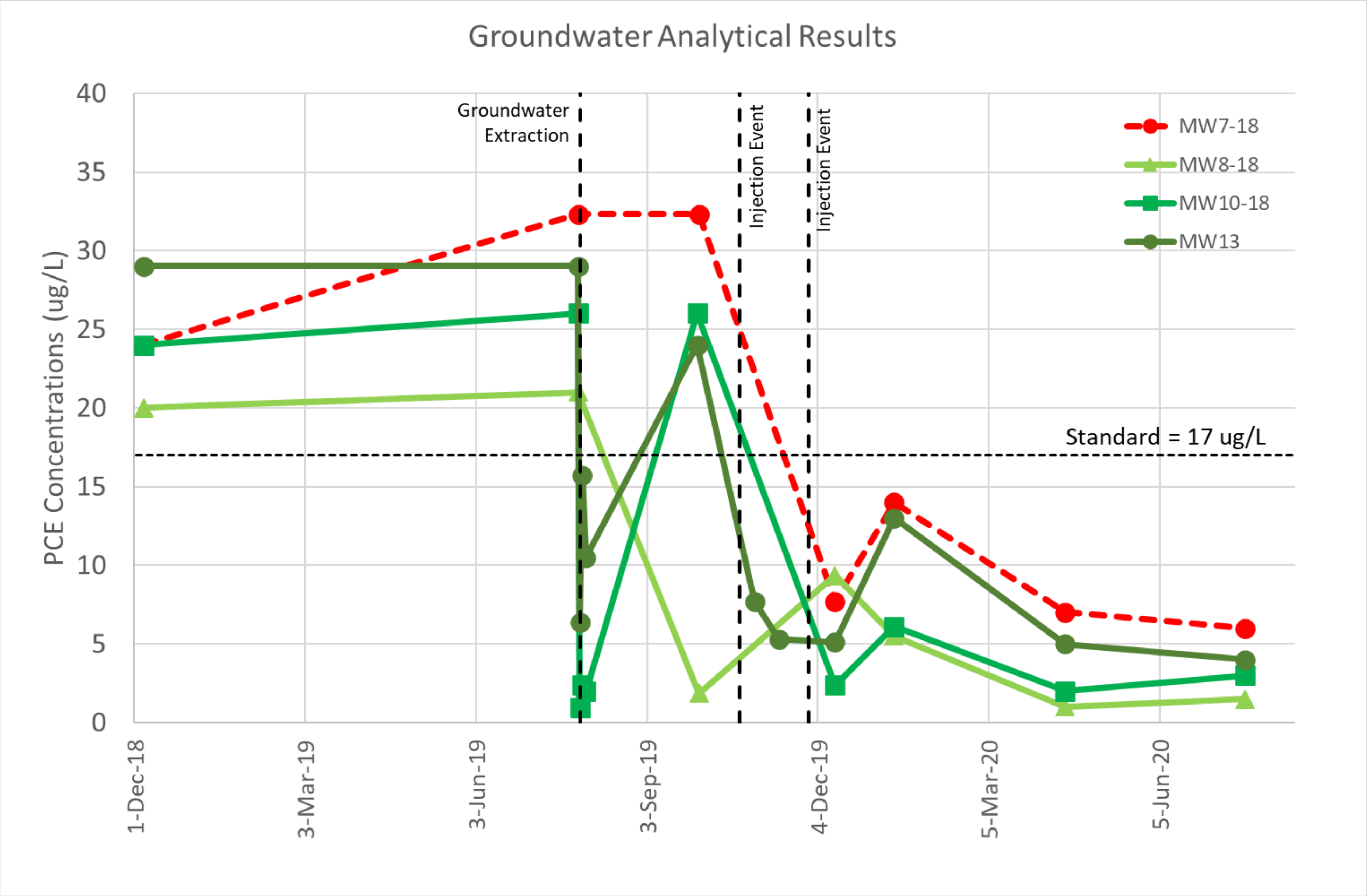
Deep Plume– 8 to 13.5 m



Deep Plume (bedrock)

Shallow Plume (bedrock / soil)

Portable Groundwater Extraction System


Groundwater Analytical Results
PCE Concentrations (ug/L)
40
35
30
25
20
15
10
5
0
1-Dec-18
3-Mar-19
3-Jun-19
3-Sep-19
4-Dec-19
5-Mar-20
5-Jun-20
Groundwater Extraction
Injection Event
Injection Event
Standard = 17 ug/L
MW7-18
MW8-18
MW10-18
MW13

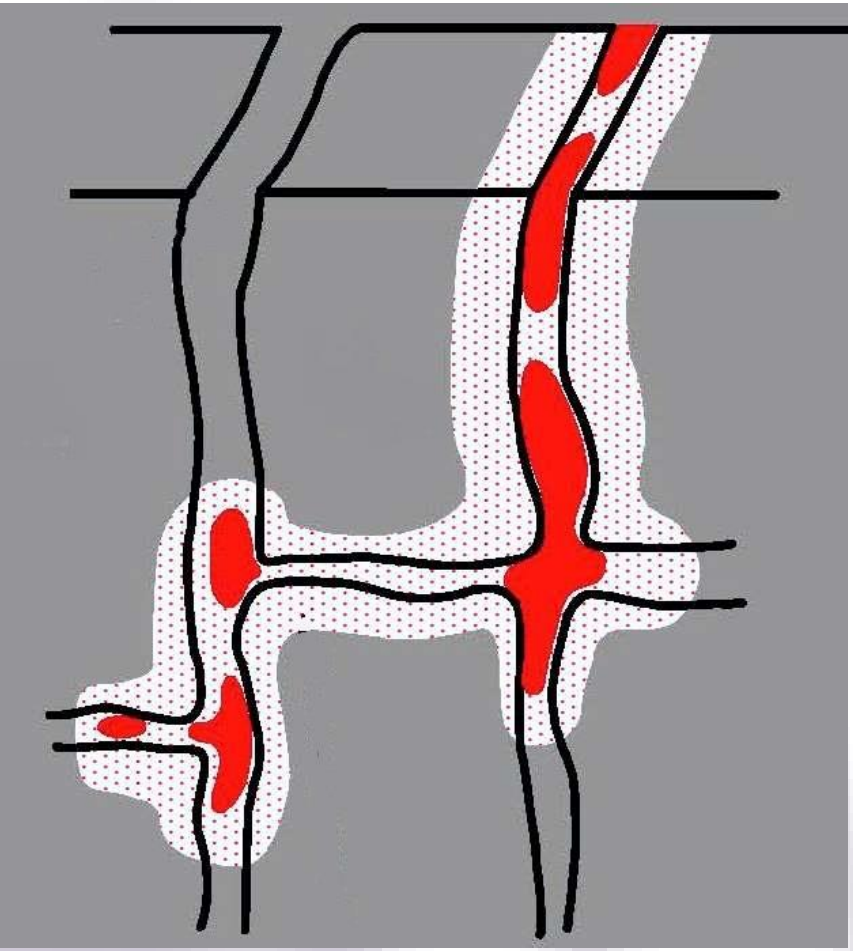
Bedrock Case Study #3 Wrap-Up

Remediation of Bedrock with Chlorinated Solvents (PCE):

- Groundwater Extraction
  - Helped to understand the Plume (e.g. no hot spots)
- Trap and Treat BOS100® and PAC
  - Controlled back diffusion (will allow natural bio to occur)
- Result: Clean Site

Closing

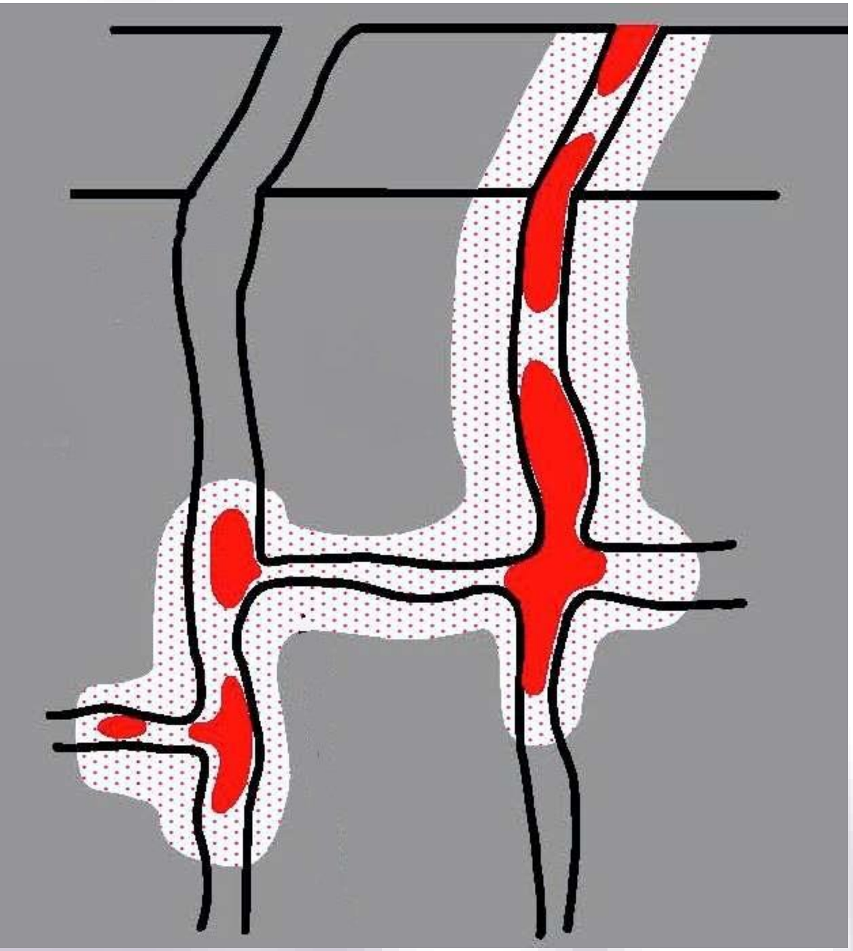
Take Aways / Lessons Learned



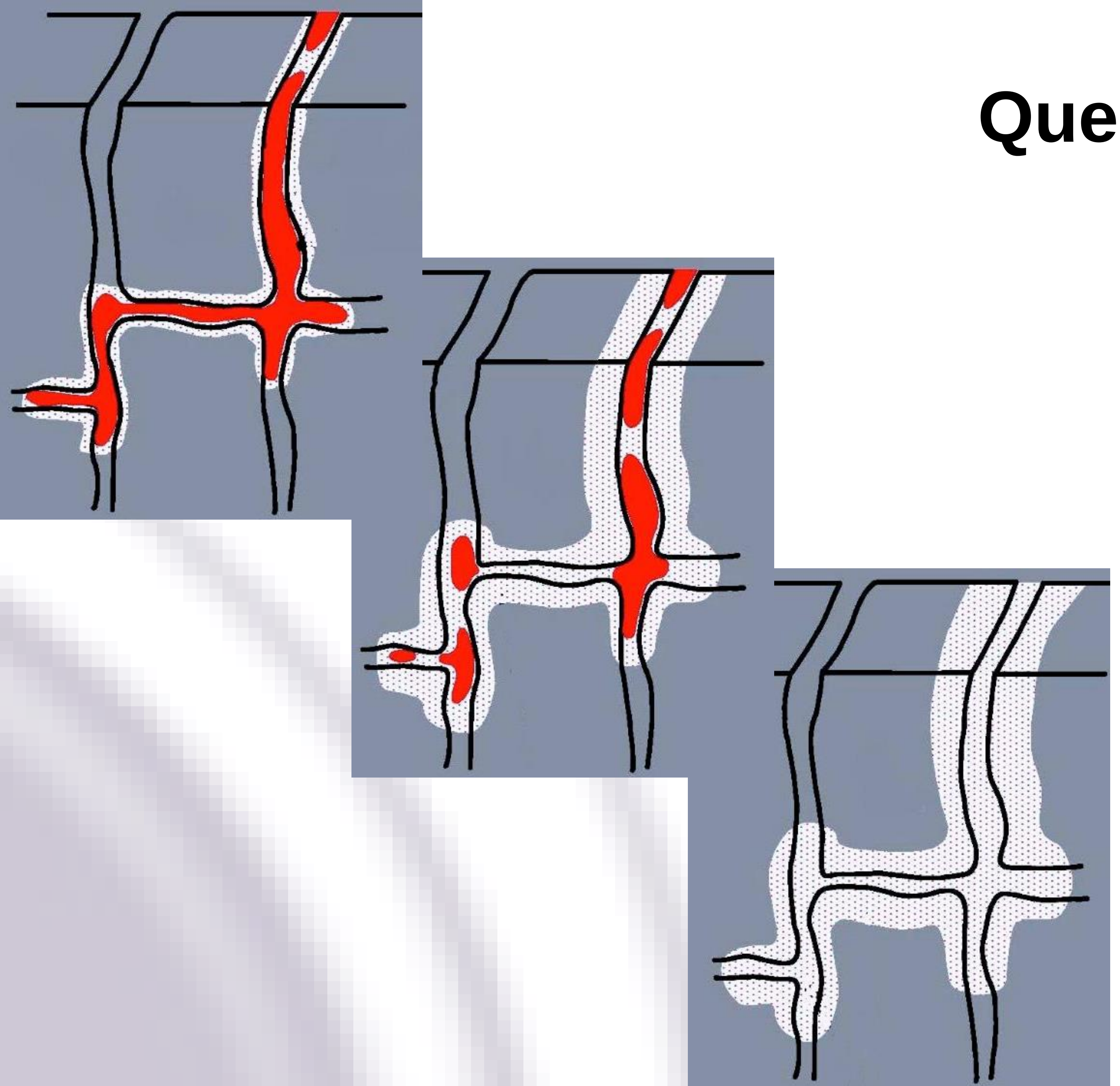
Performing Bedrock Remediation

- Address LNAPL by aggressive means
  - Excavation (Case Study #1)
- Back Diffusion
  - Use a Remedial Amendment that can handle Back Diffusion
    - Trap and Treat (Case Study #1 and #3)
    - Zero Valent Iron (Case Study #2)
- In-Situ (Injections) Can Work
  - With proper drilling and proper injection technique

Take Aways / Lessons Learned



What once was considered Impossible **is now Possible**!



Questions?

Thank You for Your Time

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