VEI CONTRACTING

REMEDIATION & RISK MANAGEMENT

DEWATERING & WATER TREATMENT

Remediation Technologies Symposium 2025

Remediation Case Studies Gone Wrong:

From Bench- to Full-Scale & the Cost of Assumptions

October 17, 2025

RemTech

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

VEI Contracting Inc.

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REMEDIATION & RISK MANAGEMENT

DEWATERING & WATER TREATMENT

Presentation Overview

- Introduction
  - Bench-Scale Testing
- Case Studies
  1. Permeable Reactive Barrier for cVOCs
  2. PFAS Treatment
  3. PRB for PHCs
  4. Injection into Bedrock for Heavy Metals Treatment
- Take Aways
- Questions

The Presenter

Presenter

Bruce Tunnicliffe, M.A.Sc.

Environmental Engineer, President of VEI

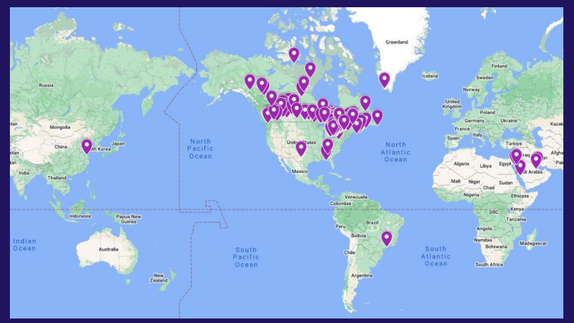
Bruce Tunnicliffe, P.Eng.

- University of Waterloo
  - Masters: Treatment of cVOCs in Fractured Rock
- Founded VEI in 2003

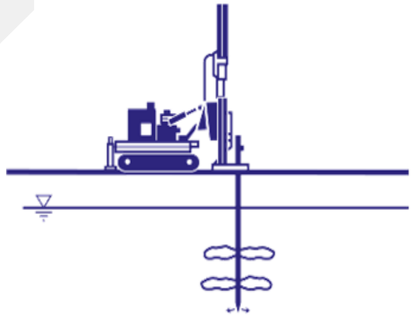
Bruce @ UW, 1998

The Firm

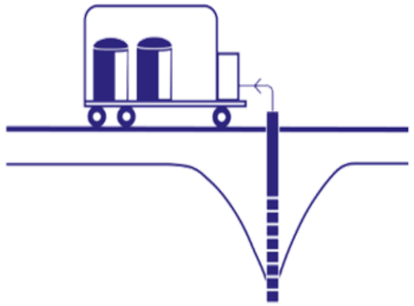
- VEI Contracting Inc. (formerly called Vertex Environmental Inc.)
- Specialty Remediation Contractor



Since 2003, Over 1100 Projects Successfully Completed – Across Canada and Beyond

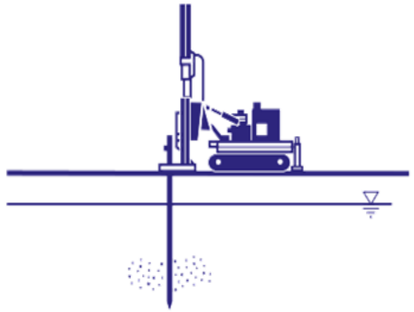


In-Situ Remediation

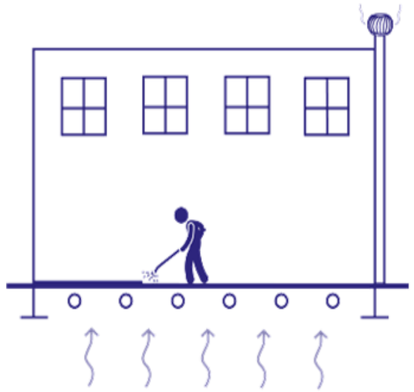


Water Treatment systems & Dewatering

Ex-Situ Remediation



HRSC & RDC



Vapour Intrusion

Bench-Scale Testing

Remedial Design

Outreach

info@vei.ca
https://vei.ca/

Bench-Scale Testing Overview

Bench-Scale Testing – Types of Tests

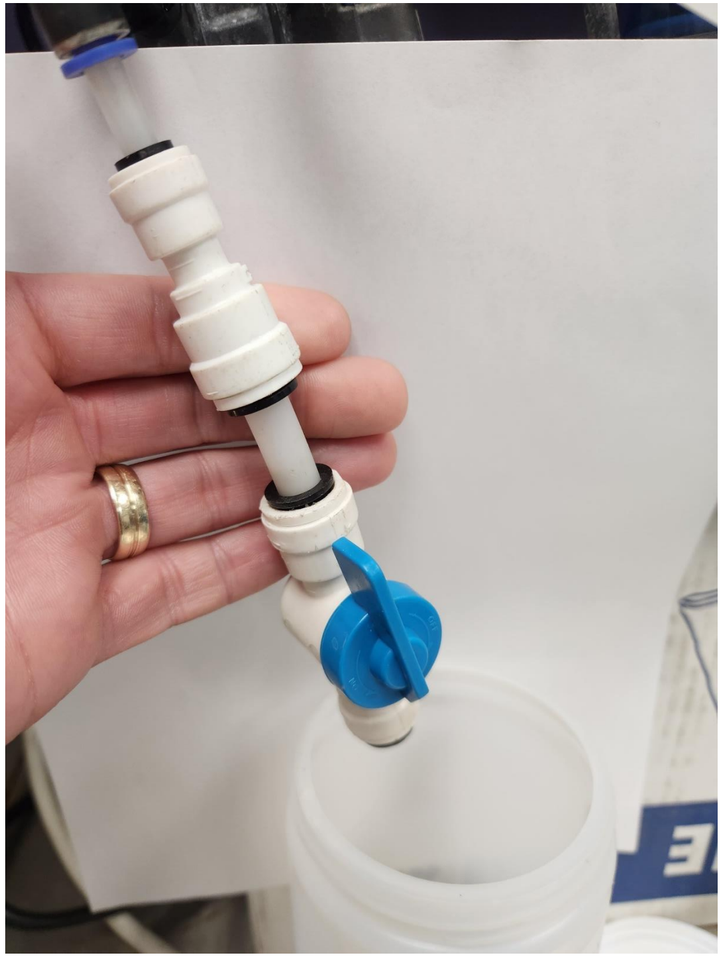
Batch Reactor Tests

Flow-Through Column Reactor Testing

Bench-Scale Testing – Types of Column Studies

Greater than 1 m in length

Less than 30 cm in length



Very tiny – RSSCT

RSSCT = Rapid small-scale column test

Bench-Scale Testing – What and Why

What is it?

- Treatment conducted on actual samples of soil, groundwater or free-product samples
- Assess feasibility and effectiveness of treatment options
- Small-scale, multi-variable, low-cost testing used to refine full-scale treatment approaches

Why Bench-Scale Testing?

- Screening treatment options for a new/uncommon contaminant
- Mixture of contaminants
- Complex water geochemistry
- Site-specific efficacy
- High Risk Site
- Nervous Client
- Tight Budget/Timeline

Bench-Scale Testing – What and Why

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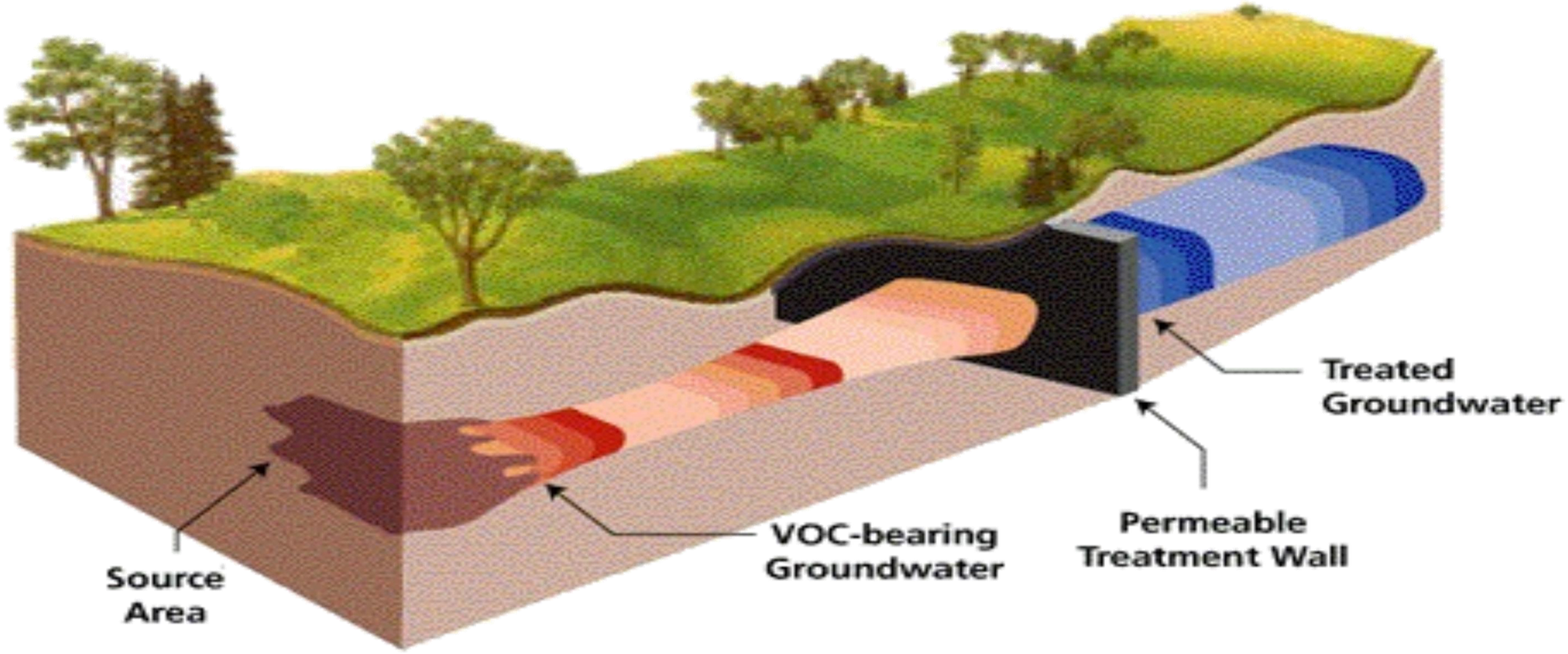
Case Study 1

A Permeable Reactive Barrier (PRB) Horror Story

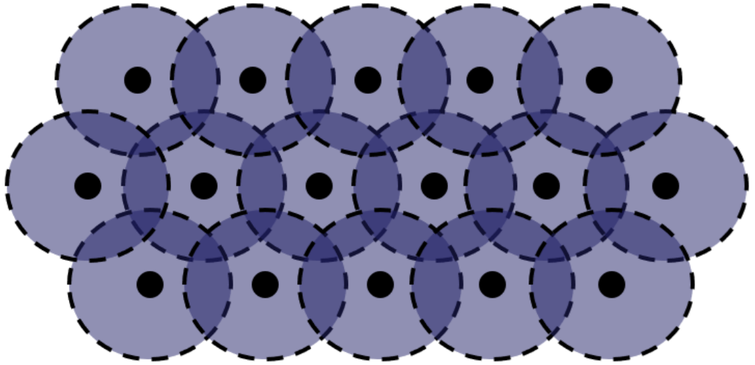
Permeable Reactive Barrier (PRB)



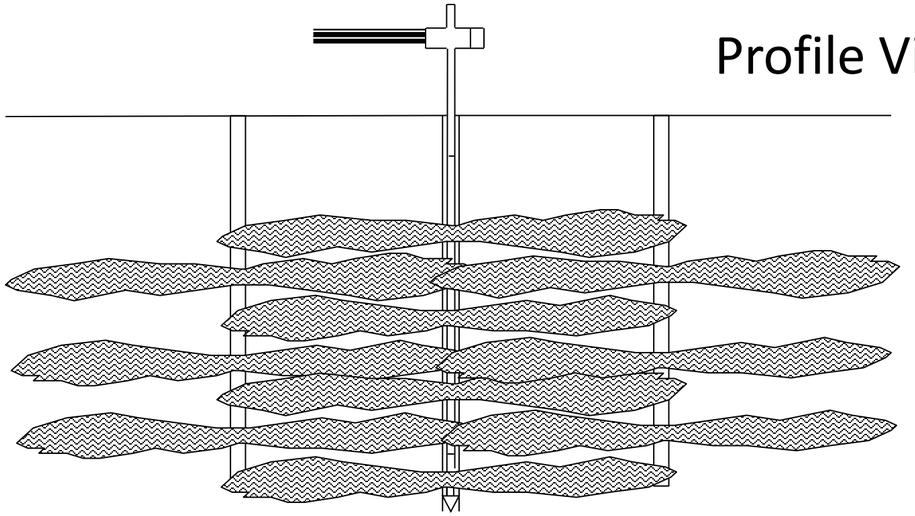
PRB Installation Techniques: Excavation

Macro Zero Valent Iron (ZVI)

PRB Installation Techniques: Injection

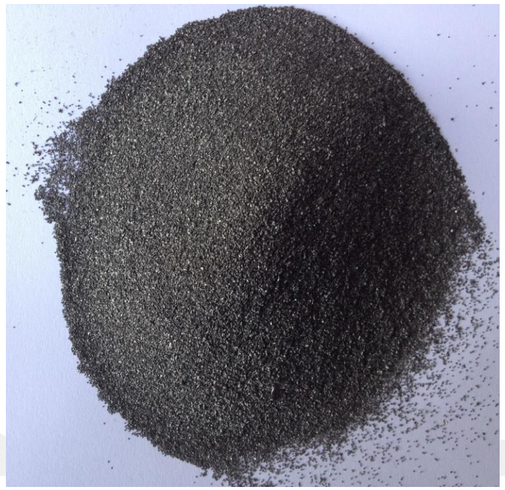


Plan View

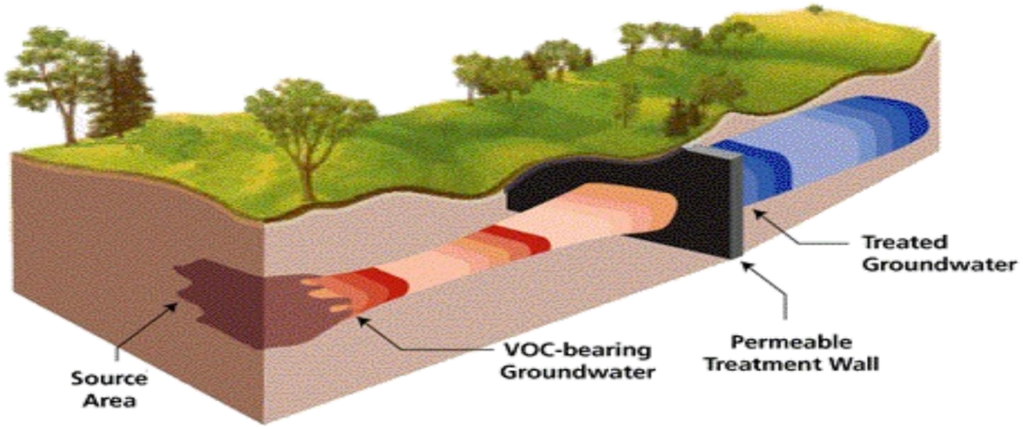


Profile View

Micro Zero Valent Iron (ZVI)



A Permeable Reactive Barrier (PRB) Horror Story



- Client vs Consultant vs Contractor story
- PRB needed to treat cVOCs migrating into water body
- The Client hired a Consultant…ConsultCo
- ConsultCo was responsible for:
  - The PRB design
  - RFP Process / Construction administration
  - On-Site supervision and QA/QC of PRB install
- ConsultCo also carried out bench-scale testing
- DumbContractor, won the bid to install the PRB
- End Result?
  - Improper PRB install and Client launces a lawsuit
- ConsultCo blames DumbContractor
- VEI is brought in by lawyers to sort it out

A Permeable Reactive Barrier (PRB) Horror Story

- PRB:
  - trenched cut and fill construction approach
  - using conventional excavation methods
  - a biopolymer slurry for sidewall stabilization
  - Amendment: Zero Valent Iron (ZVI)
  - 20% ZVI in PRB (mixed with sand)
- Post-installation sampling:
  - target ZVI % was not achieved
- Why? What happened?
- Four (4) mistakes were made resulting in ZVI design and installation failure

Mistake 1: PRB Bench-Scale Testing

- ConsultCo's Bench-Scale Team ran column studies to verify treatment with different amounts of ZVI
- The Bench Team calculated % ZVI by weight as:

$$\%ZVI = \frac{ZVI\ Mass}{Total\ Mass}$$

- What is "Total Mass" with regards to %ZVI?

$$\%ZVI = \frac{ZVI}{ZVI + Sand}$$

- The Bench Team calculated it as:

$$\%ZVI = \frac{ZVI}{ZVI + Sand + Water}$$

Mistake 1: PRB Bench-Scale Testing

Why does this mistake matter?

The ConsultCo Bench-Scale Team thought they tested:

$$\%ZVI = \frac{ZVI}{ZVI+Sand+Water} = \frac{850g}{850g+5{,}610g+2{,}140g} = 9.9\%\ ZVI$$

$$\%ZVI = \frac{ZVI}{ZVI+Sand+Water} = \frac{1{,}680g}{1{,}680g+4{,}820g+2{,}200g} = 19.3\%\ ZVI$$

They actually tested:

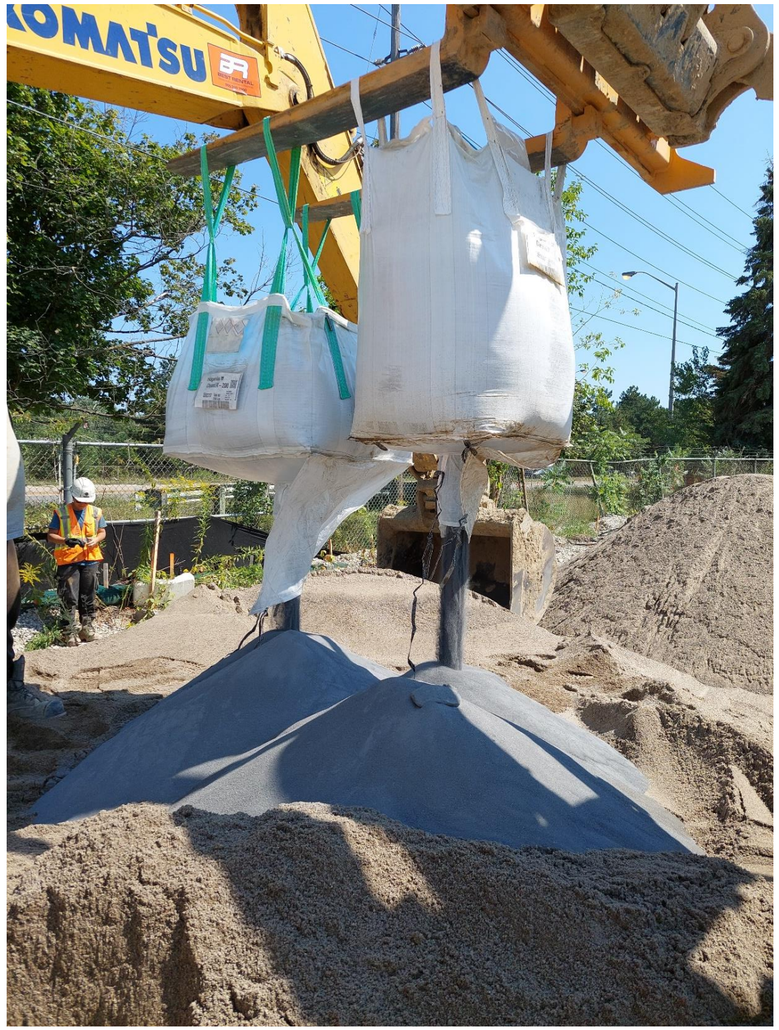
$$\%ZVI = \frac{ZVI}{ZVI+Sand} = \frac{850g}{850g+5{,}610g} = 13.2\%\ ZVI$$

$$\%ZVI = \frac{ZVI}{ZVI+Sand} = \frac{1{,}680g}{1{,}680g+4{,}820g} = 25.8\%\ ZVI$$

Result:

1.34x more ZVI used in the test than reported in the report

Mistake 2: ZVI Calculation for PRB Design



- ConsultCo's Bid Team had to write an RFP to get bids from contractors.
- Remember how to calculate %ZVI?

$$\%ZVI = \frac{ZVI\ Mass}{Total\ Mass} = \frac{ZVI}{ZVI + Sand}$$

- How did the Bid Team calc it?

$$\%ZVI = \frac{ZVI}{Sand}$$

- Recall…the Bench Team:

$$Z\%ZVI = \frac{ZVI}{ZVI + Sand + Water}$$

Mistake 2: ZVI Calculation for PRB Design

Why does this mistake matter?

The ConsultCo Bid Team thought they were telling the Contractor:

$$\%ZVI = \frac{ZVI}{Sand} = \frac{188\ US\ tons}{942\ US\ tons} = 20.0\%\ ZVI$$

What they were actually telling the Contractor:

$$\%ZVI = \frac{ZVI}{ZVI+Sand} = \frac{188\ US\ tons}{942\ US\ tons + 188\ US\ tons} = 16.6\%\ ZVI$$

Result:

ConsultCo is telling Contractor to use 0.83 of the ZVI

Mistakes So Far:

- 25.8% - Bench Team said this was 20%
- 16.6% - Bid Team said this was 20%
- This is a difference of more than 1.5x

Mistake 3: Field Direction of DumbContractor

- ConsultCo awards the work to DumbContractor
- No one trusts DumbContractor, the RFP and Design Specs are written as follows:

2.06 ZVI AND SAND MIX BACKFILL

A. ZVI AND Sand Mix Backfill shall consist of homogeneous mixture of 20 percent Zero Valent Iron in Sand Backfill (dry weight basis). The Contractor shall mix ZVI and Sand on Site and the mix will be verified by the Engineer.

- The ZVI and sand “mix will be verified by the Engineer.”
- So who is this Field Engineer?
- The most junior person in the office

Mistake 3: Field Direction of DumbContractor

- VEI reviewed field notes to see how ConsultantCo's Engineer has directed DumbContractor to do the work.
- Field notes: SuperGreen Field Engineer of ConsultantCo has verified the proper blending rato of:
  - **3 super sacks of ZVI to 7 loader scoops of sand**
- CAT 930 loader specs = bucket capacity of
  - between 2.1 to 5.0 cubic meters (m^3)
  - between 4.2 MT to 10 MT of sand
- ZVI super sac = 1 MT
- 7 loader scoops of sand = 29.4 to 70 MT
- 3 super sacs of ZVI = 3 MT

Mistake 3: Field Direction of DumbContractor

Why does this mistake matter?

What the SuperGreen Field Engineer wanted tell DumbContractor:

$$\%ZVI = \frac{ZVI}{ZVI+Sand} = 20.0\%\ \text{ZVI}$$

What SuperGreen was actually telling the Contractor:

$$\%ZVI = \frac{ZVI}{ZVI+Sand} = \frac{3\ MT}{3\ MT + 70\ MT} = 4.1\%\ \text{ZVI}$$

$$\%ZVI = \frac{ZVI}{ZVI+Sand} = \frac{3\ MT}{3\ MT + 29.4\ MT} = 9.3\%\ \text{ZVI}$$

Result:

ConsultCo is telling Contractor to use 0.2 to 0.46 of the ZVI

Mistakes So Far:

- 25.8% - Bench Team
- 16.6% - Bid Team
- 4.1% - Field Engineer
- 20.0% - what they all thought

Surely these errors were caught in the field with proper QA/QC

…..onto Mistake 4

Mistake 4: Quality Assurance / Quality Control (QA/QC) Testing

- Magnetic testing is typically conducted real-time in the field once the ZVI and sand are mixed, and usually before the mixture is placed into the PRB, to verify the %ZVI
- ConsulantCo's magnetic testing was **not functioning properly**
- And no secondary verification of %ZVI was used
  - e.g. count the number of ZVI super sacs left

A Permeable Reactive Barrier (PRB) Horror Story: Cumulative Mistakes

- Standard of Care was not met for a 20% ZVI PRB
  - Bench-work: tested **25.8% ZVI**
  - Bid Team: wrote in **16.6% ZVI**
  - Field Engineer: directed as low as **4.1% ZVI**
  - QA/QC testing: **none**

- Technical Result: Significant underdosing of ZVI in the PRB
- Business Result: ConsultCo is in a law-suit, its not looking good

- How to avoid:
  - Integrate entire team, so each can check others work
  - The devil is in the details – double check key assumptions (e.g. % ZVI)
  - Properly train, and prepare, and check your field staff
  - *Actually* do QA/QC in the field

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Case Study 2

Emerging Contaminant (PFAS) in a Complex Treatment Situation

PFAS in a Complex Treatment Situation

- Industrial client accidentally released PFAS to sewer system
- A lagoon in the local municipal wastewater treatment plant (WWTP) was affected
- Remediation of this WWTP lagoon was required
- But the lagoon water also had:
  - High Total Suspended Solids (TSS)
  - High Dissolved Organic Compounds (DOC)
  - Petroleum Hydrocarbons
  - …and who knows what else
- Problems:
  - PFAS is an emerging contaminant. How to treat?
    - DOC was dominant in the water matrix
    - Could PFAS rollover from adsorptive media be significant?

PFAS in a Complex Treatment Situation

- Total PFAS concentrations were about 200 ng/L
- Technologies considered:
  - Ion Exchange (IX) and Reverse Osmosis (RO)
    - but Lagoon water expected to lead to fouling problems
  - Granular Activated Carbon (GAC), selected
  - Modified Clay Amendment, Fluoro-Sorb®, selected
  - Foam fractionation, selected
- Ultimately adsorption was most practical at full-scale:
  - VEI worked with media suppliers for estimates
  - Bench-scale testing: To confirmed media capacity

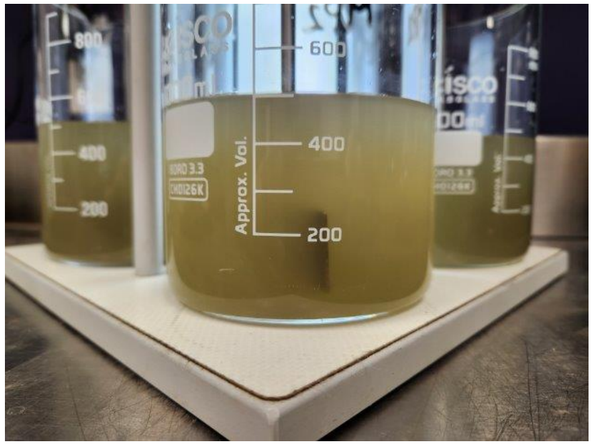
PFAS Bench-Scale Testing – Batch Reactors

Step 1) Upfront Solids Removal

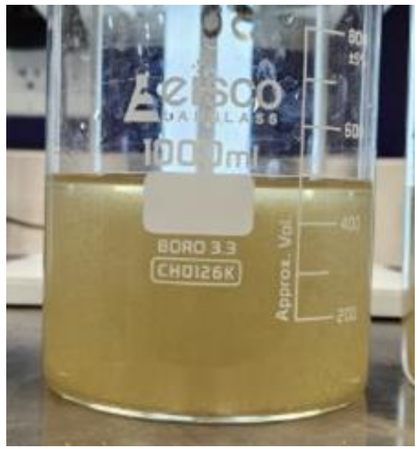
Variety of chemical coagulants and flocculants were tested at a range of doses

Objective is TSS & DOC reduction (TSS = Total Suspended Solids, DOC = Dissolved Organic Carbon)

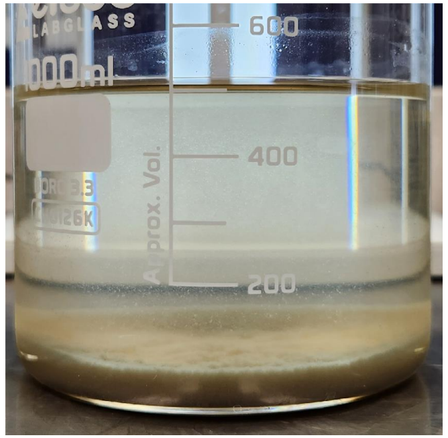
Original Lagoon Water



Coagulant



Coagulant (after 5 min)



Flocculant (after 1 min)

Results:

Turbidity from 100 FAU to 0 FAU after 60 min settling time

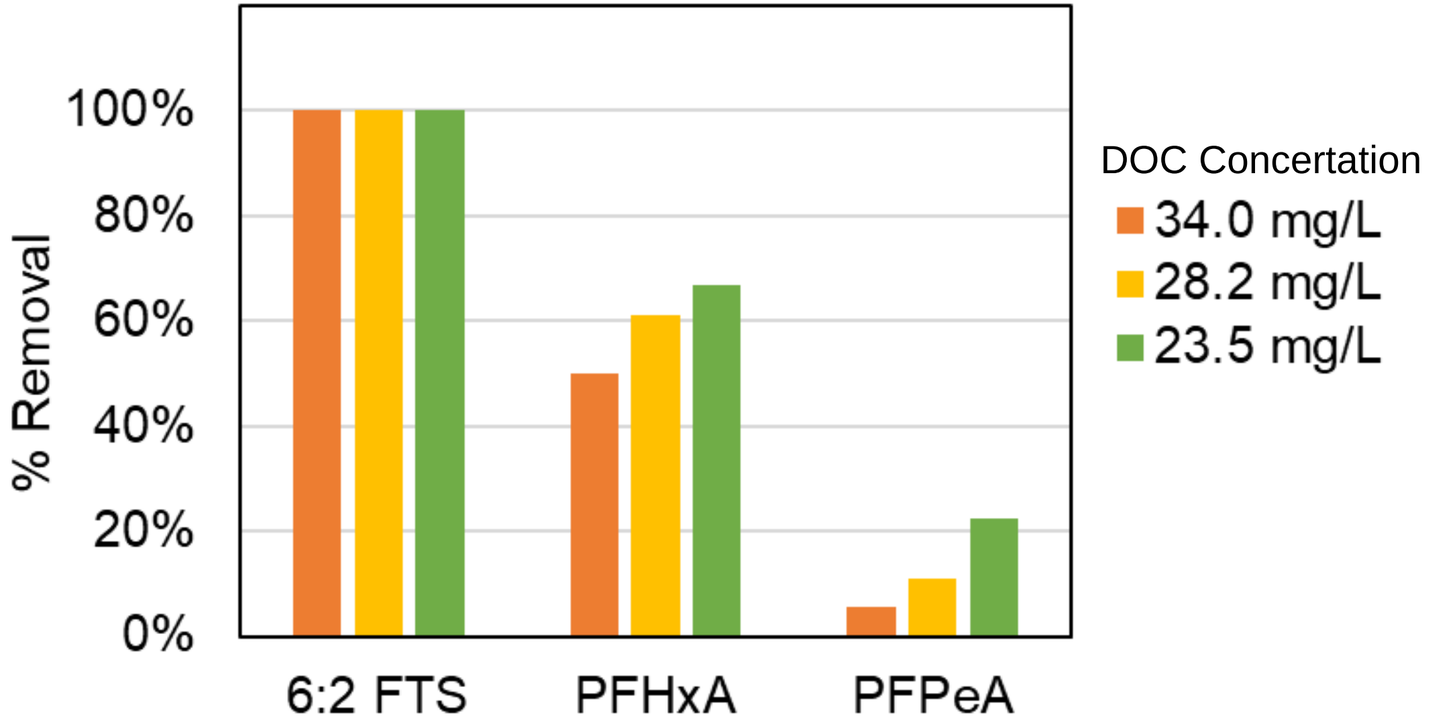
31% decrease in DOC concentrations (34 mg/L to 23.5 mg/L)

PFAS Bench-Scale Testing – Batch Reactors

Step 1) Upfront Solids Removal

PFAS Removal at different DOC (dissolved organic carbon) concentrations

Concentration Comparison
23,500,000 ng/L to 34,000,000 ng/L DOC vs 200 ng/L PFAS



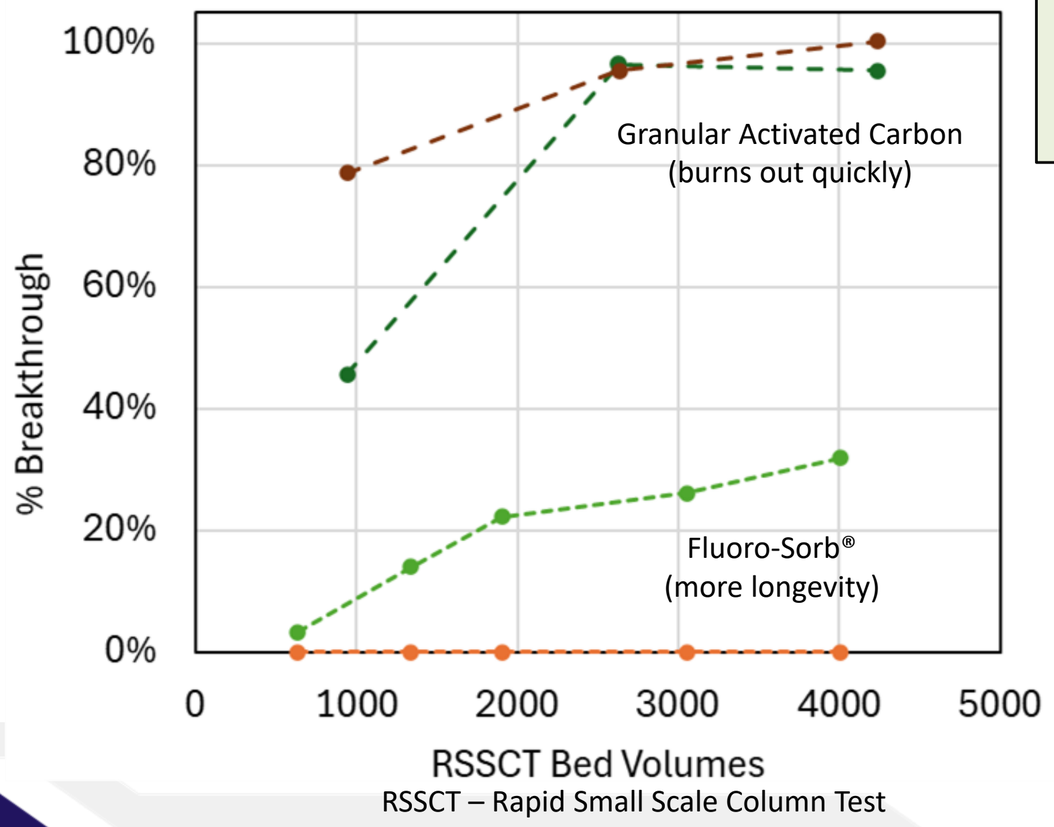
Only 6% reduction in PFPeA concentrations at 34 mg/L DOC

PFAS Bench-Scale Testing – Column Study (RRSCT)

Step 2) Dissolved Phase Treatment

Bench-Scale Column Tests (RSSCT - Rapid Small Scale Column Test)

Assessing Activated Carbon vs Modified Clay (Fluoro-Sorb®)



RSSCT – Rapid Small Scale Column Test

Results:

- Fluorosorb significantly outperformed GAC
- But the complex water chemistry led to both media under-performing expectations

PFHxA - GAC	Granular Activated Carbon
6:2 FTS - GAC	Granular Activated Carbon
PFHxA - FS	Fluoro-Sorb® (Modified Clay)
6:2 FTS - FS	Fluoro-Sorb® (Modified Clay)

PFAS in a Complex Treatment Situation: Bench-Scale Results

Activated Carbon

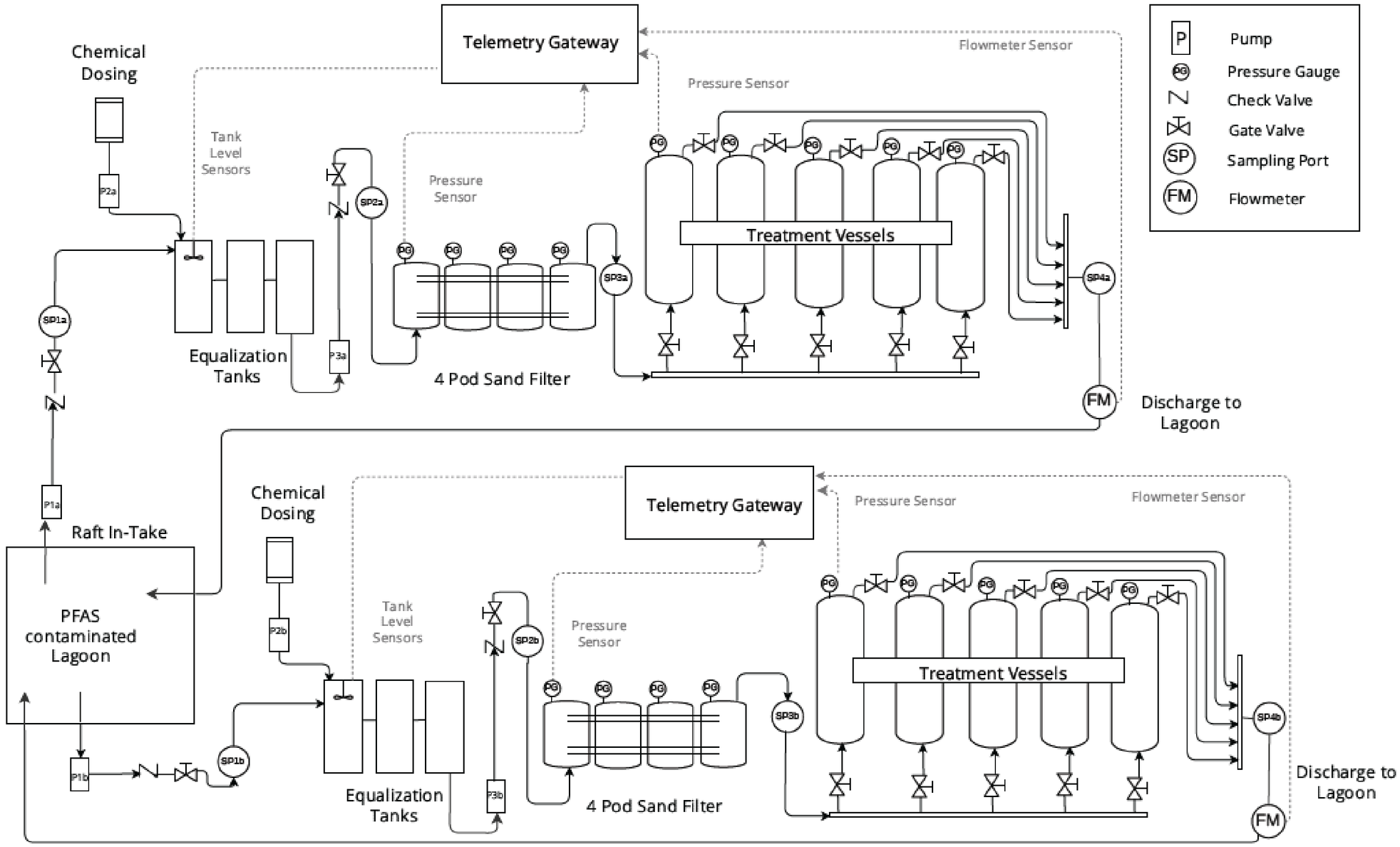
Modified Clay
(Flurosorb)

- Activated carbon was not used in the final full-scale design
  - GAC was not economically viable (it burns out too quickly)
- And the full-scale design for the modified clay changed significantly

- Without considering bench results, the original design estimated:
  - 11,000 lbs (5,000 kg) of Fluoro-Sorb®
  - 750 litres per minute treatment flow
- After bench-scale testing:
  - 392,000 lbs (178,000 kg) of Fluro-Sorb®
  - 2,200 lpm treatment flow
- Actual results:
  - 320,000 lbs (145,000 kg) of Fluro-Sorb®
  - 2,200 lpm treatment flow

This is **35 times** as much media

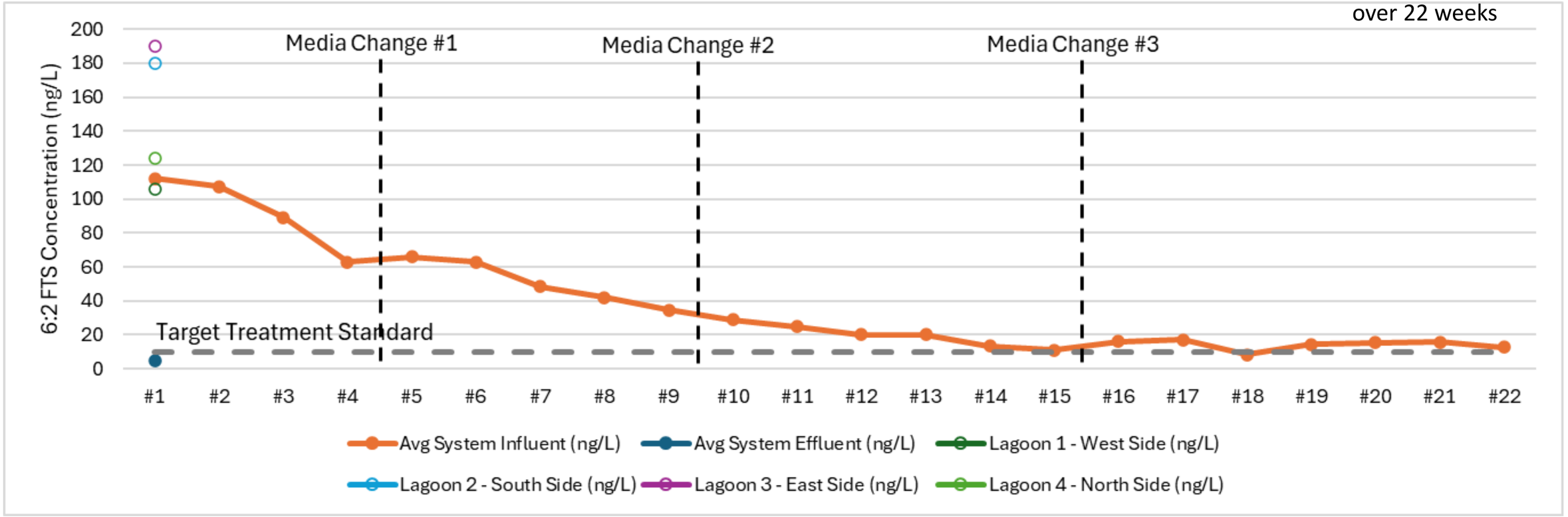
PFAS Full-Scale Design

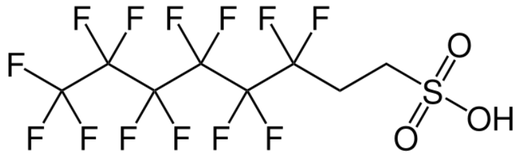


PFAS Full-Scale Installation

PFAS Full-Scale Results – 6:2 FTS

650,000,000 L treated
over 22 weeks





PFAS Full-Scale Results – 6:2 FTS

650,000,000 L treated
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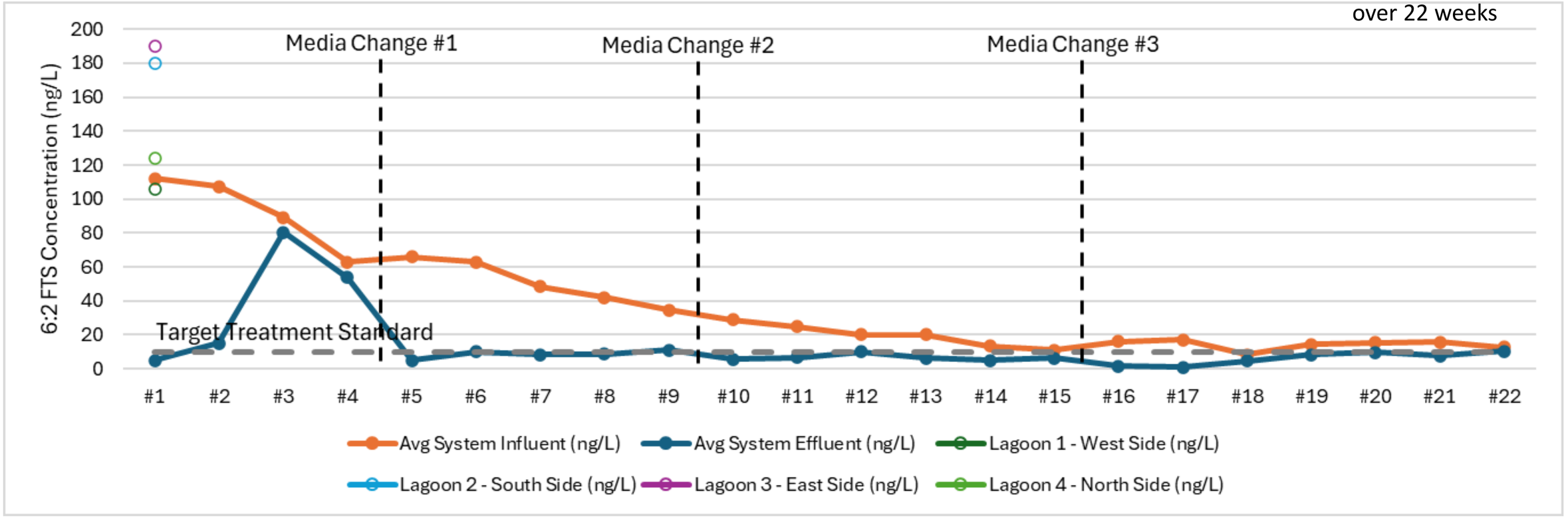
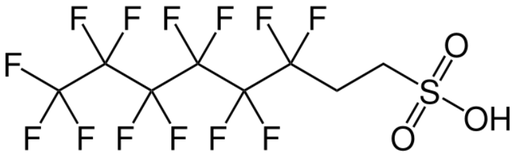
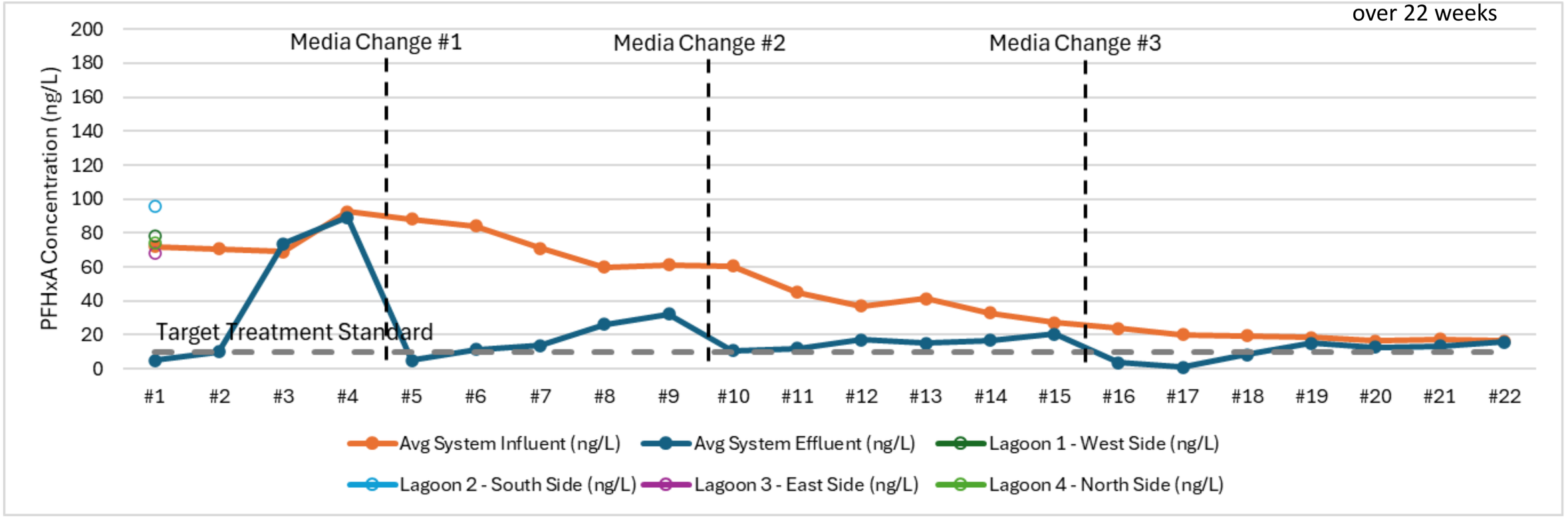
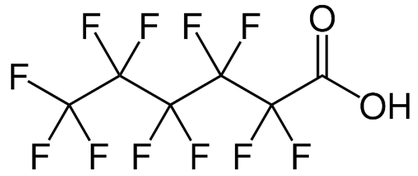




PFAS Full-Scale Results – PFHxA

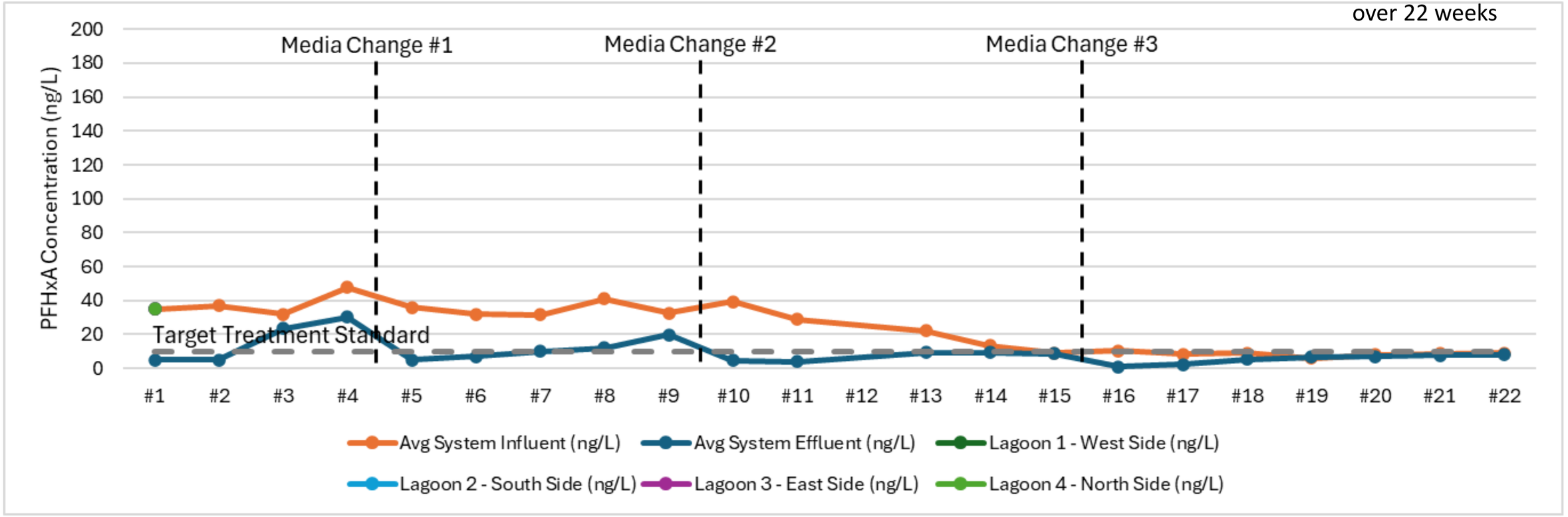
650,000,000 L treated
over 22 weeks

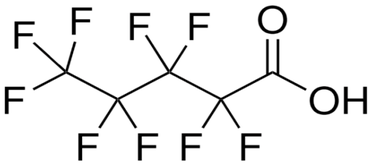




PFAS Full-Scale Results – PFPeA

650,000,000 L treated
over 22 weeks





PFAS in a Complex Treatment Situation: Summary

- Bench-scale batch reactors helped to define:
  - DOC and PFAS interactions
  - PFAS roller over challenges
- Bench-scale column testing:
  - Helped to define type of media to use
  - Set expectations for full-scale operations
- Full-Scale was successful because of the bench testing
  - And the work was ultimately completed under budget

Modified Clay
(Flurosorb)

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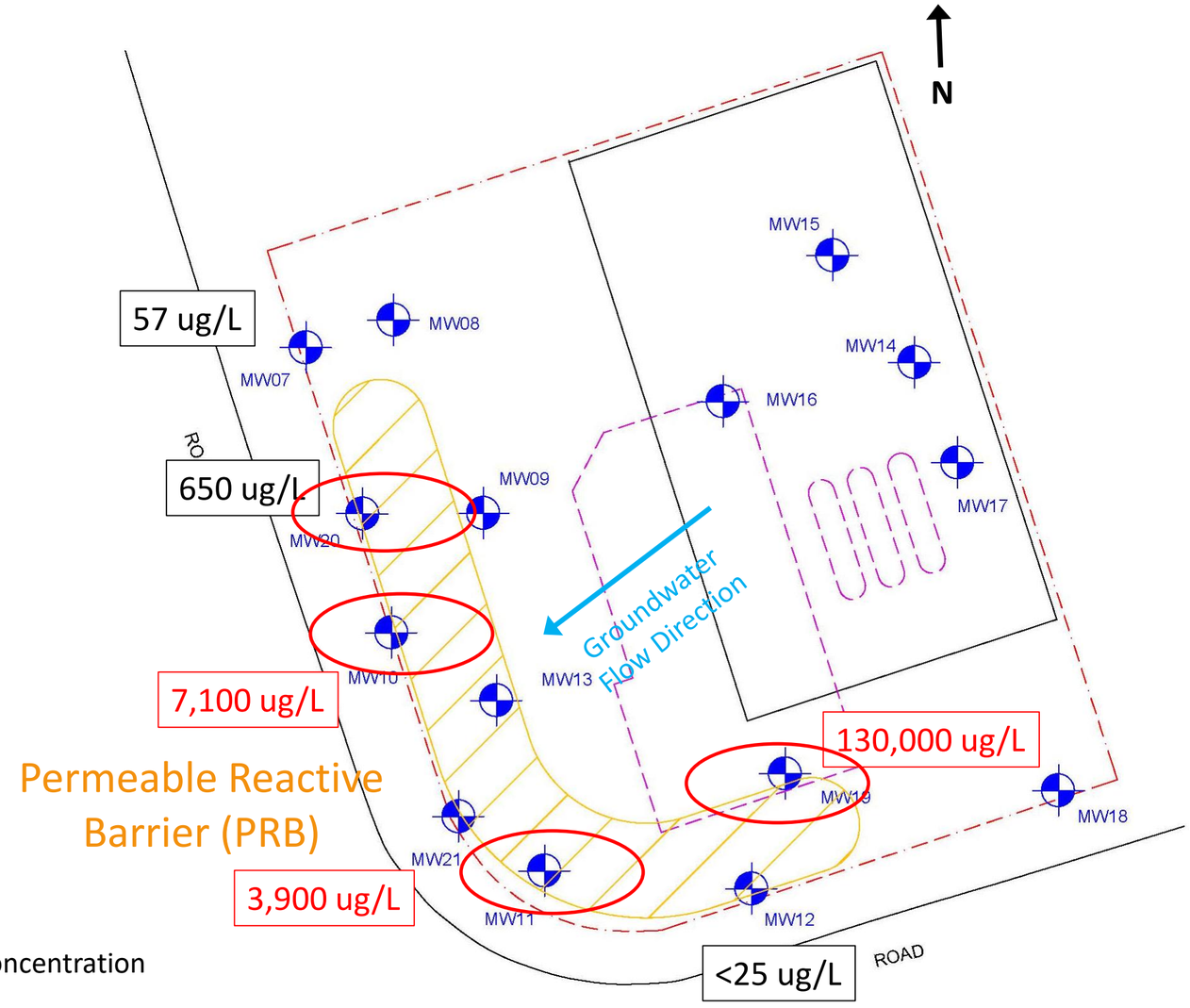
Case Study 3

Another Horror Story: PRB for PHCs With No Upfront Work

A Horror Story: PRB for PHCs With No Upfront Work

- Commercial Site
- Former gas station
- PHC(F1) concentrations aren't high…but:
- PHC(F1) is 130,000 ug/L on-site, and
- Light Non-Aqueous Phase Liquid (LNAPL) was noted during drilling (in the BH logs)
- A contractor proposes a PRB using colloidal carbon, and,
- Proposes no upfront bench-scale or pilot-scale testing

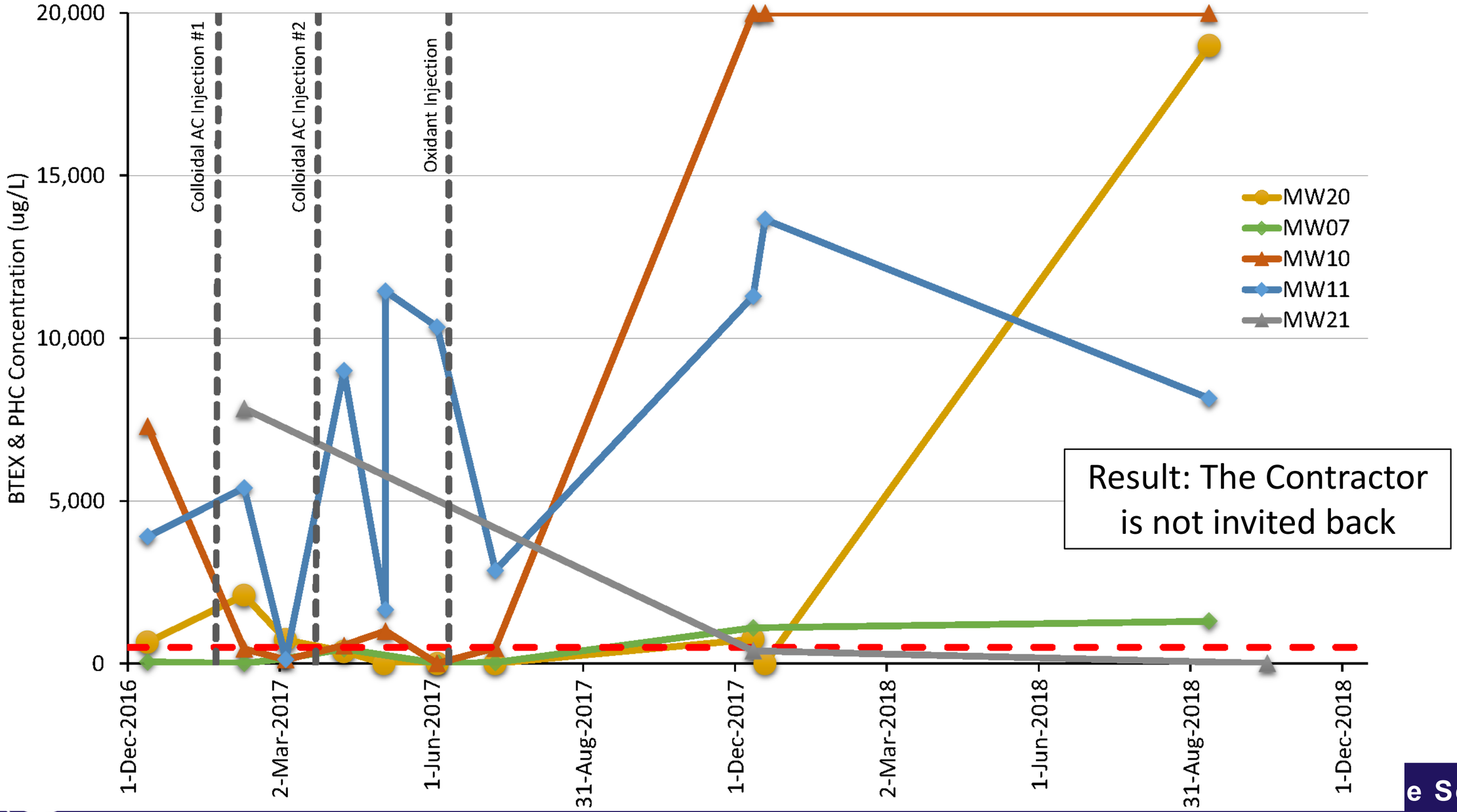


Legend

57 ug/L — PHC(F1) Concentration

LNAPL Noted in BH Logs

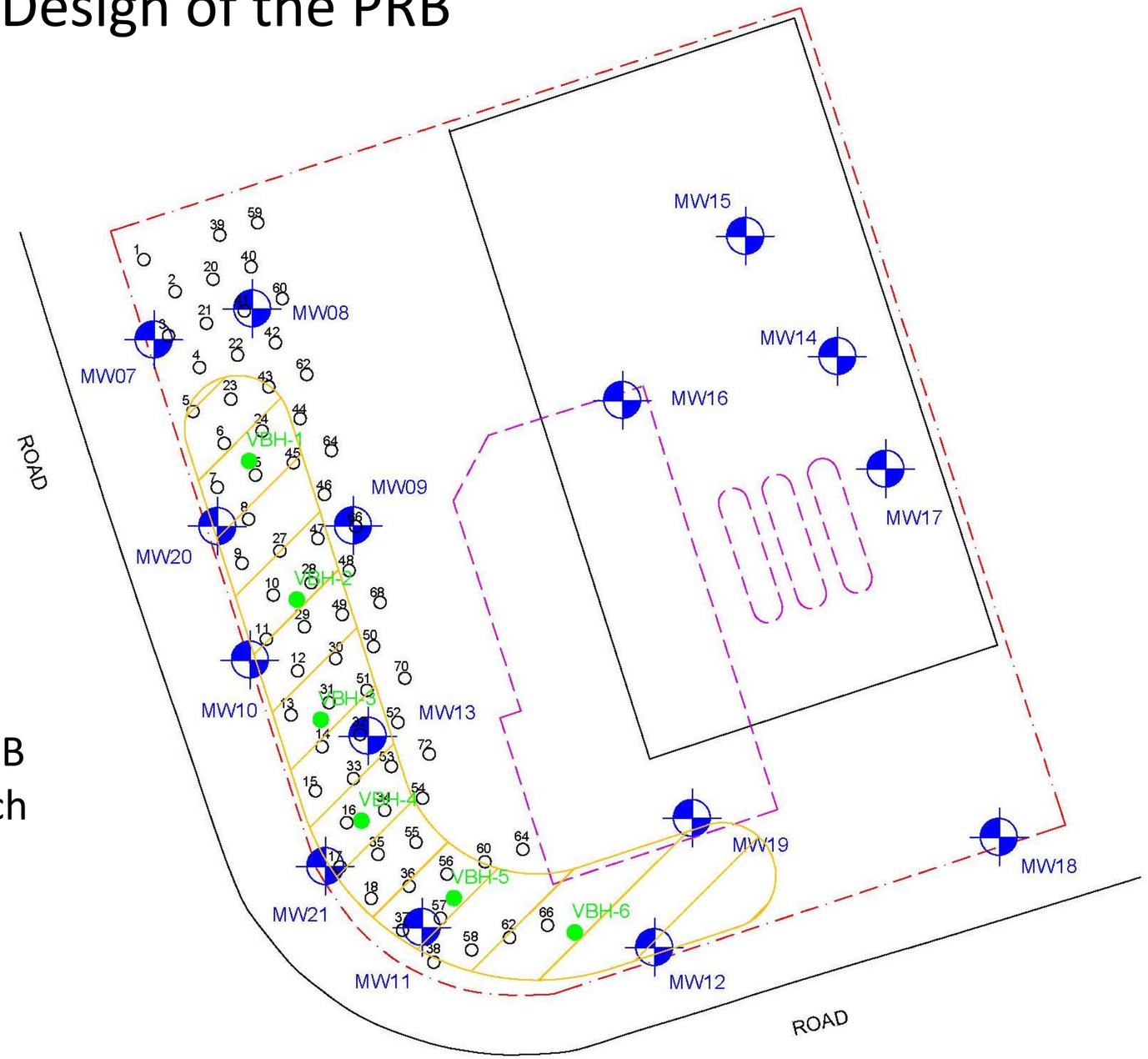
A Horror Story: PRB for PHCs With No Upfront Work



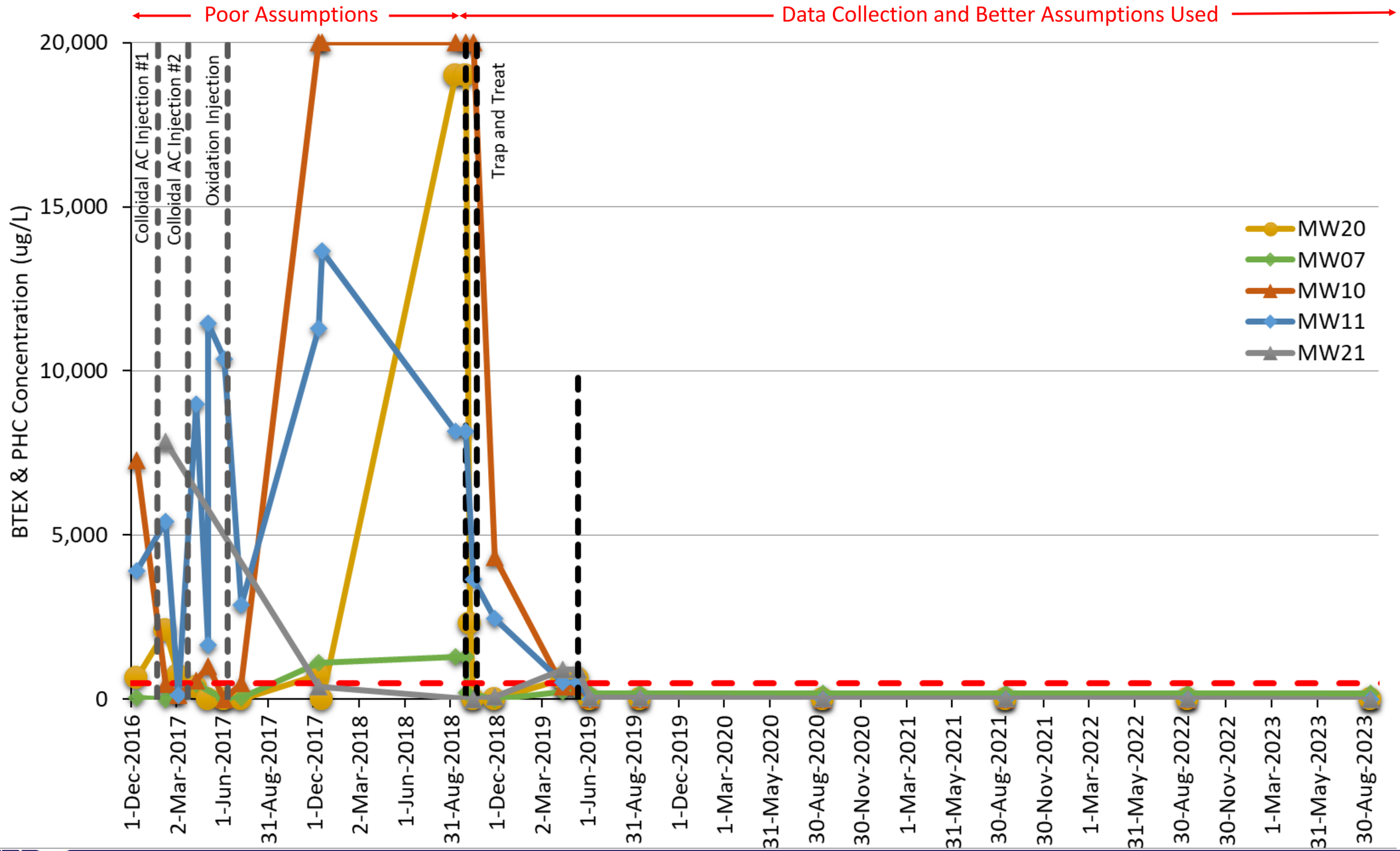
Result: The Contractor is not invited back

Proper Design of the PRB

- VEI now involved
- Remedial Design Characterization (RDC)
- Six (6) boreholes, 1 day of work
- 27 soil samples
  - Detailed analysis of PHCs with depth
- 12 groundwater samples
- Allowed for detailed understanding of PHC contaminated zones
- Permeable Reactive Barrier Design
- Designed and implemented a more robust PRB using an activated carbon product that is much more robust: Trap and Treat, BOS200



A Turn Around Story: Proper PRB Design



A Horror Story: PRB for PHCs With No Upfront Work

- If LNAPL is mentioned, take extreme caution
  - The groundwater concentrations seemed OK, but the ground was heavily contaminated. The LNAPL was hidden.
- Know your technology design and your amendments
  - Do not underdose – colloidal carbon has low total AC mass
  - Design, plan and inject the amendment properly
- Have a budget for upfront work
  - Bench-scale work can save you in the long run
  - Remedial Design Characterization (RDC) is important
  - Pilot-scale testing is also very valuable

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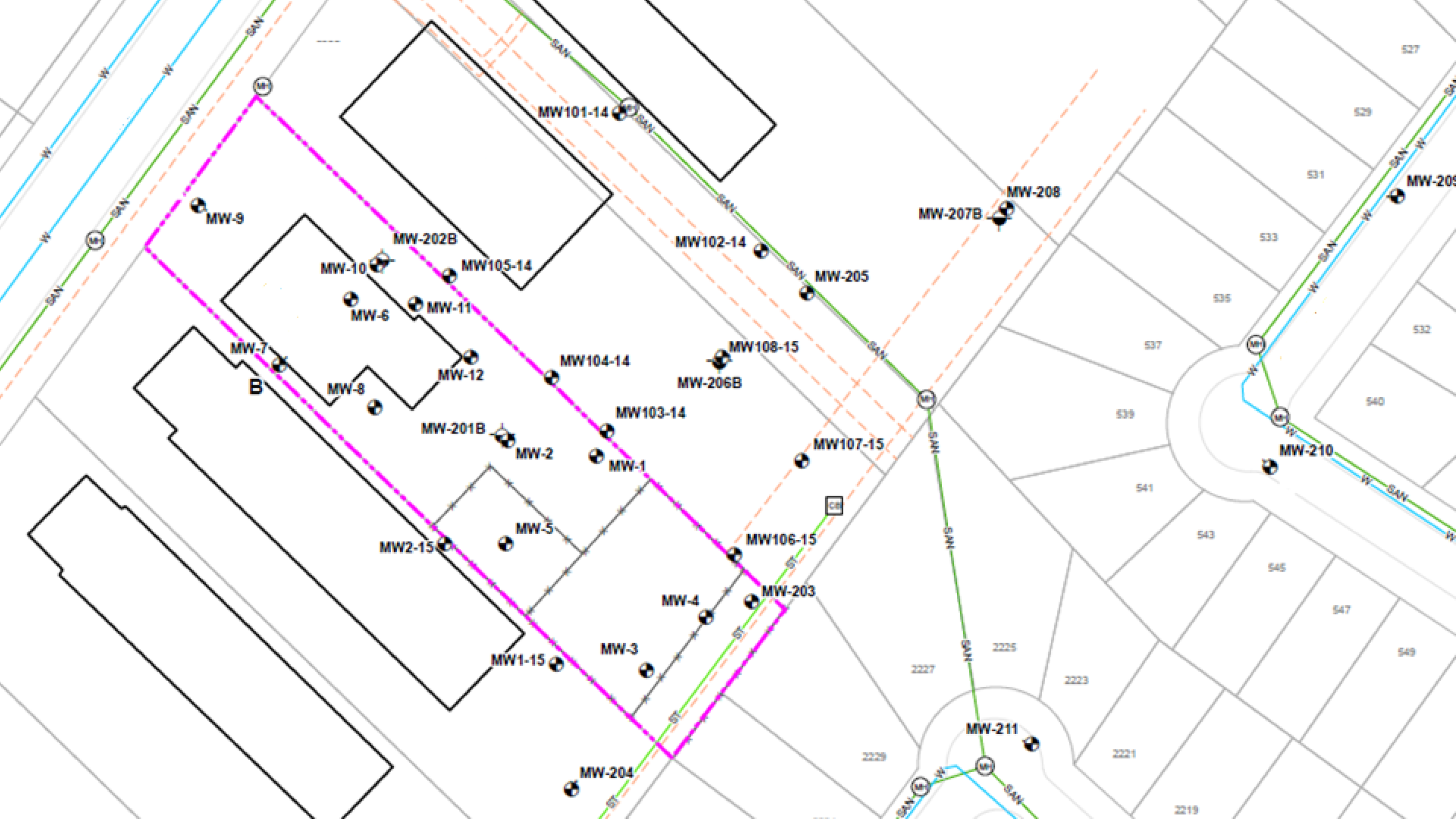
Case Study 4

Bench- and Pilot-Scale Testing For Heavy Metals Treatment in Bedrock

Heavy Metals Treatment in Bedrock

- Chrome plating facility has a hex chrome plume migrating off-site
- Groundwater in bedrock
- Very high gw concentrations:
  - 2,300,000 ug/L Hex Chrome
  - 140 ug/L – the Standard
- High pressure on client, due to neighbours and the Ministry
- How to treat these concentrations in bedrock?

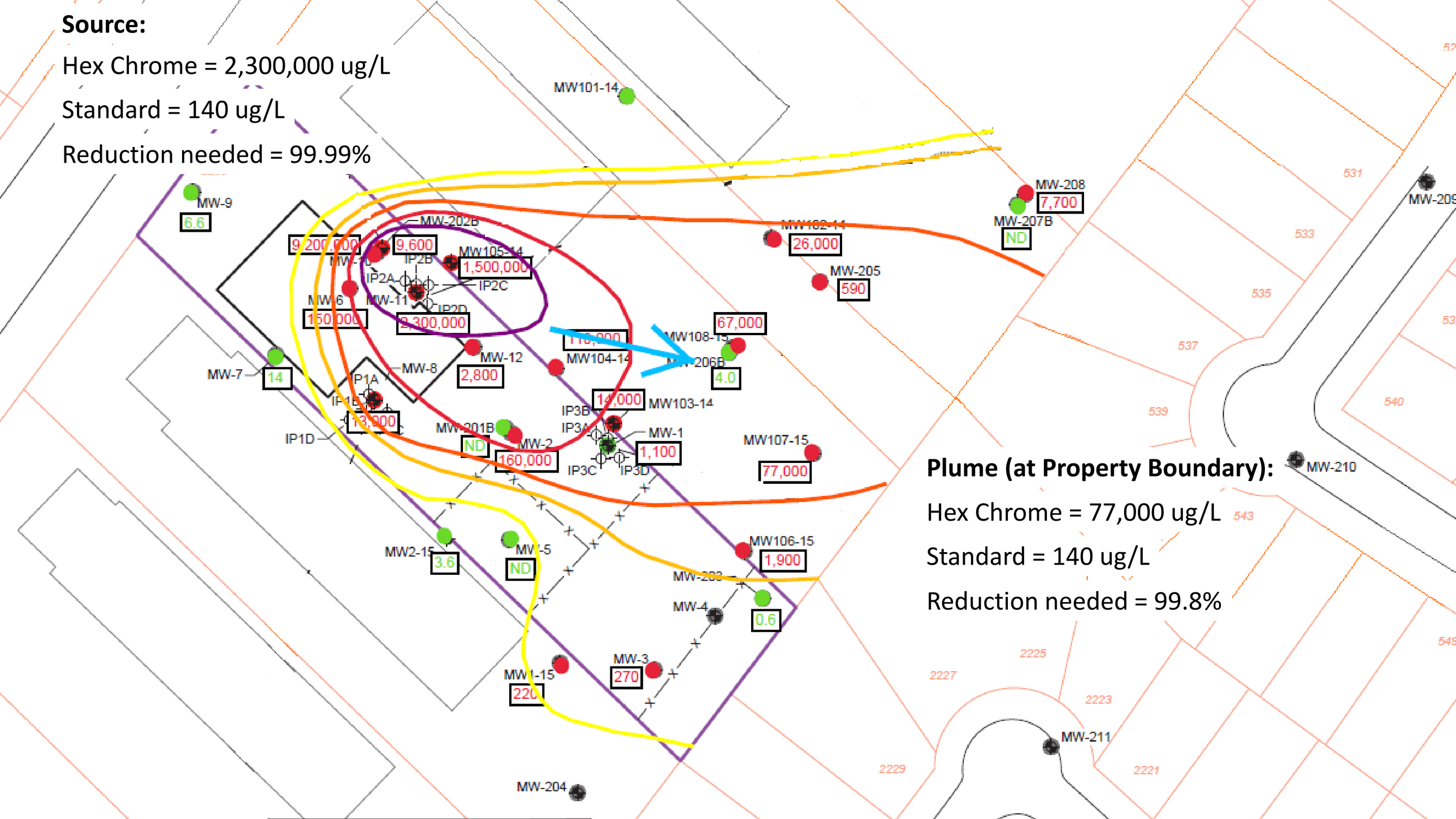

MW-9
MW-202B
MW-10
MW105-14
MW-6
MW-11
MW-7
MW-12
MW-8
B
MW-201B
MW-2
MW-1
MW2-15
MW-5
MW1-15
MW-3
MW-4
MW-204
MW101-14
MW102-14
MW-205
MW-207B
MW-208
MW104-14
MW108-15
MW-206B
MW103-14
MW107-15
MW106-15
MW-203
MW-211
MW-210
MW-209
SAN
W
ST
527
529
531
533
535
537
539
540
532
541
543
545
547
549
2225
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

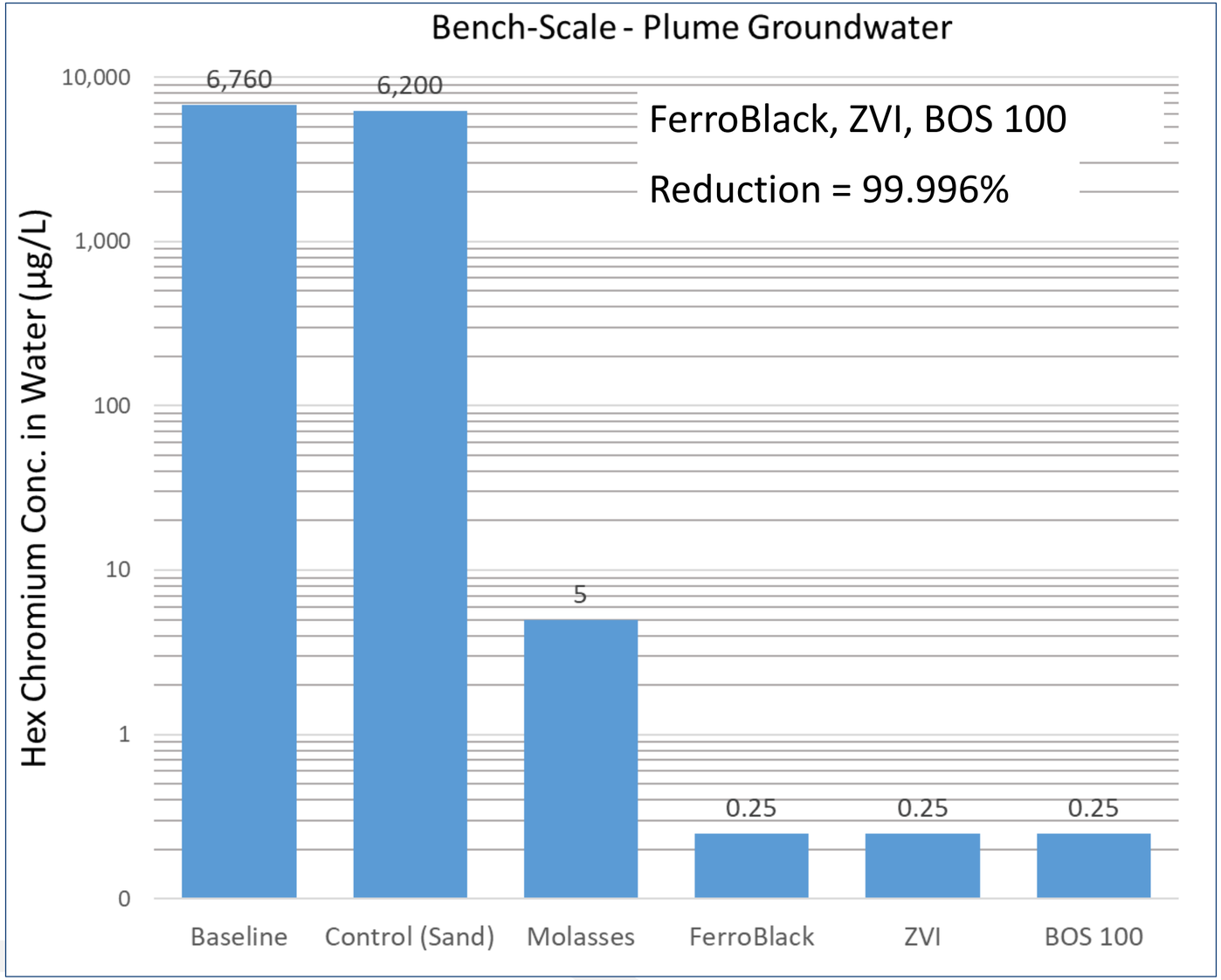
Reduction needed = 99.8%

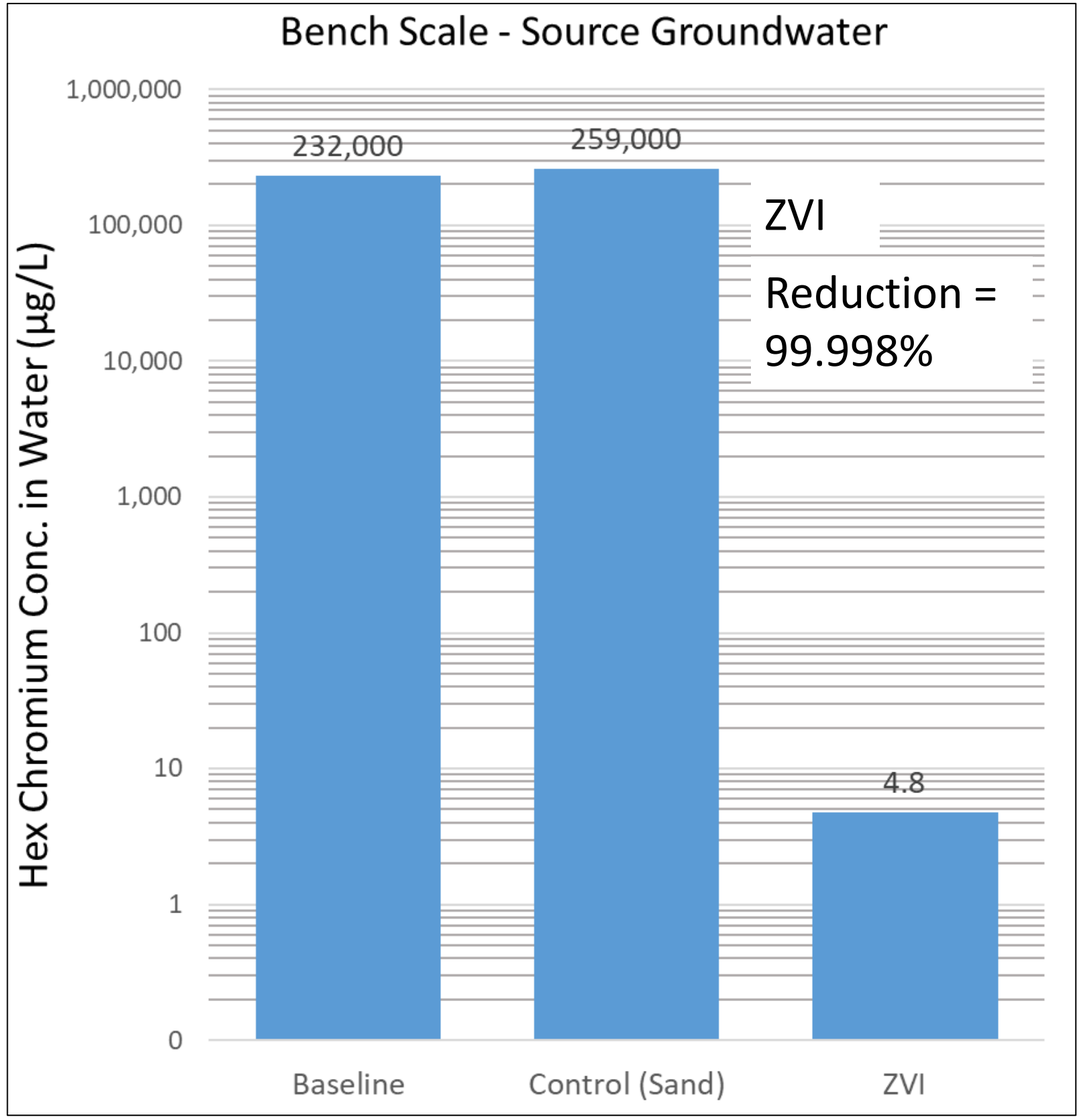
Bench-Scale Testing – Batch Reactors

<u>Remediation Amendments Tested</u>

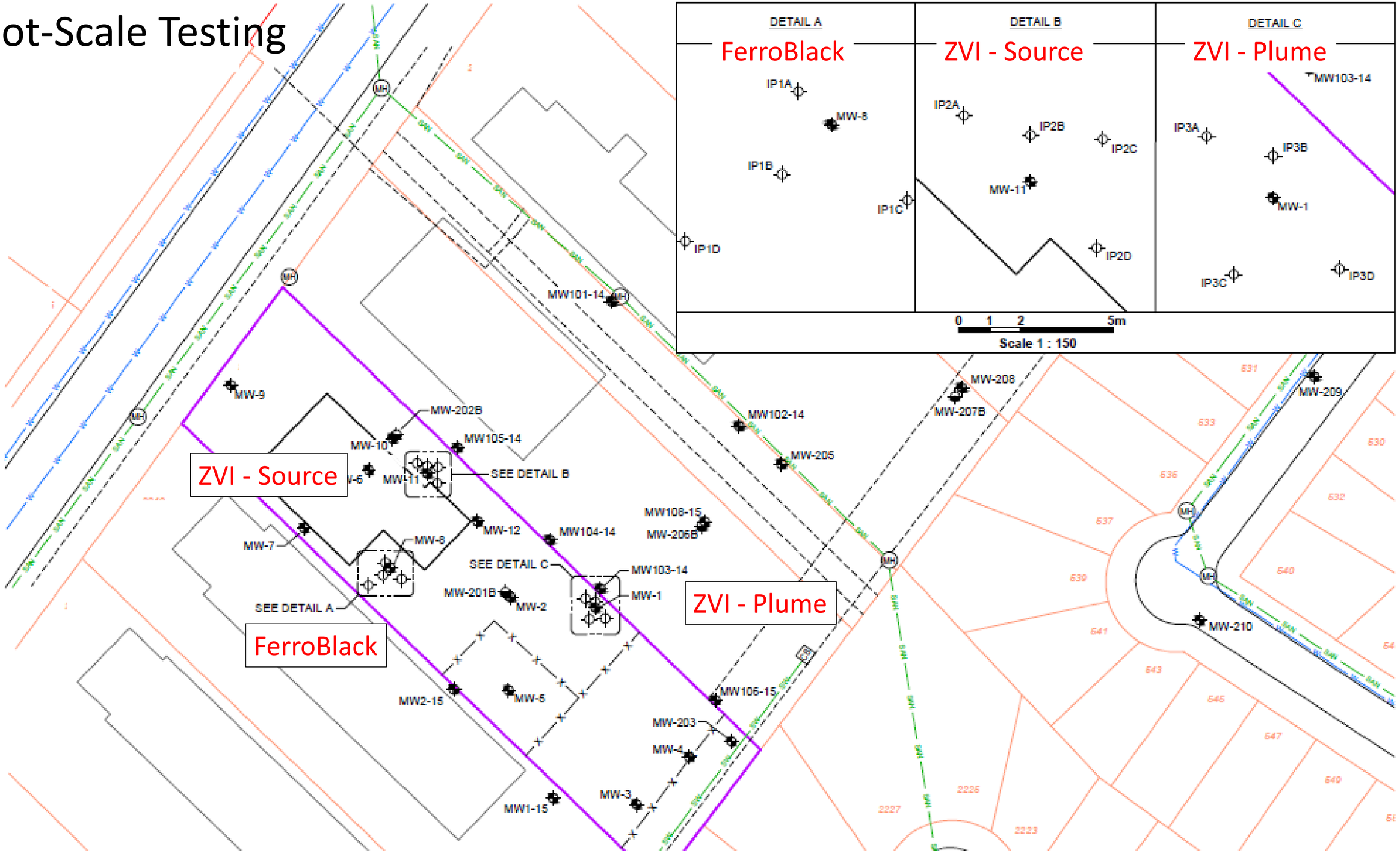
- Molasses
- FerroBlack®
- Zero Valent Iron (ZVI)
- Trap & Treat® BOS 100®

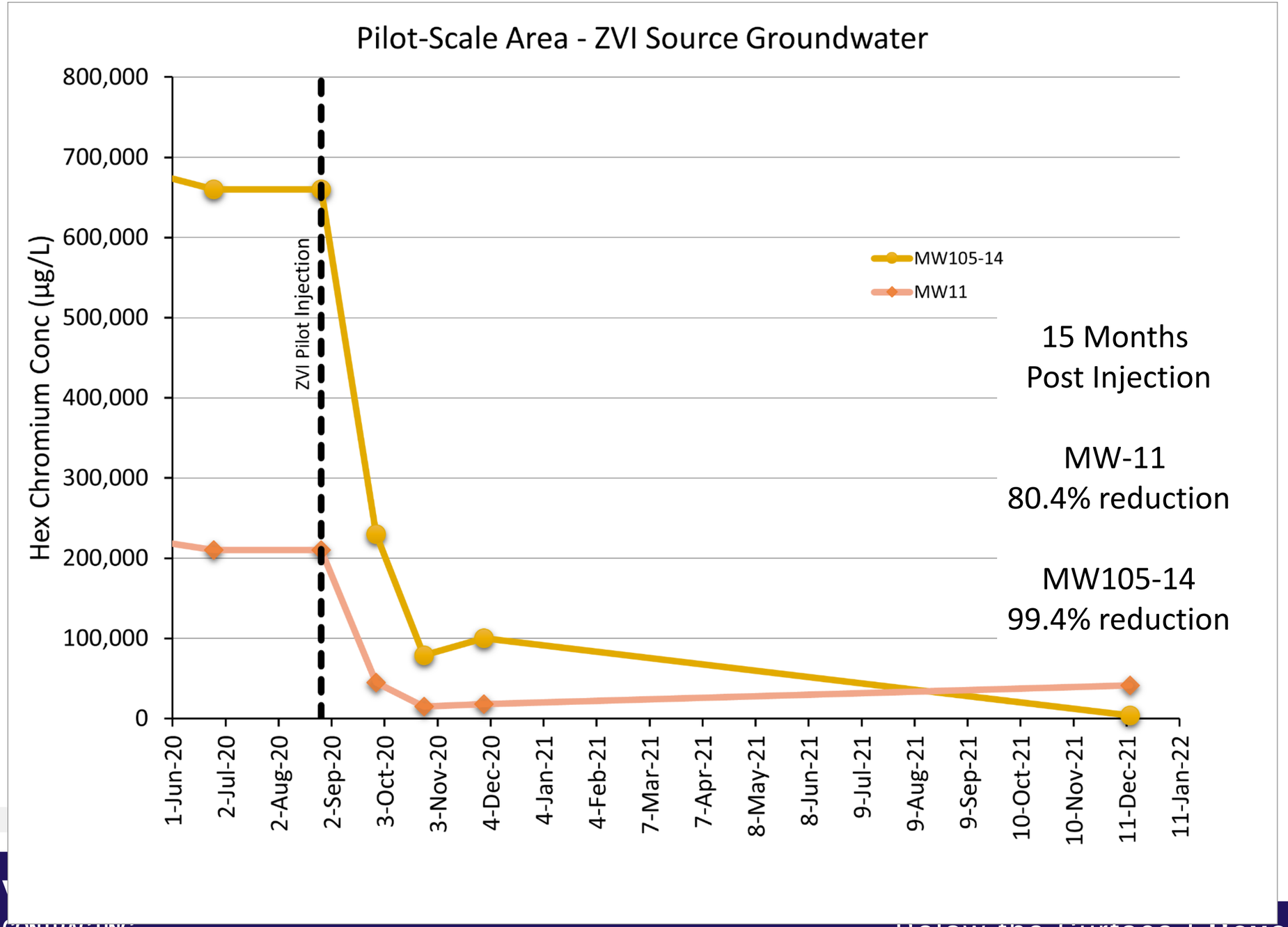
Bench-Scale Testing – Batch Reactors

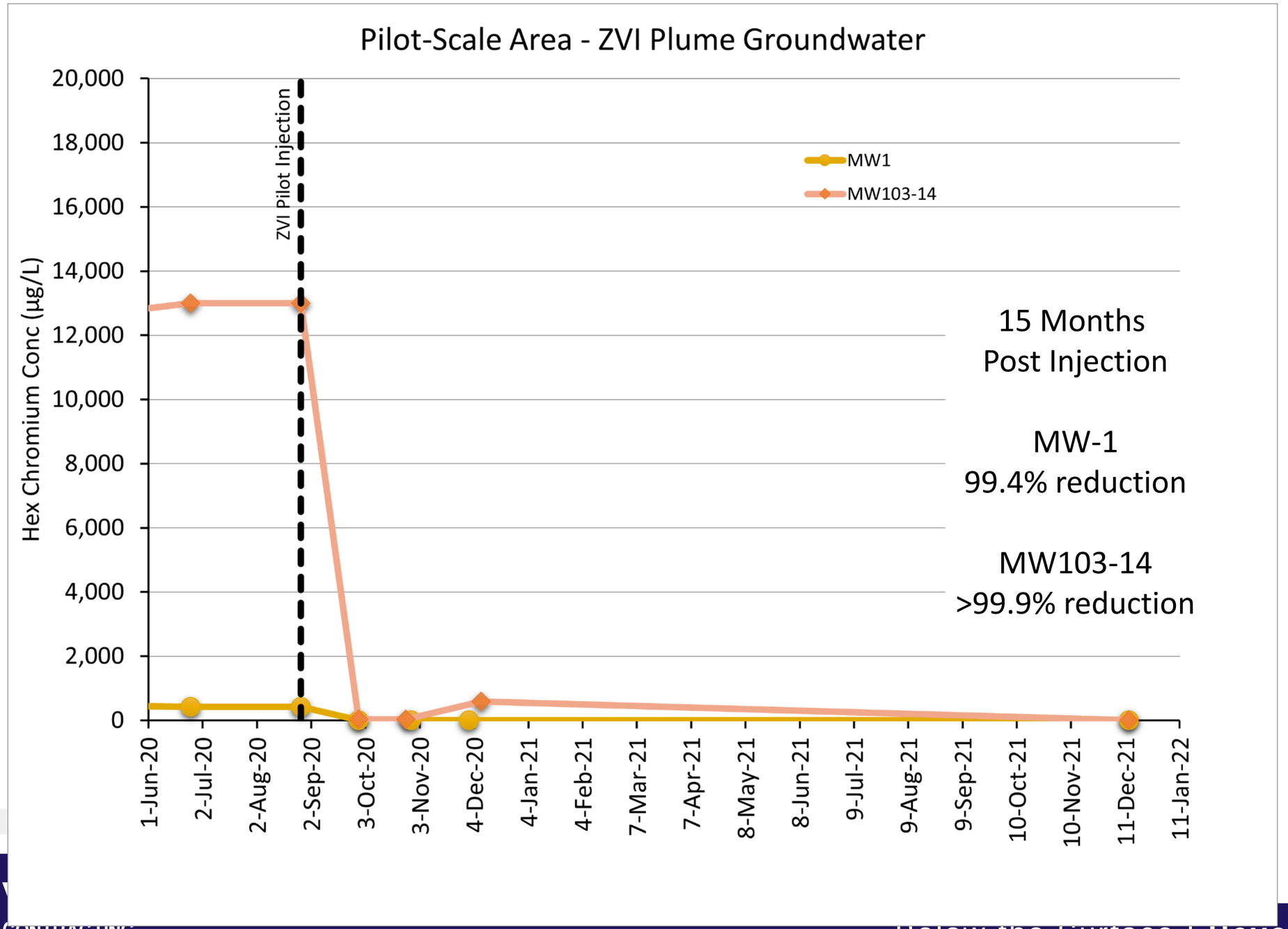




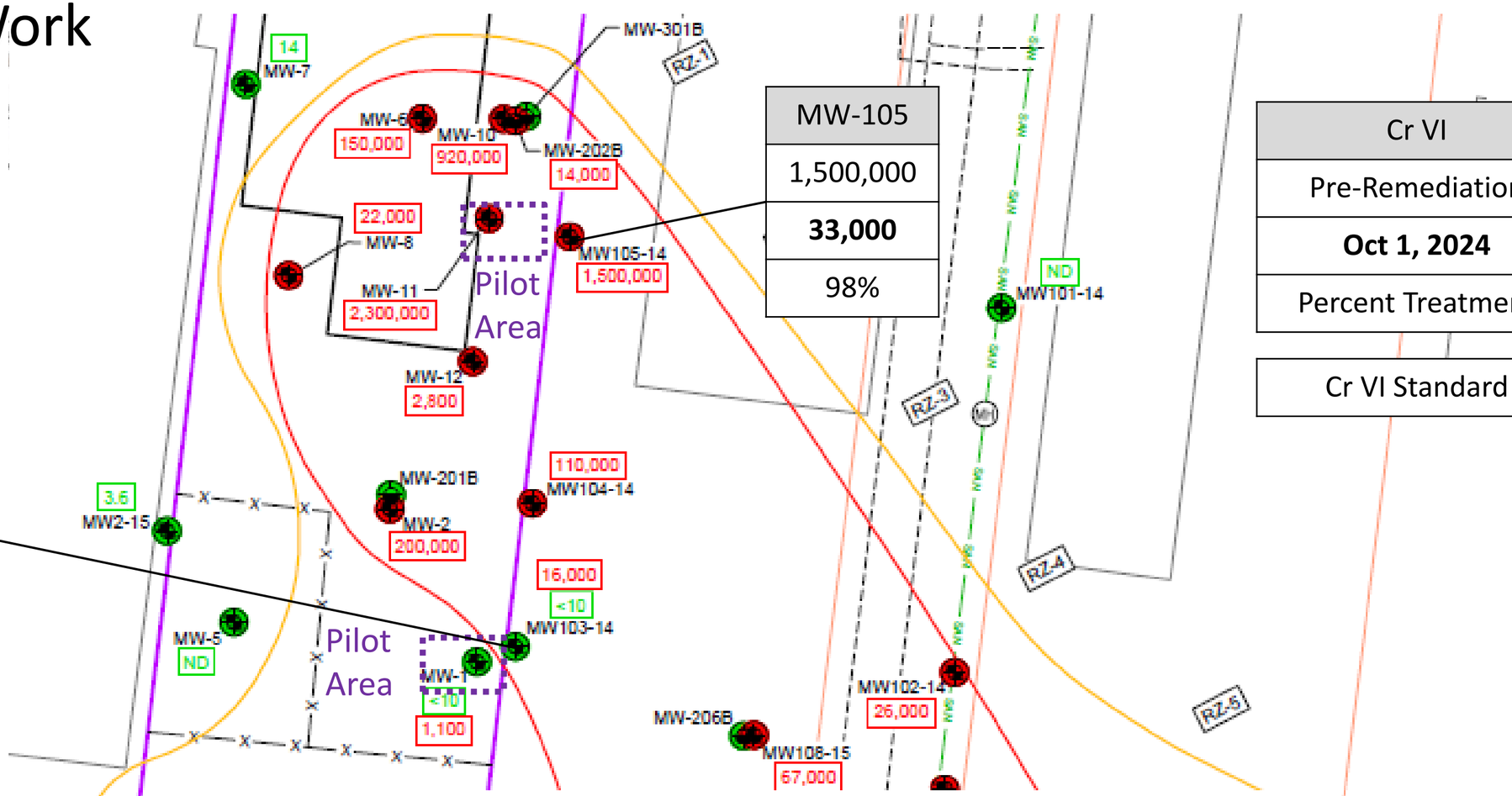
Pilot-Scale Testing




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
ZVI Pilot Injection
MW105-14
MW11
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
15 Months
Post Injection
MW-11
80.4% reduction
MW105-14
99.4% reduction


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 Work



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

MW-103
16,000
440
97%

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-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%

No Hex Chrome leaving the Site

Heavy Metals Treatment in Bedrock

- Recommendation: Spend the time to understand:
  - Treatment mechanisms
  - What amendment to use
  - How to inject at your site
- Bench-scale, pilot-scale and phased full-scale work completed
- And we have a happy Ministry of the Environment

Take Aways

Take Aways

- At the start of a project assess your unknowns.
- Allow time for bench-scale and pilot-scale testing.
- Lessons Learned:
- Case Study 1 [%ZVI for PRB]:
  - Check your teams' calculations. Train your field staff.
- Case Study 2 [PFAS in lagoon]:
  - Run bench-scale tests for emerging contaminants, especially in complex environments. We used simple bench tests to define full-scale.
- Case Study 3 [Colloidal Carbon PRB for PHCs (LNAPL)]
  - Bad assumptions may result in total remediation failure.
- Case Study 4 [Heavy metals in bedrock]:
  - Careful bench & pilot work = successful full-scale & a happy Ministry

VEI CONTRACTING

Presenter

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Environmental Engineer, President of VEI

Questions?

Thank You for
Your Time

Bruce Tunnicliffe

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