Where Did the Amendment Go?
Using Multiple Techniques to Monitor Injection Effectiveness.

RemTech Presentation

October 11, 2018

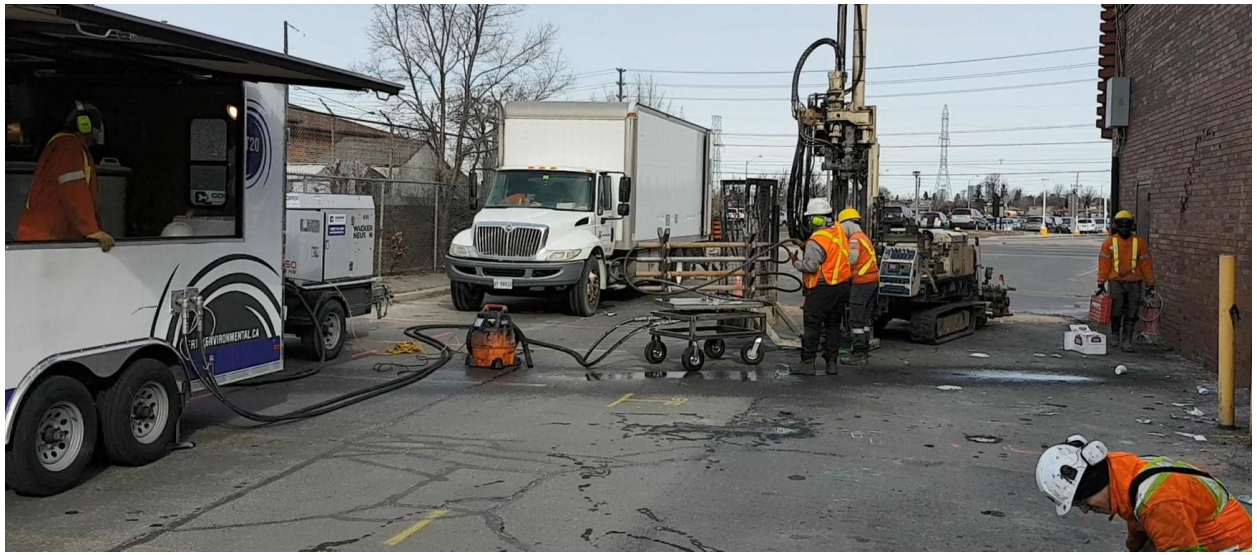
Nathan Lichti, B.A.Sc., P.Eng.
Vertex Environmental Inc.

Introduction – Agenda

- Introduction
- Background
  - Injection Challenges
  - How Can You Monitor Effectiveness?
- Case Studies
  - Active Dry Cleaner Site
  - ZVI PRB Case Study
- Conclusions

Introduction – Vertex

- Nathan Lichti, B.A.Sc., P.Eng.
  - Environmental Engineer
  - University of Waterloo, Canada
- Vertex Environmental Inc.
  - Environmental Contractor
  - Remediation services across Canada

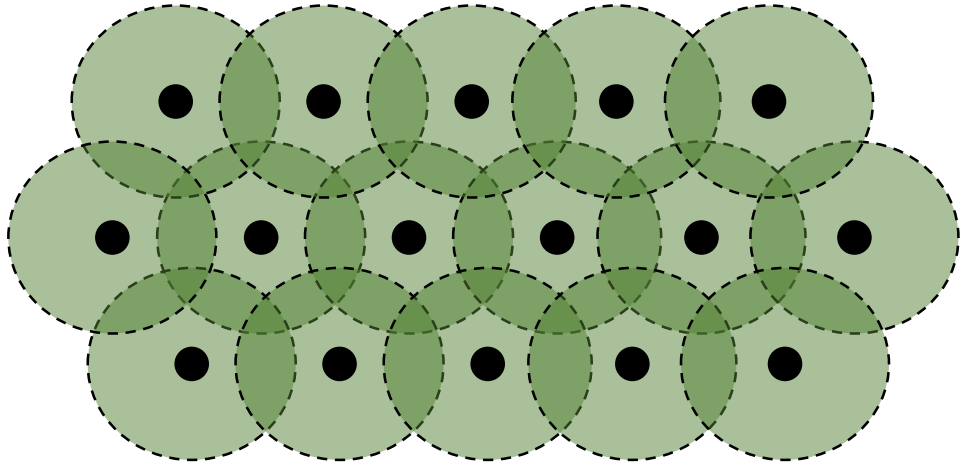


Background – Injection Challenges

Background – Injection Challenges

The Goal:

- Uniform Distribution
- Intimate contact between injectants and contaminants



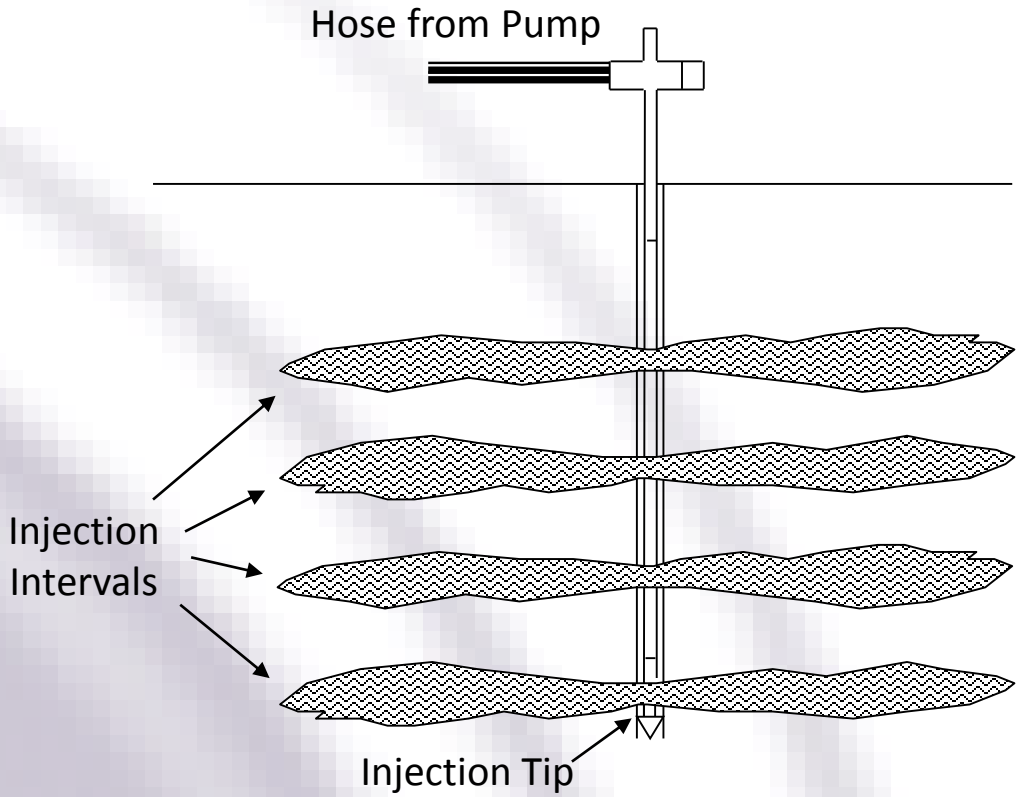
The Challenges:

- Matrix variation
- Preferential pathways & daylighting
- Improper injection design
- Hydraulic push/plume spreading
- Drilling refusal

Background – Injection Challenges

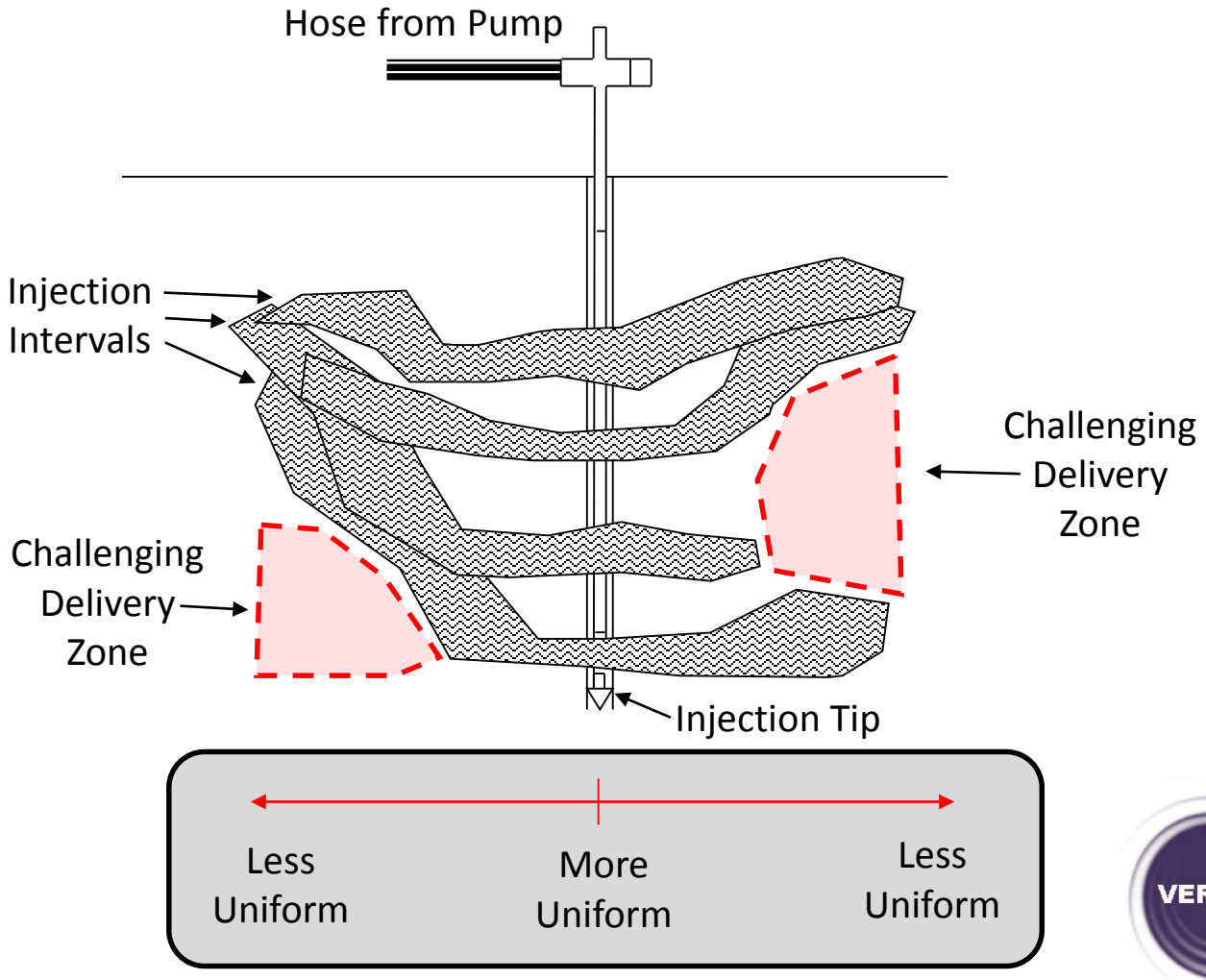
Theoretical Delivery:

- Single Injection Location



Actual Delivery:

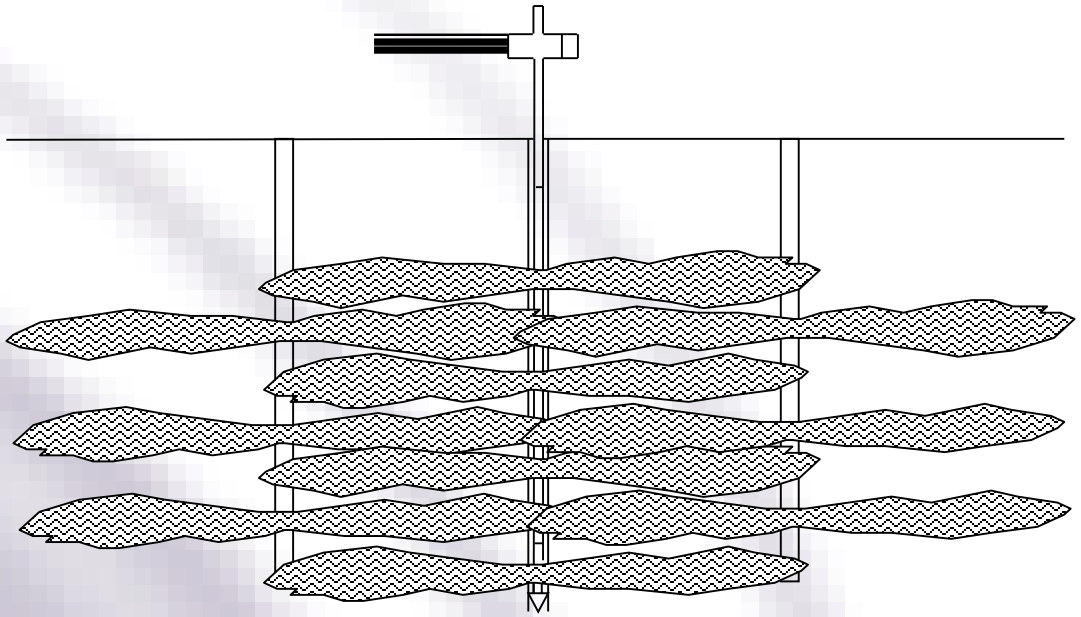
- Single Injection Location



Background – Injection Challenges

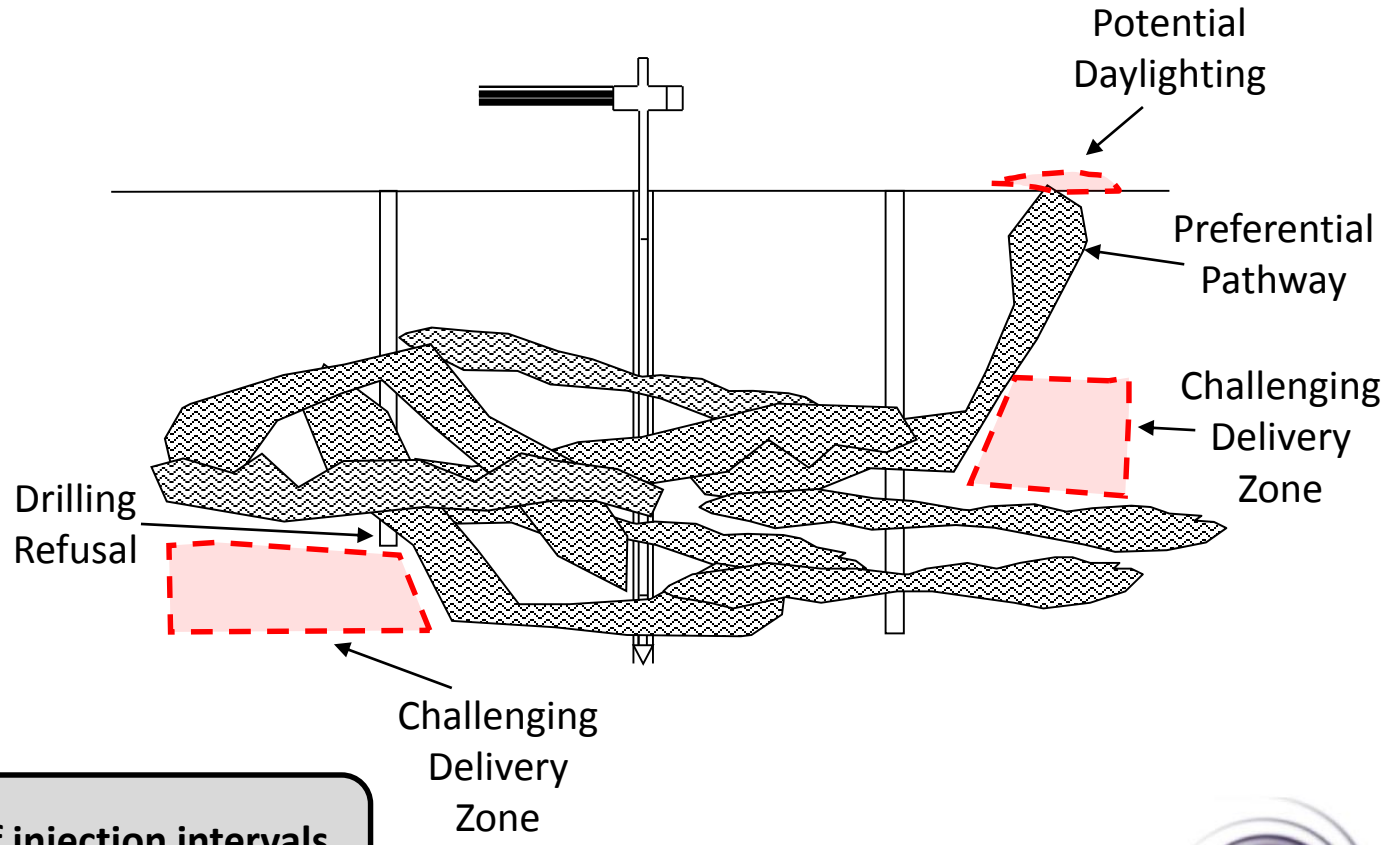
Theoretical Delivery:

- Row of Injection Locations



Actual Delivery:

- Row of Injection Locations



3-D grids of injection intervals even more complicated

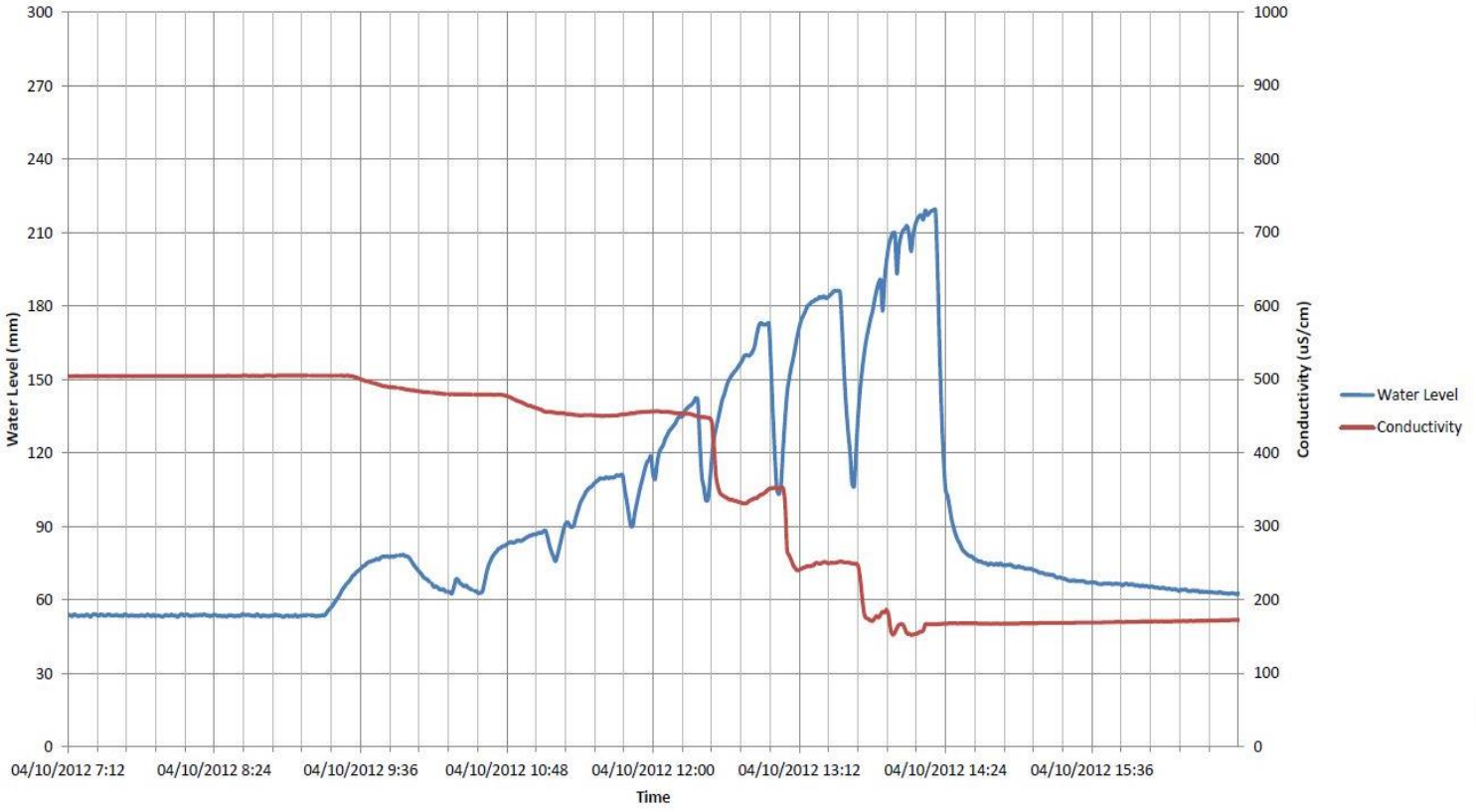
Background – How Can You Monitor Injection Effectiveness?

Monitoring Wells

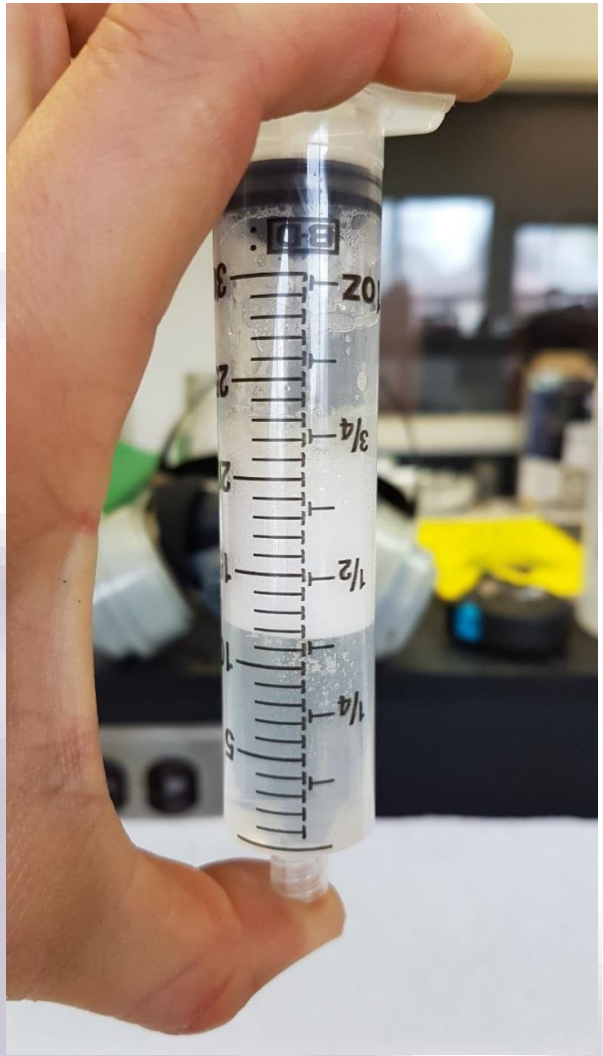
- Use existing well network (inexpensive)
- Hydraulic influence, amendment influence
- Collect real-time data

Limitation:

- Only as good as existing well network

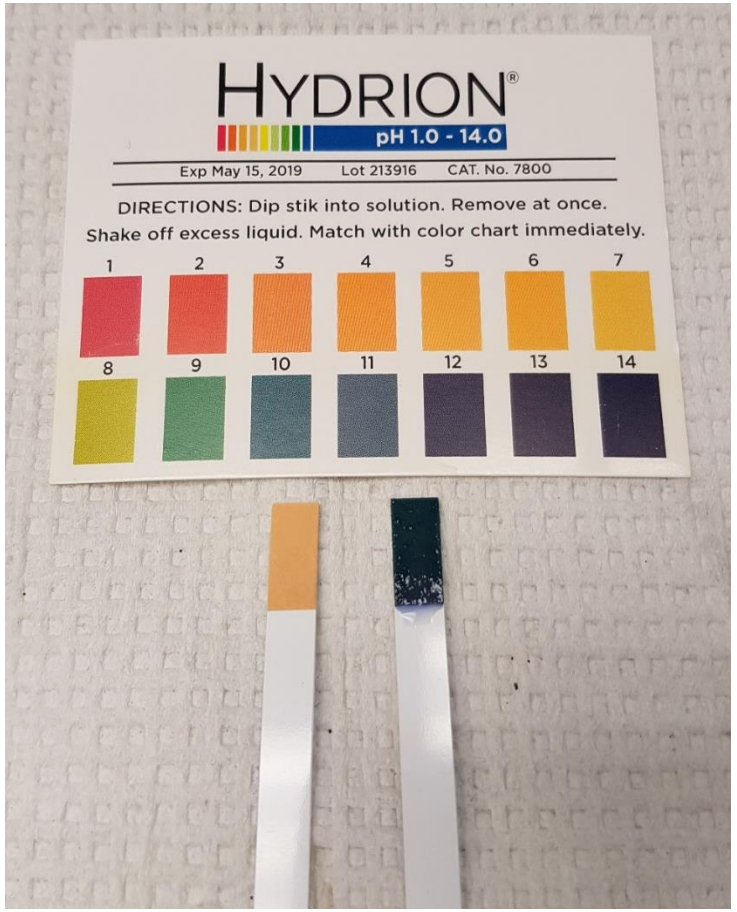


Background – How Can You Monitor Injection Effectiveness?



Field Test Kits

- Semi-quantitative analysis
- Amendment concentrations
- Geochemistry changes



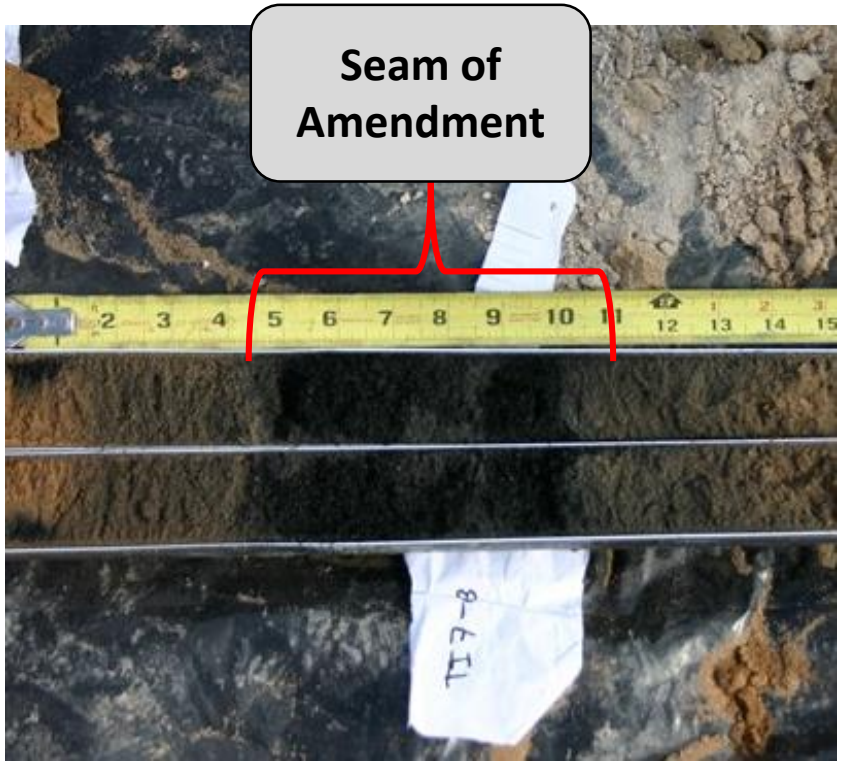
Background – How Can You Monitor Injection Effectiveness?

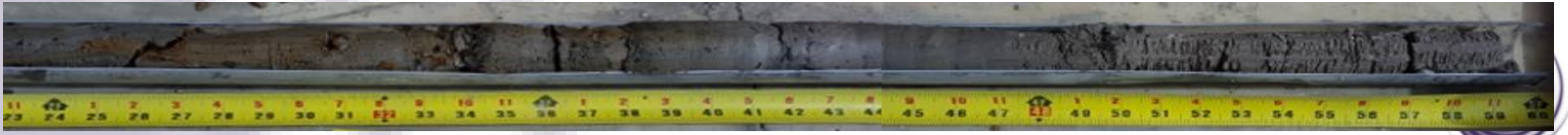
Forensic Soil Cores

- Confirmatory boreholes to analyze delivery
- Can be interspersed during injection program (i.e., during injection mixing)
- Inexpensive
- Minimal Impact to Site

Limitation:

- Need detection method for the amendment (i.e., visual, test kit, or tracer)





Background – How Can You Monitor Injection Effectiveness?

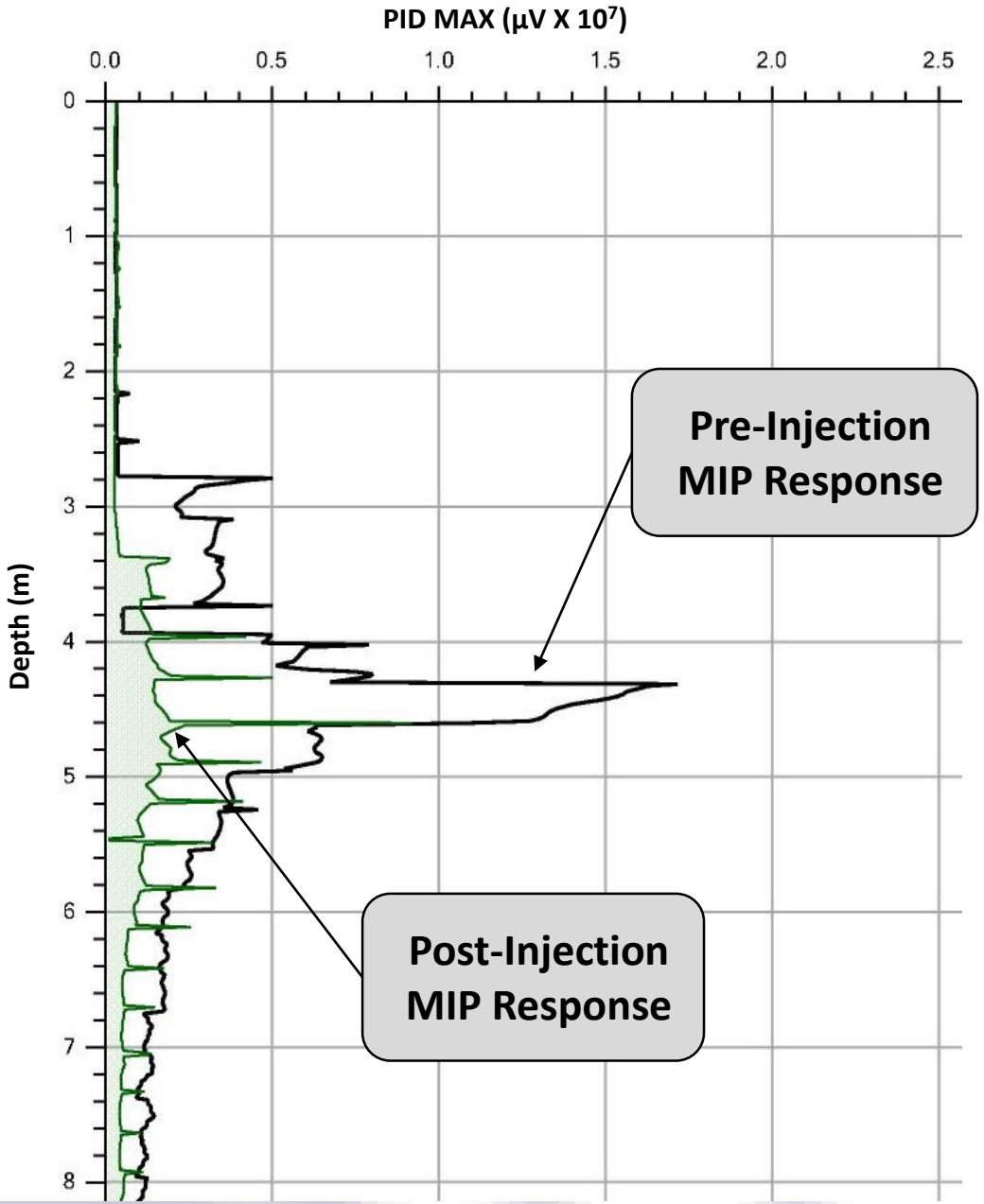
Tracers / Dyes

- Can be co-injected with amendments
- Use to measure radius of influence
- Detect in monitoring wells or soil borings

Limitation:

- Need to understand chemical & physical properties of tracer (i.e., interactions with soils, background concentrations)

Background – How Can You Monitor Injection Effectiveness?



High Resolution Monitoring

- Detect contaminant concentration trends (via MIP or LIF)
- Detect amendments (EC changes)
- Continuous data

Limitation:

- Requires different equipment (separate site visit?)
- Background interference

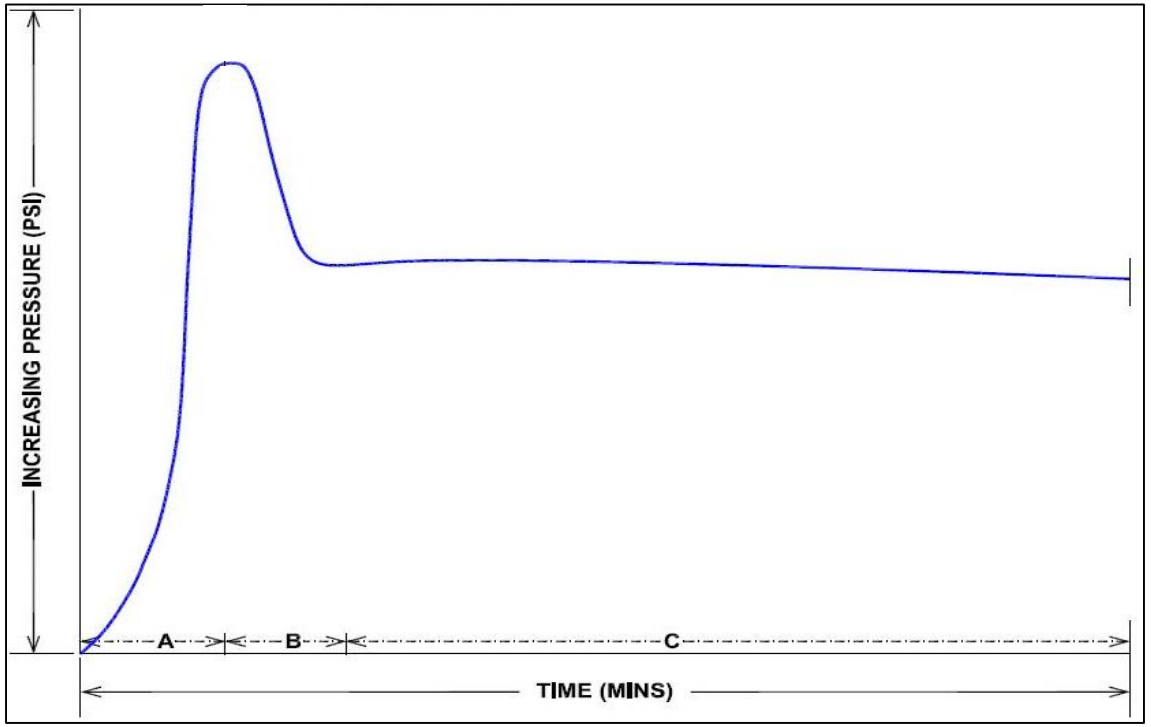
Background – How Can You Monitor Injection Effectiveness?

Injection Parameters

- Flowrates & Pressure Signatures
- Real-time data
- Can identify when injection *not* behaving as expected

Limitation:

- Needs other methods to understand abnormalities



Background – How Can You Monitor Injection Effectiveness?

Real-Time Data	**Injection Parameters** • Flowrate • Pressure Signatures	**Monitoring Wells** • Hydraulic influence • Geochemistry influence • Daylighting / Surfacing
Interim Data	**Direct Push Rig** • Forensic soil cores • High resolution sampling • High resolution characterization	**Laboratory Analysis** • Soil and groundwater • Amendment concentrations

Multiple Lines of Evidence are Critical

VERTEX

Case Study #1
Active Dry Cleaner Site

Case Study #1 – Active Dry Cleaner Site

Site Background

- Ongoing dry cleaner operations
- Former excavations (2002)
- cVOCs in groundwater and soil

Remedial Objective

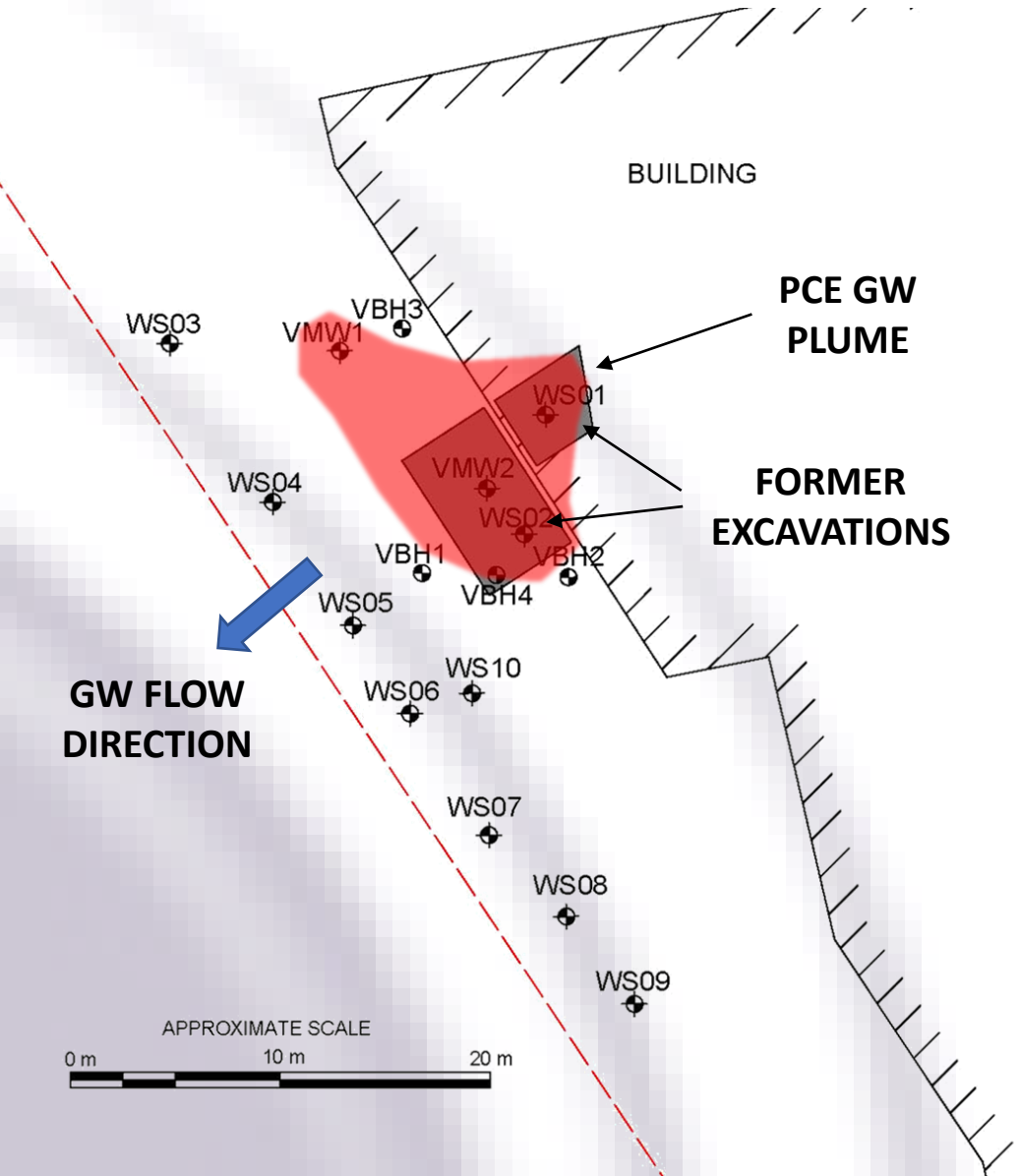
- Generic groundwater/soil standards

Obstacles

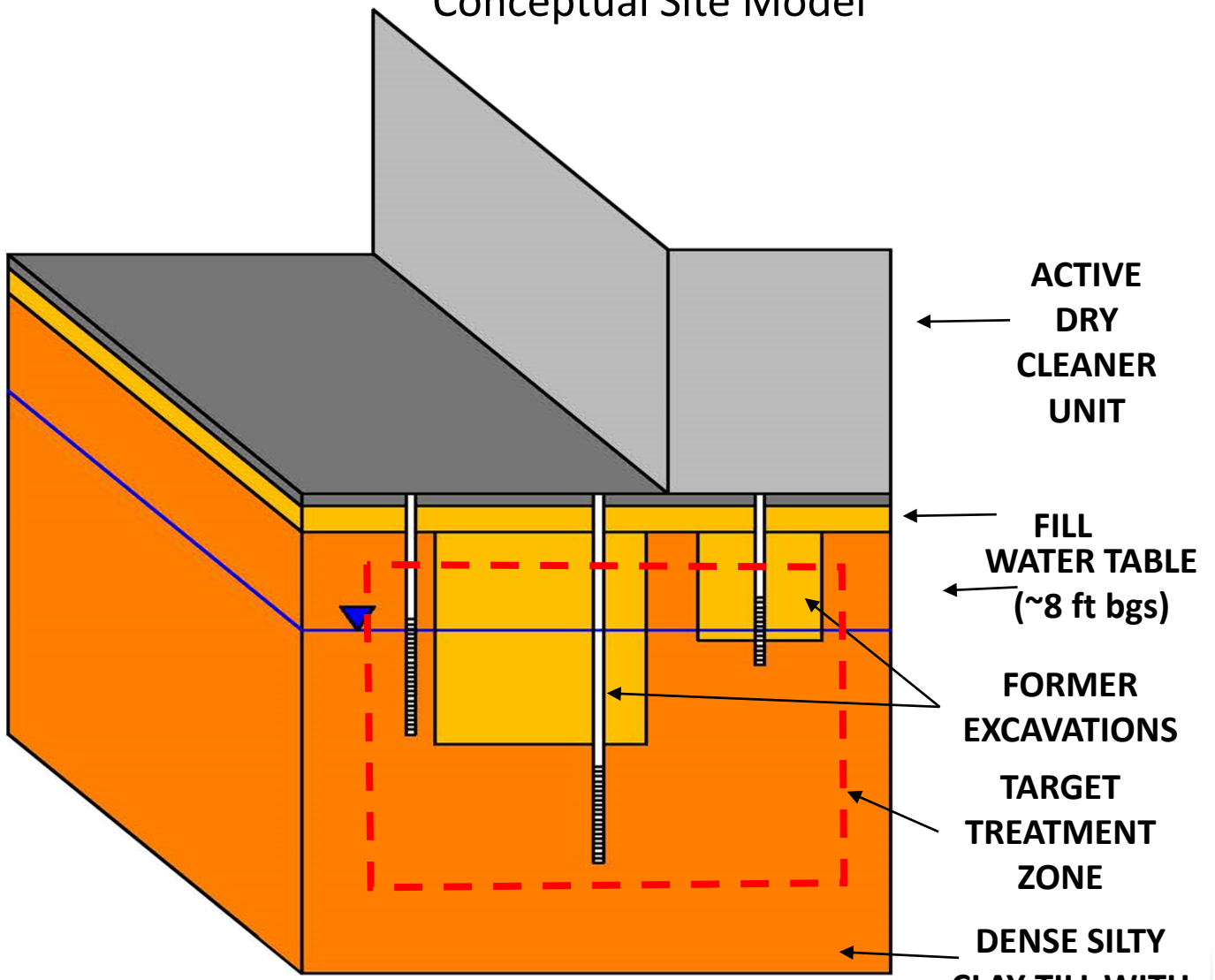
- Delivery around former excavations
- Short time-frame

Case Study #1 – Active Dry Cleaner Site

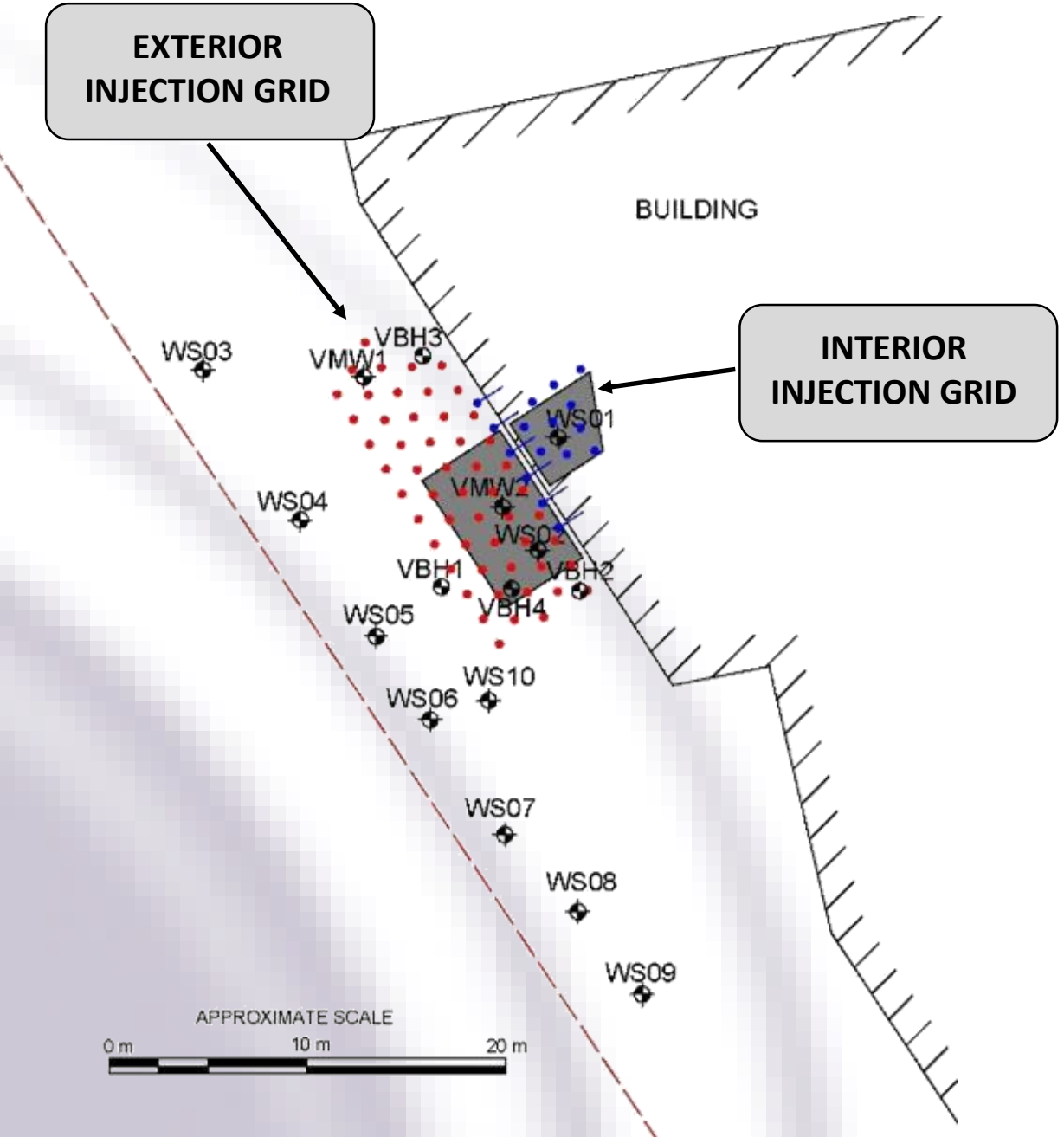
Site Map

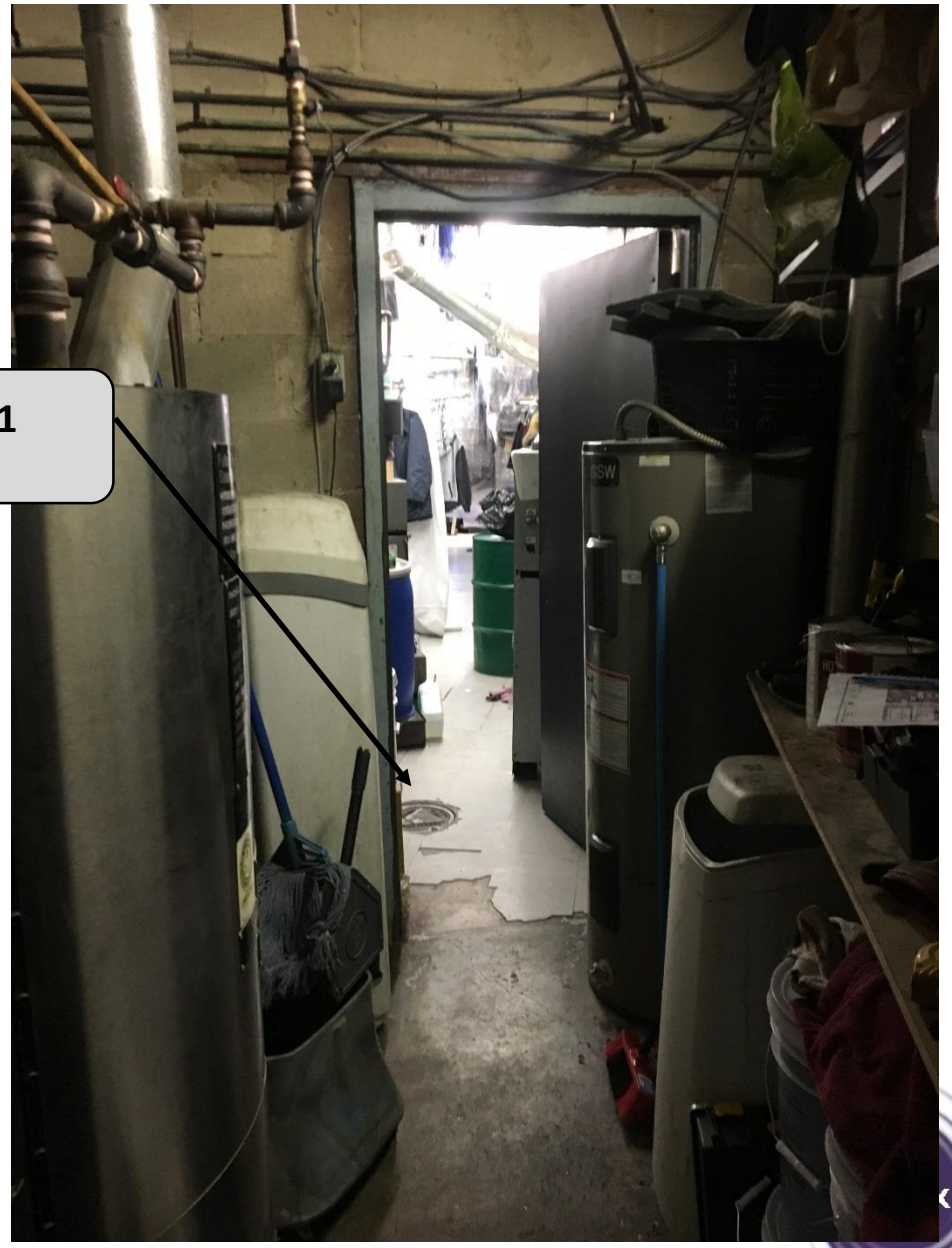


Conceptual Site Model



Case Study #1 – Active Dry Cleaner Site





Case Study #1 – Active Dry Cleaner Site

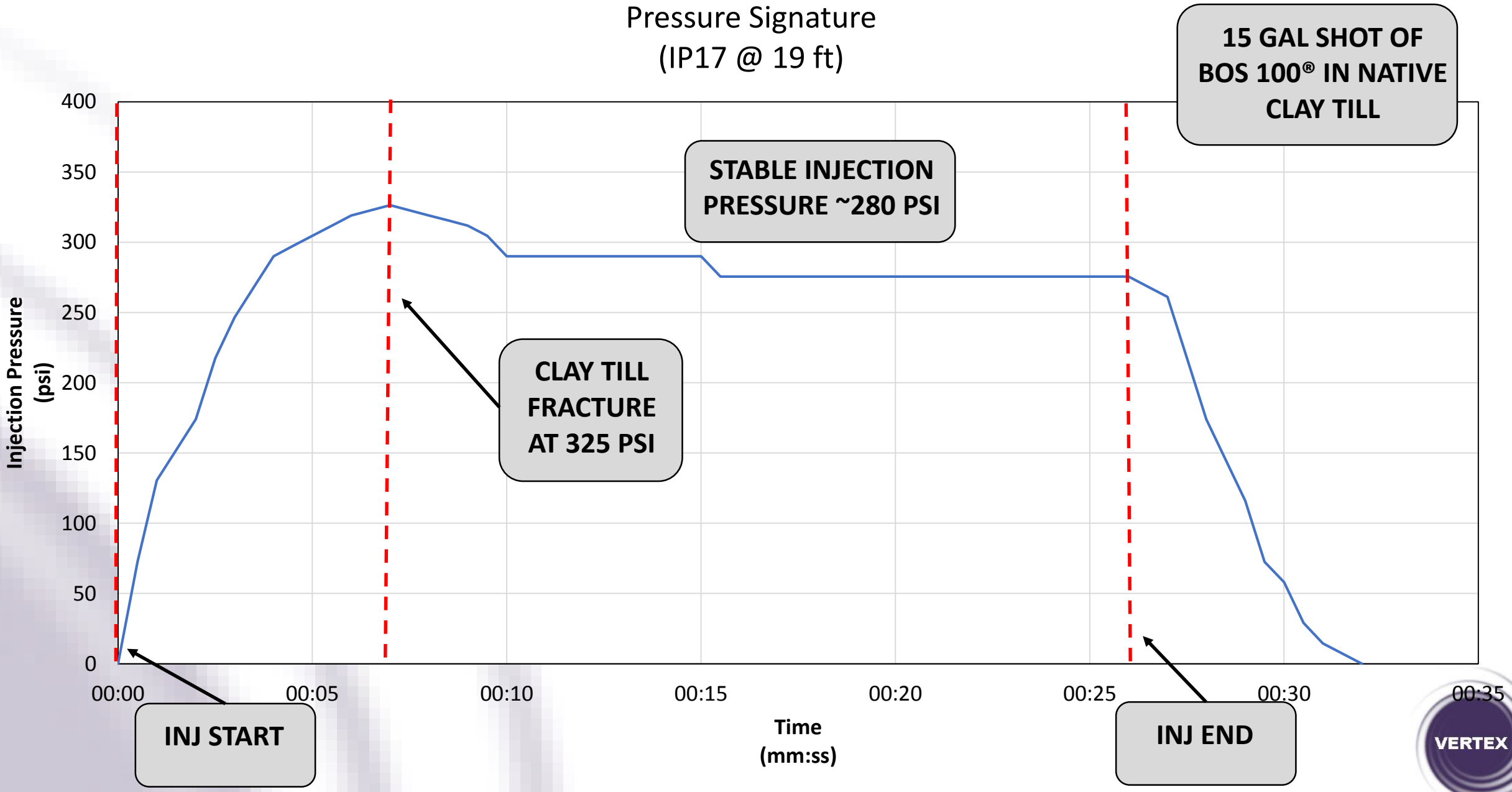
Case Study #1 – Active Dry Cleaner Site

Injection Parameters

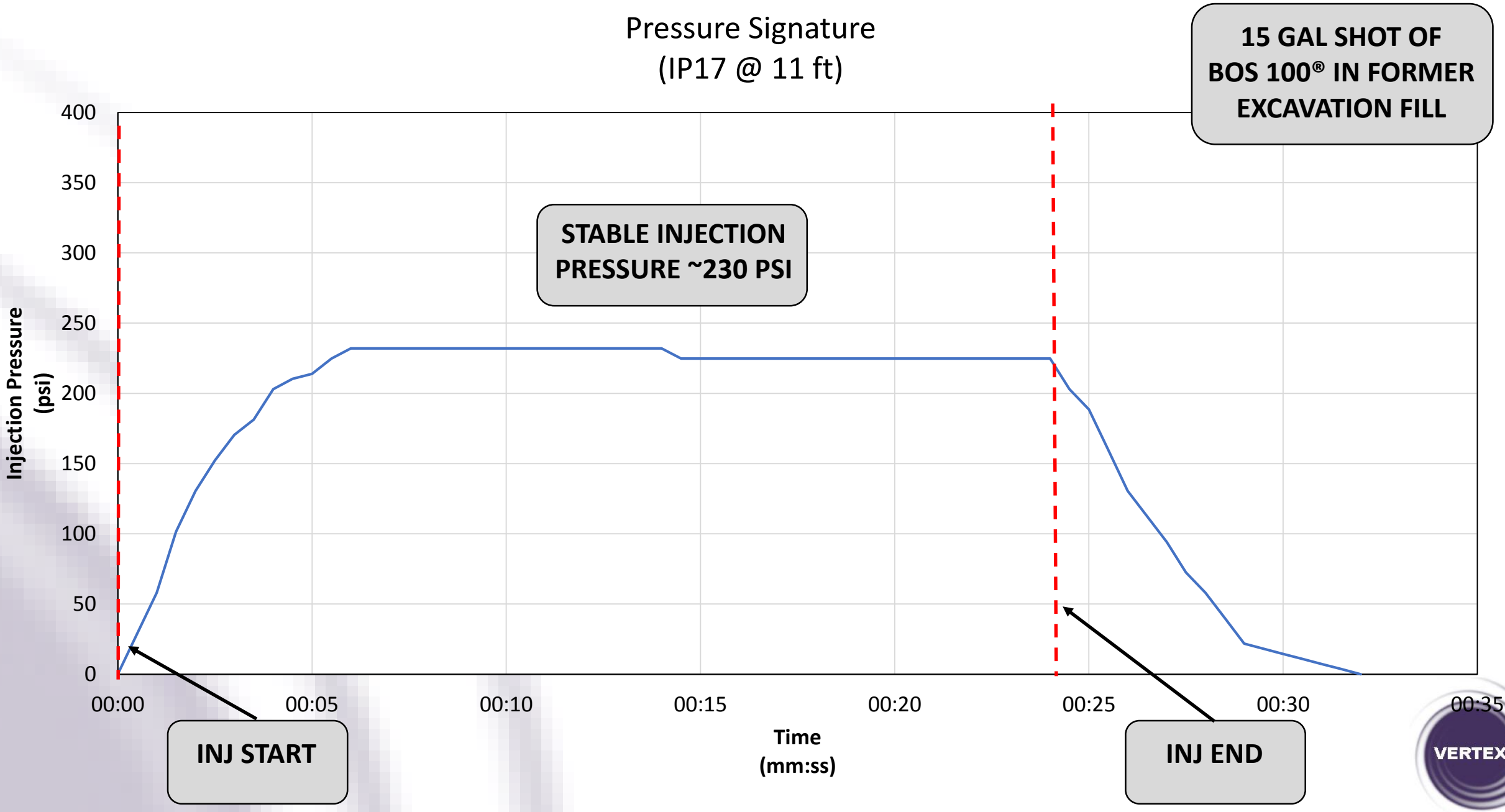
- **Flowrate**
  - Positive displacement pump (constant 34 GPM)
  - 10 to 20 GAL of BOS 100® slurry per shot
- **Injection Pressure**
  - Within former excavations fill:
    - 275 psi (avg peak pressure)
  - Within native clay till:
    - 350 psi (avg peak pressure)

Real-Time	**Injection Parameters**	Monitoring Wells
Interim	Direct Push Verification	Laboratory Analysis

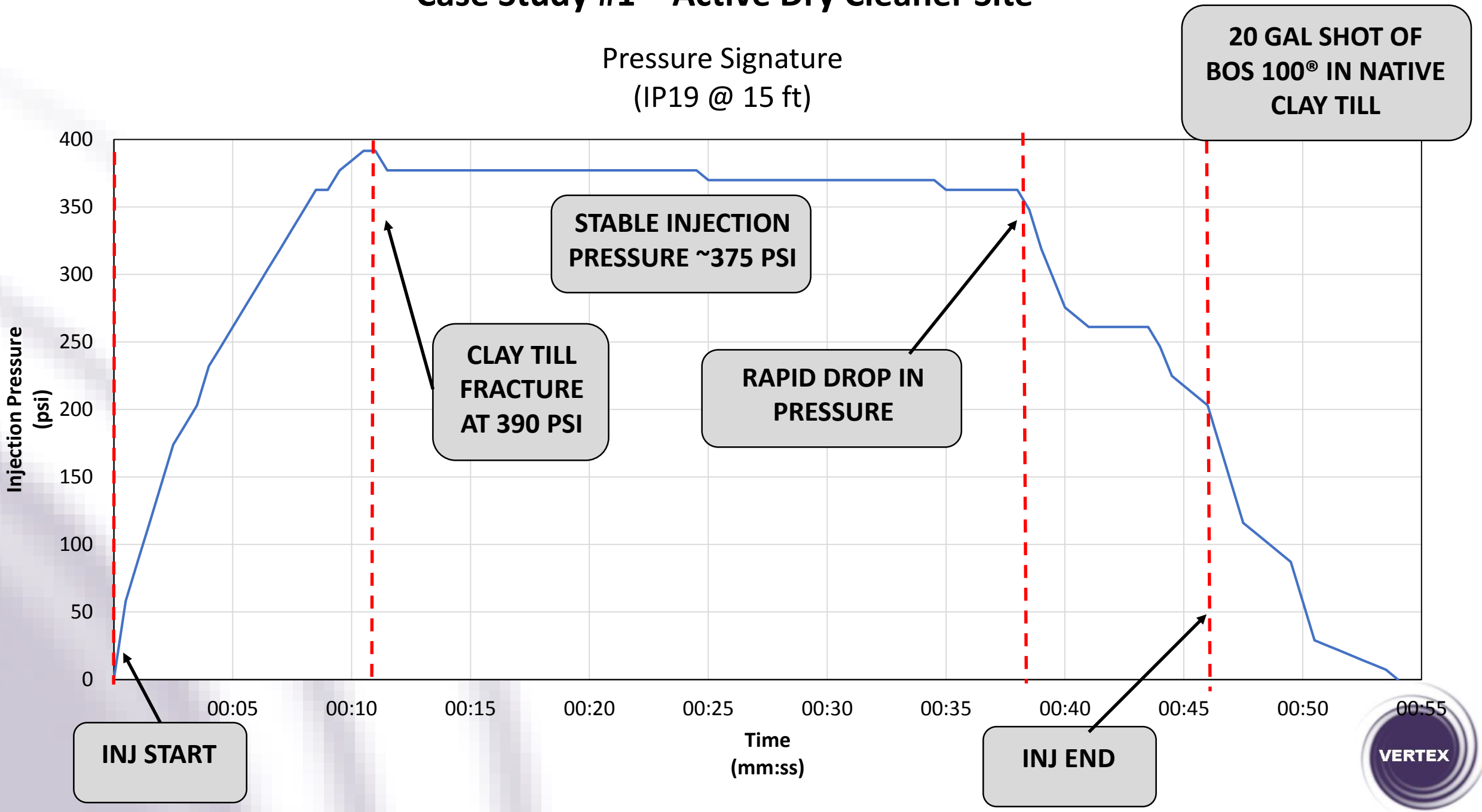
Case Study #1 – Active Dry Cleaner Site



Case Study #1 – Active Dry Cleaner Site



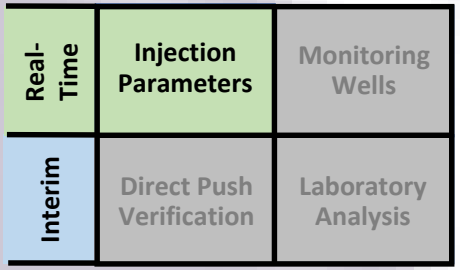
Case Study #1 – Active Dry Cleaner Site



Case Study #1 – Active Dry Cleaner Site

Pressure Signatures Summary

Benefits	Limitations
• Data available real-time in Injection Trailer • Establish expected pressure signatures during pilot-test (for each geology) • Use pressure signatures real-time to assess delivery patterns and flag variations for further investigation	• Soil heterogeneities (i.e. sand seams in clay layer) can raise false flags • Pressure signatures will indicate that “something” is happening but may need other lines of evidence to understand (i.e., forensic drilling, monitoring wells)



Case Study #1 – Active Dry Cleaner Site

Forensic Soil Cores – Edge of Former Excavation

0 to 5 ft

None

5 to 10 ft

8’-0” (fill)
8’-5” (fill)
9’-0” (sand)
9’-2” (clay)

10 to 15 ft

11’-6” (clay)
12’-8” (sand)
12’-11” (clay)
14’-6” (sand)

15 to 20 ft

15’-8” (sand)
17’-1” (clay)
17’-3” (clay)
18’-8” (clay)
19’-2” (sand)

		Monitoring Wells
Interim	Direct Push Verification	Laboratory Analysis

Case Study #1 – Active Dry Cleaner Site

Forensic Soil Cores – Edge of Former Excavation

BOS 100® Seam in Sand @ 9’-0”

BOS 100® Seam in Clay @ 12’-11”

BOS 100® Seam in Sand @ 19’-2”

Case Study #1 – Active Dry Cleaner Site

Forensic Soil Cores – North of Excavation

0 to 5 ft

None

5 to 10 ft

6’-1” (sand)
7’-6” (clay)
8’-0” (sand)
8’-3” (clay)
8’-10” (clay)
9’-1” (sand)
9’-3” (clay)
9’-7” (sand)
10’-0” (clay)

10 to 15 ft

10-8” (sand)
11’-8” (clay)
13’-0” (sand)
13’-4” (clay)
14’-0” (sand)

15

Real-Time	Injection Parameters	Monitoring Wells
Interim	**Direct Push Verification**	Laboratory Analysis

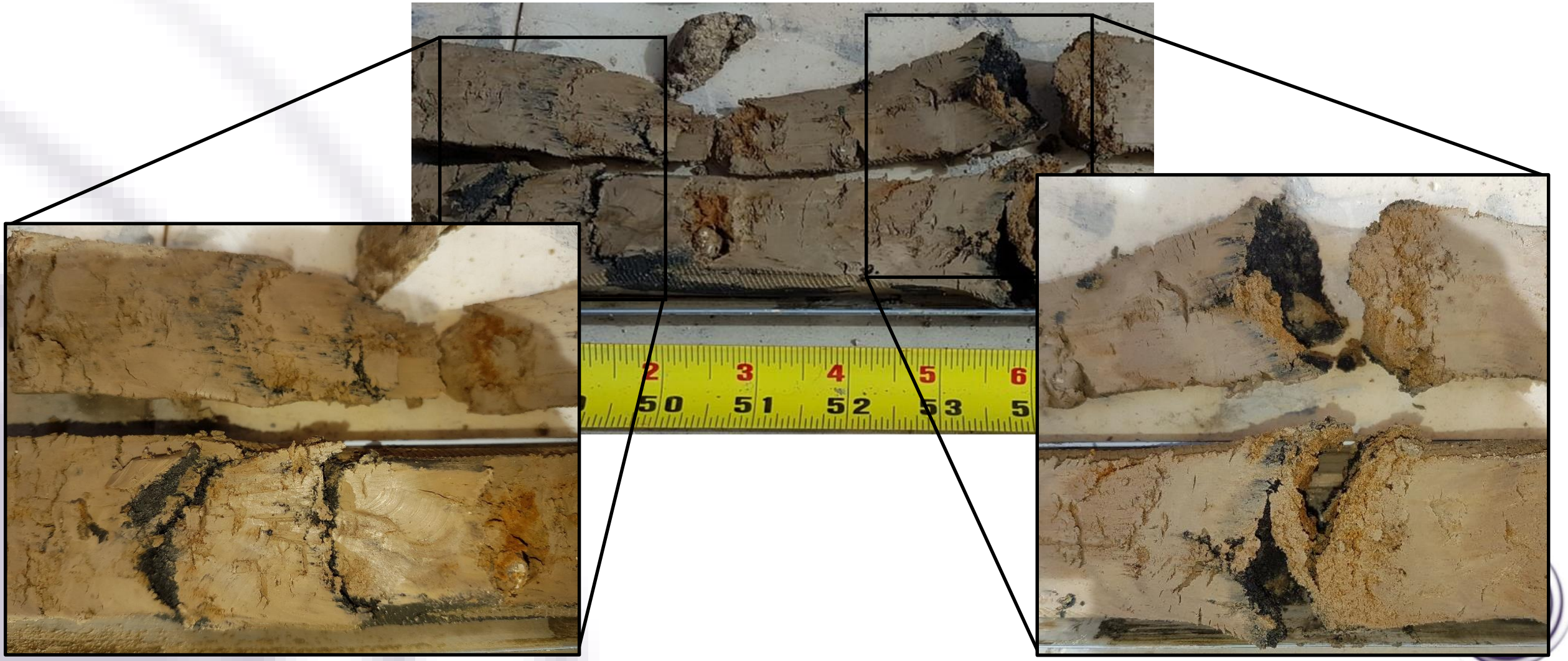
BOS 100® RE-ALLOCATED TO TARGET 16 – 20 ft

15’-10” (clay)

Case Study #1 – Active Dry Cleaner Site

Forensic Soil Cores – North of Excavation

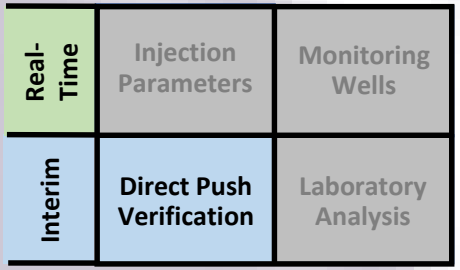
BOS 100® Seams in Sandy Clay @ 9’-0” to 9’-6”



Case Study #1 – Active Dry Cleaner Site

Forensic Soil Core Summary

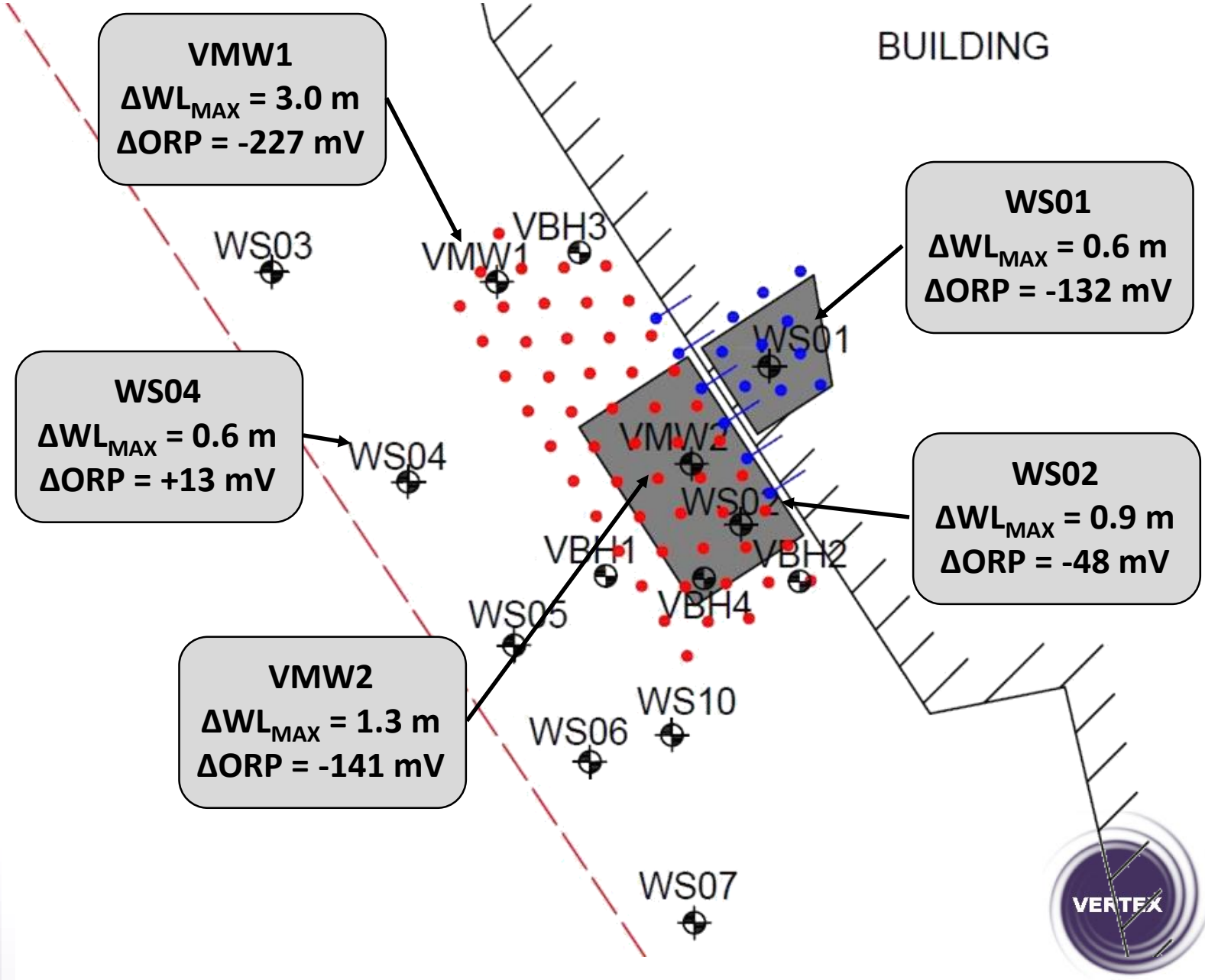
Benefits	Limitations
• Critical evidence for confirming delivery within each unique geologic units • Useful tool to investigate pressure signature flags	• Time & budget to complete • Not real-time data



Case Study #1 – Active Dry Cleaner Site

Monitoring Well Influence

- Hydraulic Influence
  - Observed at all wells within injection zone
  - Influence ranging from 0.6 to 3.0 m
- Geochemistry Influence
  - Avg ORP = -182 mV (pre-injection)
  - Avg ORP = -320 mV (post-injection)

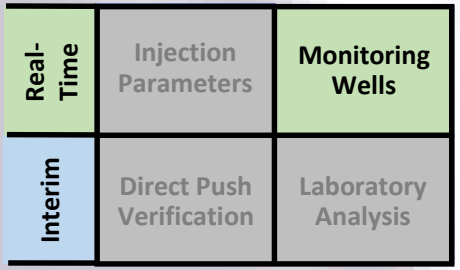


Real-Time	Injection Parameters	Monitoring Wells
Interim	Direct Push Verification	Laboratory Analysis

Case Study #1 – Active Dry Cleaner Site

Monitoring Well Influence

Benefits	Limitations
• Real-time data • Confirm delivery and radius of influence (ROI) assumptions • Monitor downgradient receptors and property boundaries • Make adjustments to injection program based on real-time MW responses	• Relies on existing well network (which may be inadequate) • Well screens often straddle multiple geological layers



Case Study #1 – Active Dry Cleaner Site

Project Summary

- **Key Monitoring Parameters**
  - Injection pressures utilized to flag intervals with unexpected signatures
  - Forensic soil cores utilized to confirm BOS 100® delivery/ROI assumptions, and identify zones for re-application
  - Monitoring well evidence for delivery/ROI assumptions, and that amendments stayed within the target zone (no offsite migration)
- **Analytical Results**
  - Initial cVOCs GW results >90% decrease (initial “Trap”)
  - Subsequent GW samples and soil cores to be collected by Consultant

Real-Time	Injection Parameters	Monitoring Wells
Interim	Direct Push Verification	Laboratory Analysis

Case Study #2
Property Boundary Control – ZVI PRB Injection

Case Study #2 – Property Boundary Control

Site History

- Client owned a former dry cleaning facility
- Client to protect downgradient property (commercial)
  - Legal issues with downgradient owner

Contaminant Situation

- Plume of cVOCs in groundwater migrating off-site
- Mostly **cis-1,2-DCE**, a breakdown product of PCE, at concentrations of up to **880 ug/L**
- PCE Historical at Source = 223,000 ug/L PCE

Remedial Objective – Certainty

- Reduce cVOCs leaving site to **below risk-based** standards
- Meet Generic Standards? All the better

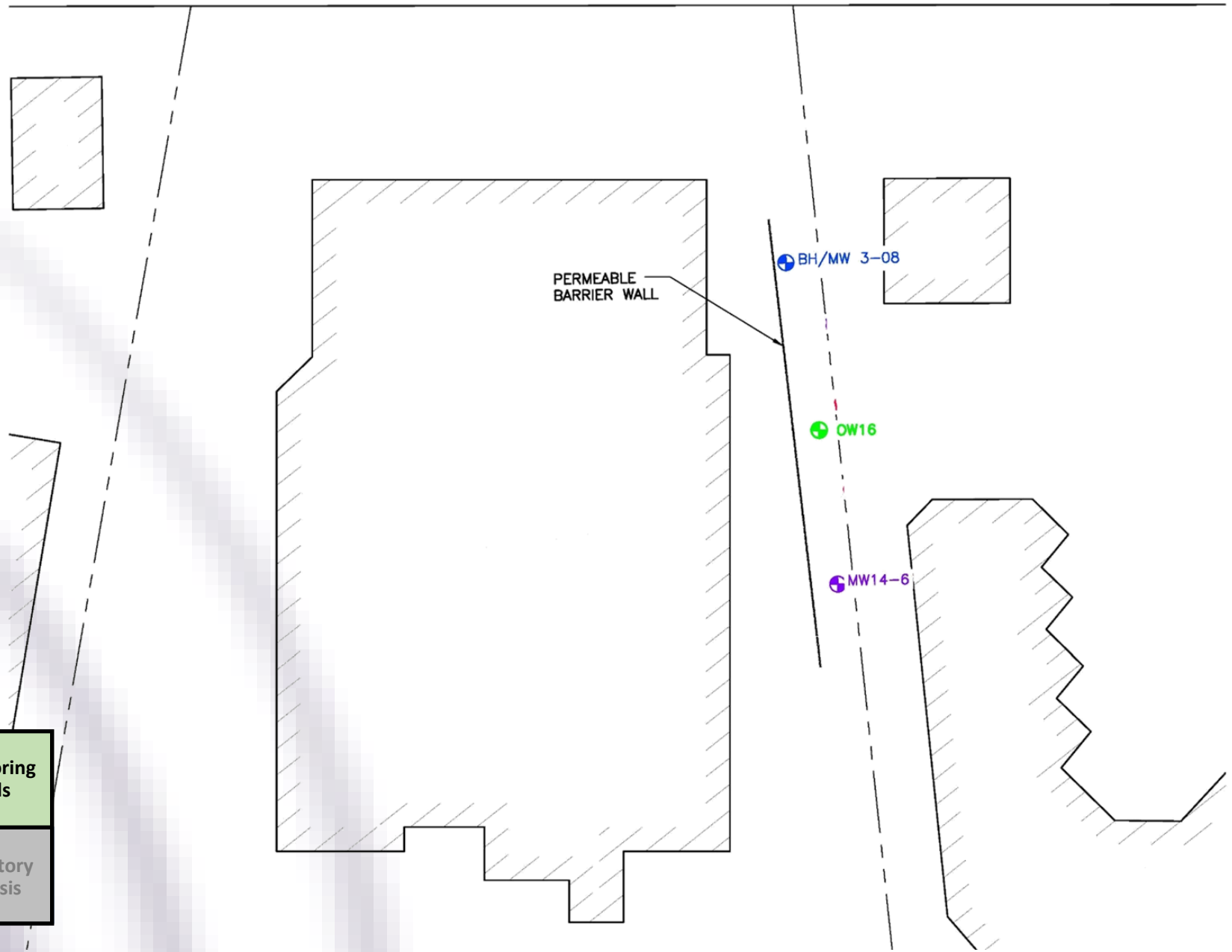
VERTEX

Case Study #2 – Property Boundary Control

PRB Notes

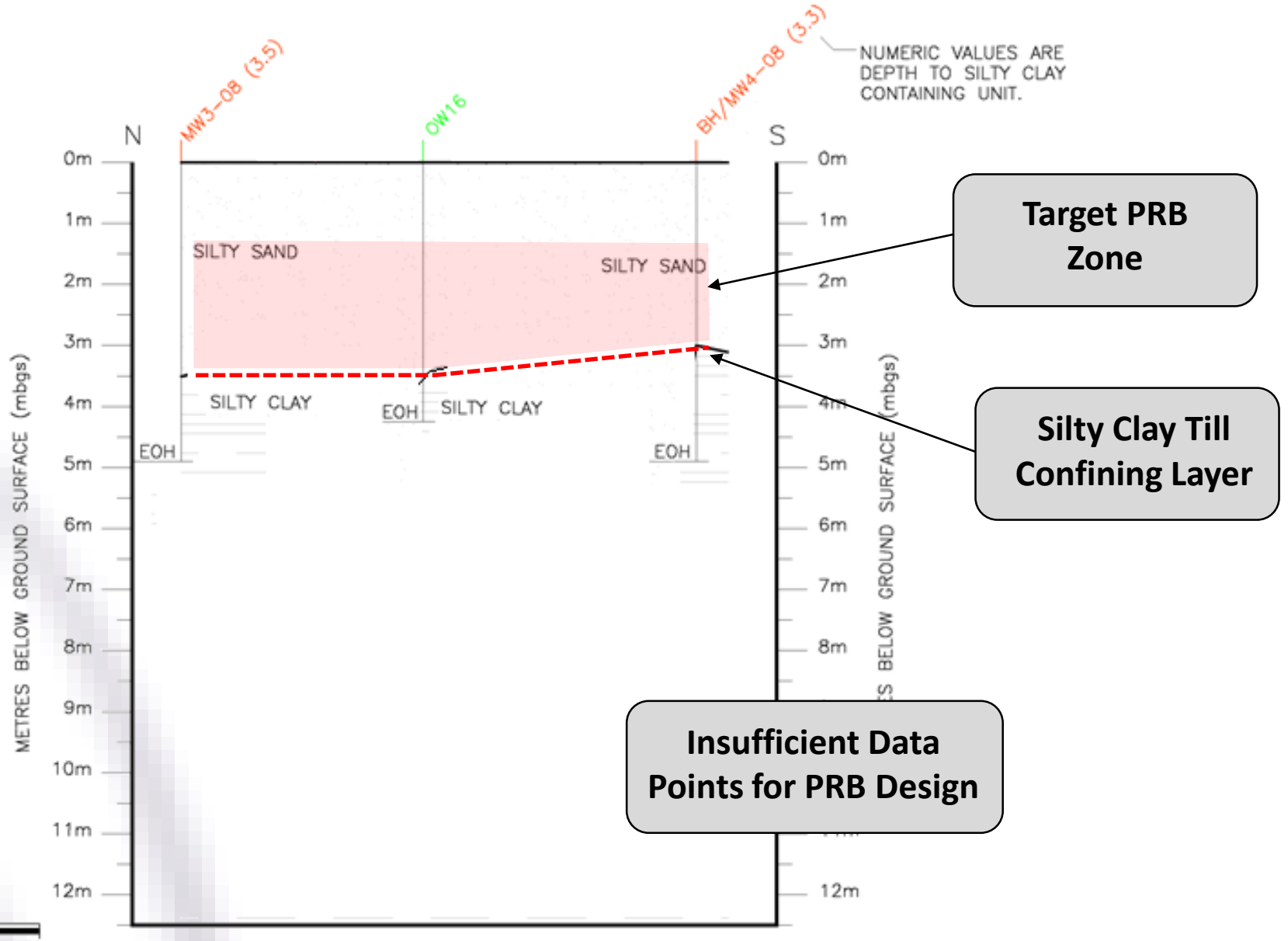
- PRBs intercept and treat contaminated plumes
- Allow groundwater to flow through unimpeded
- Passive & Sustainable (no energy use to operate)

Case Study #2 – Property Boundary Control



Real-Time	Injection Parameters	**Monitoring Wells**
Interim	Direct Push Verification	Laboratory Analysis

Case Study #2 – Property Boundary Control



Target PRB Zone

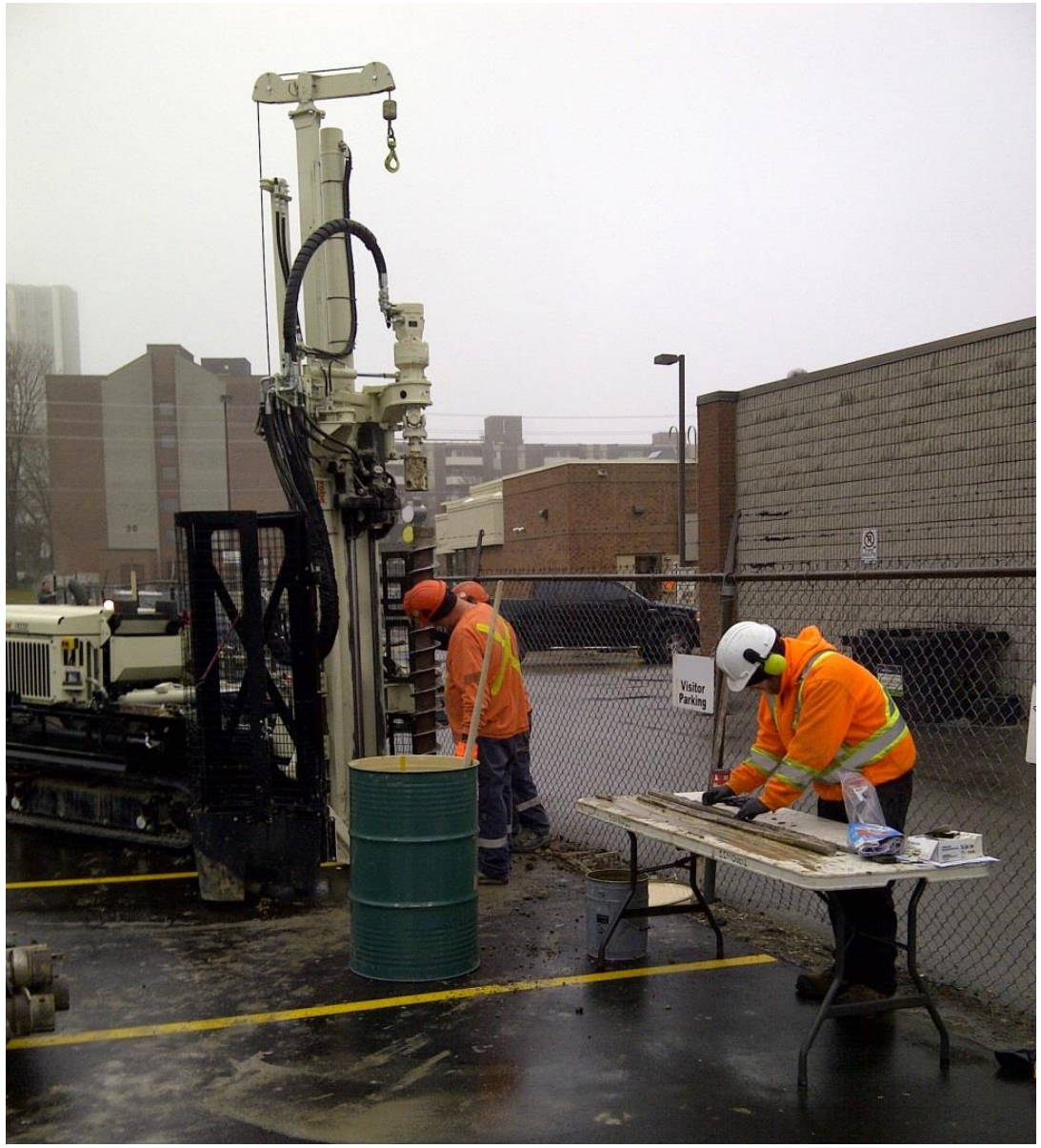
Silty Clay Till Confining Layer

Insufficient Data Points for PRB Design

Real-Time	Injection Parameters	**Monitoring Wells**
Interim	Direct Push Verification	Laboratory Analysis

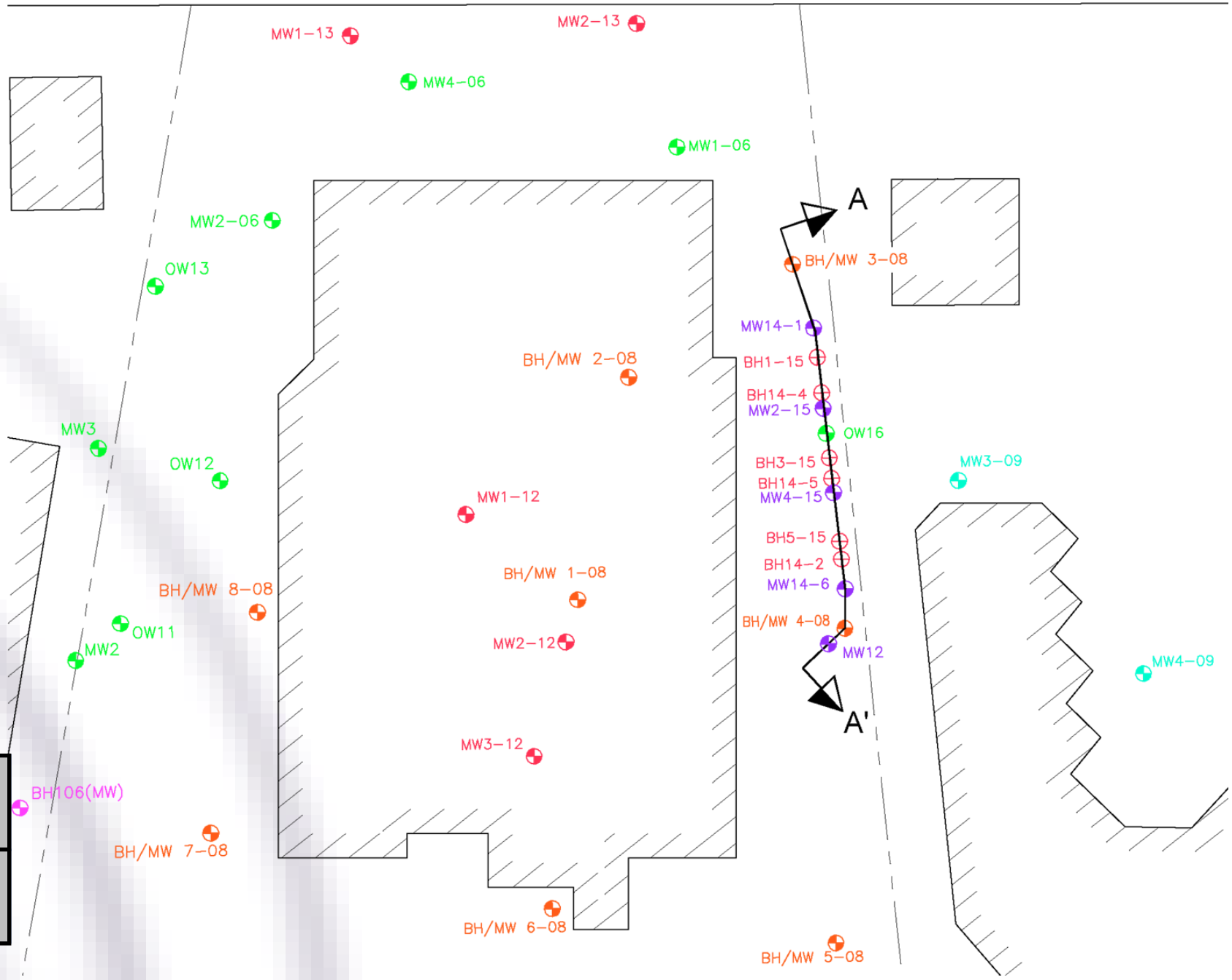
0 2.5m 5m 7.5m 20m 30m

Case Study #2 – Property Boundary Control



Real-Time	Injection Parameters	Monitoring Wells
Interim	**Direct Push Verification**	Laboratory Analysis

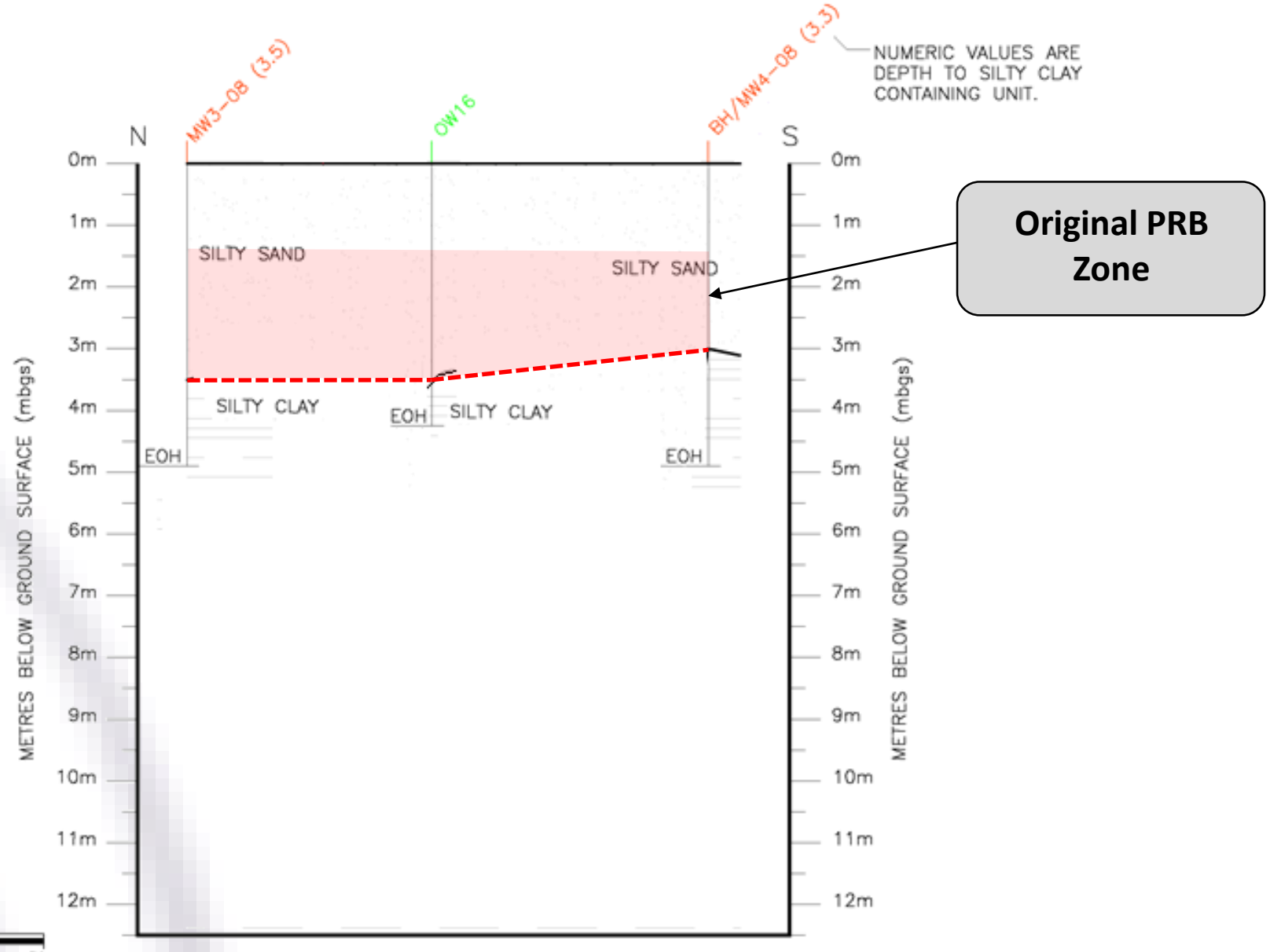
Case Study #2 – Property Boundary Control



Real-Time	Injection Parameters	Monitoring Wells
Interim	Direct Push Verification	Laboratory Analysis

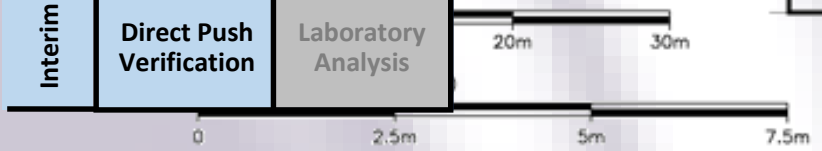
VERTEX

Case Study #2 – Property Boundary Control

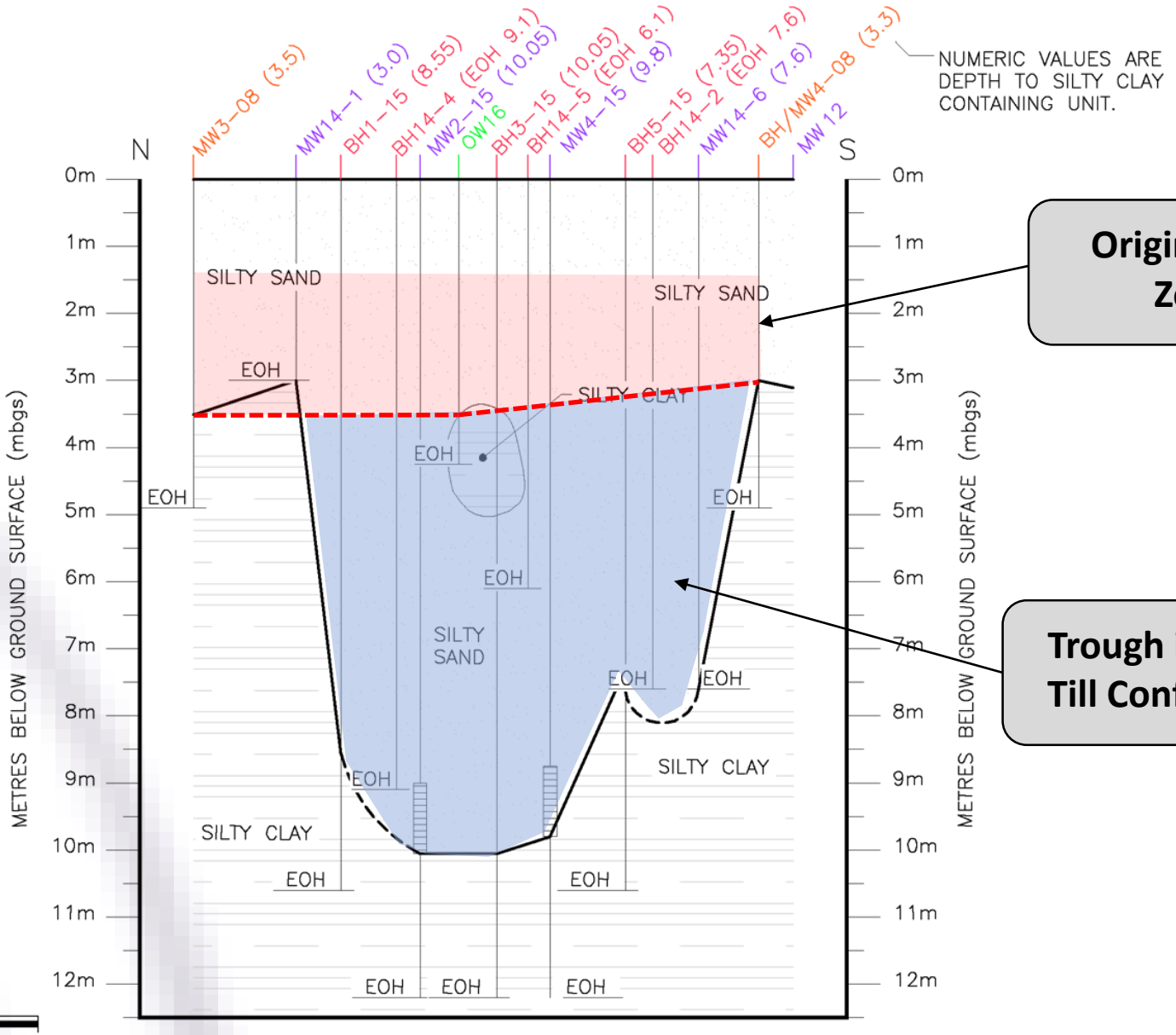


Original PRB Zone

Real-Time	Injection Parameters	Monitoring Wells
Interim	**Direct Push Verification**	Laboratory Analysis

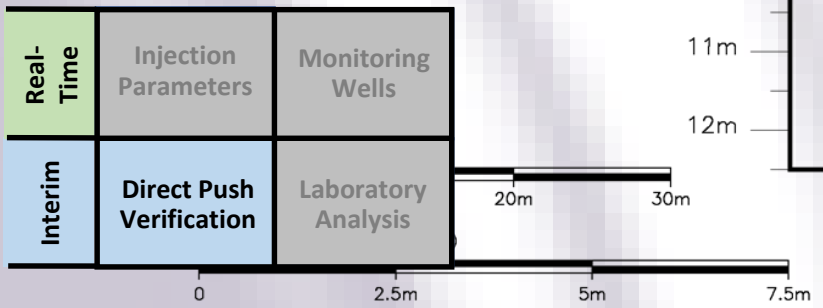


Case Study #2 – Property Boundary Control



Original PRB Zone

Trough in Silty Clay Till Confining Layer



Case Study #2 – Property Boundary Control

Obstacles / Observations

- cVOCs discovered in a “trough” to a depth of 10 m
- Below depths of ~6 m **“heaving”** sands encountered
- Excavation approach (“cut & fill”) would require shoring & dewatering
  - Assess Injected PRB
- High ZVI loading required to achieve treatment standards

Remedial Approach

- Vertical profiling
- Design: **Injected ZVI (Zero-Valent Iron) PRB**
- Pilot-Test
  - Confirm design parameters
- Full-scale Injection

Mixing ZVI slurry for injection

Case Study #2 – Property Boundary Control

Case Study #2 – Property Boundary Control

Work Completed

- Two 55 m long reactive lines of temporary injection points
- 30,000 kg of micro-scale ZVI in 75,000 L of slurry injected 1.5 to 10.5 mbgs
- Completed over 30 working days

Strong Controls over Vertical Injection Intervals:

Track ZVI delivery for each vertical injection interval

Line A

	1	2	3	4	5	6	7	8	9	10
5-7 ft	0	0	0	0	0	100	0	100	0	0
7-9 ft	0	0	0	0	0	100	0	100	0	0
9-11 ft	50	50	50	0	0	50	50	50	50	50
11-13 ft	50	50	50	0	0	50	50	50	50	50
13-15 ft	50	50	50	0	0	50	50	0	50	50
15-17 ft								0	25	100
17-19 ft								0	25	100
19-21 ft								0	25	0
21-23 ft								0	25	0
23-25 ft								0	25	0
25-27 ft								50	50	50
27-29 ft								50	50	50
29-31 ft								50	50	50
31-33 ft								50	50	50
33-35 ft								50	50	50

Line B

	1	2	3	4	5	6	7	8	9	10	11	12	13
5-7 ft	0	0	0	0	0	0	0	0	0	0	0	0	0
7-9 ft	0	0	0	0	0	0	0	0	0	0	0	0	0
9-11 ft	50	50	50	50	50	50	50	50	50	50	50	50	50
11-13 ft	50	50	50	50	50	50	50	50	50	50	50	50	50
13-15 ft	50	50	50	50	50	50	50	50	50	50	50	50	50
15-17 ft								100	0	0	0	0	0
17-19 ft								100	0	0	0	0	0
19-21 ft								0	0	0	0	0	0
21-23 ft								0	0	0	0	0	0
23-25 ft								0	0	0	0	0	0
25-27 ft								50	50	50	50	50	50
27-29 ft								50	50	50	50	50	50
29-31 ft								50	50	50	50	50	50
31-33 ft								50	50	50	50	50	50
33-35 ft								50	50	50	50	50	50

50 value indicates volume of ZVI slurry to inject (L) for each 2' interval, formulated
0 injections 100% complete - do not inject in these zones
do not inject into this interval

Line A

	1	2	3	4	5	6	7	8	9	10
5-7 ft	0	0	0	0	0	100	0	100	0	0
7-9 ft	0	0	0	0	0	100	0	100	0	0
9-11 ft	50	50	50	0	0	50	50	50	50	50
11-13 ft	50	50	50	0	0	50	50	50	50	50
13-15 ft	50	50	50	0	0	50	50	0	50	50
15-17 ft								0	25	100
17-19 ft								0	25	100
19-21 ft								0	25	0
21-23 ft								0	25	0
23-25 ft								0	25	0
25-27 ft								50	50	50

Real-Time	Injection Parameters	Monitoring Wells
Interim	Direct Push Verification	Laboratory Analysis

Case Study #2 – Property Boundary Control

Field Monitoring

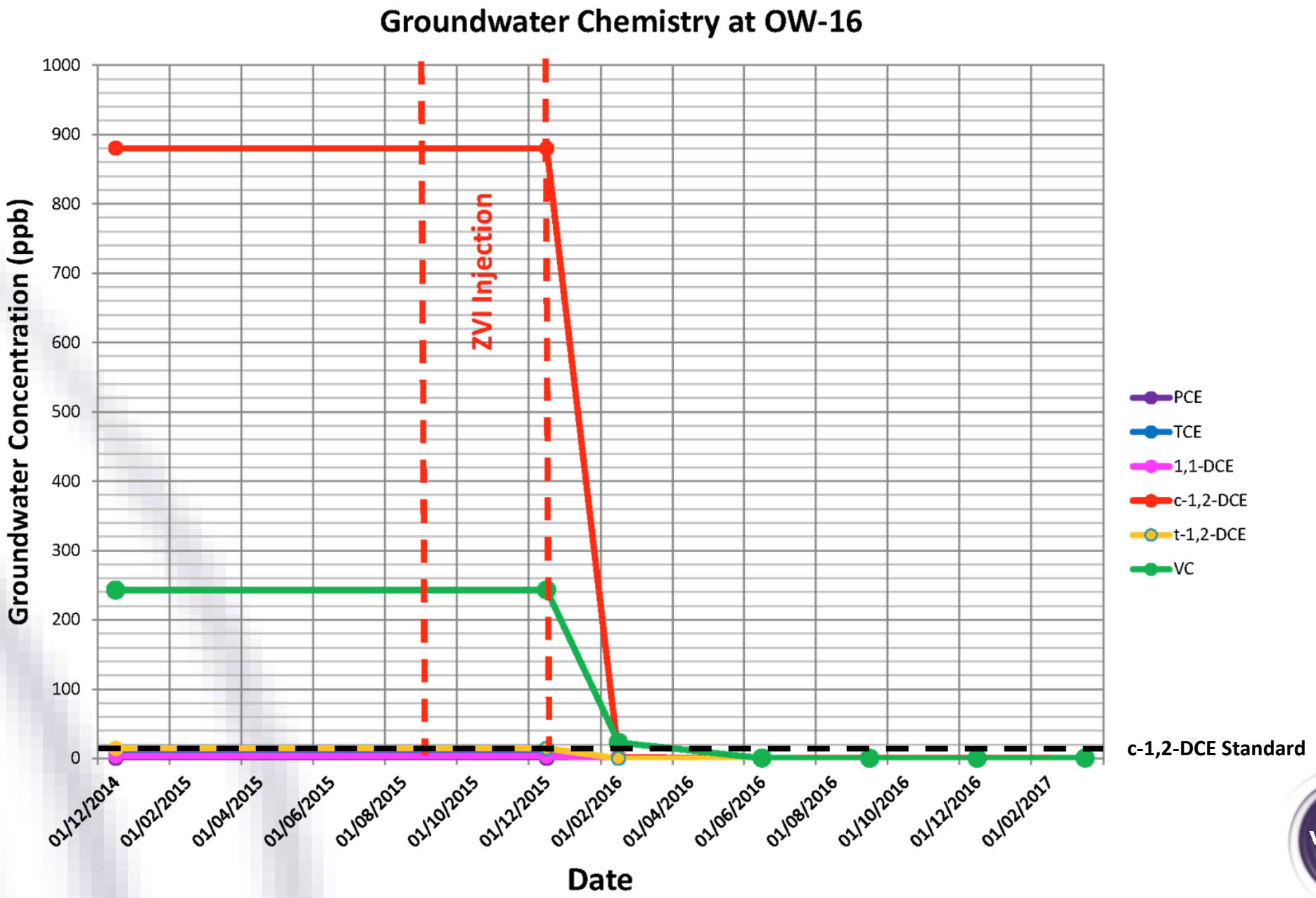
- Continuous monitoring for hydraulic and iron influence at existing monitoring wells
- Forensic Soil Sampling & Magnetic Separation tests:

Borehole Number	Depth (m)	Relative Location	Depth Orientation	Iron Conc. (%)
BH15-1	0.0-1.2	Near MW2-15 (deep interval)	Outside injection interval	0.8%
	1.2-2.4			0.8%
	6.1-7.3		Just above injection interval	2.6%
	7.3-8.5		Within injection interval	2.9%
	8.5-9.8			1.9%
BH15-2	0.0-1.2	Near OW16 (shallow interval)	Outside injection interval	0.7%
	1.2-2.4		Within injection interval	0.5%
	2.4-3.7			0.8%
BH15-3	0.0-1.2	Near OW16 (shallow interval)	Just above injection interval	2.1%
	1.2-2.4			0.5%
Increase in Average Iron Concentration Within Injection Interval				0.9%

Confirm ZVI Concentration with Depth

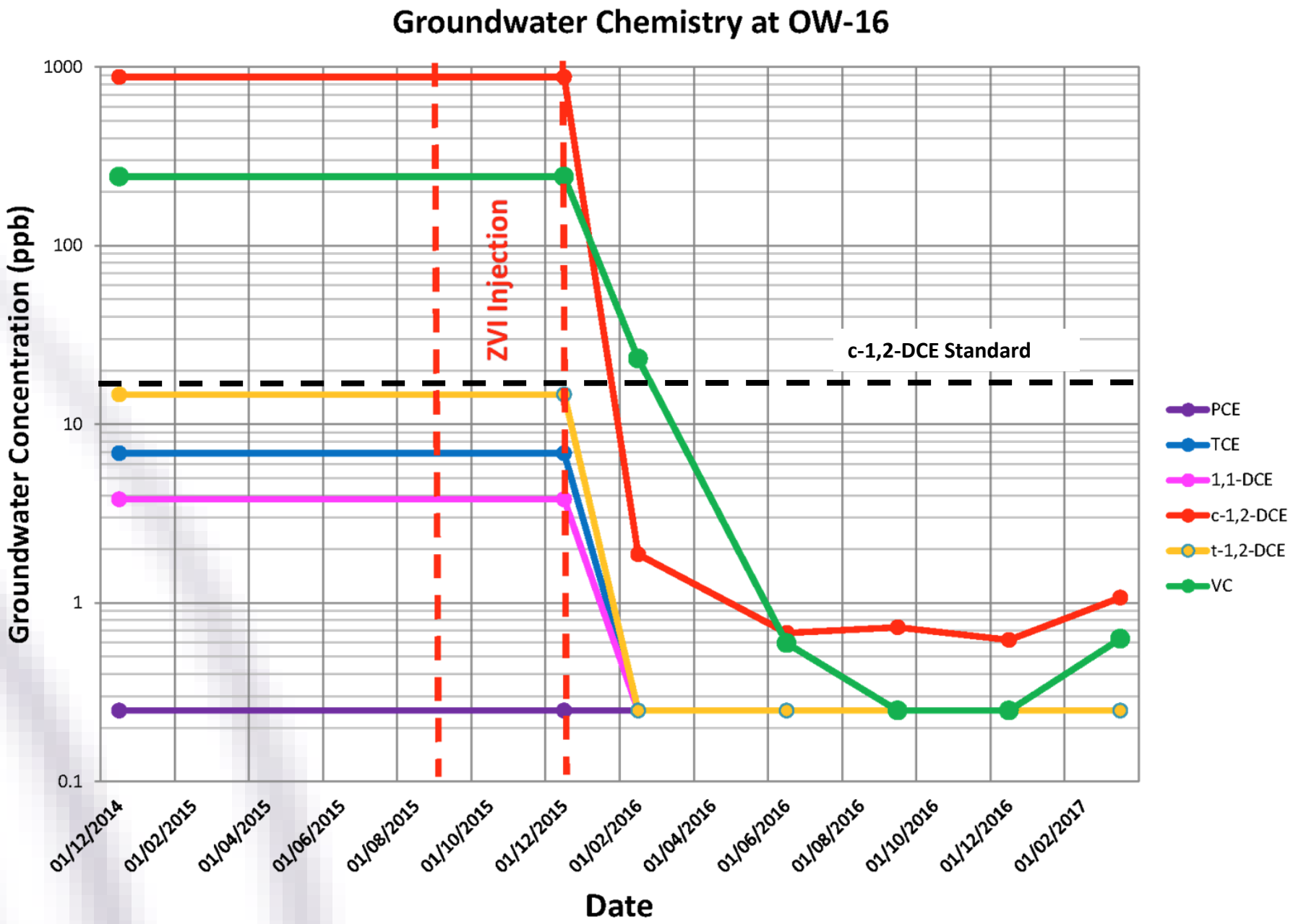
Real-Time	Injection Parameters	Monitoring Wells
Interim	**Direct Push Verification**	Laboratory Analysis

Case Study #2 – Property Boundary Control



Real-Time	Injection Parameters	Monitoring Wells
Interim	Direct Push Verification	**Laboratory Analysis**

Case Study #2 – Property Boundary Control



Real-Time	Injection Parameters	Monitoring Wells
Interim	Direct Push Verification	**Laboratory Analysis**

Case Study #2 – Property Boundary Control

Project Summary

- Upfront Forensic Soil Sampling was essential
  - Vertical profiling for detailed design
  - “Found” deep trough of contaminated groundwater
  - Re-evaluated options and redesigned remedial approach
- Pilot-scale test
  - Completed to validate design assumptions
- Full-scale program
  - Use feedback from **multiple** field monitoring techniques:
    - Real-time field data (injection parameters, MWs influence)
    - Interim sampling data (soil cores, magnetic separation, analytical testing)
- Remedial objective achieved – below Generic Standard
  - cVOCs remain low 2 years after PRB Installation

Monitoring Injection Effectiveness – Lessons Learned

Stage	Description
Pre-Injection	Identify data gaps and address Identify “Key Monitoring Parameters” for the Site
During Injection	Assess design assumptions during Pilot-Test (or on 1st day) • Drilling • Delivery • Radius of influence Use feedback from “Key Monitoring Parameters” to make in-field adjustments • Monitoring wells and preferential pathways • Pressure signatures • Forensic soil cores • High Res / Tracers
Post Injection	Post-mortem soil and groundwater sampling

VERTEX

Questions

Thank You for Your Time

Nathan Lichti
Vertex Environmental Inc.
nathanl@vertexenvironmental.ca
519-653-8444