Vertex Environmental Inc.

Three Case Studies: In-Situ Remediation of PHCs in Bedrock

October 14, 2015

Bruce Tunnicliffe

Agenda

- Bedrock Background
- Case Study 1: LNAPL in House
- Case Study 2: Gas Station
- Case Study 3: Heating Oil
- Questions

Vertex

Contracting Firm

Vertex Services:

- Remediation:
  - ISCO, ISCR, enhanced bio
  - In-Situ and Ex-Situ treatment
- Treatment Systems
- High-Resolution Characterization
  - LIF, MIP, HPT

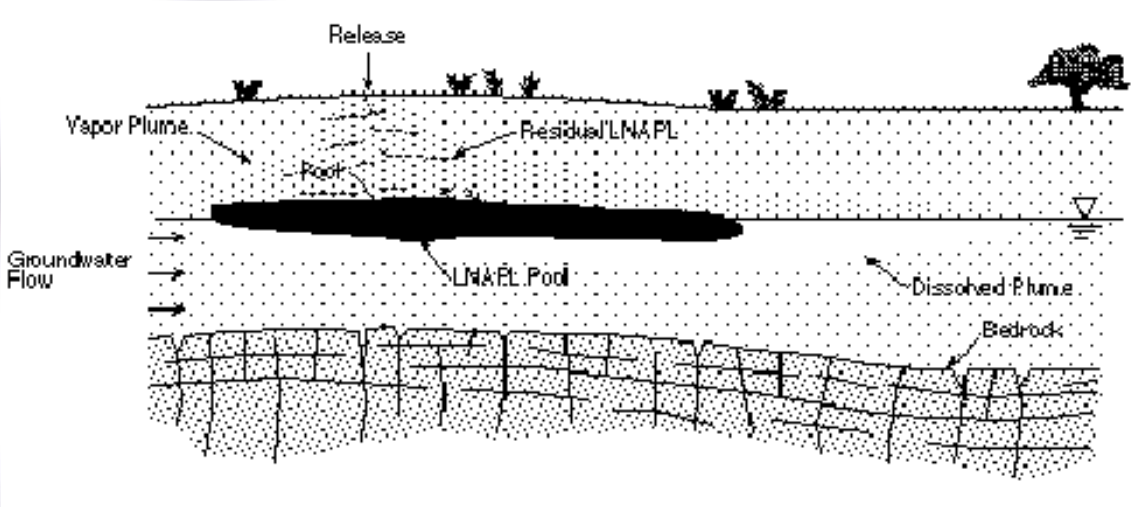
Bedrock

vs.
Porous
Media

Bedrock

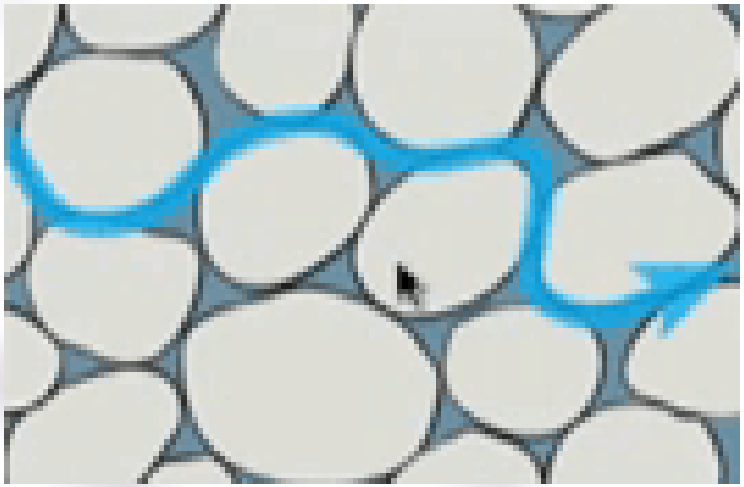
Contaminant **Migration & Remediation** in Bedrock is Affected By:

- Groundwater & NAPL **<u>Advection</u>**
- Groundwater & NAPL **<u>Diffusion / Adsorption</u>**



Groundwater Advection

Flow Through Porous Media



Flow Through Fractured Media

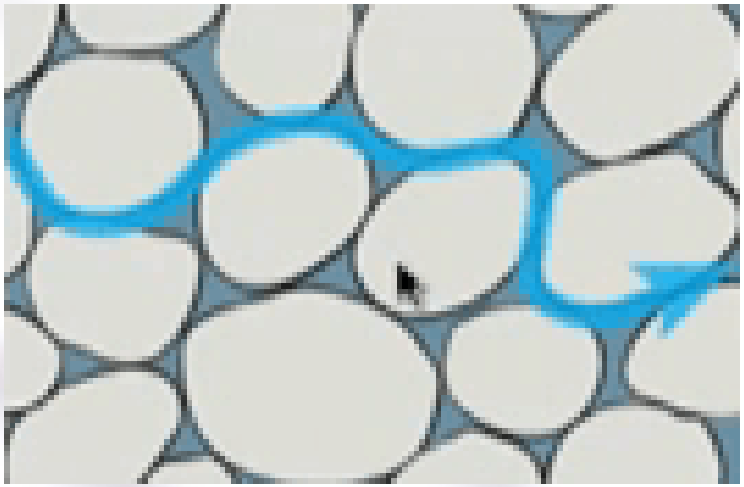
Flow governed by Darcy's Law:

$$Q = K\ i\ A$$

Q = Flow rate (m^3/s)
K = Hydraulic Conductivity (m/s)
i = Hydraulic Gradient (unitless)
A = Area (m^2)

Groundwater Advection

Porous Media Flow (by Darcy's Law):

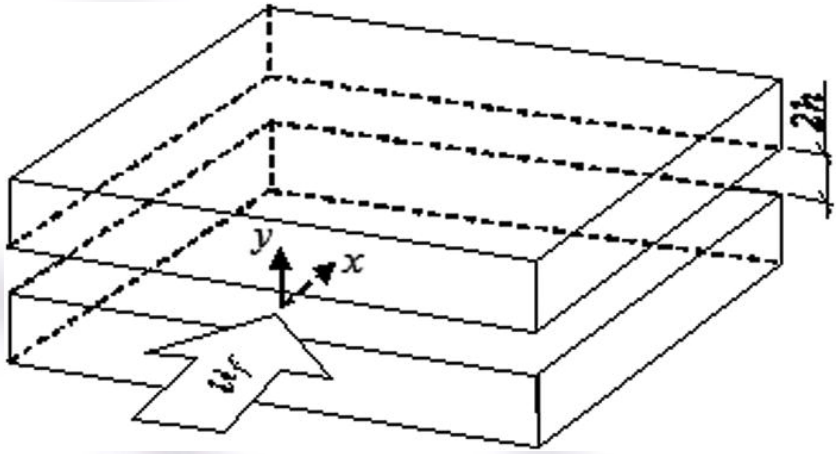


$$v = -\frac{K\,i}{n}$$

v = Groundwater Velocity (m/s)
K = Hydraulic Conductivity (m/s)
i = Hydraulic Gradient (unitless)
n = Porosity (unitless)

Groundwater Advection

Bedrock Fracture Flow (by Darcy's Law & the Cubic Law):



$$v = -\frac{\rho\, g}{12\,\mu}\,(2b)^2\, i$$

v = Velocity Through Fracture (m/s)
ρ = Density of Fluid (kg/m^3)
g = Acceleration of Gravity (m/s^2)
μ = Viscosity of Fluid (Pa s)
2b = Fracture Thickness (m)
i = Hydraulic Gradient (unitless)

VERTEX

Groundwater Advection

Porous Media

$$v = -\frac{K\ i}{n}$$

Sand	
K	10^{-4} m/s
i	0.001
n	0.30
Velocity	10 m/yr

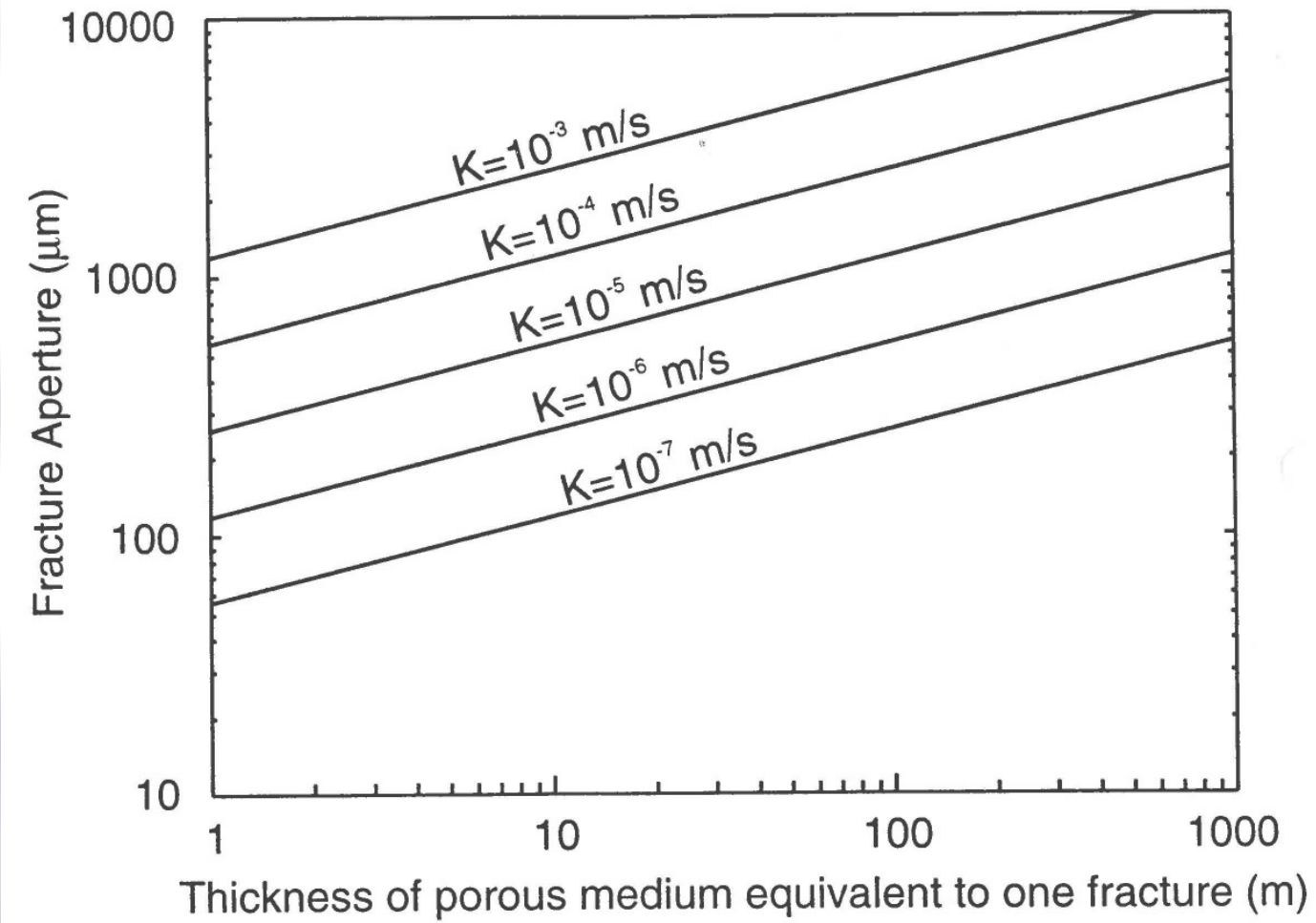
Bedrock Fracture

$$v = -\frac{\rho\ g}{12\ \mu}\ (2b)^2\ i$$

Bedrock	
i	0.001
Velocity	10 m/yr
Fracture Ht (2b)	19 um

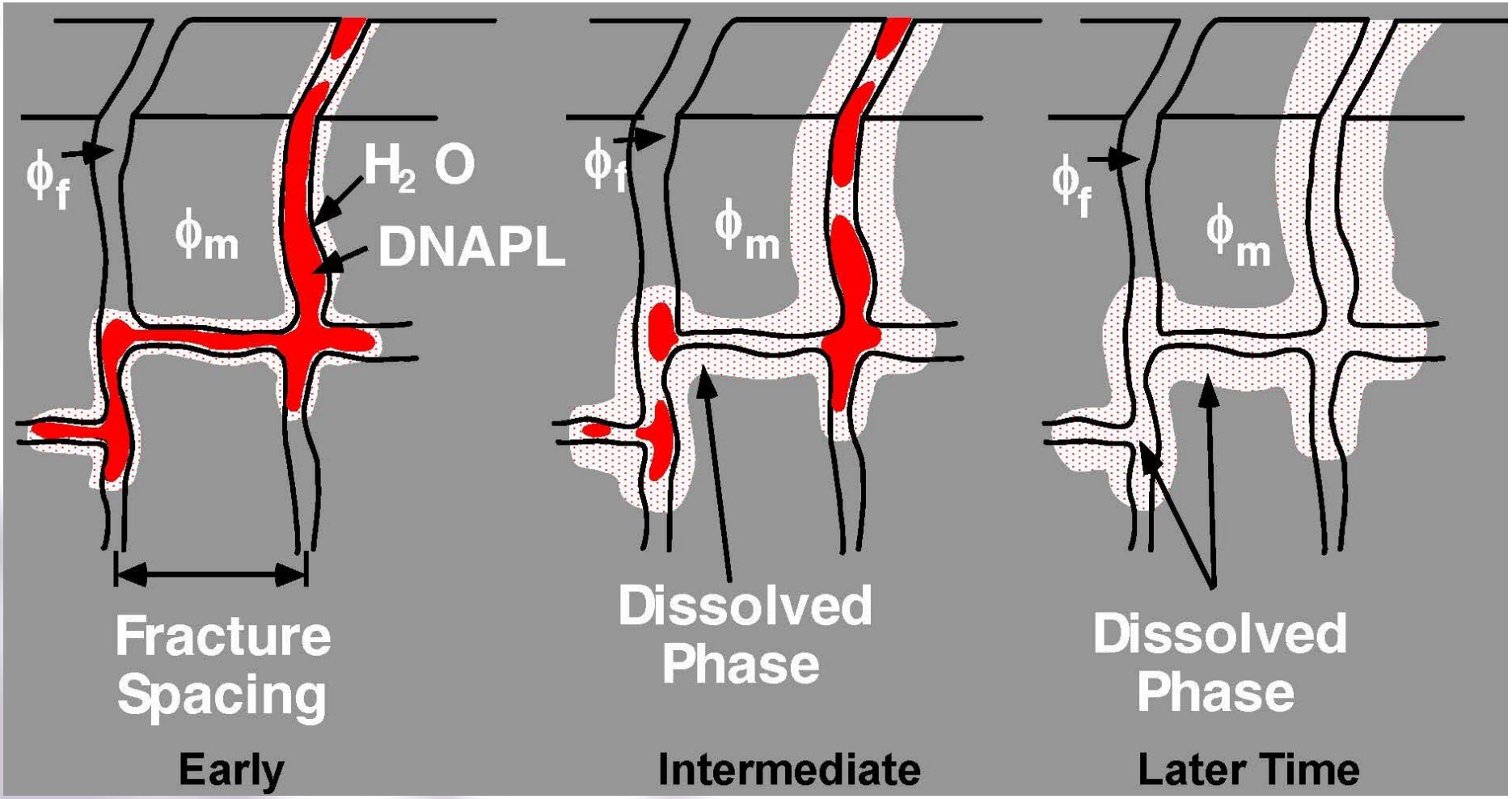
Groundwater Advection

Bedrock Fracture Aperture K vs Porous Media K:



K = Hydraulic Conductivity

Contaminant Diffusion into Bedrock



Rule of Thumb: “It takes 20 times longer to get contamination out of a matrix than it takes to diffuse into a matrix.”

Source: Beth Parker

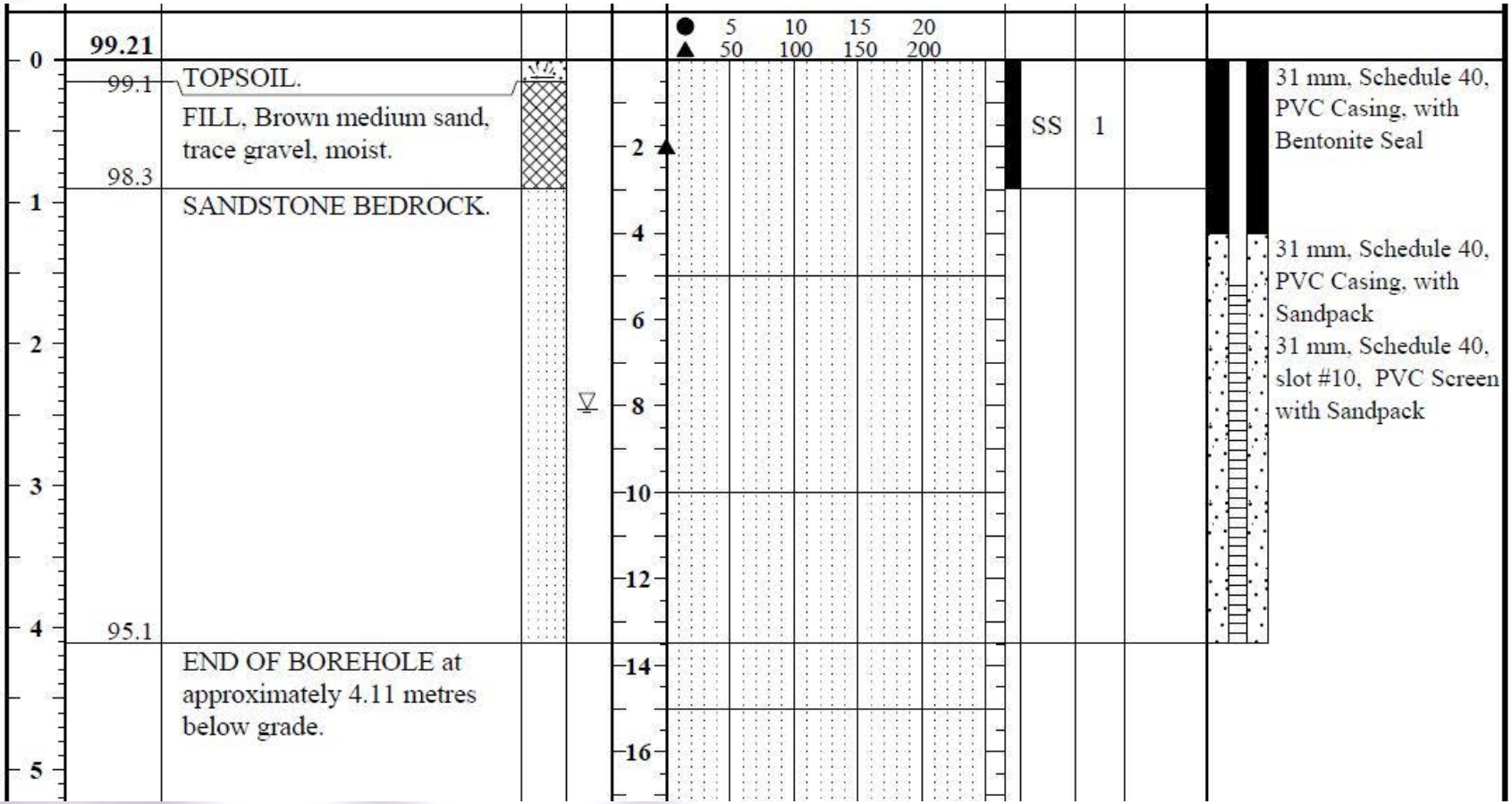
Case Studies

Case Study #1
LNAPL In House

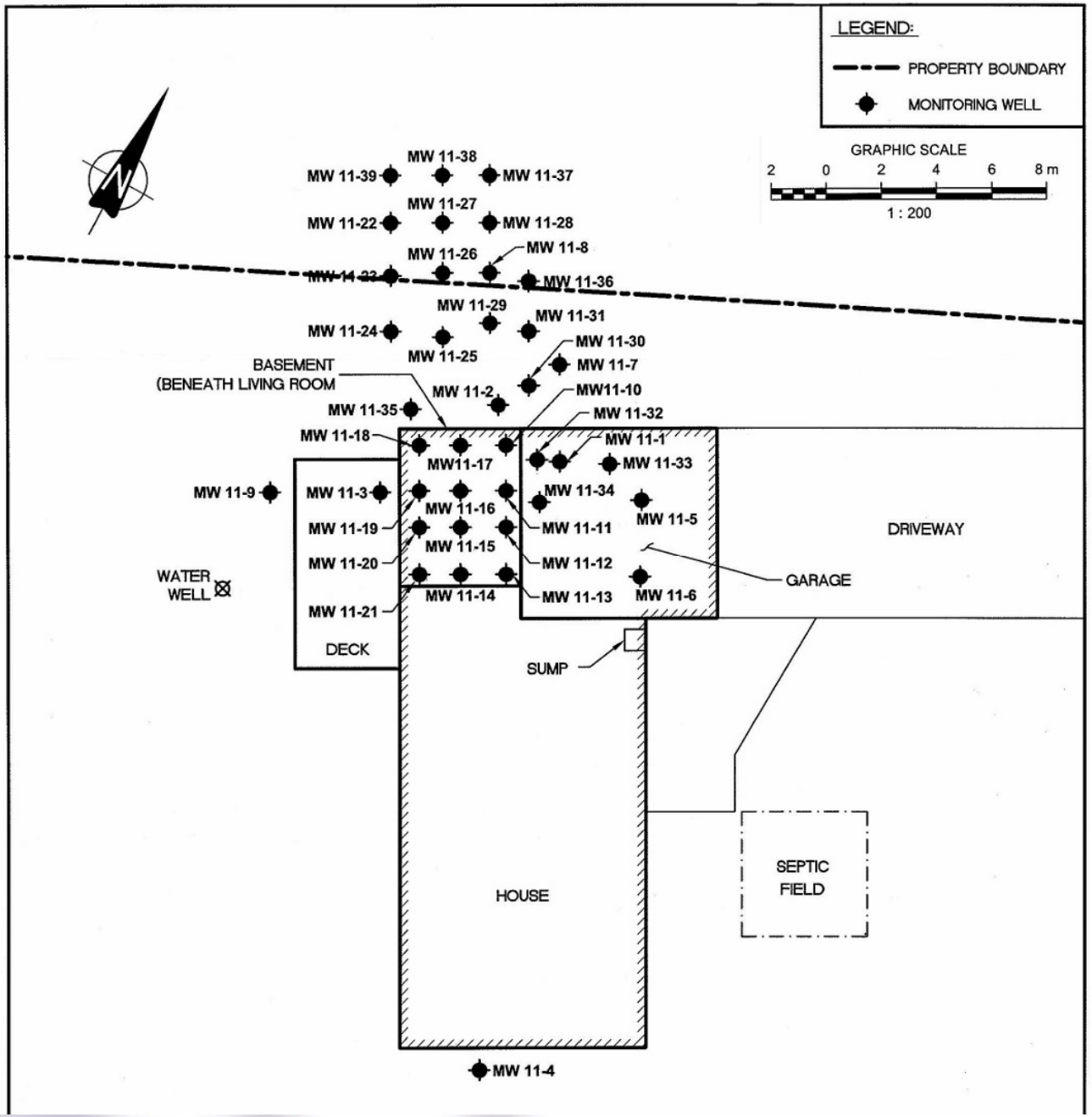
Case Study – LNAPL in House

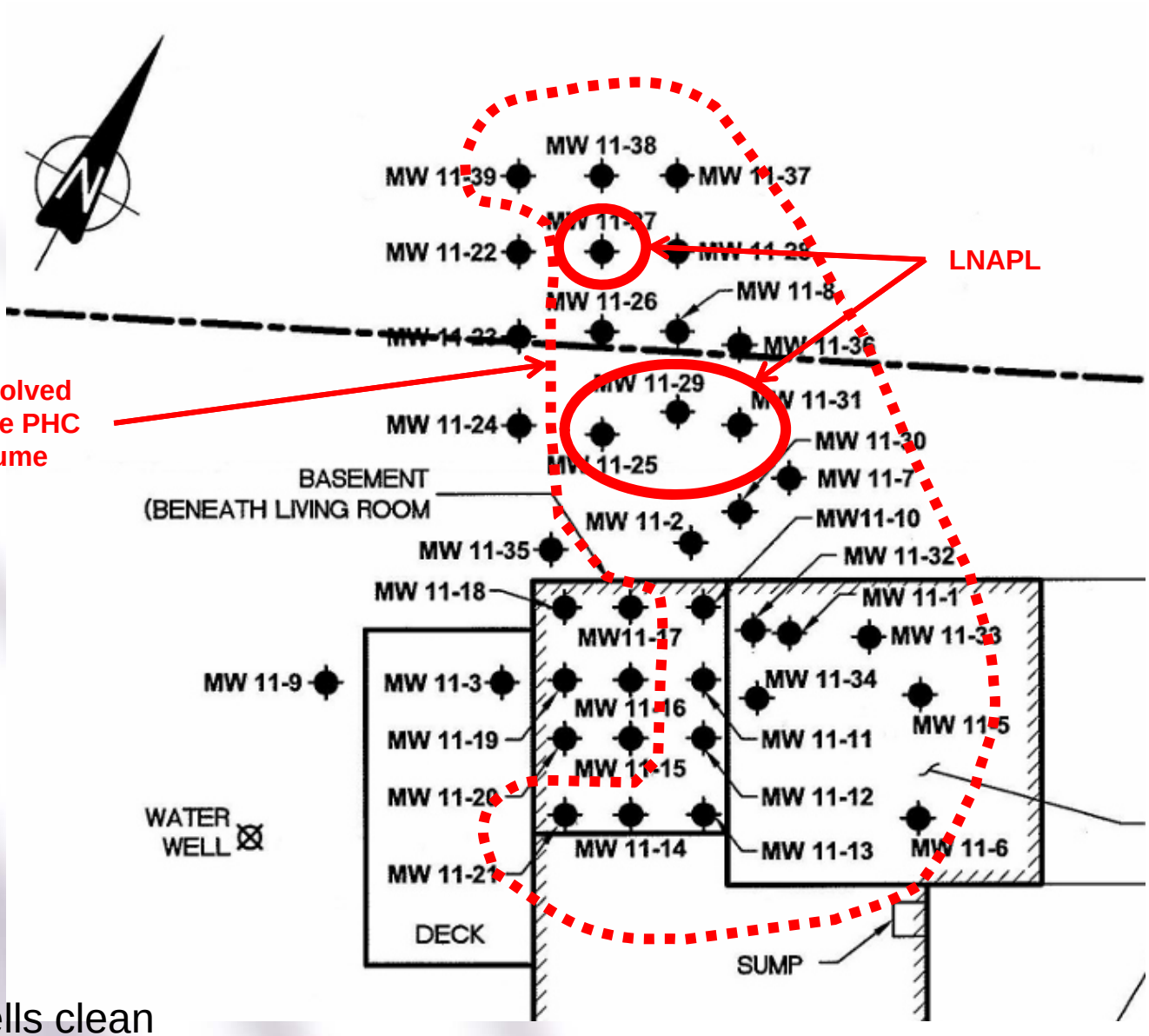
- Heating oil release
  - Home owner woke up to oil pooling in his garage
  - Under the crawl space
  - Into the backyard
  - Around the foundation of his home
- Insurance Claim
- Quick action undertaken
  - Vacuum truck and booms to remove LNAPL
  - Excavation of shallow soils
- Install Bedrock Monitoring Wells
  - Vacuum LNAPL (Vac Truck)
  - LNAPL consistently returned to MWs
  - More aggressive approach required

Case Study – LNAPL in House



Borehole Log for MW11-08


LEGEND:
PROPERTY BOUNDARY
MONITORING WELL
GRAPHIC SCALE
2 0 2 4 6 8 m
1 : 200
MW 11-38
MW 11-39
MW 11-37
MW 11-27
MW 11-22
MW 11-28
MW 11-26
MW 11-8
MW 11-36
MW 11-29
MW 11-31
MW 11-24
MW 11-25
MW 11-30
MW 11-7
BASEMENT
(BENEATH LIVING ROOM
MW 11-2
MW11-10
MW 11-35
MW 11-32
MW 11-18
MW11-17
MW 11-1
MW 11-33
MW 11-9
MW 11-3
MW 11-16
MW 11-34
MW 11-5
MW 11-19
MW 11-11
DRIVEWAY
MW 11-15
MW 11-20
MW 11-12
WATER
WELL
GARAGE
MW 11-14
MW 11-13
MW 11-6
MW 11-21
DECK
SUMP
SEPTIC
FIELD
HOUSE
MW 11-4



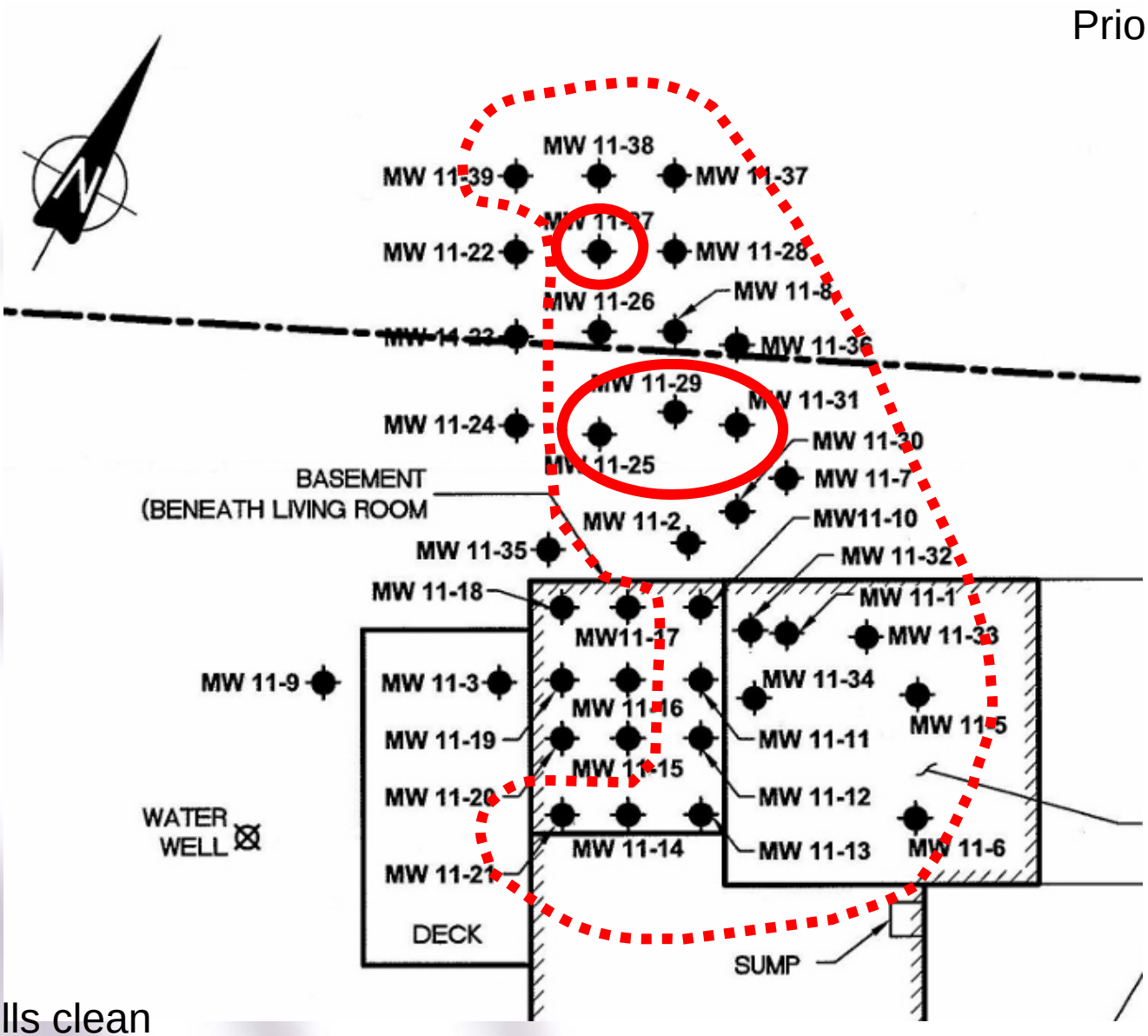
At start:

- 14 wells clean
- 25 wells contaminated

Case Study – LNAPL in House

- In-Situ Chemical Oxidation (ISCO) Approach
  - Persulphate
  - Alkaline activation
  - Inject small volume (2,000 L)
    - Injection = 1 day
  - Inject frequently (~ every 2 months)
    - Inject for 1 year (5 events)
  - Reassess the plume

Prior to ISCO



At start:

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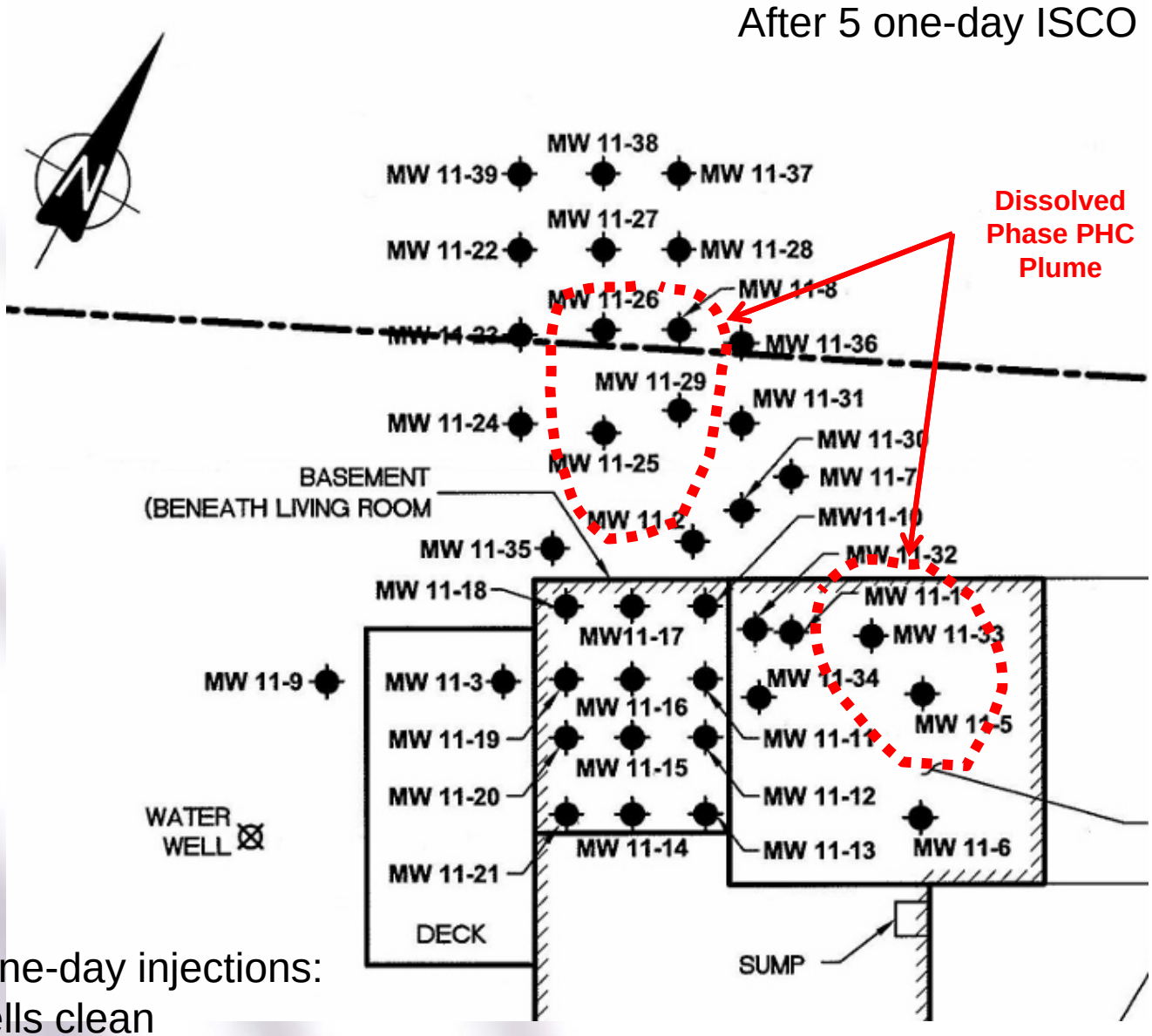
After 5 one-day ISCO Injections

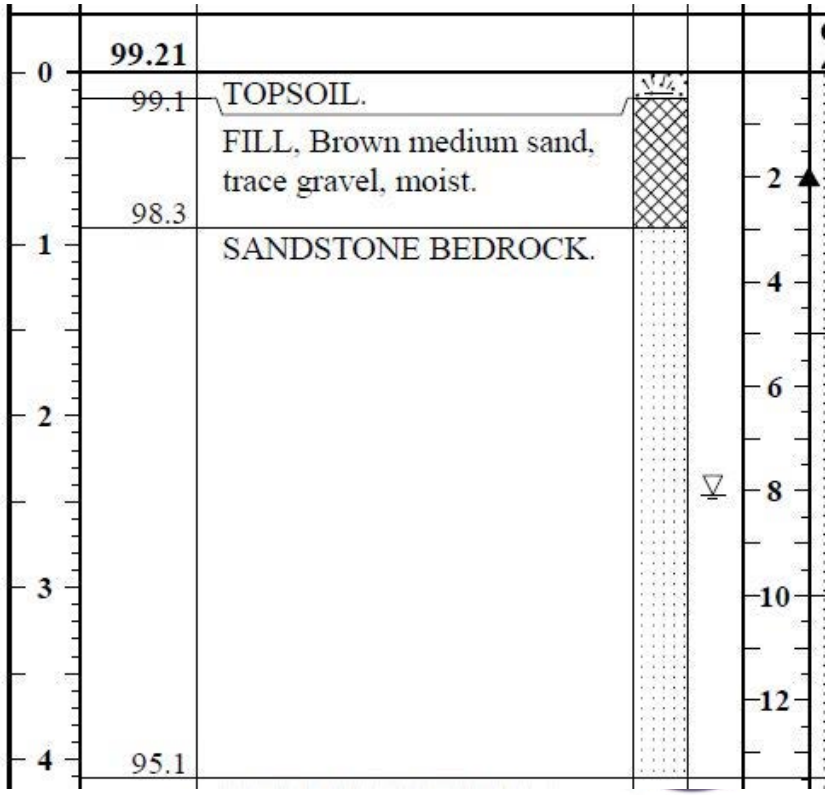


After 5 one-day injections:

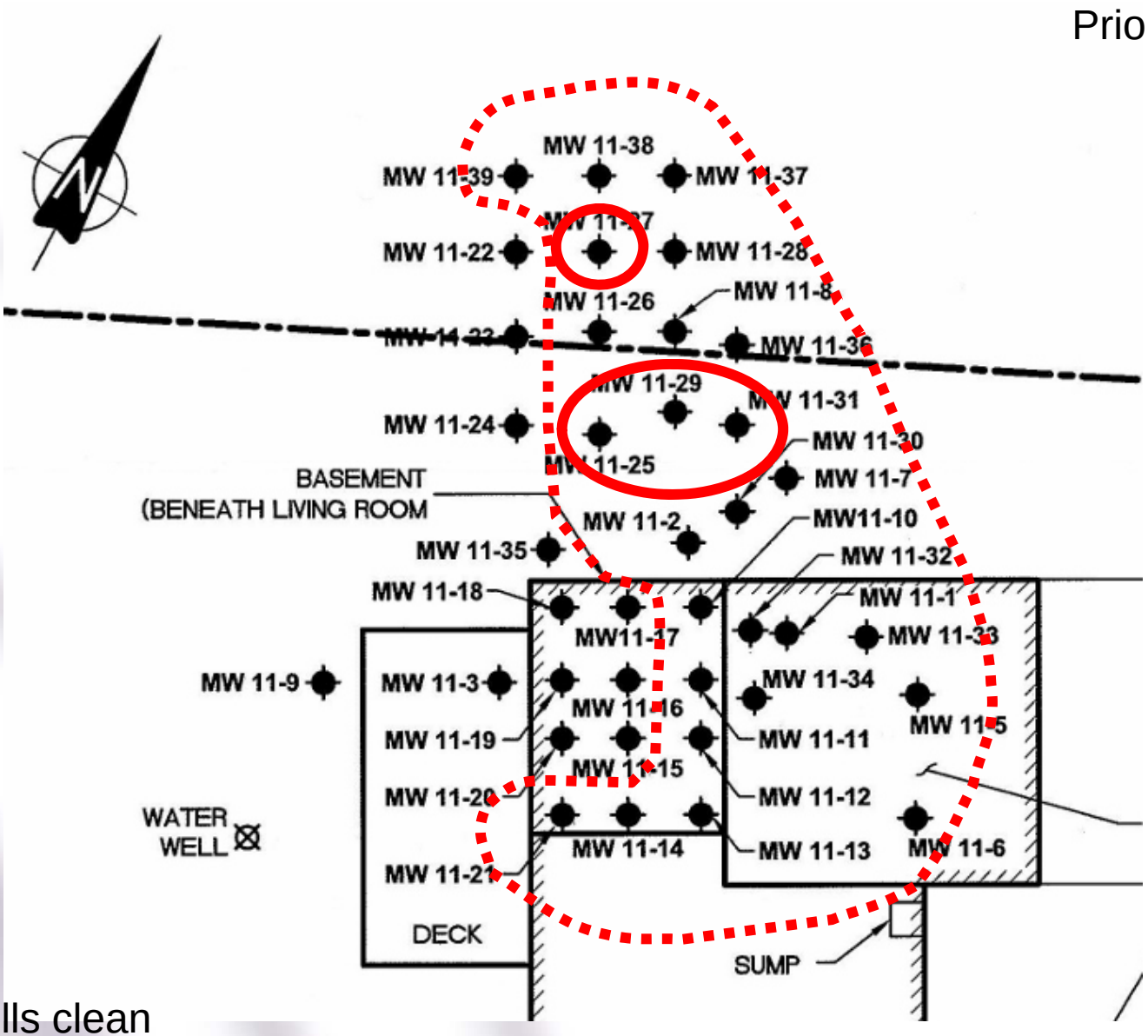
- 33 wells clean
- 6 wells contaminated

Case Study – LNAPL in House

- Enhanced ISCO
  - Focused persulphate injections
  - Use of enhanced gradient
    - Vacuum on wells
    - Enhanced gradient during injection
    - Influence unsaturated zone
  - Use of surfactant



Prior to ISCO



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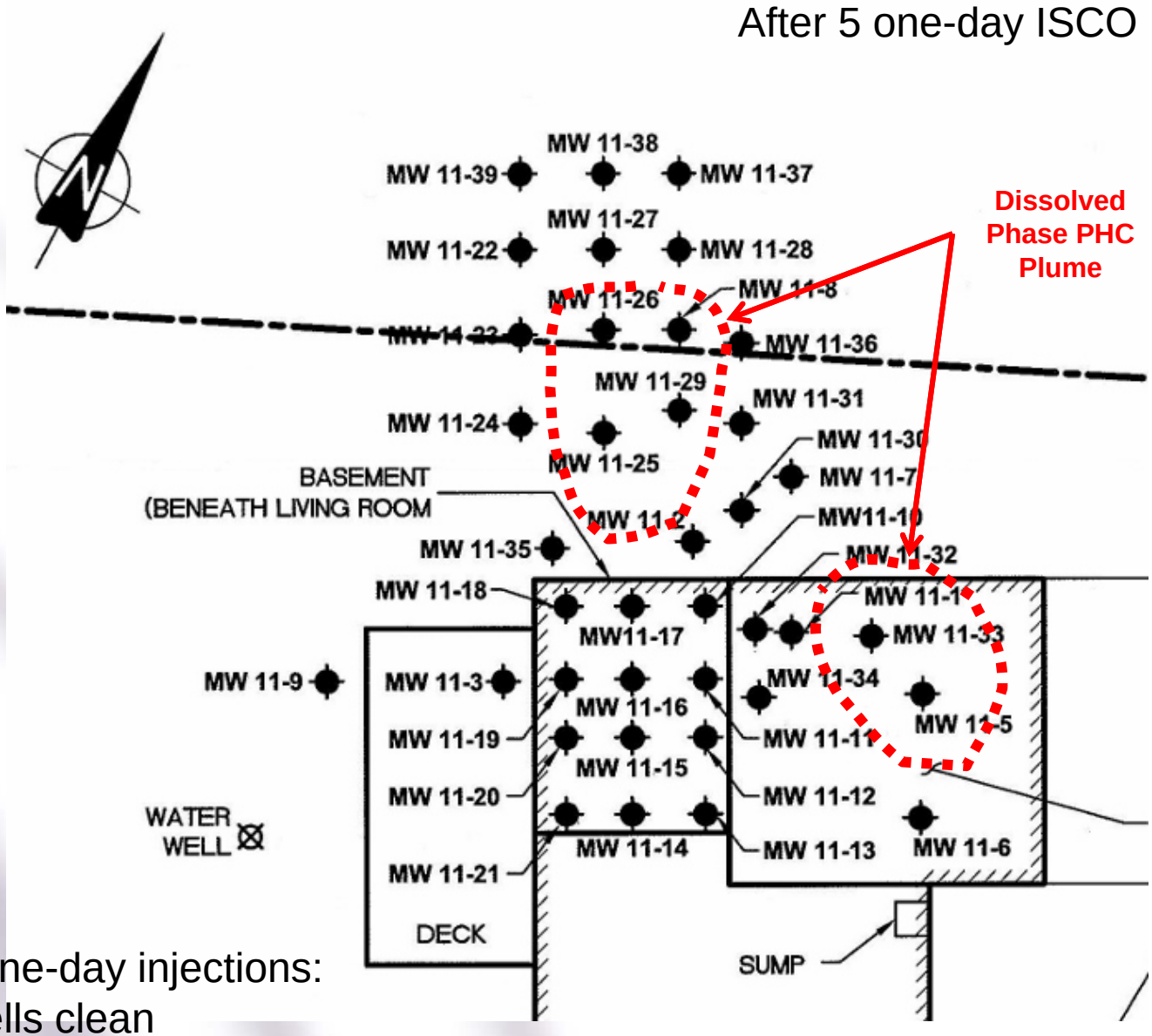
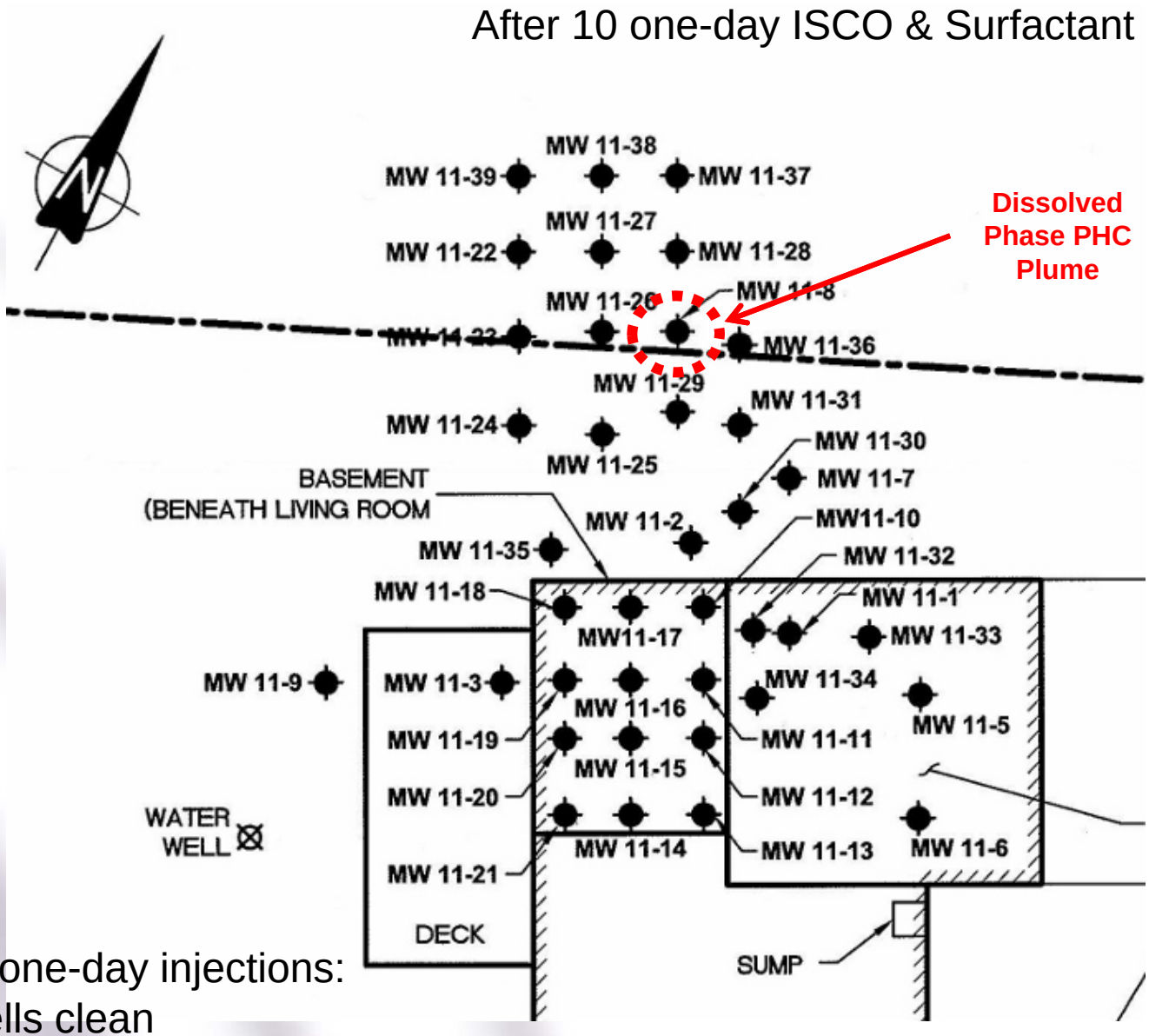


After 5 one-day injections:

- 33 wells clean
- 6 wells contaminated

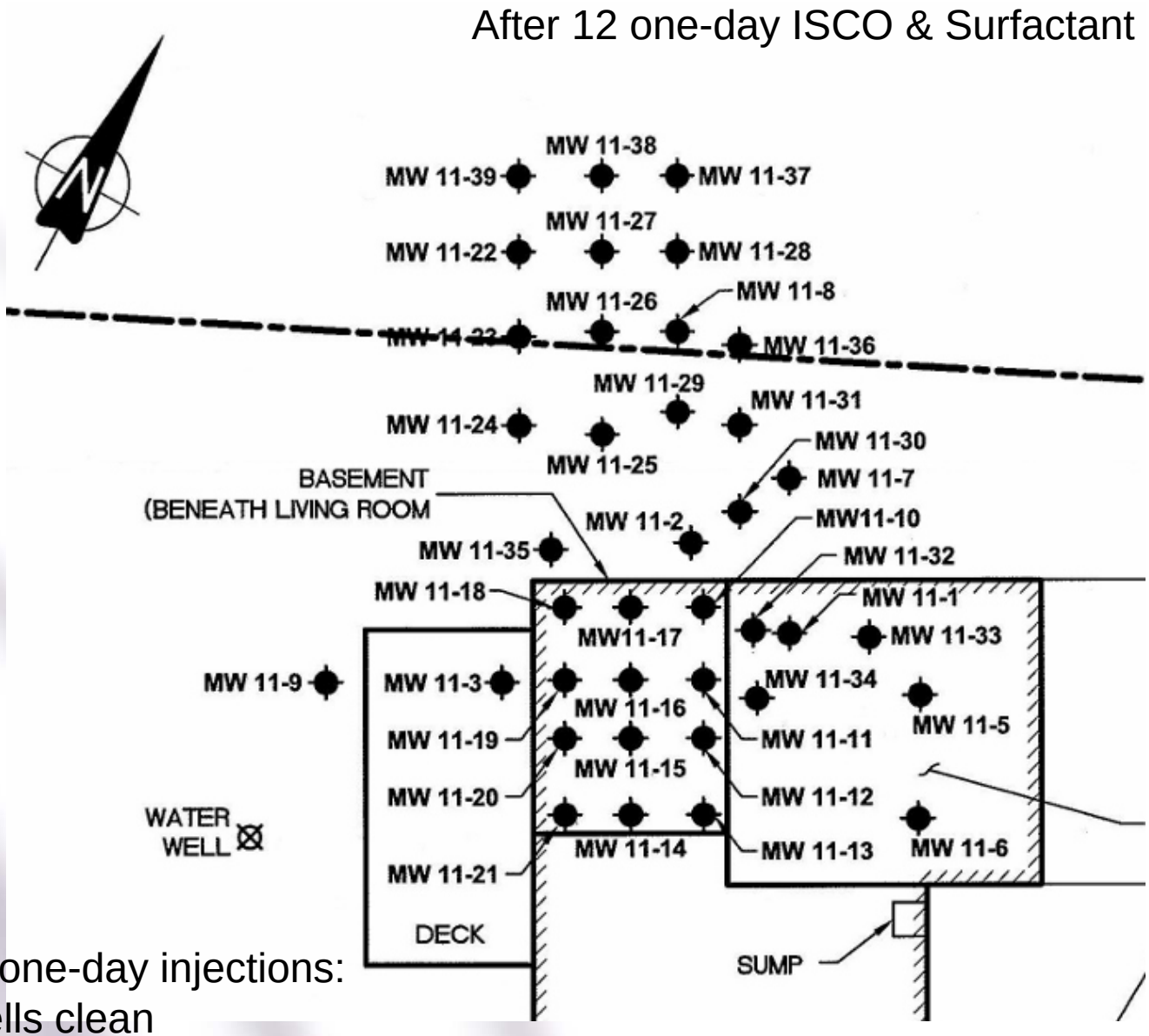
After 10 one-day ISCO & Surfactant Injections



After 10 one-day injections:

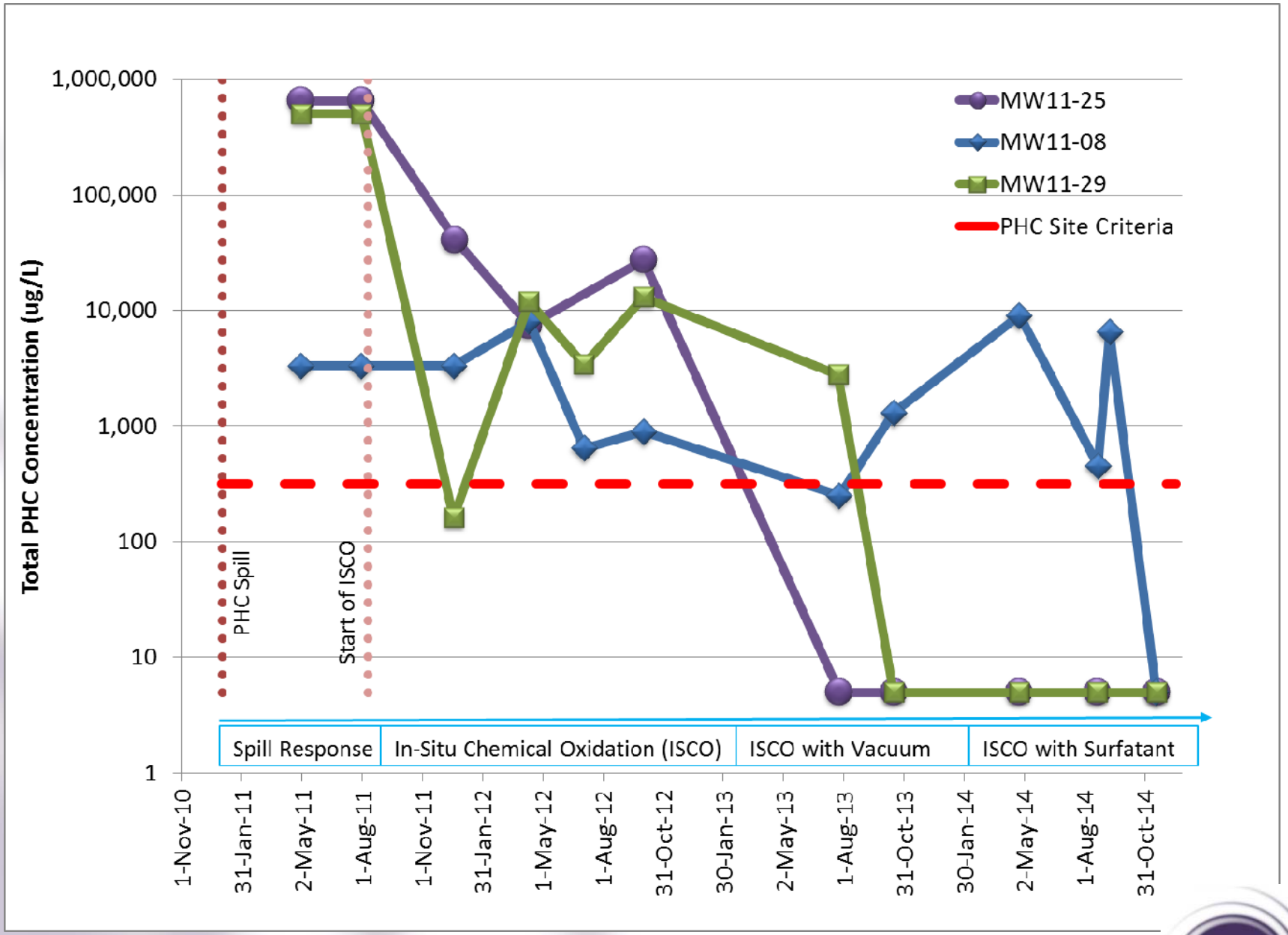
- 38 wells clean
- 1 well contaminated

After 12 one-day ISCO & Surfactant Injections



After 12 one-day injections:

- 39 wells clean
- 0 well contaminated


Total PHC Concentration (ug/L)
1,000,000
100,000
10,000
1,000
100
10
1
MW11-25
MW11-08
MW11-29
PHC Site Criteria
PHC Spill
Start of ISCO
Spill Response
In-Situ Chemical Oxidation (ISCO)
ISCO with Vacuum
ISCO with Surfatant
1-Nov-10
31-Jan-11
2-May-11
1-Aug-11
1-Nov-11
31-Jan-12
1-May-12
1-Aug-12
31-Oct-12
30-Jan-13
2-May-13
1-Aug-13
31-Oct-13
30-Jan-14
2-May-14
1-Aug-14
31-Oct-14

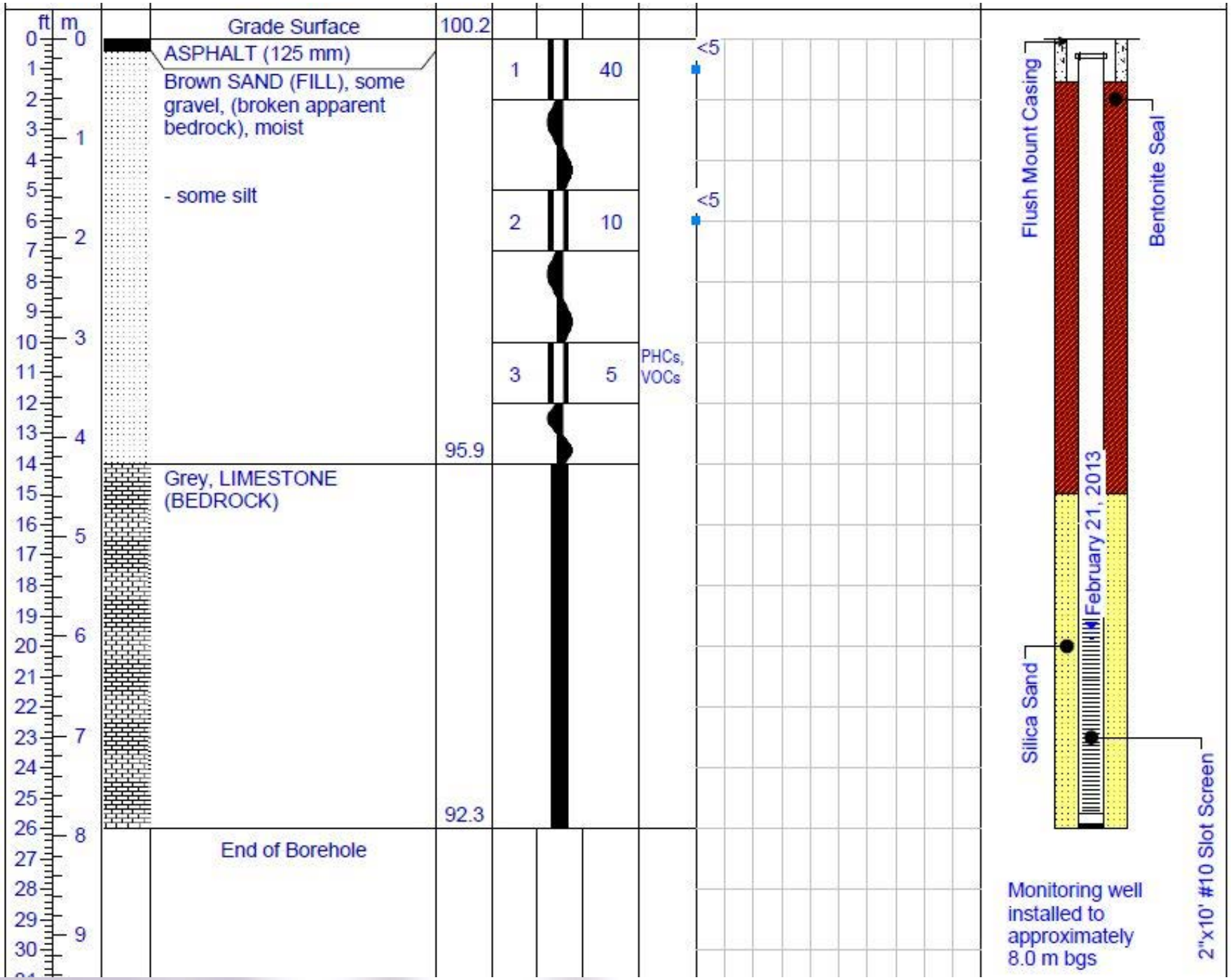
Case Study – LNAPL in House

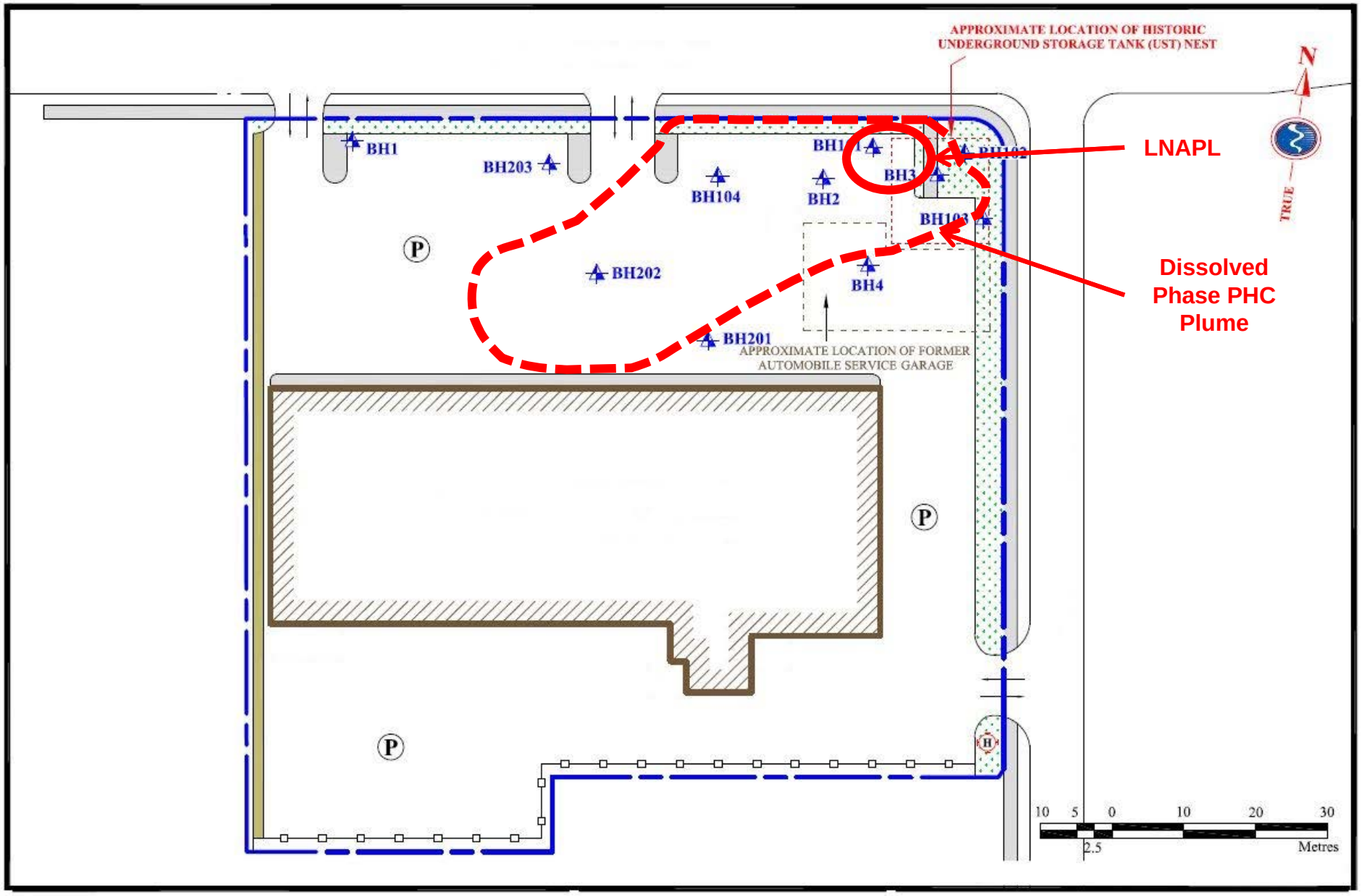
- Conclusions
  - Remediated LNAPL & GW to MOECC Standards
  - Shallow soils excavation
  - Vacuum removal of LNAPL from wells
  - Bedrock remediation accomplished through intelligent use of:
    - ISCO
    - Enhanced Delivery using Vacuum
    - Surfactant
  - Result: LNAPL & dissolved PHCs removed from bedrock

Case Study #2
Gas Station

Case Study – Gas Station

- Historical gas station and auto body shop
  - Operated for many decades
  - Bedrock blasted to place 4 Underground Storage Tanks (USTs) in north-east corner of Site
  - USTs removed in 1996
    - No soil was excavated
    - PIDs were low, assumed Site was clean
- Bedrock at 0.5 m to 1.0 m bgs
  - Except where USTs dug, bedrock at 4.5 m to 5.5 m bgs
- Groundwater at 6 to 7 m below ground surface (bgs)
- LNAPL found in well at edge of former UST area


ft
m
Grade Surface
100.2
ASPHALT (125 mm)
Brown SAND (FILL), some gravel, (broken apparent bedrock), moist
- some silt
95.9
Grey, LIMESTONE (BEDROCK)
92.3
End of Borehole
1
40
2
10
3
5
PHCs, VOCs
<5
<5
Flush Mount Casing
Bentonite Seal
February 21, 2013
Silica Sand
2"x10' #10 Slot Screen
Monitoring well installed to approximately 8.0 m bgs

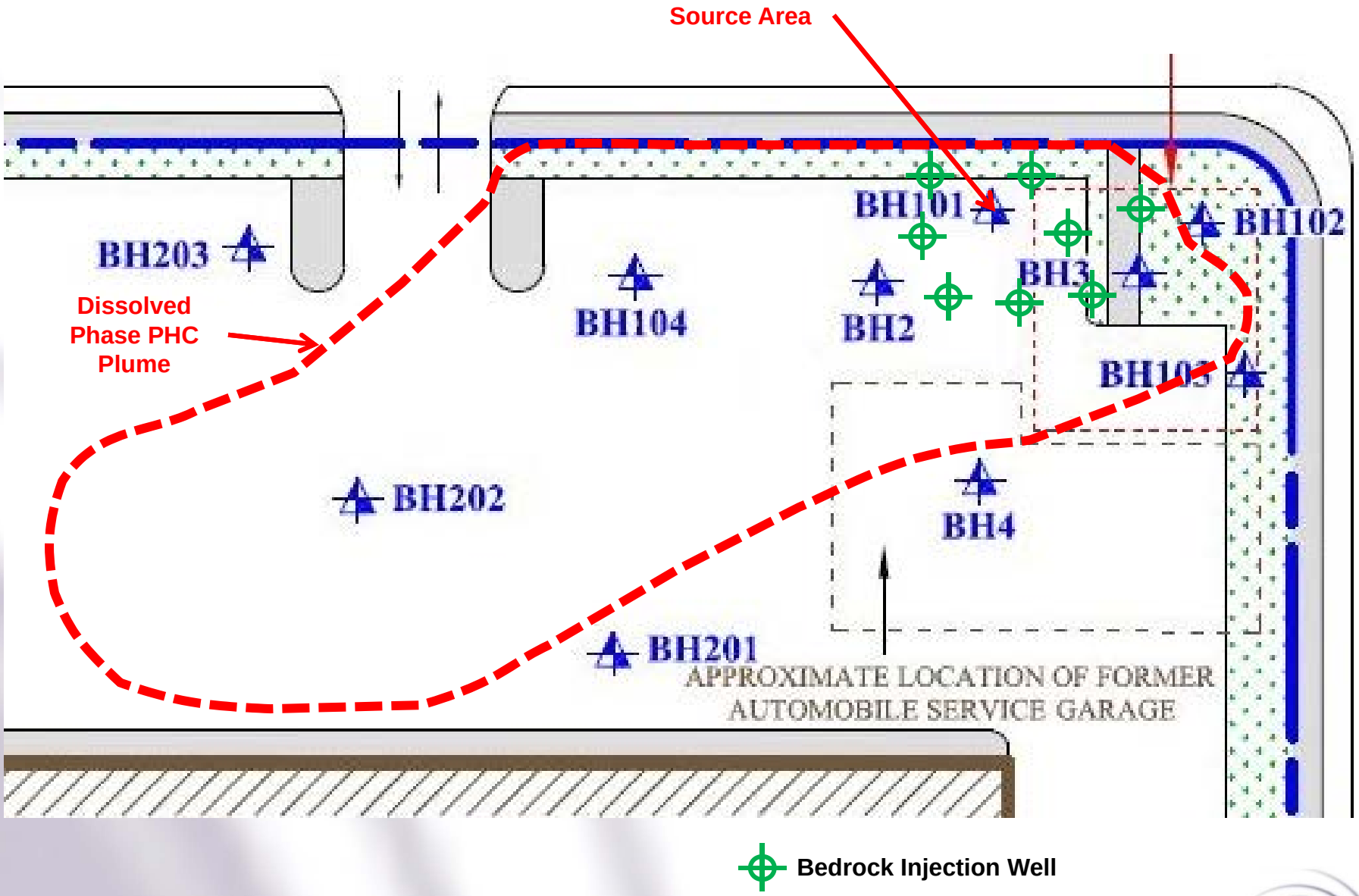

APPROXIMATE LOCATION OF HISTORIC
UNDERGROUND STORAGE TANK (UST) NEST
N
TRUE
LNAPL
Dissolved
Phase PHC
Plume
BH1
BH203
BH104
BH2
BH3
BH103
BH202
BH4
BH201
APPROXIMATE LOCATION OF FORMER
AUTOMOBILE SERVICE GARAGE
P
P
P
H
10 5 0 10 20 30
2.5
Metres

Pre-Remediation Concentrations

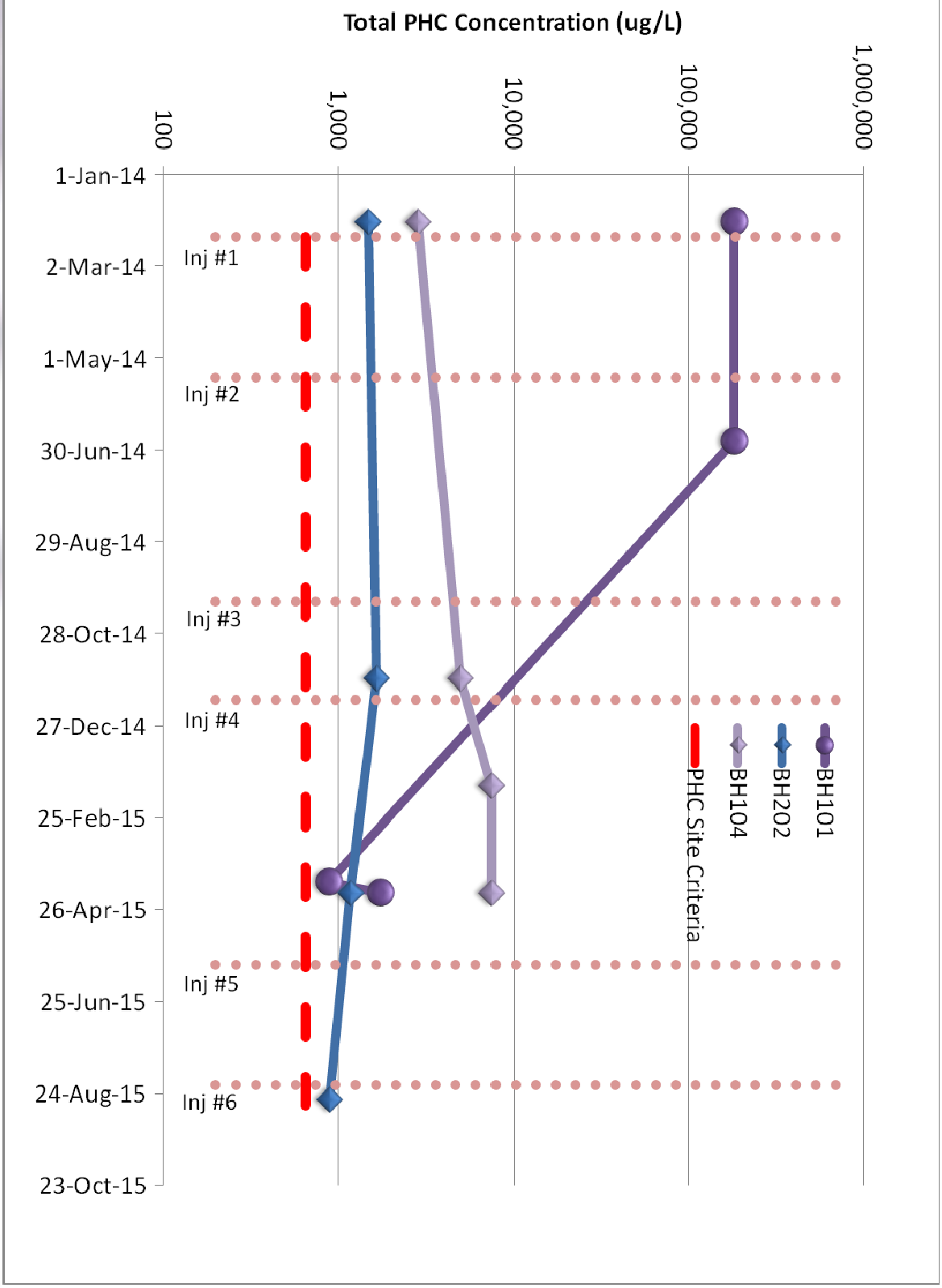
Parameter (ug/L)	MOECC Table 7	BH101 Source Area	% Reduction	BH202 Down-gradient	% Reduction
Benzene	0.50	400	99.9%	<0.20	0%
Toluene	320	71	0%	<0.20	0%
Ethylbenzene	54	1,400	96%	<0.20	0%
Xylenes	72	9,000	99.2%	<0.40	0%
PHC(F1)	420	68,000	99.4%	120	0%
PHC(F2)	150	100,000	99.9%	430	65%
PHC(F3)	500	3,400	85%	920	45%

Case Study – Gas Station

- Install Injection Wells
  - In the “Source Area”
- Surfactant Injection & Extraction
  - Dissolve as much LNAPL as possible
  - Add tracer, understand groundwater flow regime
  - Extract surfactant and tracer from subsurface
    - In total 15,000 L of tracer / surfactant injected
    - In total 25,000 L of gw / surfactant removed
- In-Situ Chemical Oxidation
  - Persulphate, base activated
    - In total 6,500 kg of persulphate injected
- Quarterly Injections
  - To date: 6 injections completed



Hint: Use Injection Wells to look for LNAPL


Total PHC Concentration (ug/L)
100
1,000
10,000
100,000
1,000,000
1-Jan-14
2-Mar-14
1-May-14
30-Jun-14
29-Aug-14
28-Oct-14
27-Dec-14
25-Feb-15
26-Apr-15
25-Jun-15
24-Aug-15
23-Oct-15
Inj #1
Inj #2
Inj #3
Inj #4
Inj #5
Inj #6
PHC Site Criteria
BH104
BH202
BH101

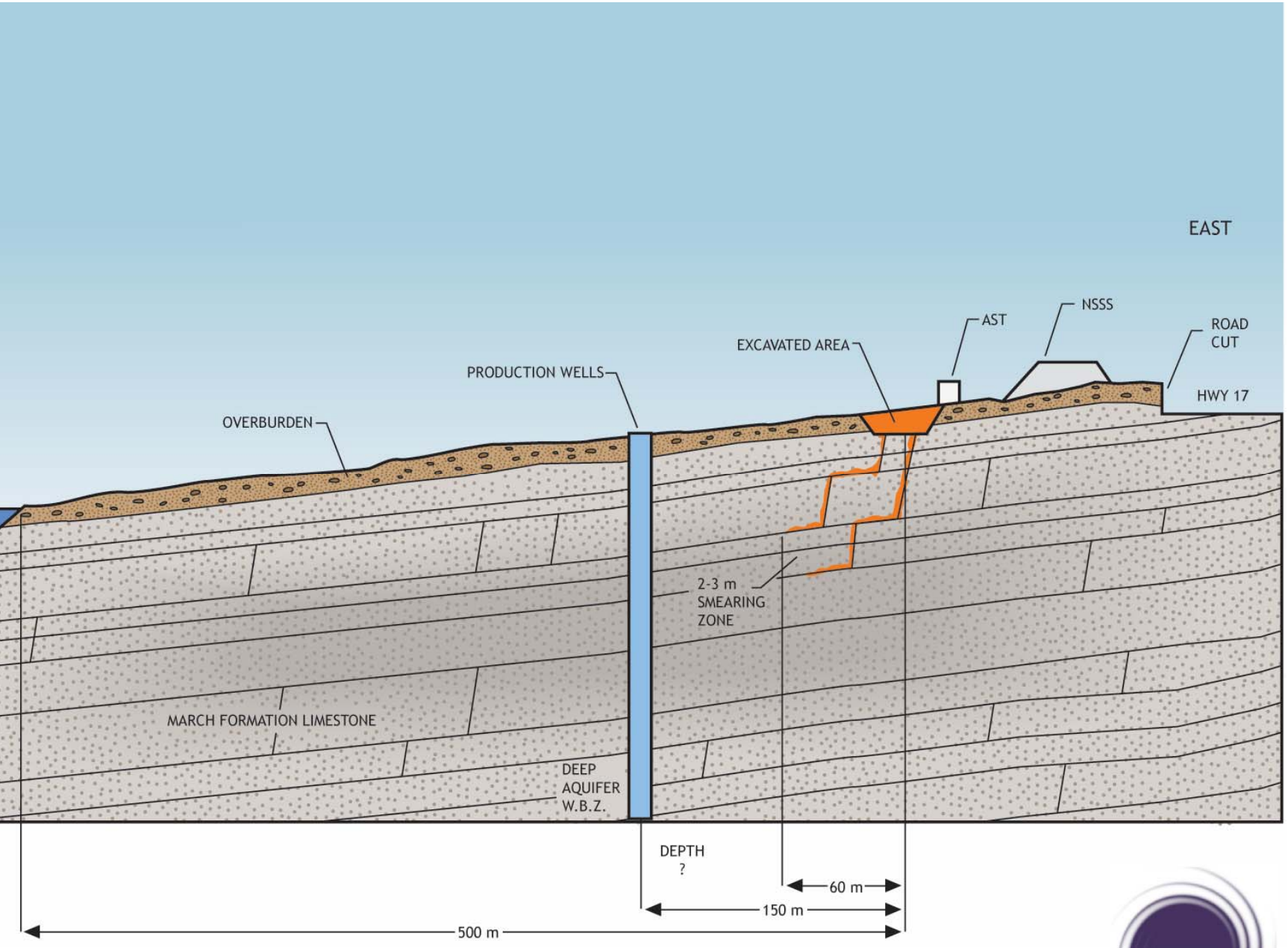
Case Study – Gas Station

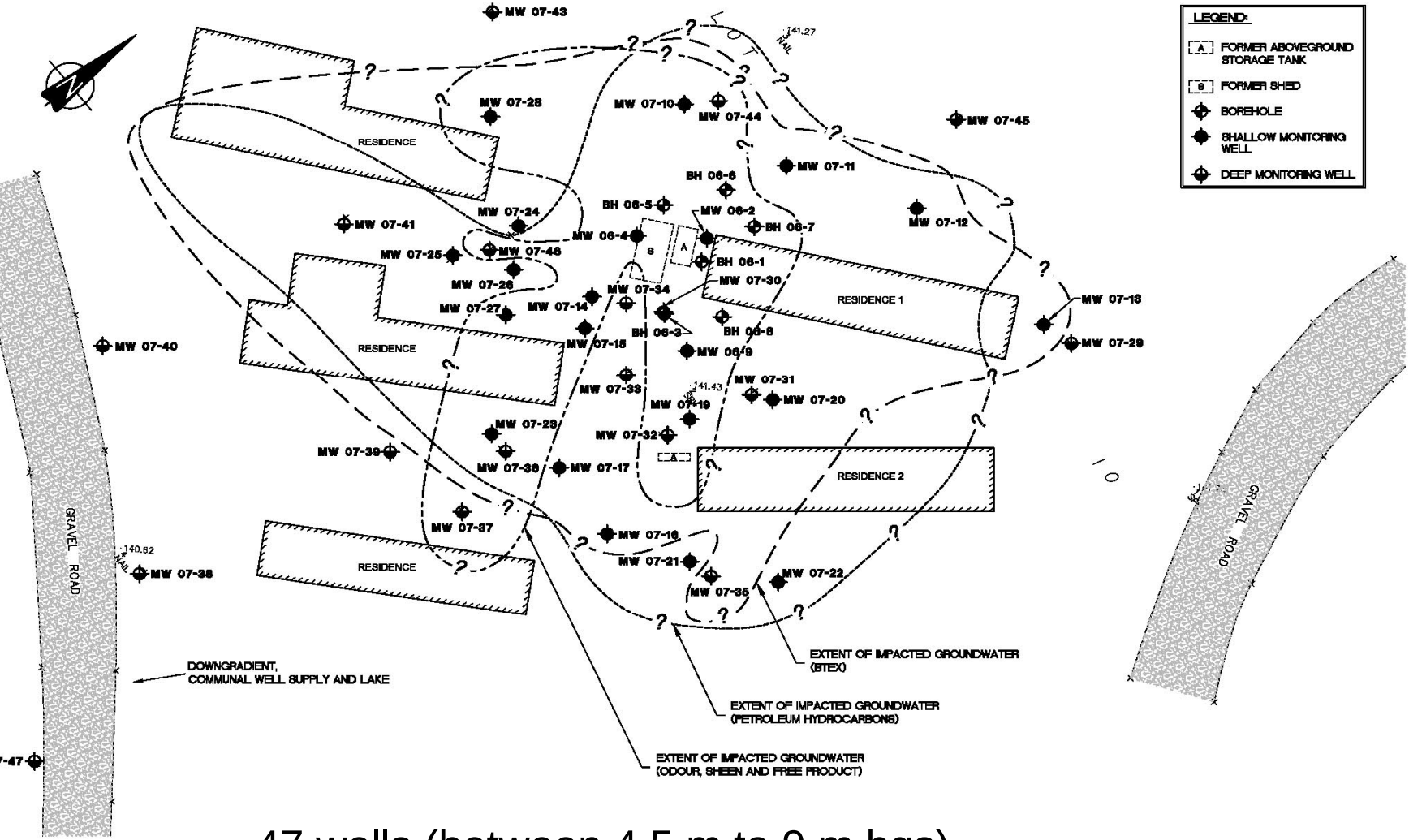
- Conclusions
  - Remediated LNAPL
  - Tracer helped to understand distribution
  - Tracer helped to extract surfactant
    - And the dissolved PHCs
  - Exceedances of MOECC Standards, but only marginally, anticipate only a limited number of additional quarterly injections
  - Bedrock remediation using:
    - ISCO
    - Enhanced Delivery using Vacuum
    - Surfactant
  - Result: LNAPL removed from bedrock

Case Study #3
Heating Oil

Case Study – Heating Oil

- Heating oil release
  - Estimated 800 L from 2 side-by-side ASTs
- Mobile home park
- Insurance Claim
- Relatively quick action required
  - Fractured rock aquifer, drinking water wells


EAST
NSSS
AST
ROAD CUT
EXCAVATED AREA
PRODUCTION WELLS
HWY 17
OVERBURDEN
2-3 m SMEARING ZONE
MARCH FORMATION LIMESTONE
DEEP AQUIFER W.B.Z.
DEPTH ?
60 m
150 m
500 m



- 47 wells (between 4.5 m to 9 m bgs)
- Plume: 60 m long, 1,300 m^2
- Time to Impact DW Wells = 245 to 750 days

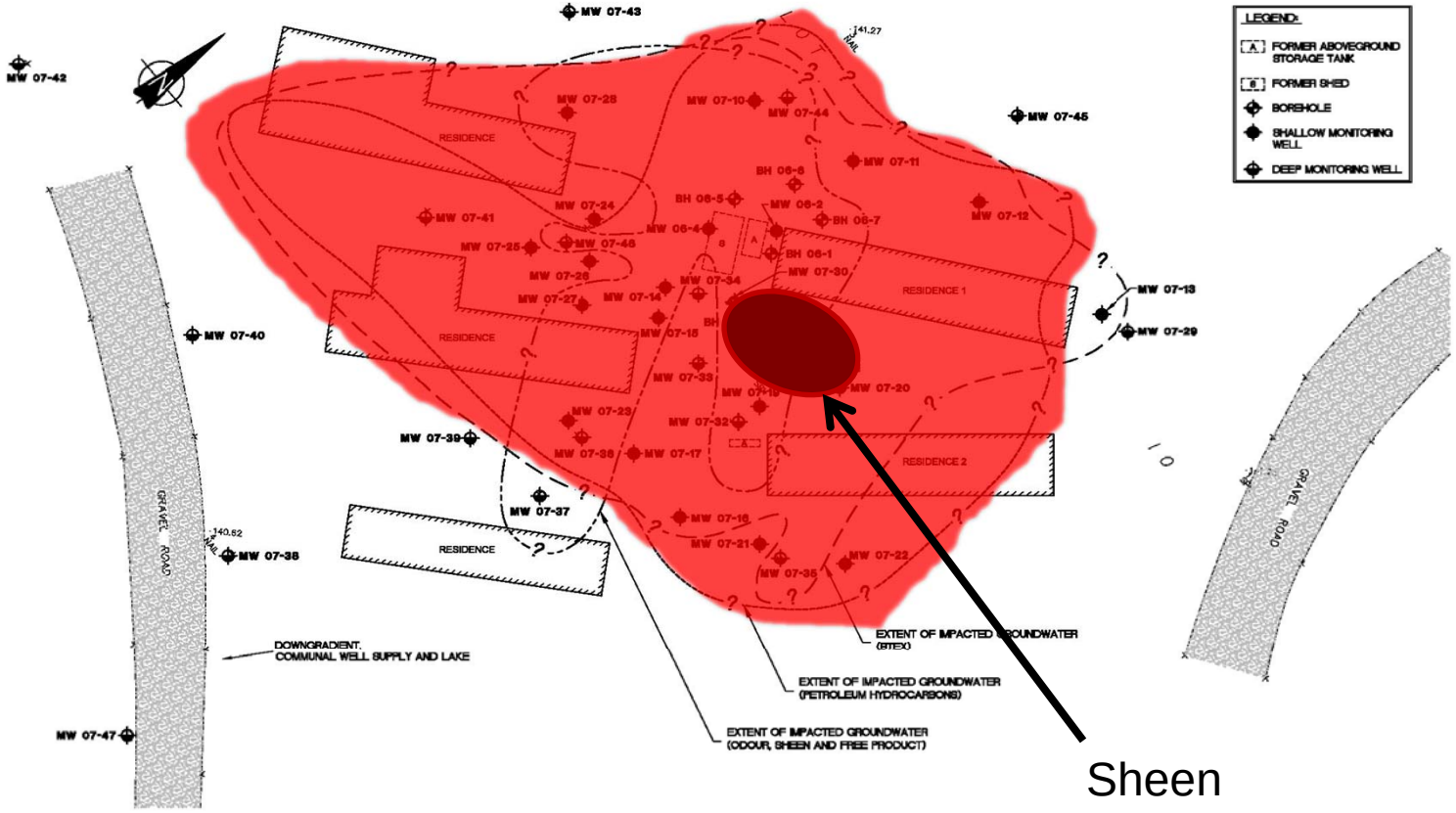
Case Study – Heating Oil

Parameter	Clean-up Standard (µg/L)	Maximum Groundwater Concentrations
Benzene	5.0	280
Toluene	24	630
Ethylbenzene	2.4	230
Xylene	300	780
PHC(F1)	F1 & F2 ≤ 1000	50,000
PHC(F2)		8,400
PHC(F3)	F3 & F4 ≤ 1000	1,300
PHC(F4)		<100

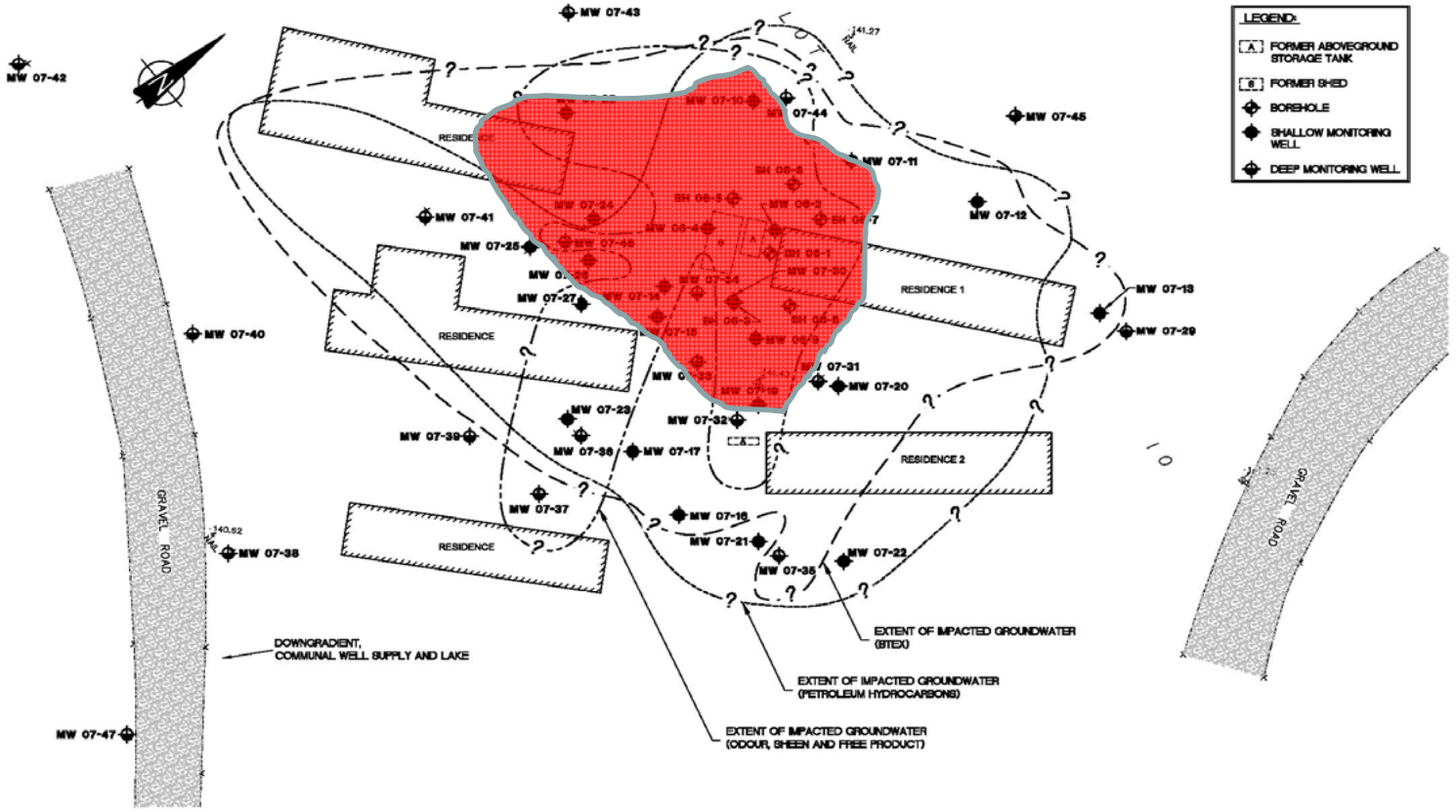
Case Study – Heating Oil

- Shallow Excavation
  - Removal of heavily impacted soils
- Monitoring Wells & Injection Wells Installed
  - Plume was constantly changing (quick moving)
- In-Situ Chemical Oxidation
  - Sodium Percarbonate ($2Na_2CO_3 3H_2O_2$)
    - In total 2,500 kg of percarbonate injected
- In-Situ Bioremediation
  - ORC (oxygen release compound)
    - In total 100 kg of ORC used

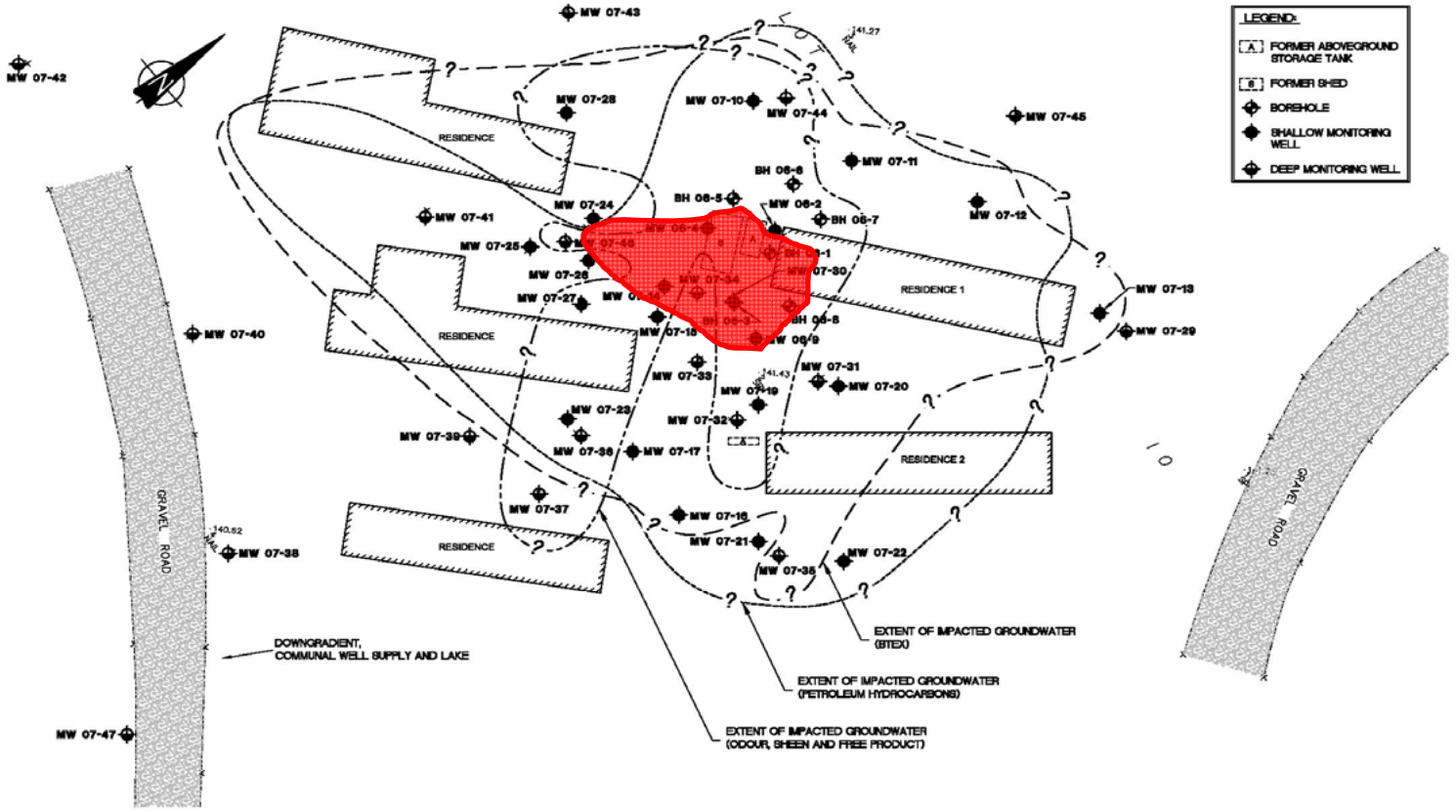
Case Study: Pre-Injection



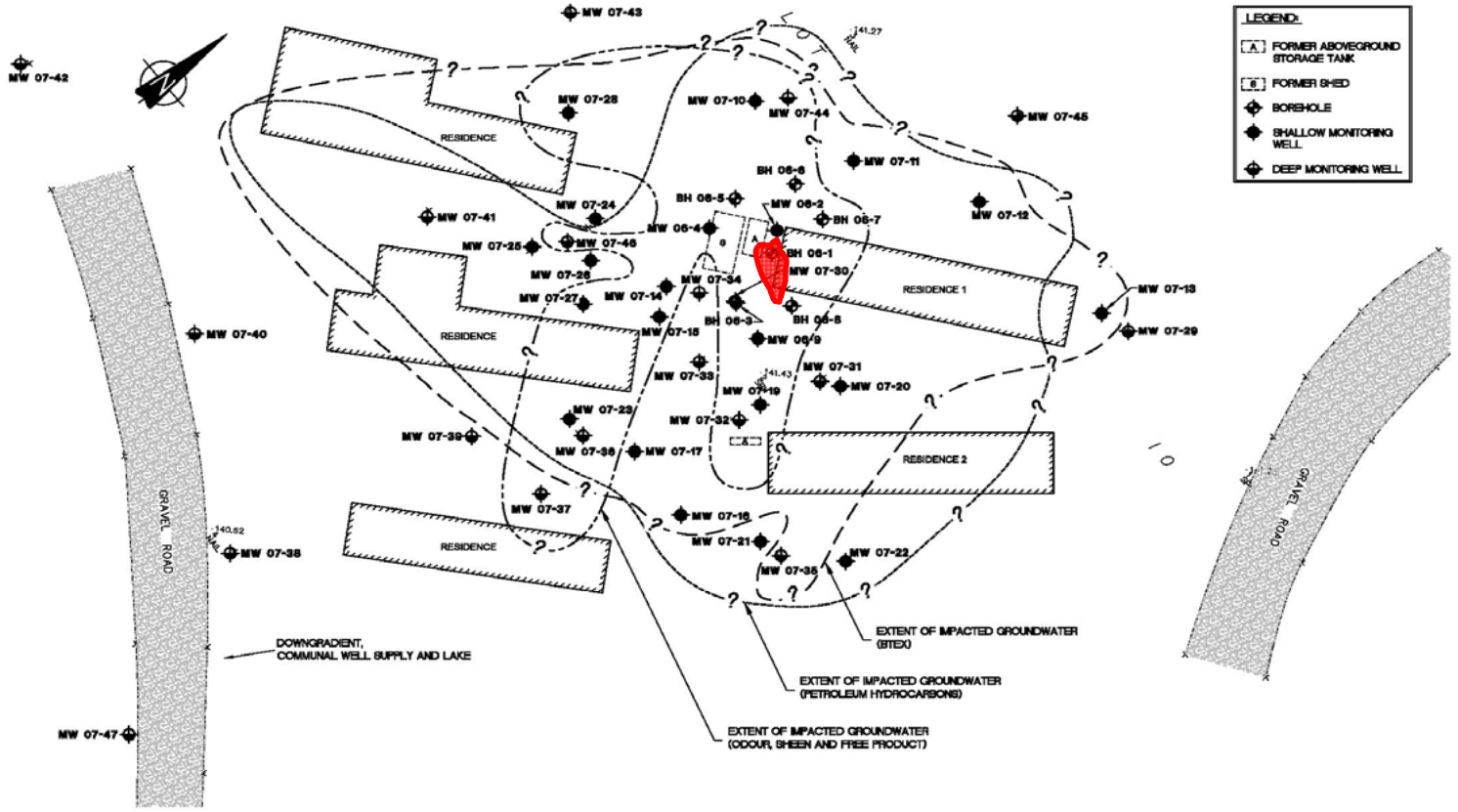
Case Study: Post Injection 2



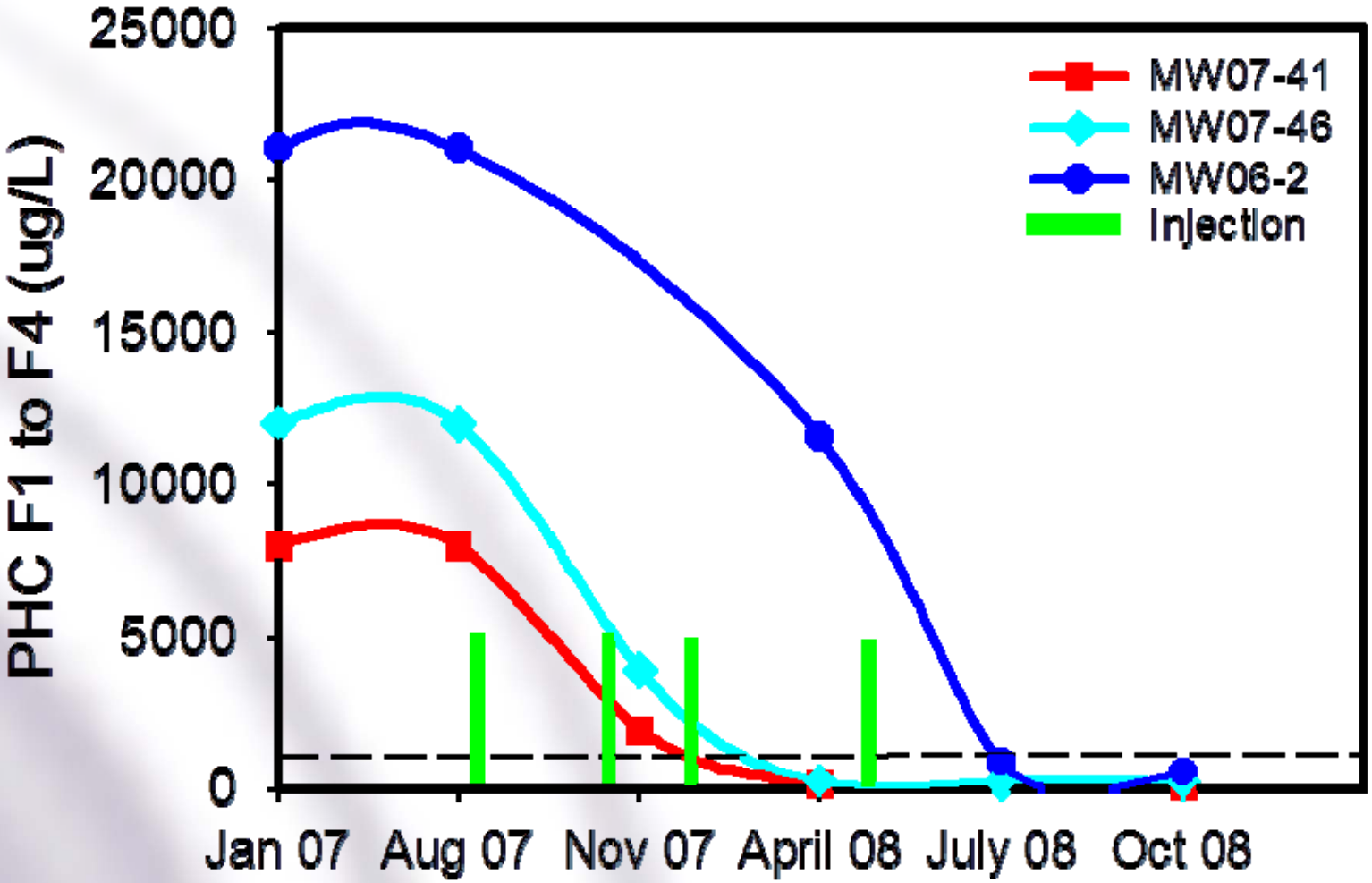
Case Study: Post Injection 3



Case Study: Post Injection 4



Case Study – Heating Oil



Case Study – Heating Oil

- Conclusions
  - Remediated LNAPL & GW to MOECC Standards
  - Shallow soils excavation
  - Vacuum removal of LNAPL from wells
  - Bedrock remediation accomplished through intelligent use of:
    - ISCO
    - Enhanced Bioremediation
  - Result: LNAPL & dissolved PHCs removed from bedrock

Closing Thoughts

Bedrock LNAPL & Dissolved Phase Movement

- Contaminant mobility mainly through fractures
- Fractures comprise a low volume
- Porosity of rock matrix is important
- Bulk of contamination may end up in rock matrix

Bedrock Remediation

- Vac Trucking LNAPL alone isn’t a remedial solution
- Excavation of overburden soils is important
- Quick response to bedrock spills is very important
  - Due to adsorption into rock matrix (remember Rule of Thumb)
- Keep volumes low and use regular injection frequency
  - To combat matrix back-diffusion
- Oxidation and surfactant flushing are effective

Questions?

Thank You for
Your Time

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