The Design of Permeable Reactive Barriers (PRBs) for the Remediation of Chlorinated Solvent Plumes

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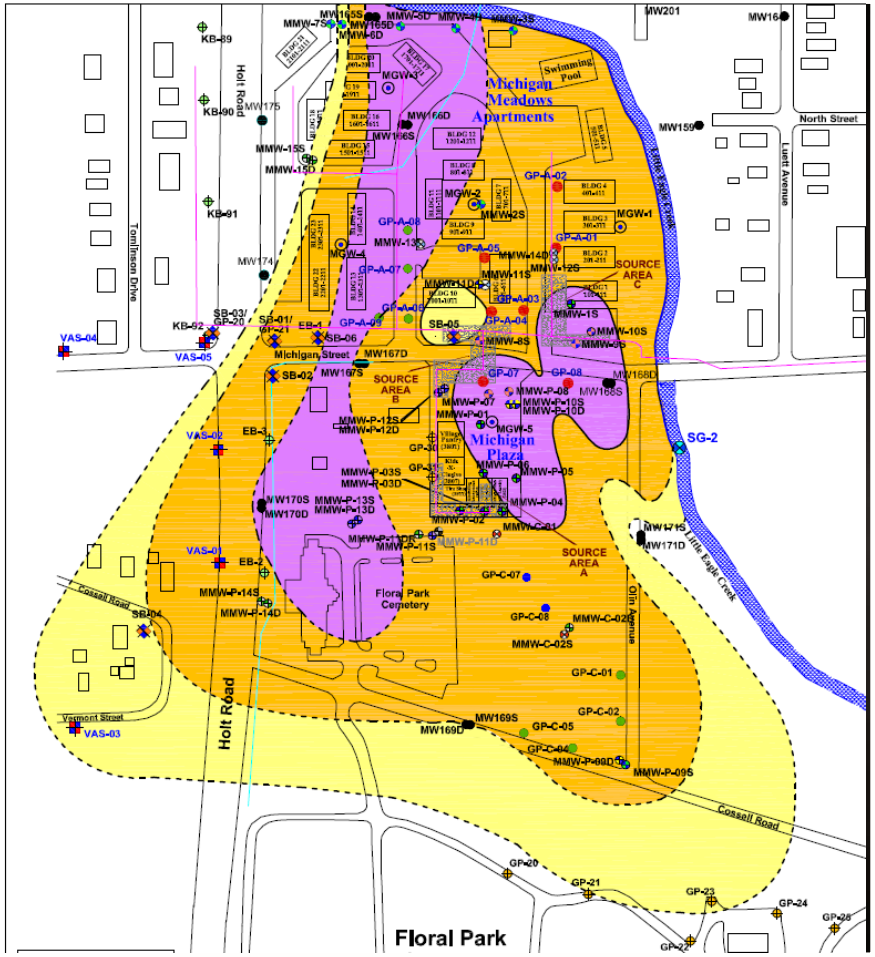
John A. Mundell, P.E., L.P.G.
MUNDELL & ASSOCIATES, INC.
Consulting Professionals for the Earth and the Environment

Talk Outline



- The challenge of remediation
- What are PRBs and what do they have to offer?
- A couple of case histories
- Lessons learned for environmental investigation and remediation

Groundwater Remediation 101

- **TO BE EFFECTIVE, YOU MUST KNOW**:
  - Where the **source** of the plume impacts are coming from.
  - Where the **dissolved chemical impacts** have gone, and how they are distributed.
  - How **significant** are the impacts.
- IF THESE REMAIN UNKNOWN, IT IS HIGHLY LIKELY THAT **YOU WILL FAIL** TO BE ABLE TO SUCCESSFULLY CLEANUP A CONTAMINANT PLUME!

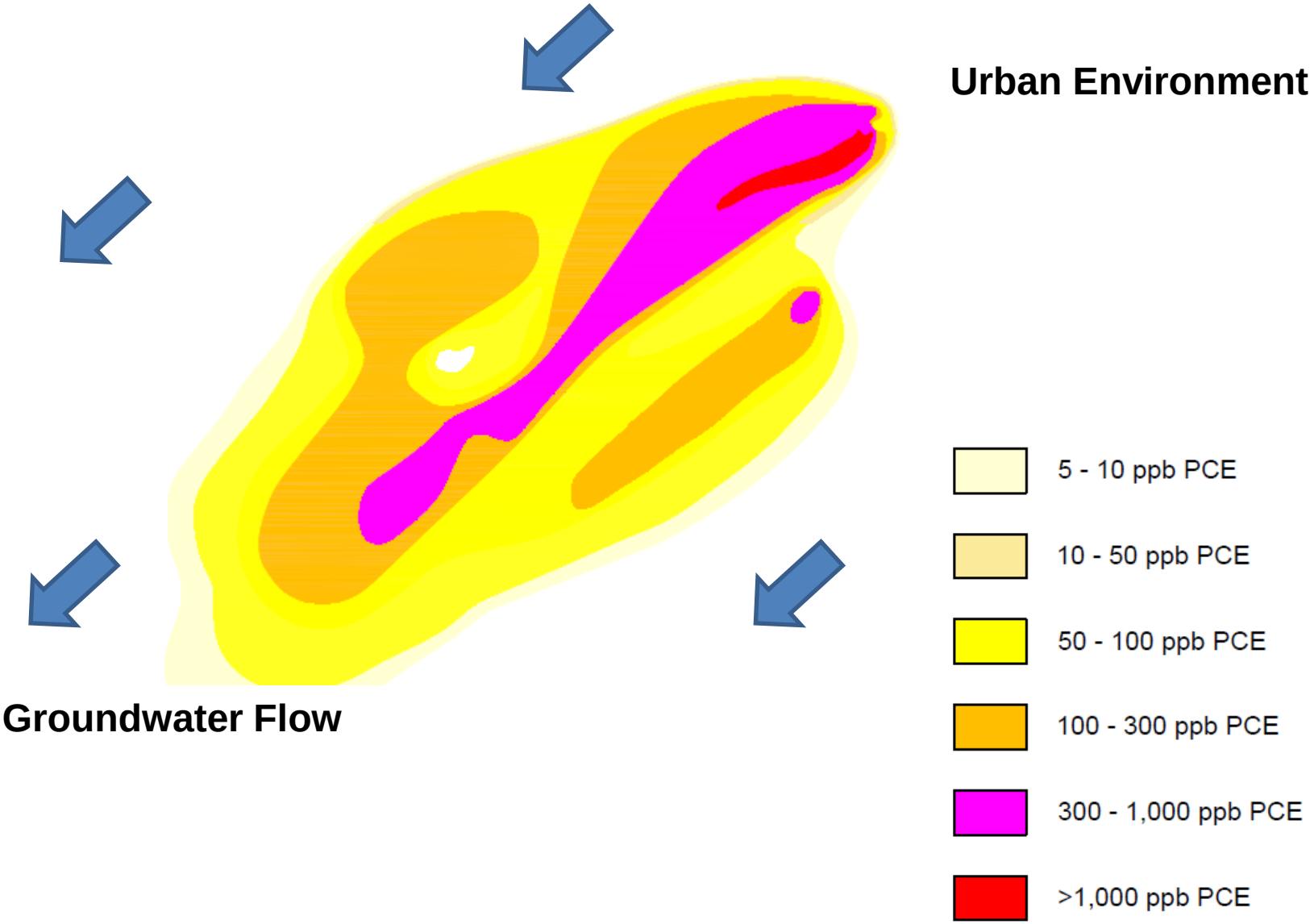
Geologic Complexity

- Can cause plume movement **in directions not expected** by subsurface conditions only described by a classic ‘widely-spaced’ soil boring and monitoring well based subsurface exploration program.
- **Subsurface data density limits** the development of an accurate ***Conceptual Site Model*** that can adequately describe groundwater movement and plume progression, especially for large impacted chlorinated plume areas (say, greater than 1000 ft in length or greater than 10’s of acres in size).

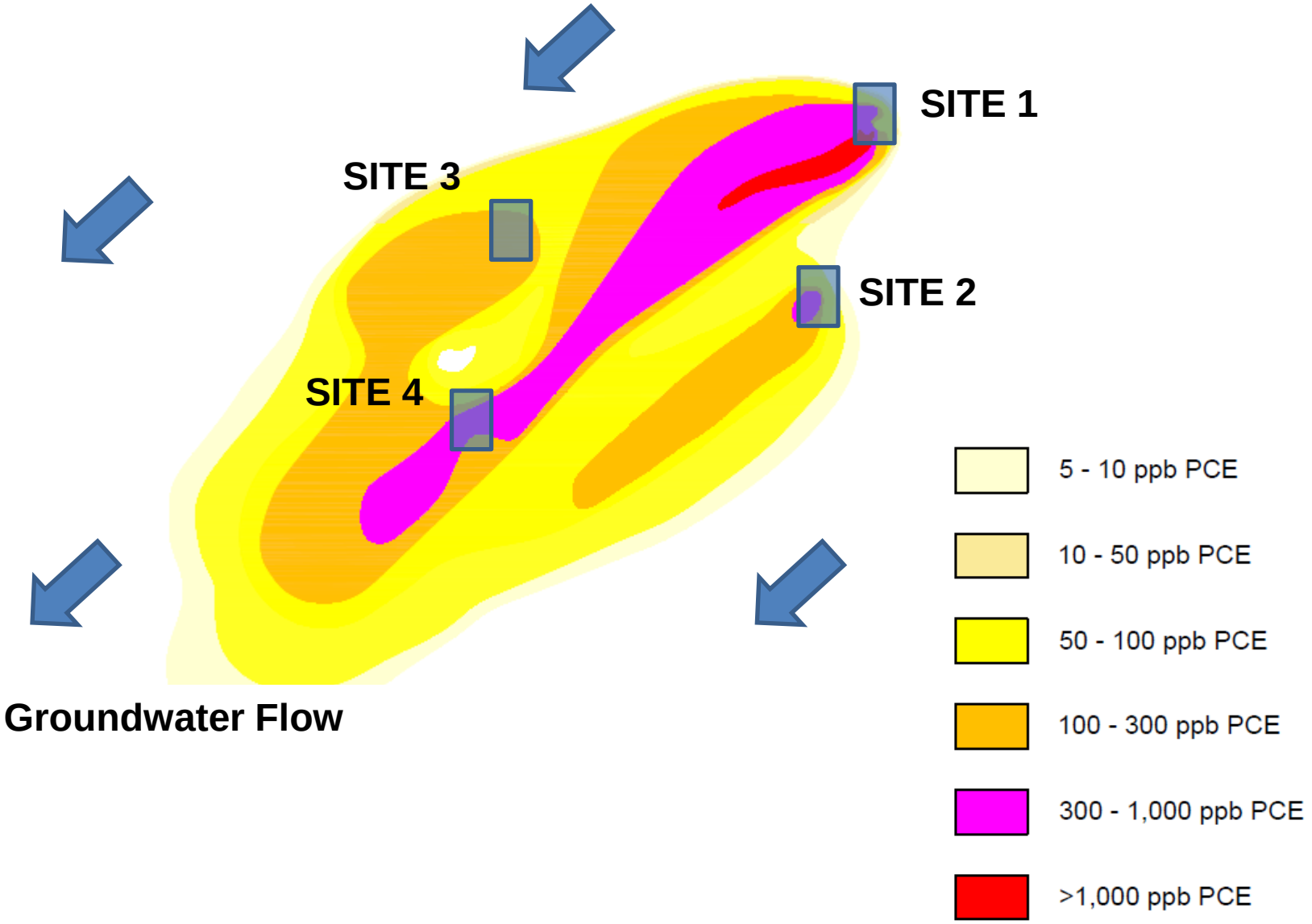
PRBs
Basic Principles

- Design dependent on thorough site characterization.
- Collection of hydrogeologic, geochemical, microbial and geotechnical data.
- Full vertical and horizontal delineation of source area and limits of impacted groundwater.

DISTRIBTUION OF PCE CONCENTRATIONS IN GROUNDWATER

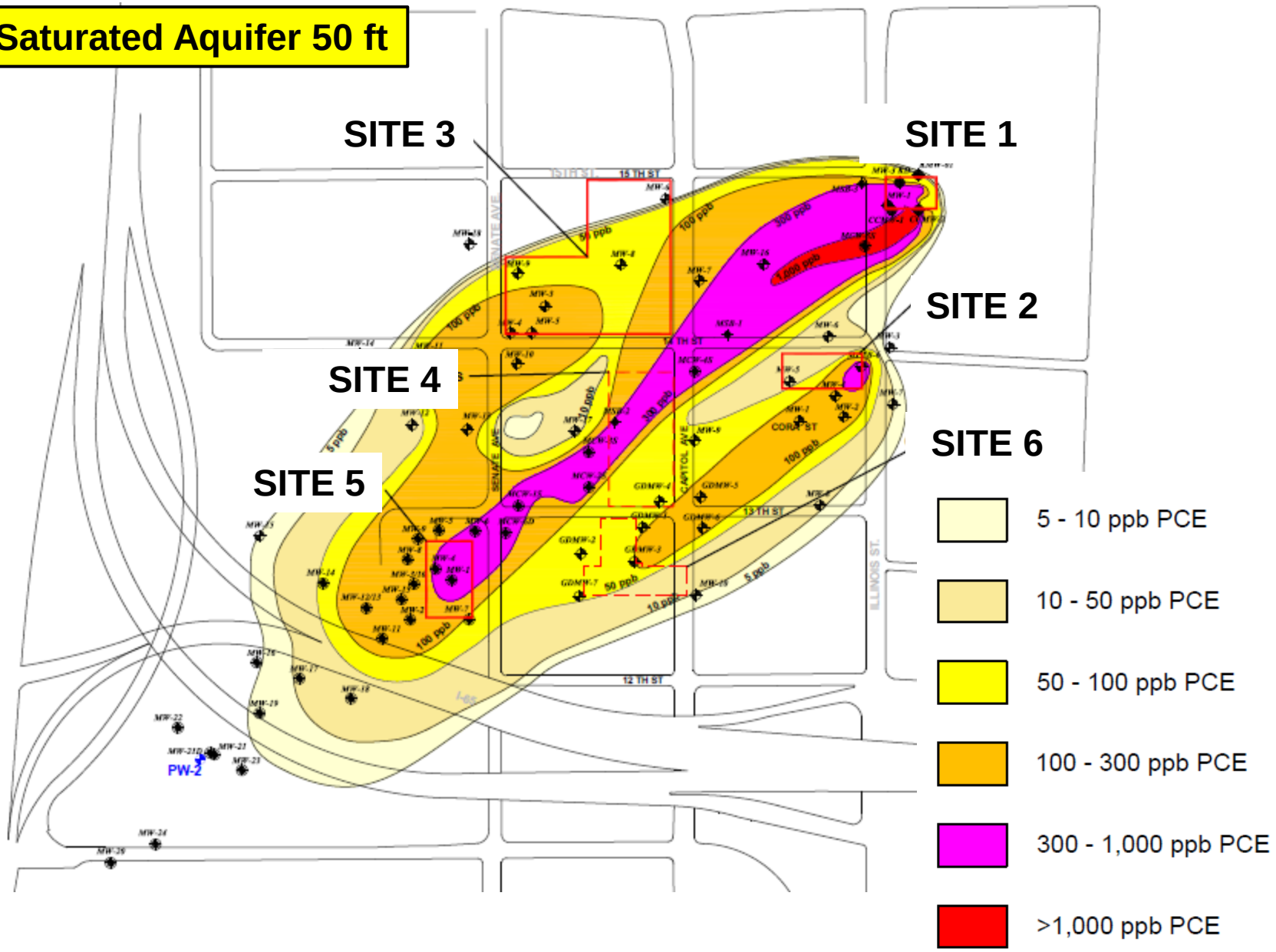


DISTRIBTUION OF PCE CONCENTRATIONS IN GROUNDWATER



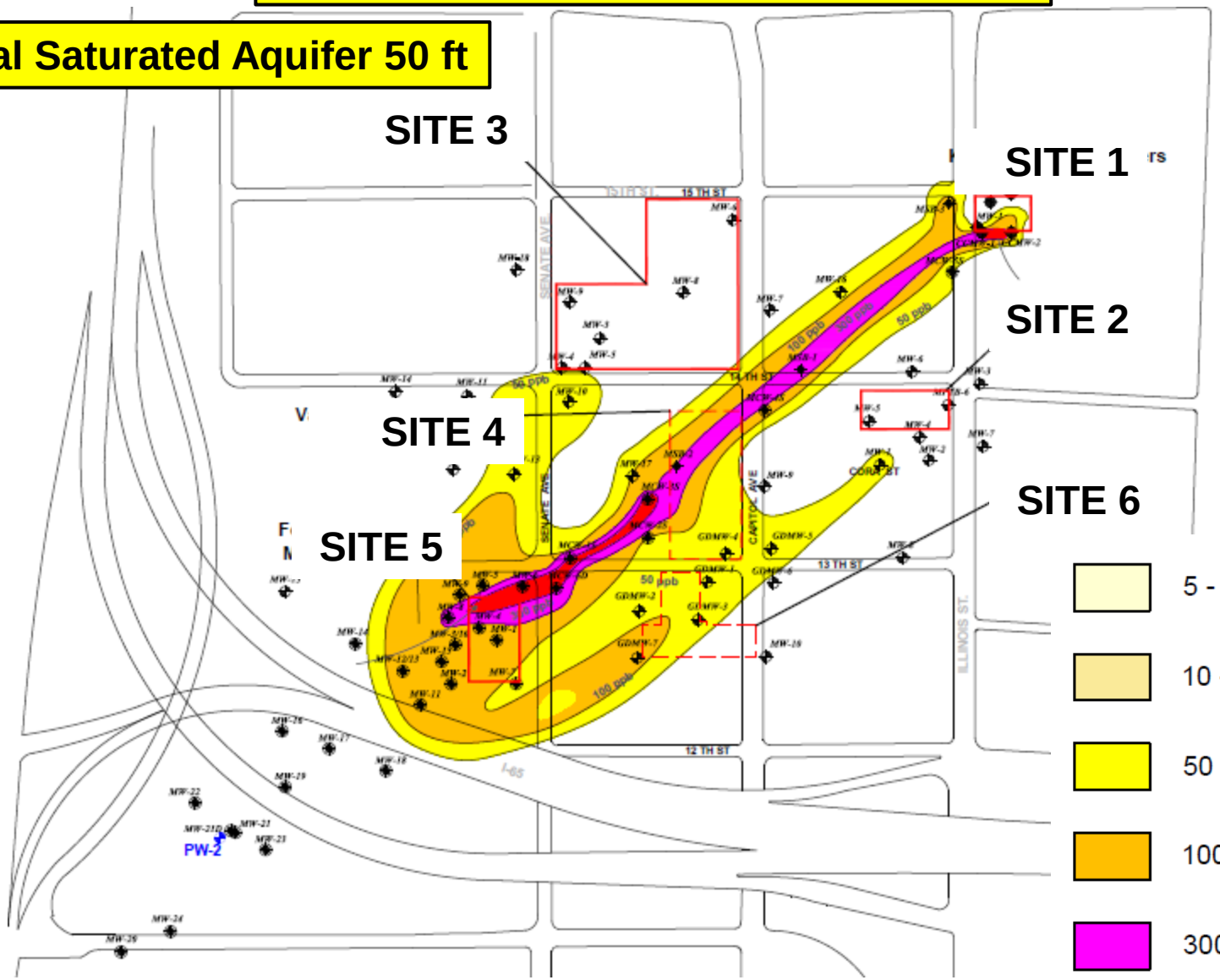
Depth Below Top of Aquifer: 0 to 10 ft

Total Saturated Aquifer 50 ft



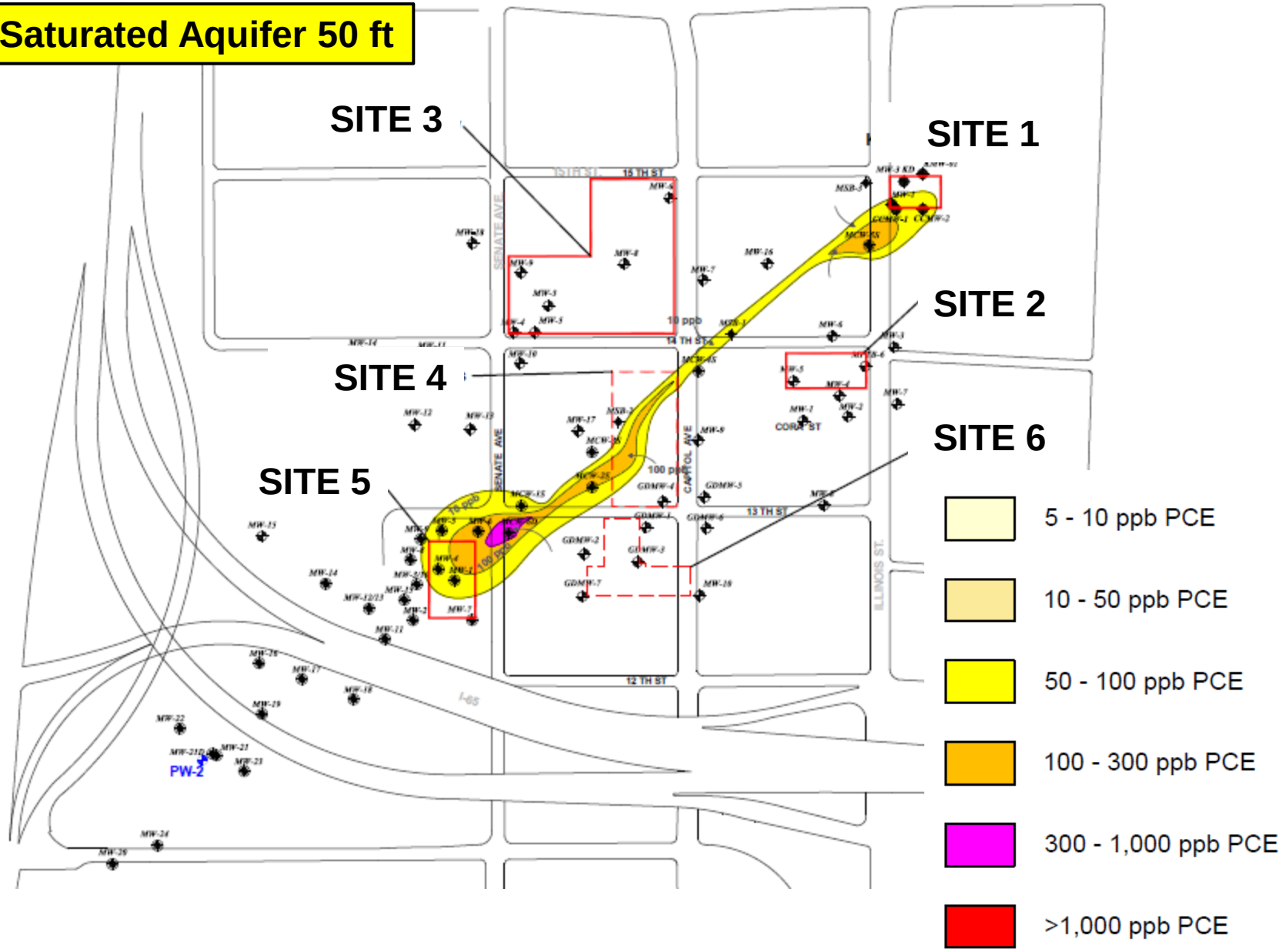
Depth Below Top of Aquifer: 10 to 20 ft

Total Saturated Aquifer 50 ft



Depth Below Top of Aquifer: 20 to 30 ft

Total Saturated Aquifer 50 ft

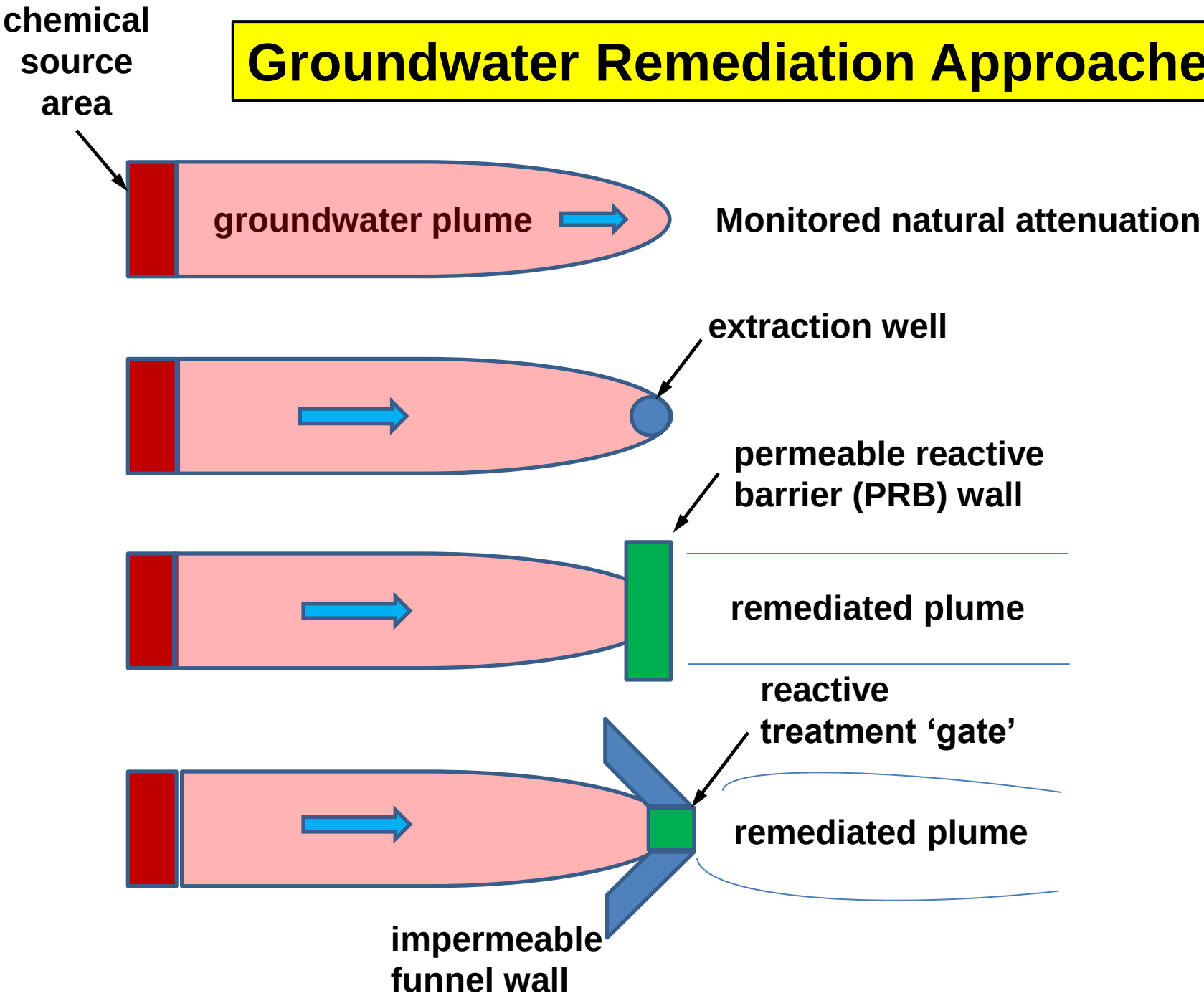


Permeable Reactive Barrier

Definition

- An in-situ permeable treatment zone designed to intercept and remediate a contaminant plume.

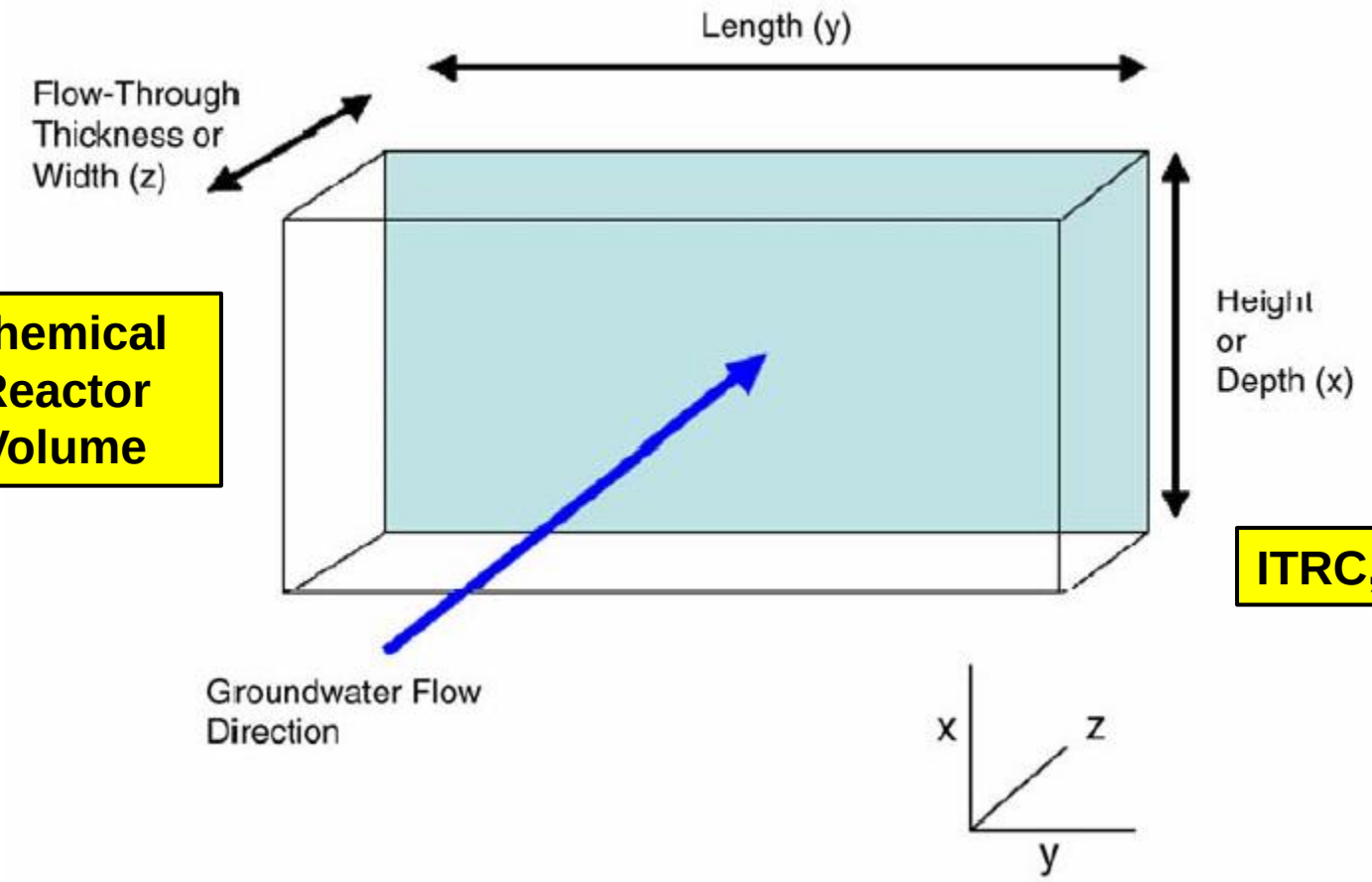
Groundwater Remediation Approaches



PRB Materials

- Treatment by physical, chemical or biological processes.
- Designed as a ‘chemical reaction vessel’ to treat contaminants, but allows groundwater to pass through.

Idealized Schematic and Dimensions of a PRB



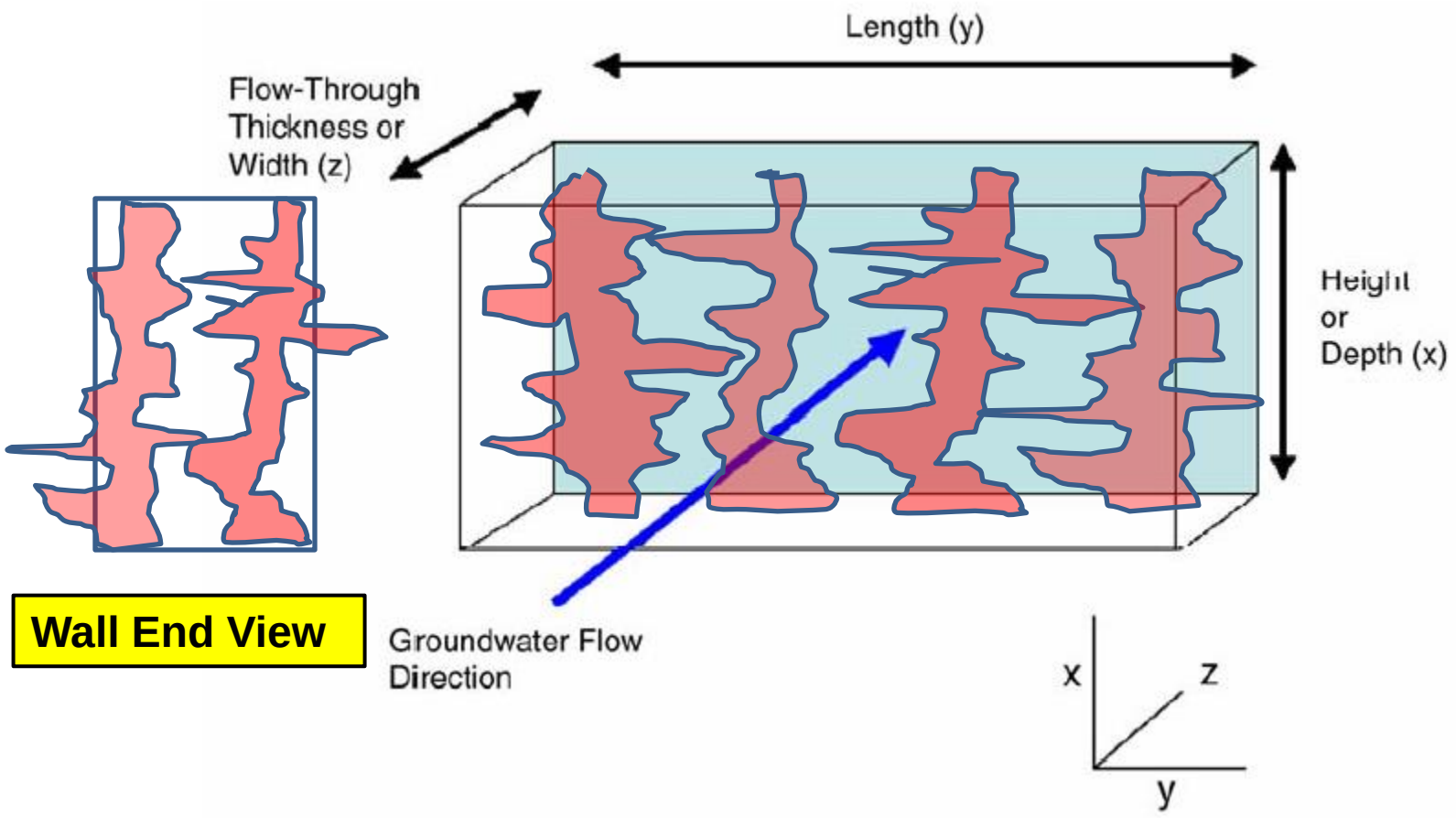
Chemical Reactor Volume

ITRC, 2005

Design Parameters:

- **Size: Length, Width (thickness), Depth**
- **Treatment Material Type, Mass, Concentration**
- **Aquifer/Wall Hydraulic Conductivity, Groundwater Velocity**
- **Parameters: Contact Residence Time, Chemical Reaction Rate**

Actual Schematic and Dimensions of a PRB



Remediation Challenges:

- **Constructability: Injection pressures, material distribution**
- **Aquifer inhomogeneity and anisotropy**
- **Aquifer geochemical variability**

Chlorinated Solvent Plumes

- Parent material products:
  - Perchloroethylene (PCE)
  - Trichloroethylene (TCE)
  - 1,1,1-Trichloroethane (1,1,1-TCA)
- Breakdown products include cis-1,2-Dichloroethylene (cis-1,2-DCE) and Vinyl chloride (VC).

Typical PRB Materials

- Granular iron (zero-valent iron (ZVI))
- Solids – compost, zeolites, granular activated carbon, sawdust, peat, synthetic resins, sucrose, cheese whey).
- Bio-barrier systems (lactate, molasses, vegetable/soybean oils)

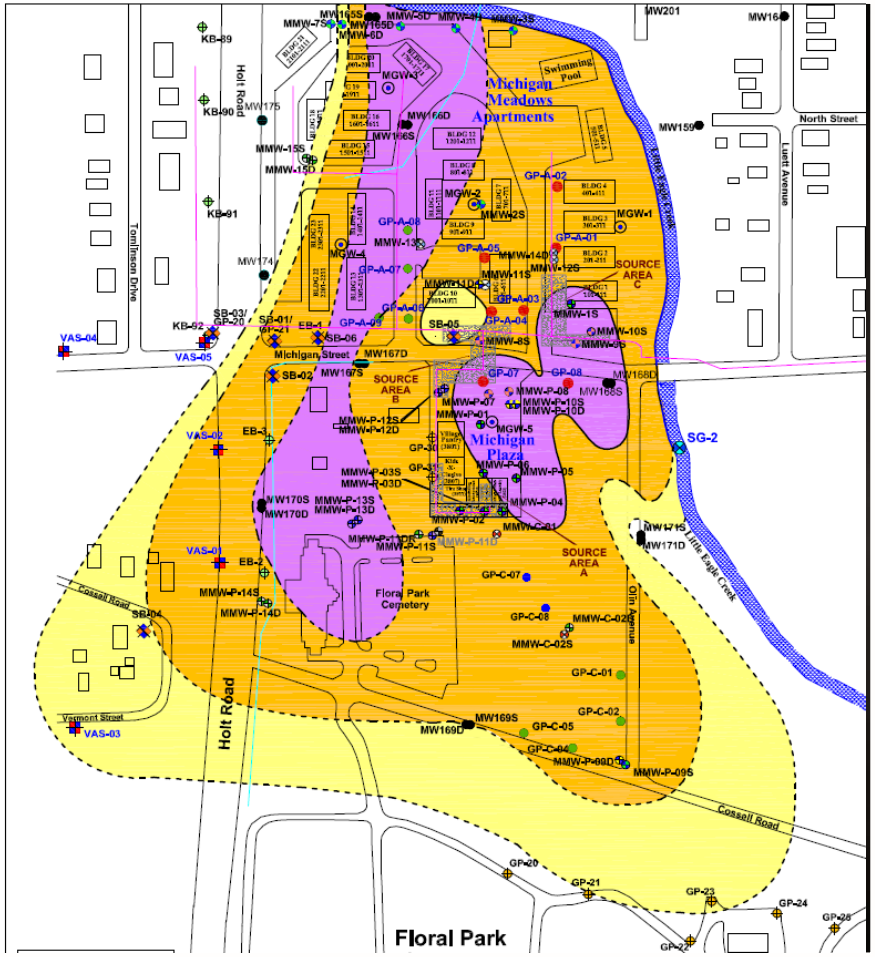
Chlorinated Solvents

- Treatment via anaerobic bioremediation.

Groundwater Remediation 101

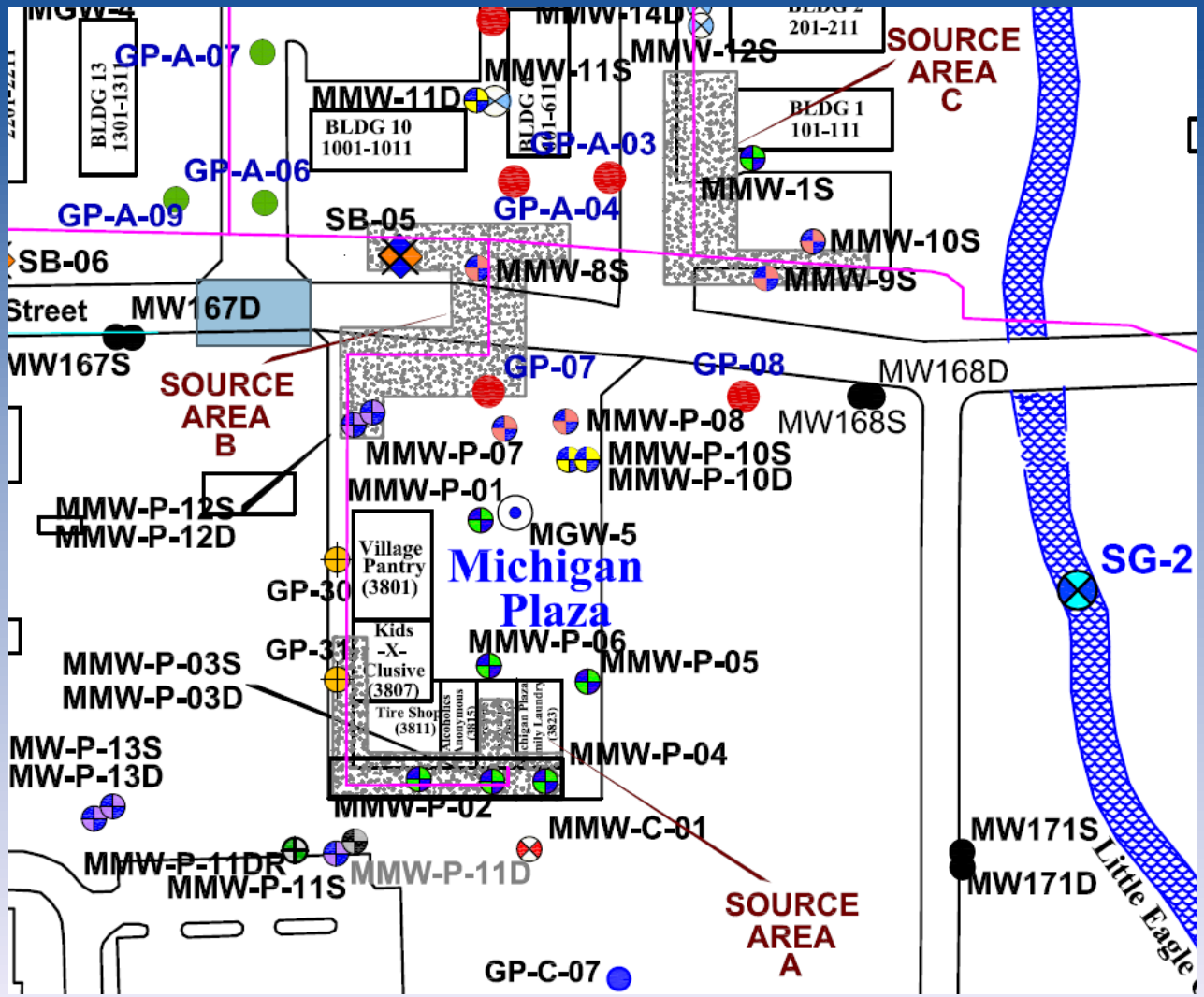
- **MOST PLUME REMEDIATION EFFORTS ARE BASED ON A LACK OF DATA AND SUBSURFACE KNOWLEDGE TO BE EFFECTIVE!**
  - The remediation takes too long or is never achieved.
  - The remediation costs too much.
  - The plume's risk to human health and the environment is never able to be controlled.

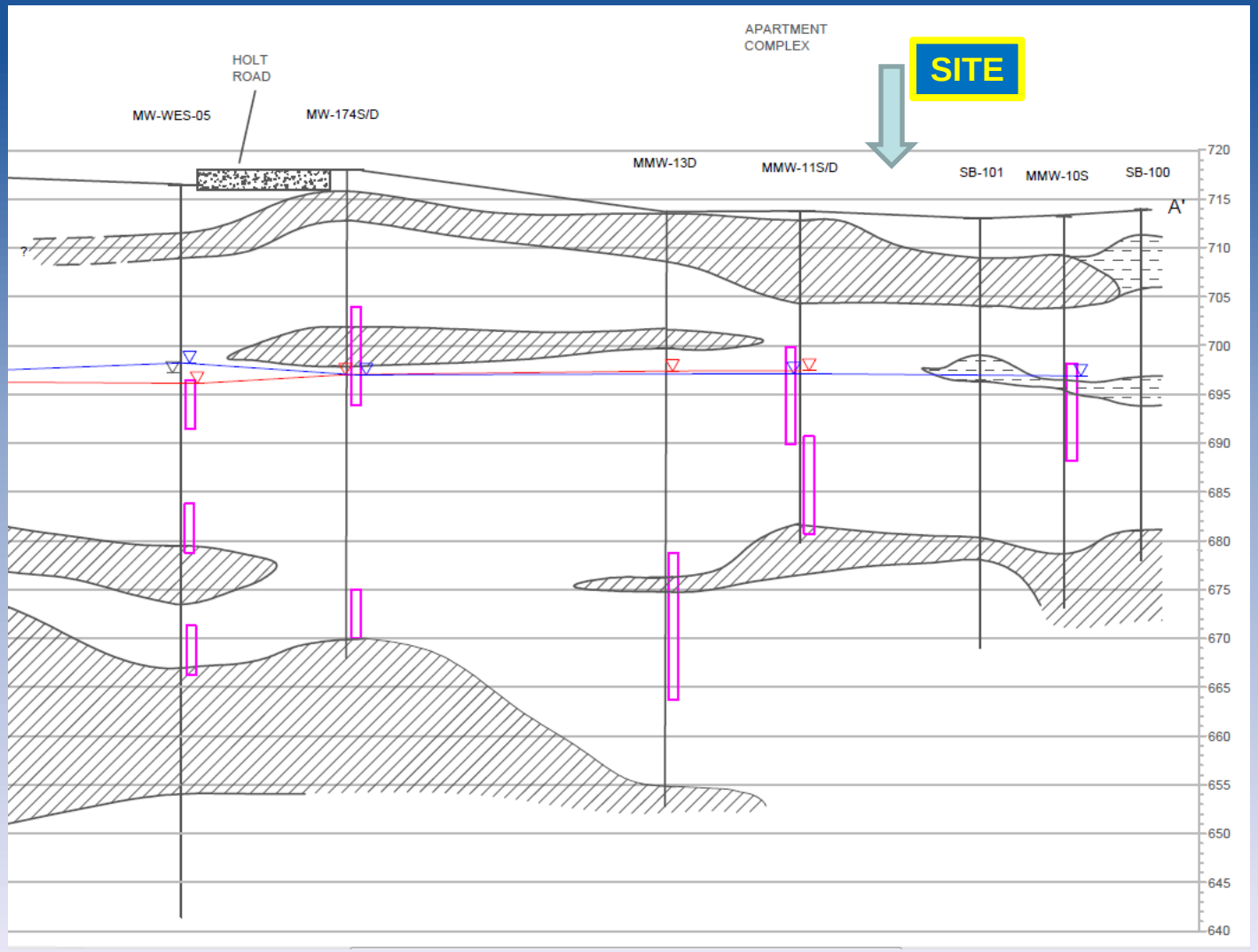
Case History No. 1

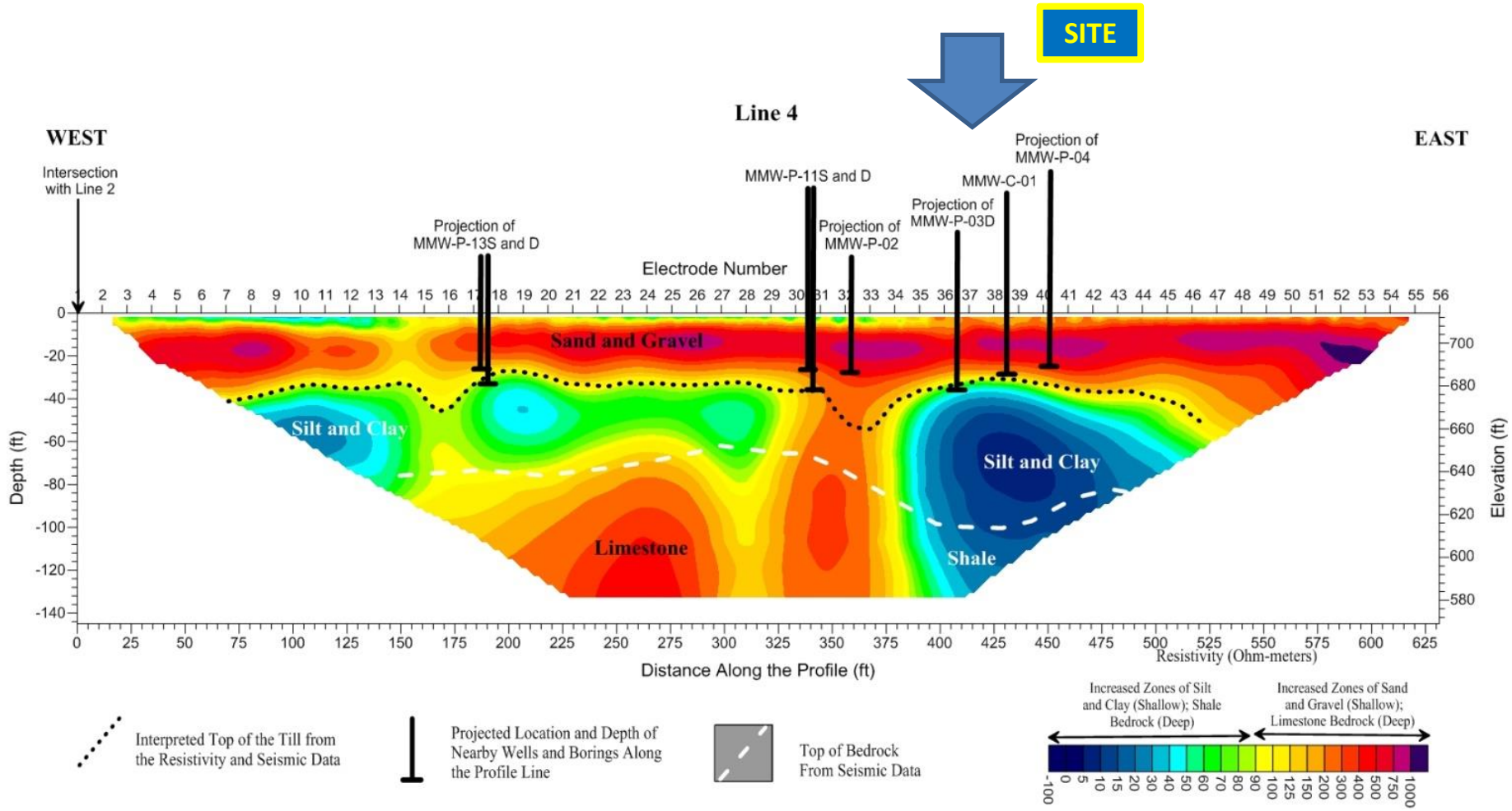


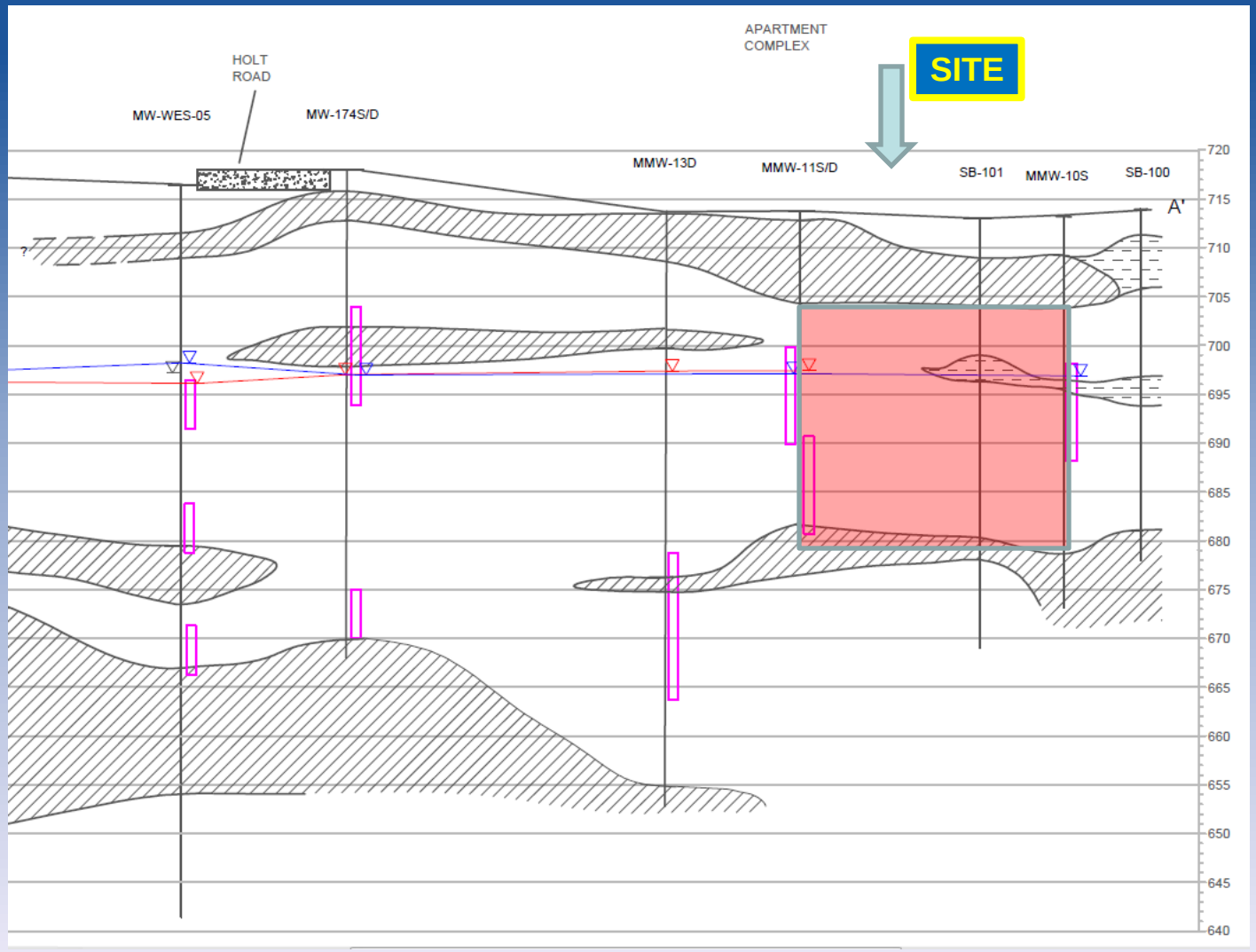
- Multiple sources
- Small plumes
- Complicated geology


CASE HISTORY NO. 1
INDUSTRIAL SITE 2
COMMERCIAL SITE 1
RESIDENTIAL AREA
CEMETERY
W Alley 700 N
N Lyons Ave
N Rybolt Ave
Tomlinson St
N Holt Rd
N Luett Ave
N Livingston Ave
Grande Ave
Holt Rd
Cossell Rd
Olin Ave
Creek Way
W Vermont St

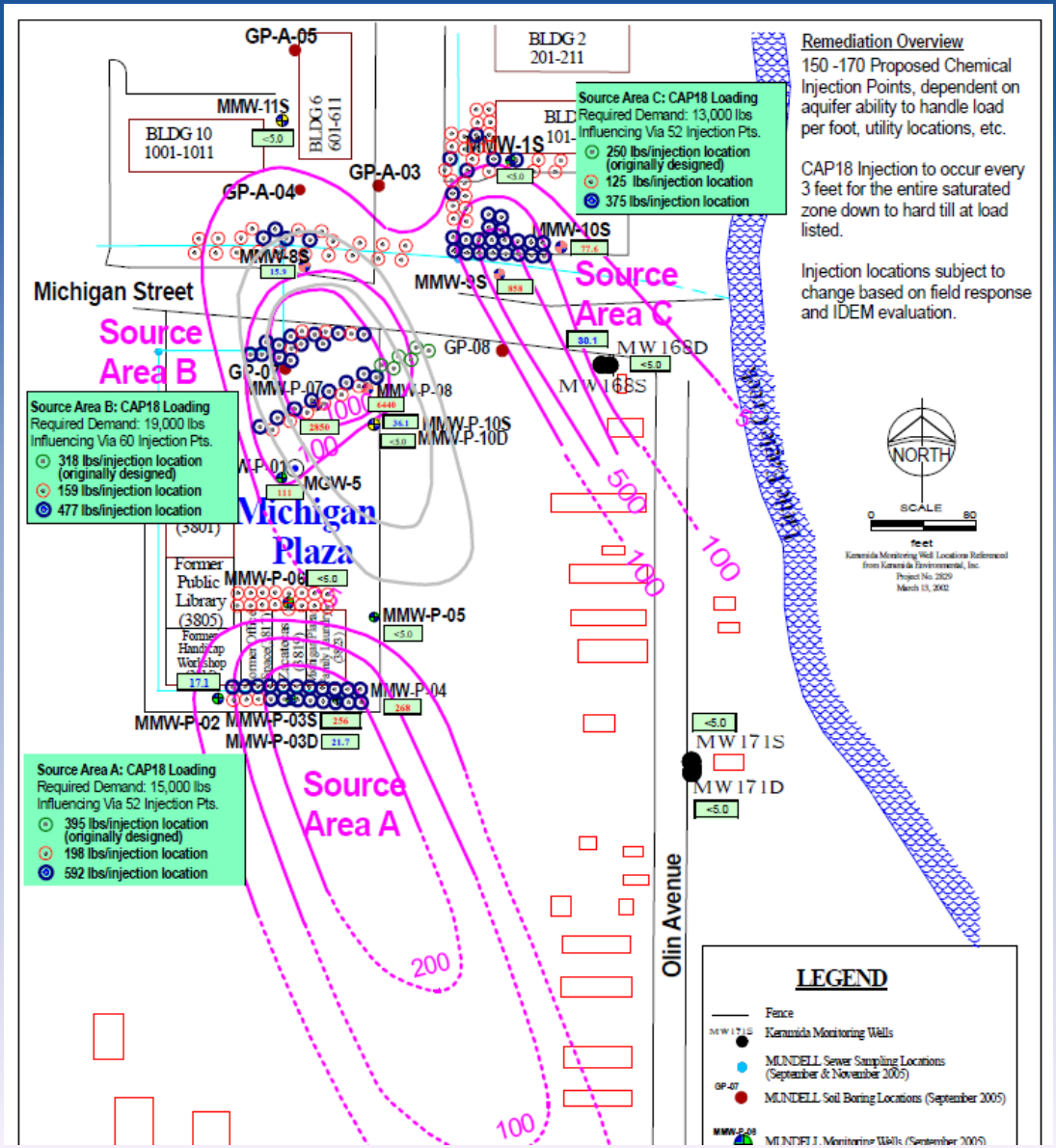

GP-A-07
MMW-11S
MMW-11D
BLDG 10
1001-1011
BLDG 13
1301-1311
BLDG 6
601-611
MMW-14D
MMW-12S
201-211
SOURCE
AREA
C
BLDG 1
101-111
GP-A-03
GP-A-06
GP-A-04
GP-A-09
SB-05
MMW-1S
MMW-10S
SB-06
MMW-8S
MMW-9S
Street
MW167D
MW167S
SOURCE
AREA
B
GP-07
GP-08
MW168D
MMW-P-08
MW168S
MMW-P-07
MMW-P-10S
MMW-P-10D
MMW-P-01
MMW-P-12S
MMW-P-12D
MGW-5
Village
Pantry
(3801)
Michigan
Plaza
SG-2
GP-30
Kids
-X-
Clusive
(3807)
GP-31
MMW-P-06
MMW-P-05
MMW-P-03S
MMW-P-03D
Tire Shop
(3811)
MW-P-13S
MW-P-13D
MMW-P-04
MMW-P-02
MMW-C-01
MW171S
MW171D
Little Eagle
MMW-P-11DR
MMW-P-11S
MMW-P-11D
SOURCE
AREA
A
GP-C-07


APARTMENT
COMPLEX
SITE
HOLT
ROAD
MW-WES-05
MW-174S/D
MMW-13D
MMW-11S/D
SB-101
MMW-10S
SB-100
A'
720
715
710
705
700
695
690
685
680
675
670
665
660
655
650
645
640


SITE
Line 4
WEST
EAST
Intersection with Line 2
Projection of MMW-P-13S and D
MMW-P-11S and D
Projection of MMW-P-02
Projection of MMW-P-03D
MMW-C-01
Projection of MMW-P-04
Electrode Number
Sand and Gravel
Silt and Clay
Limestone
Silt and Clay
Shale
Depth (ft)
Elevation (ft)
Distance Along the Profile (ft)
Resistivity (Ohm-meters)
Interpreted Top of the Till from the Resistivity and Seismic Data
Projected Location and Depth of Nearby Wells and Borings Along the Profile Line
Top of Bedrock From Seismic Data
Increased Zones of Silt and Clay (Shallow); Shale Bedrock (Deep)
Increased Zones of Sand and Gravel (Shallow); Limestone Bedrock (Deep)


APARTMENT
COMPLEX
SITE
HOLT
ROAD
MW-WES-05
MW-174S/D
MMW-13D
MMW-11S/D
SB-101
MMW-10S
SB-100
A'
720
715
710
705
700
695
690
685
680
675
670
665
660
655
650
645
640

Multiple Source Areas



Multiple Source Areas

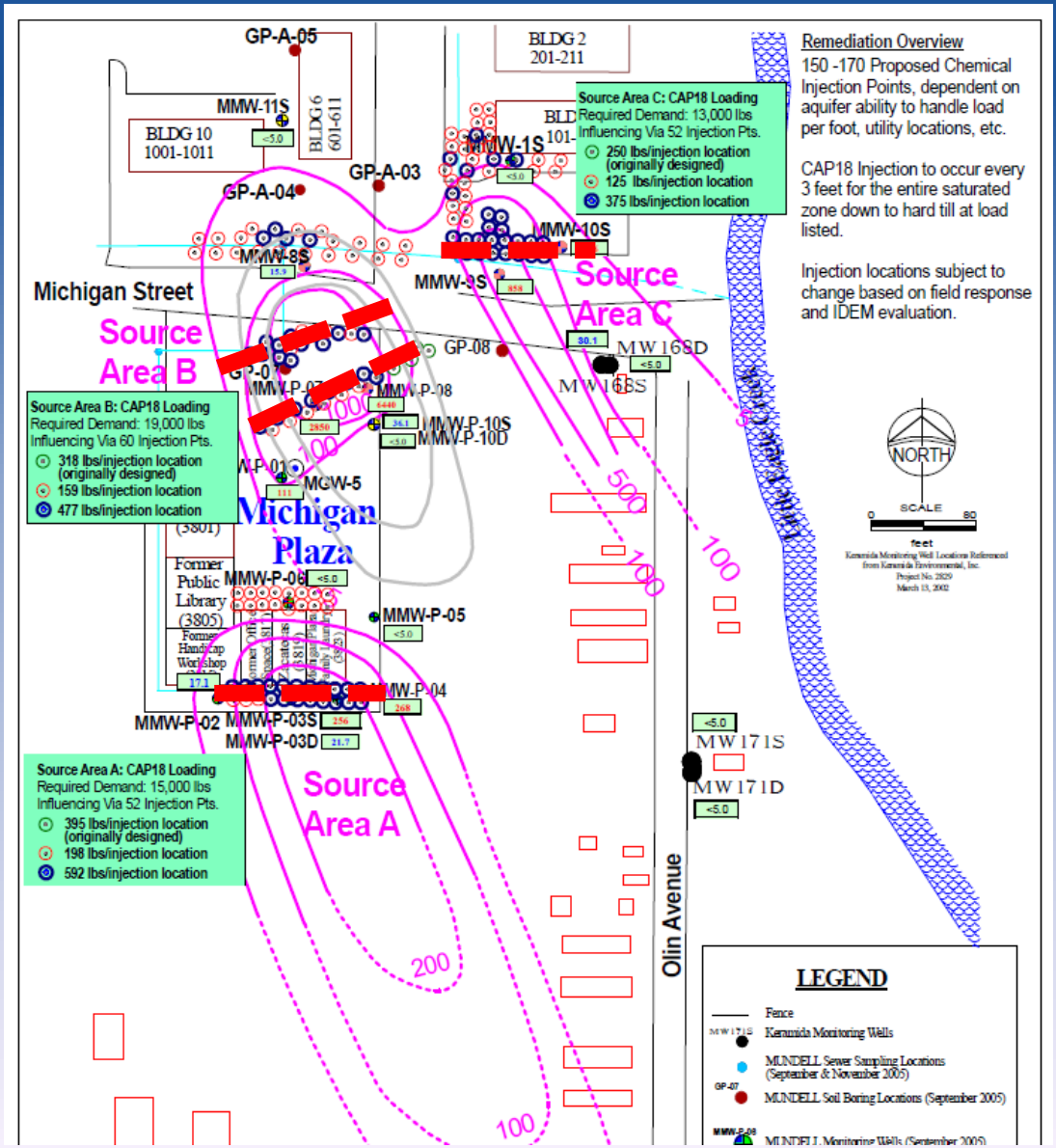
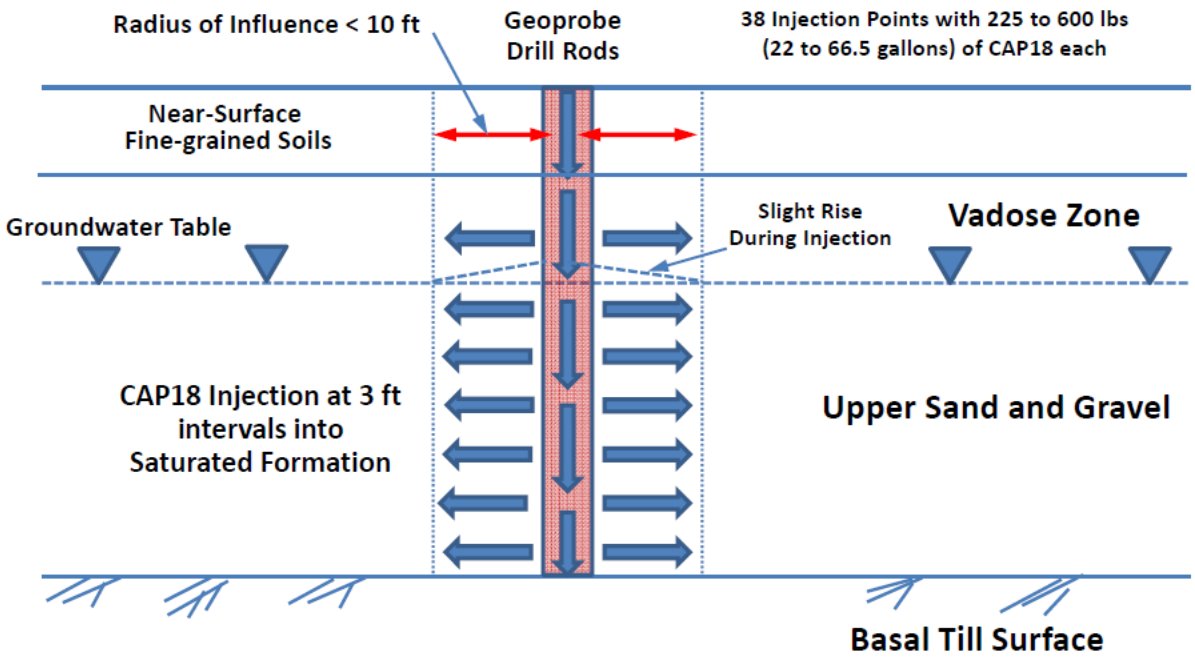
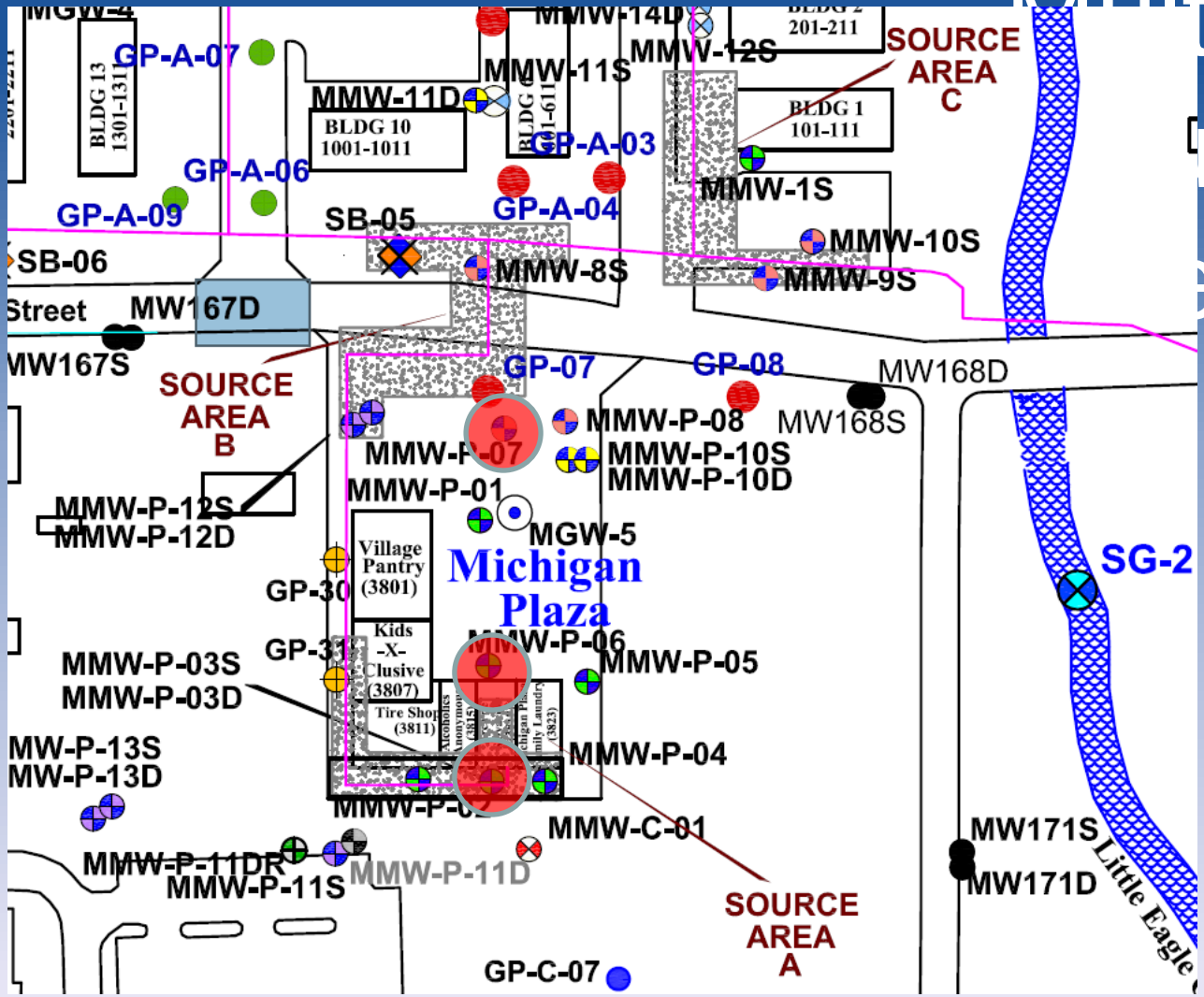


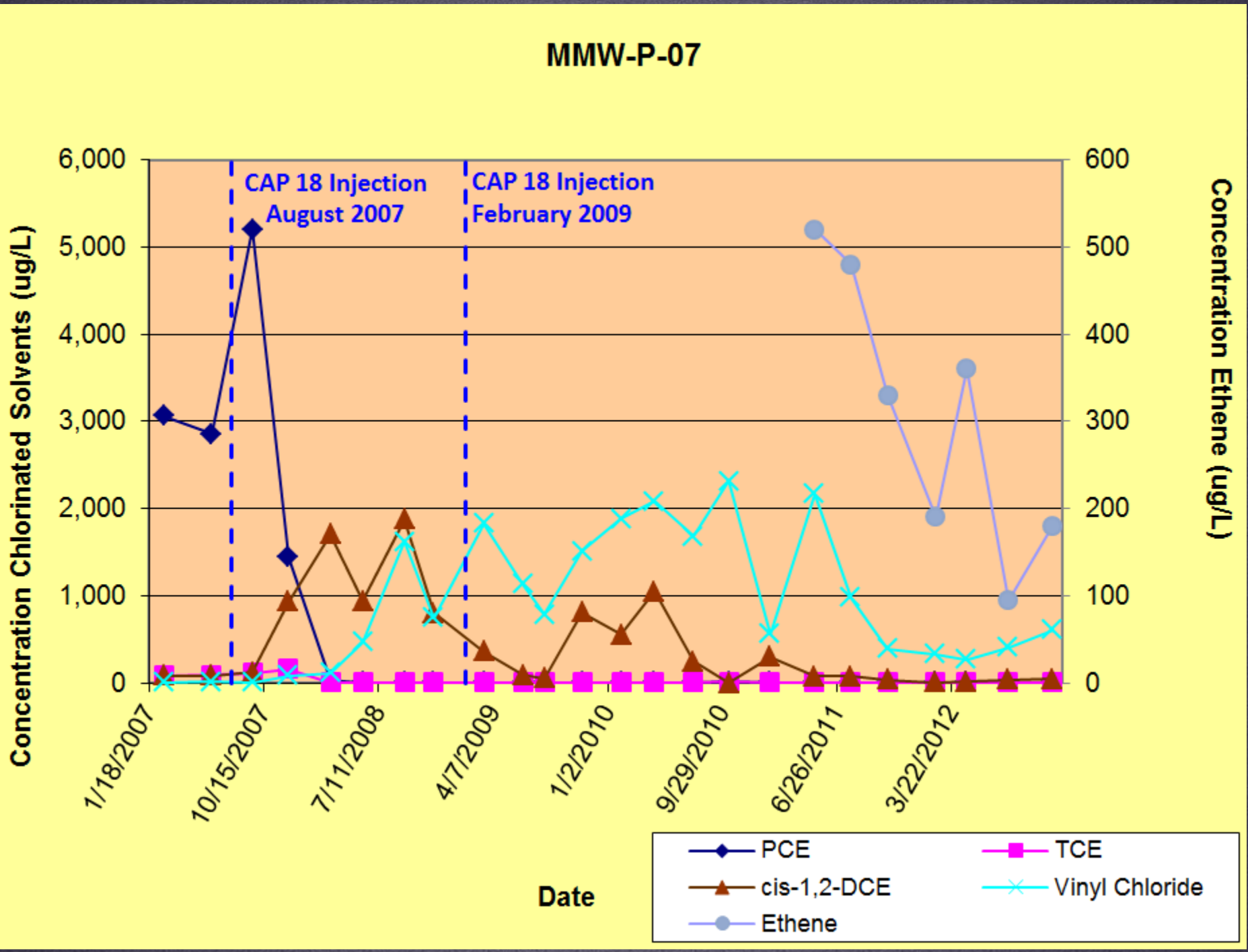
Figure 13 - Typical Cross-Section CAP18TM Injection
Chemical Source Area A
August 2007

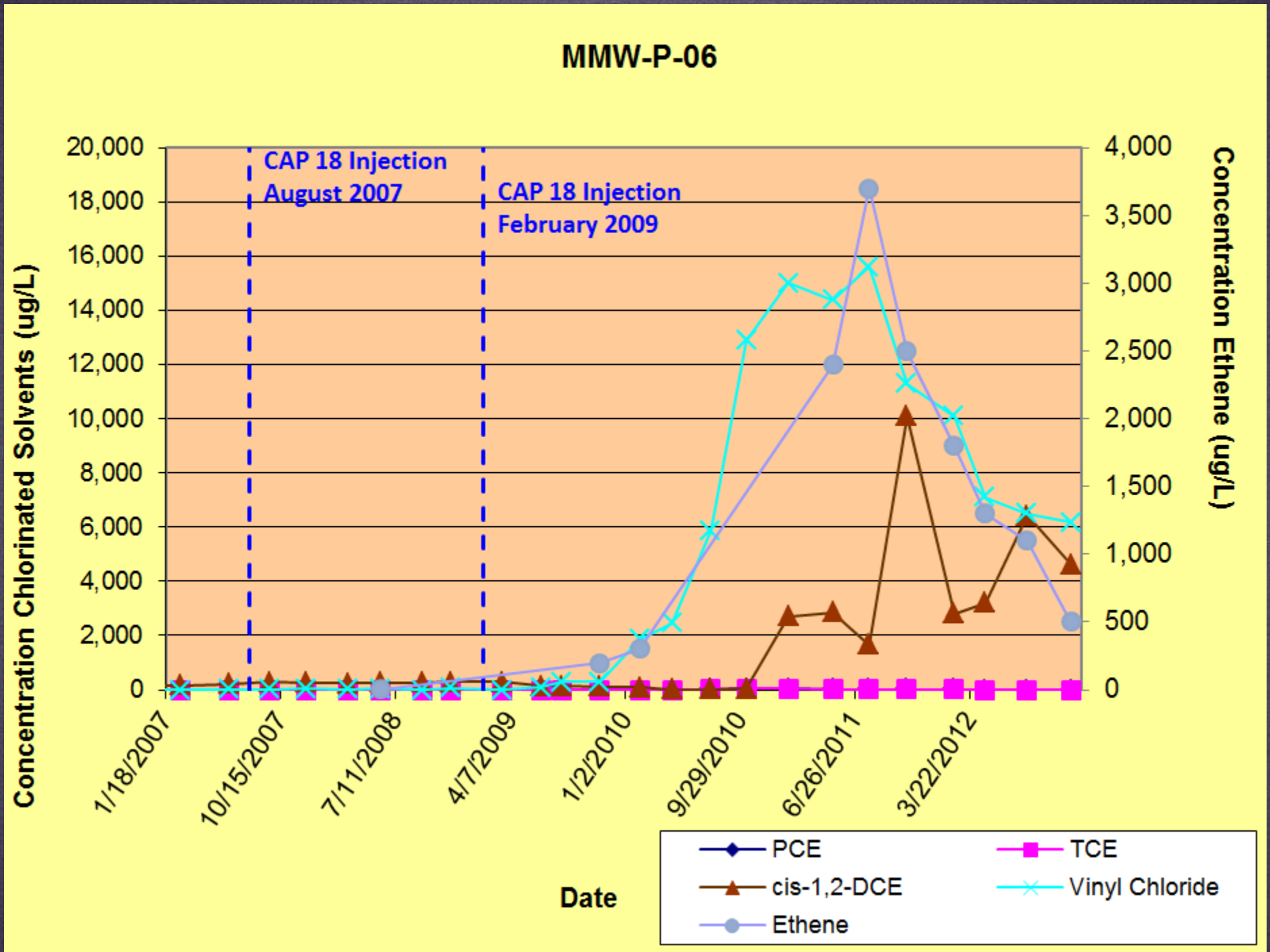


In-Situ Bioremediation with Soybean Oil

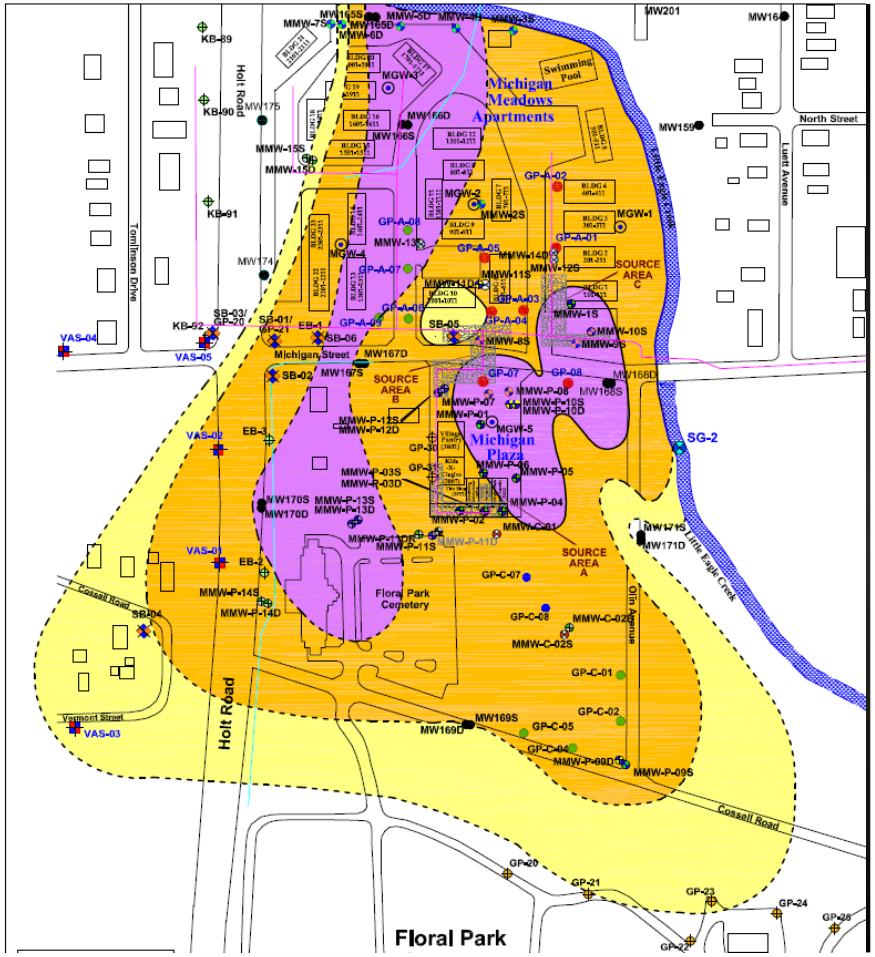
Multiple Source Areas




MMW-P-07
CAP 18 Injection
August 2007
CAP 18 Injection
February 2009
Concentration Chlorinated Solvents (ug/L)
Concentration Ethene (ug/L)
6,000
5,000
4,000
3,000
2,000
1,000
0
600
500
400
300
200
100
0
1/18/2007
10/15/2007
7/11/2008
4/7/2009
1/2/2010
9/29/2010
6/26/2011
3/22/2012
Date
PCE
TCE
cis-1,2-DCE
Vinyl Chloride
Ethene

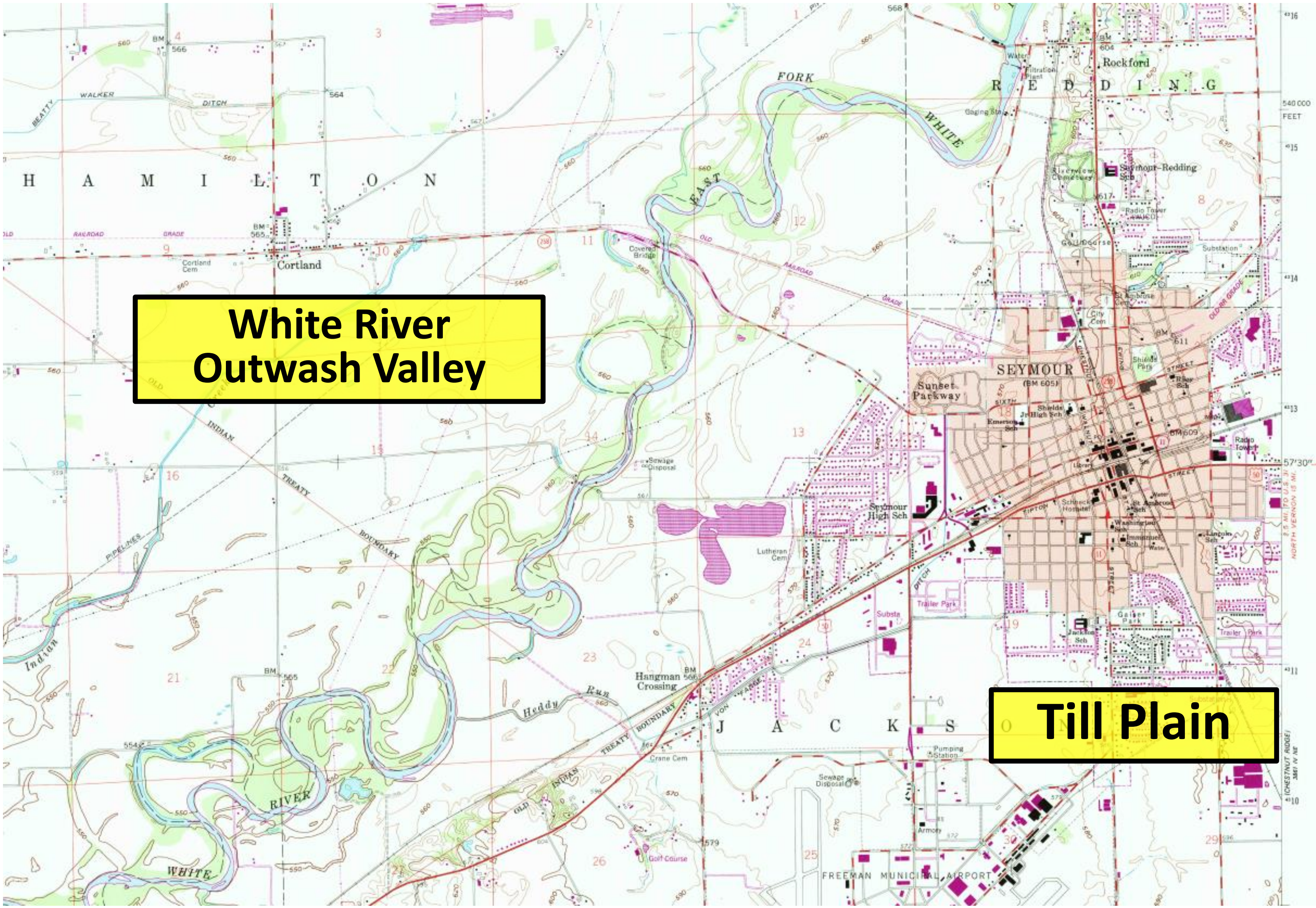

MMW-P-06
CAP 18 Injection
August 2007
CAP 18 Injection
February 2009
Concentration Chlorinated Solvents (ug/L)
Concentration Ethene (ug/L)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1/18/2007
10/15/2007
7/11/2008
4/7/2009
1/2/2010
9/29/2010
6/26/2011
3/22/2012
Date
PCE
TCE
cis-1,2-DCE
Vinyl Chloride
Ethene

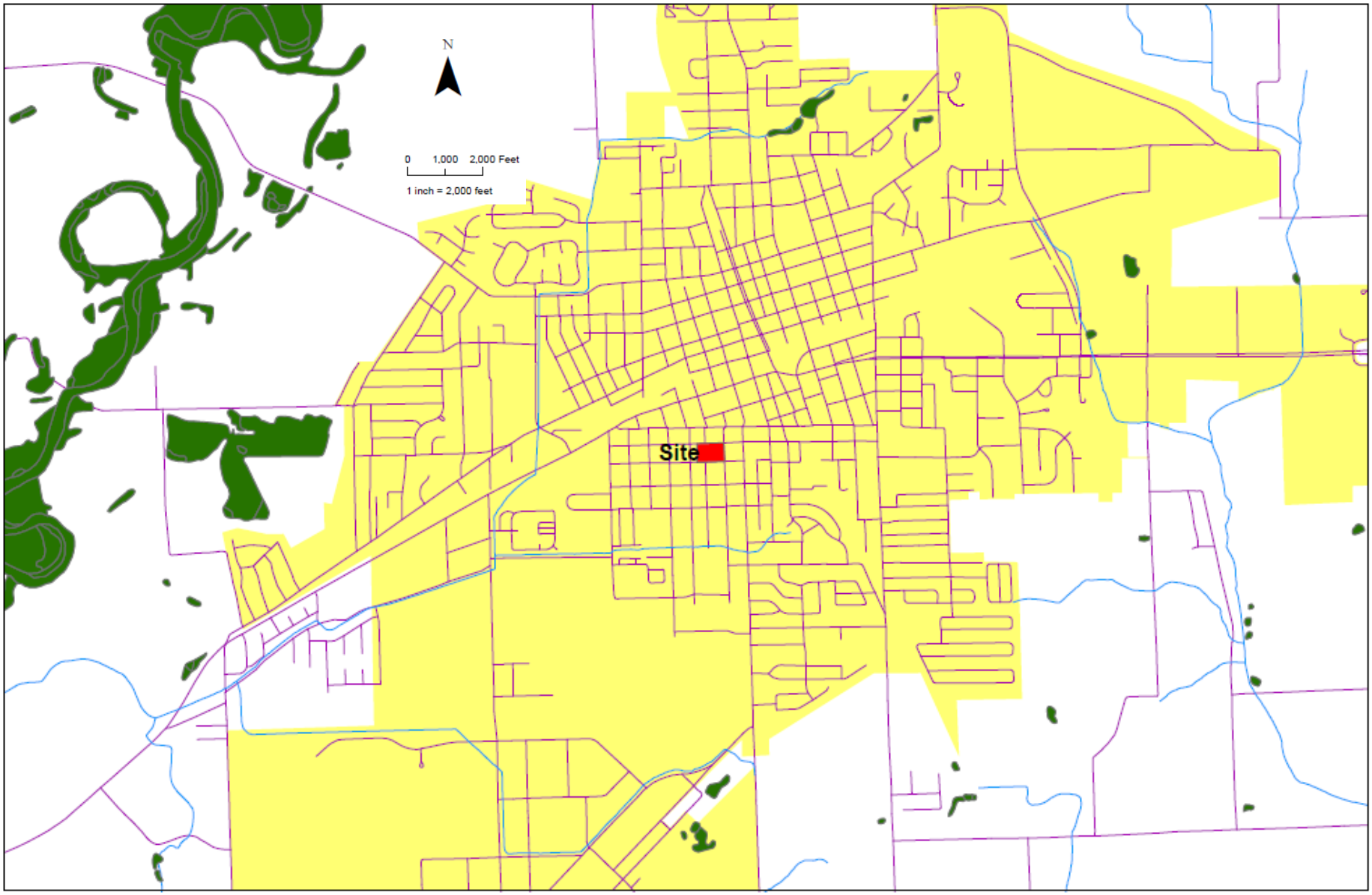
Case History No. 2

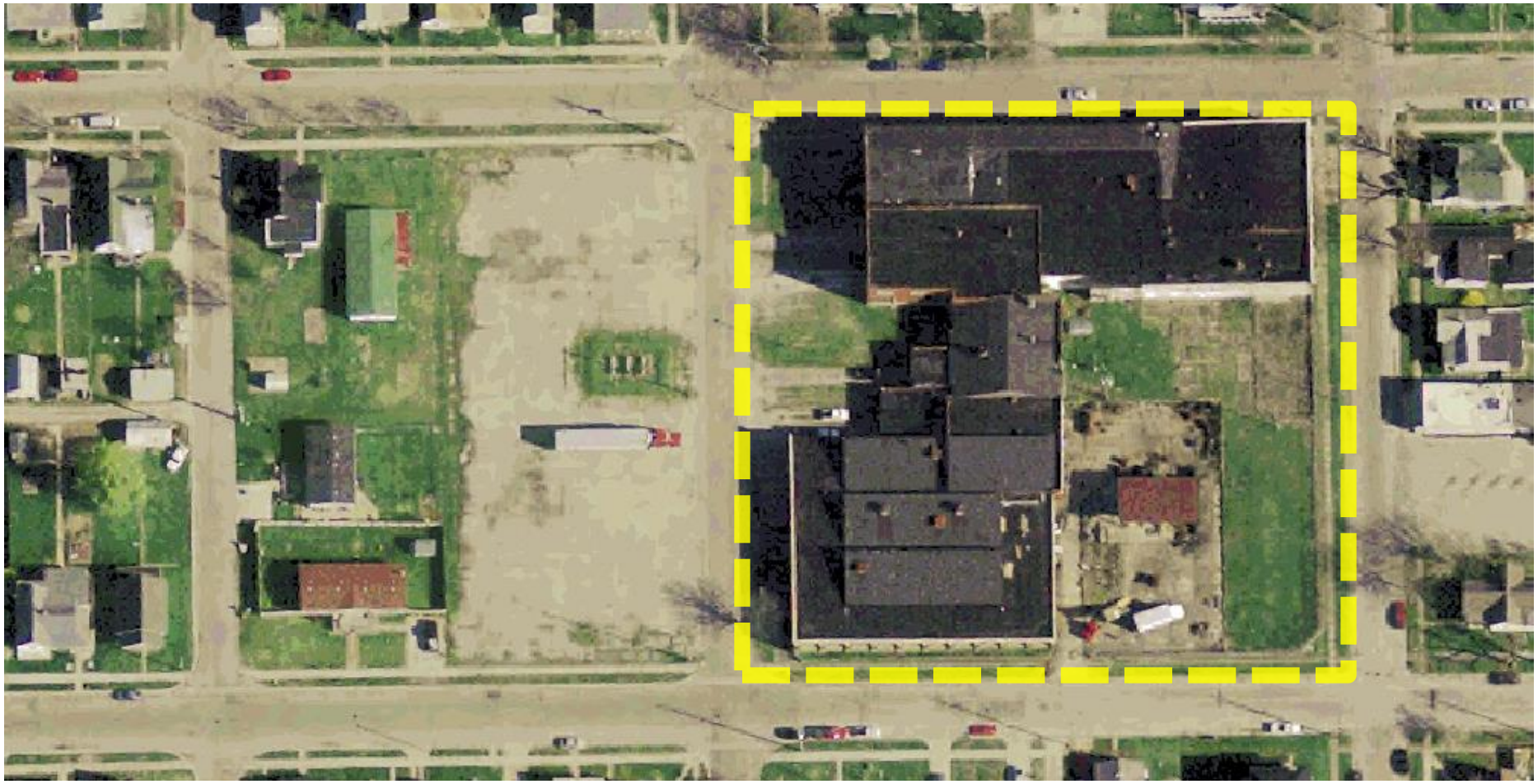


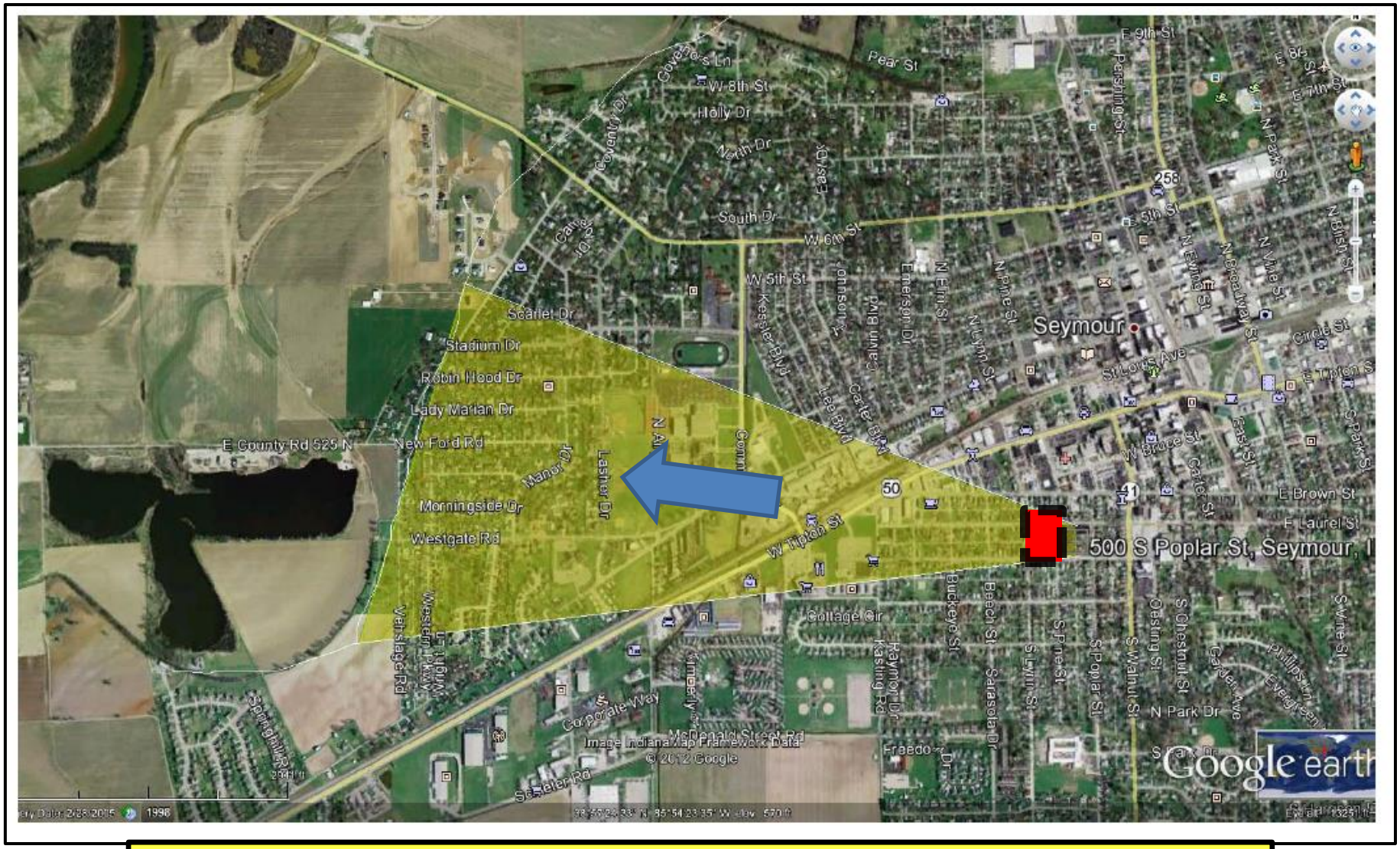
- Long plume
- Complicated geology
- How to clean it up?

Midwestern Geologic Complexity


White River Outwash Valley
Till Plain
H A M I L T O N
R E D D I N G
J A C K S O N
SEYMOUR
Cortland
Rockford
Sunset Parkway
Hangman Crossing
EAST FORK WHITE
WHITE RIVER
FREEMAN MUNICIPAL AIRPORT

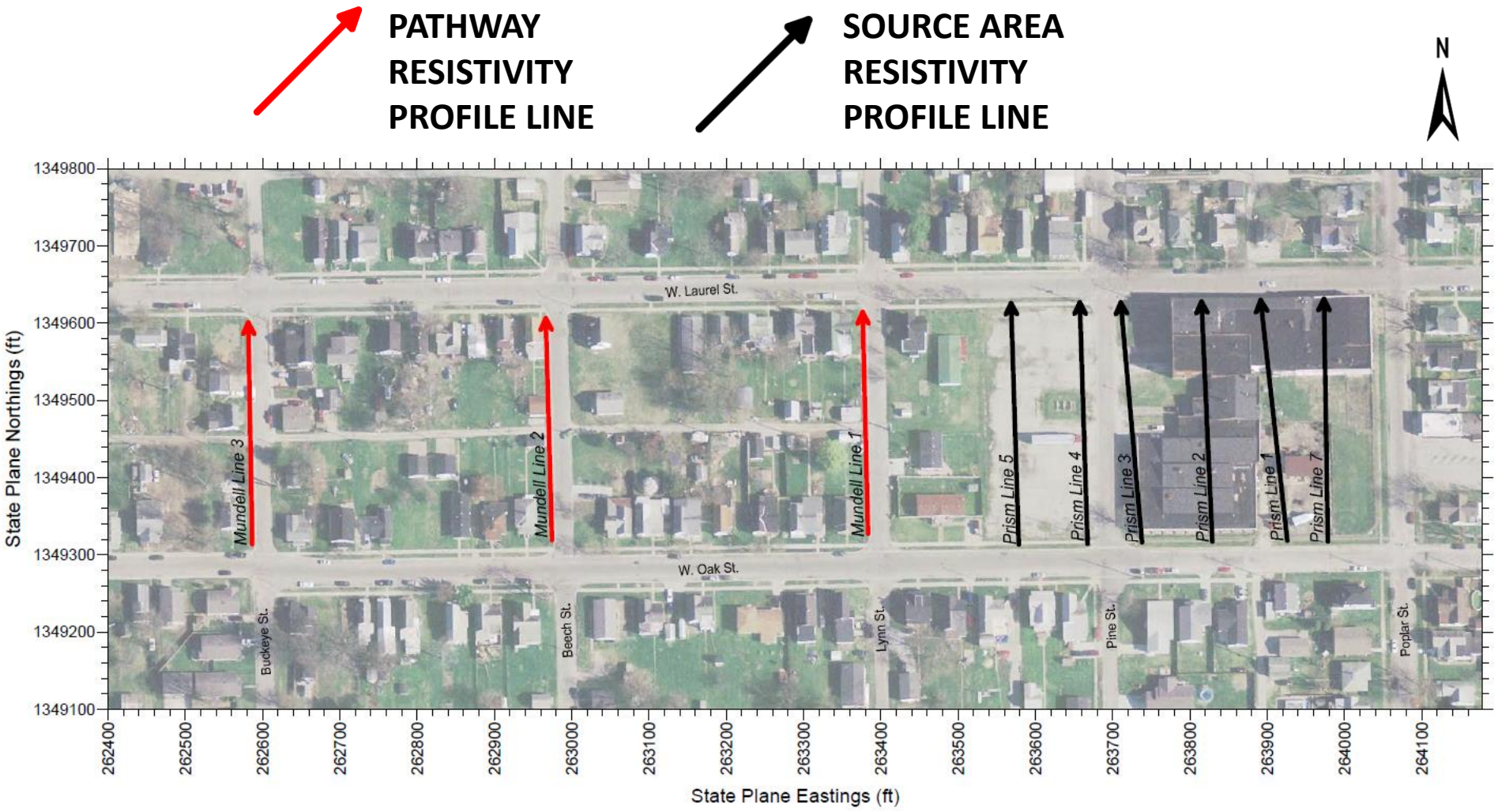

N
0 1,000 2,000 Feet
1 inch = 2,000 feet
Site





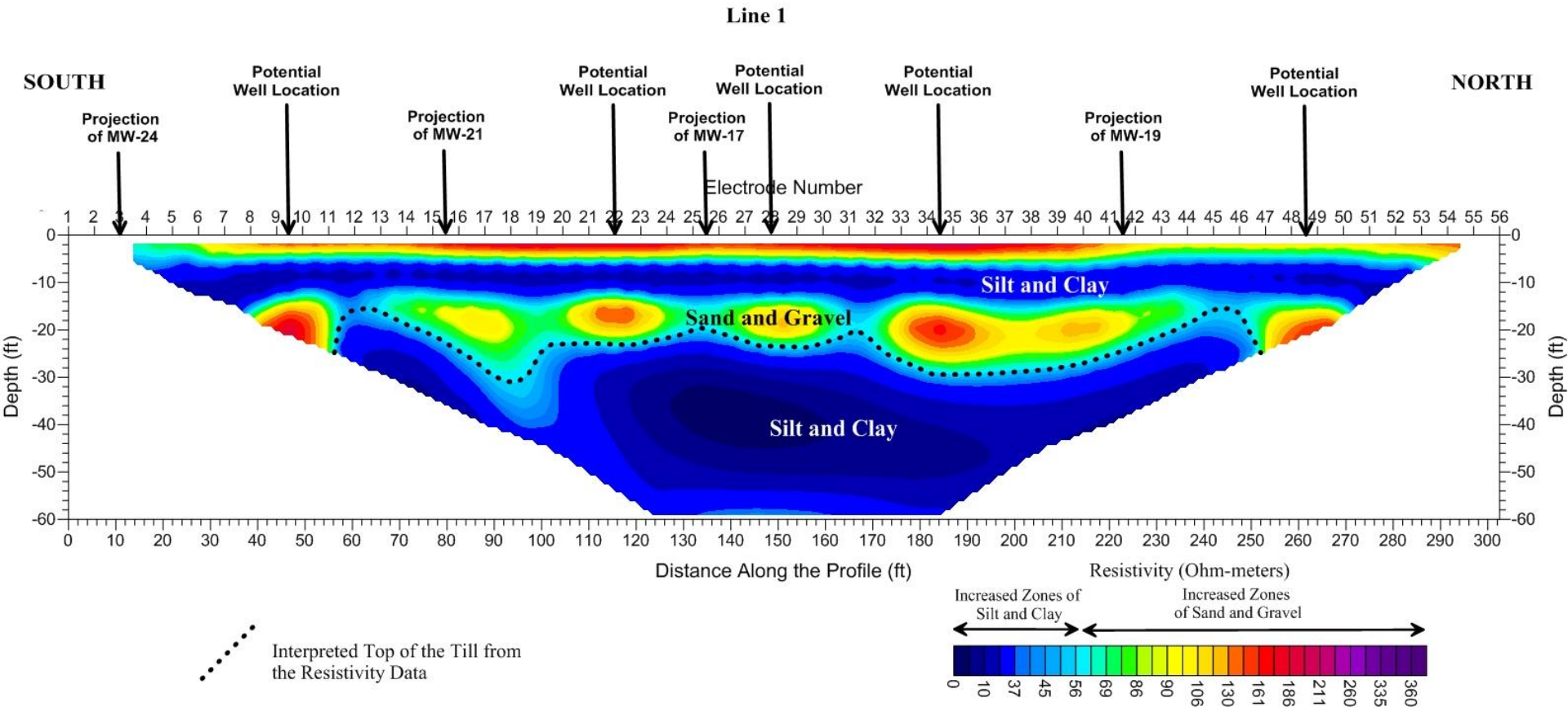
Plume Search Area – Based on Hydrogeology

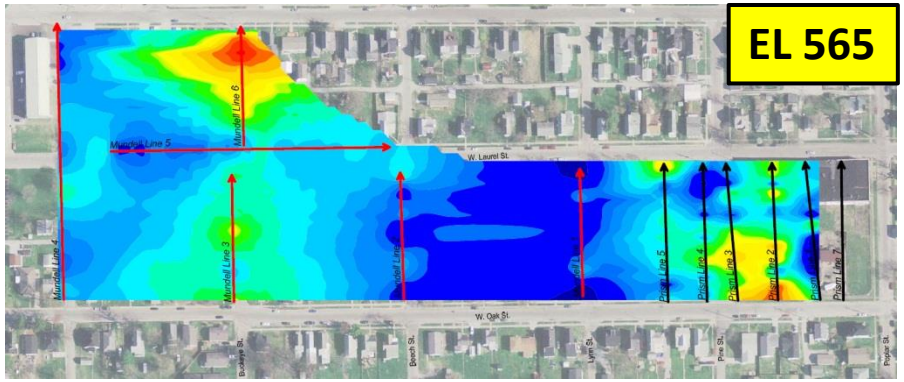

Johnson St
N Lynn St
Calvin Blvd
Lee Blvd
Carter Blvd
N Elm St
Maple Ave
St Louis Ave
Kuessner Blvd
N Airport Rd
Community Dr
50
W Bruce St
Beech St
Kasting Rd
W Towne Plaza
Commons Dr
Lynn St
500 S P

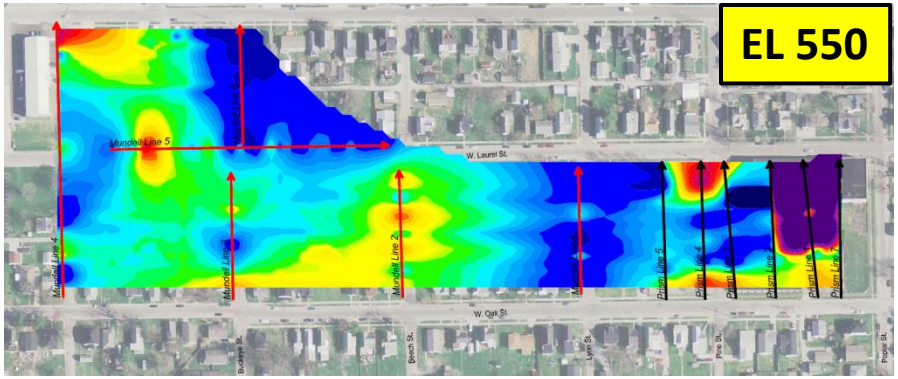

PATHWAY RESISTIVITY PROFILE LINE
SOURCE AREA RESISTIVITY PROFILE LINE
N
W. Laurel St.
W. Oak St.
Mundell Line 3
Mundell Line 2
Mundell Line 1
Prism Line 5
Prism Line 4
Prism Line 3
Prism Line 2
Prism Line 1
Prism Line 7
Buckeye St.
Beech St.
Lynn St.
Pine St.
Poplar St.
State Plane Northings (ft)
1349800
1349700
1349600
1349500
1349400
1349300
1349200
1349100
262400
262500
262600
262700
262800
262900
263000
263100
263200
263300
263400
263500
263600
263700
263800
263900
264000
264100
State Plane Eastings (ft)

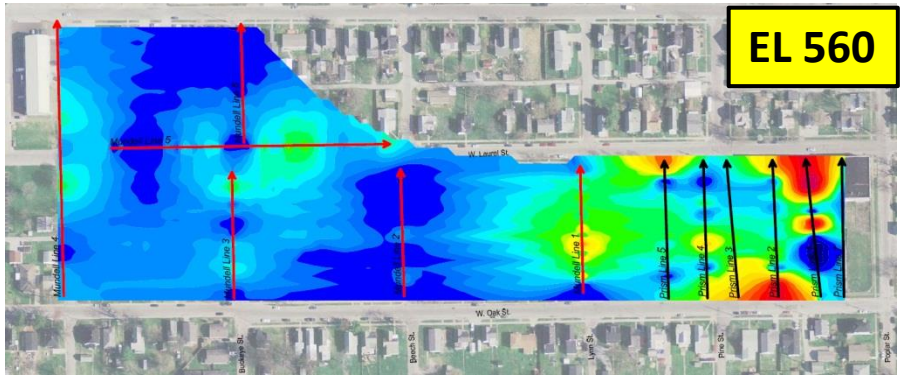

STOP
4x4

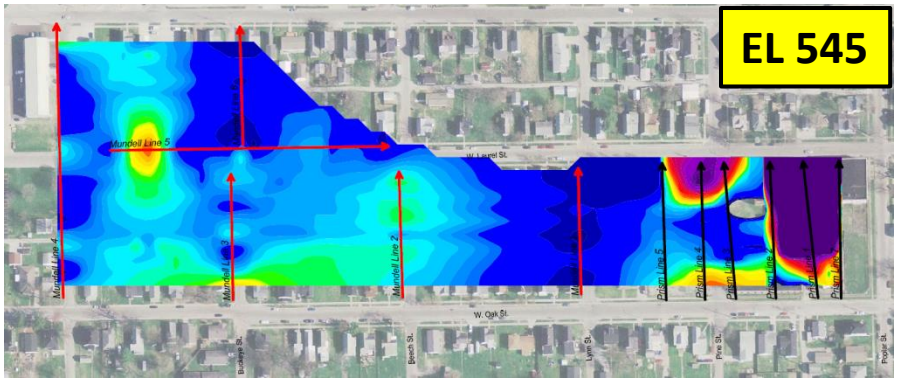
Resistivity Profile Line 1

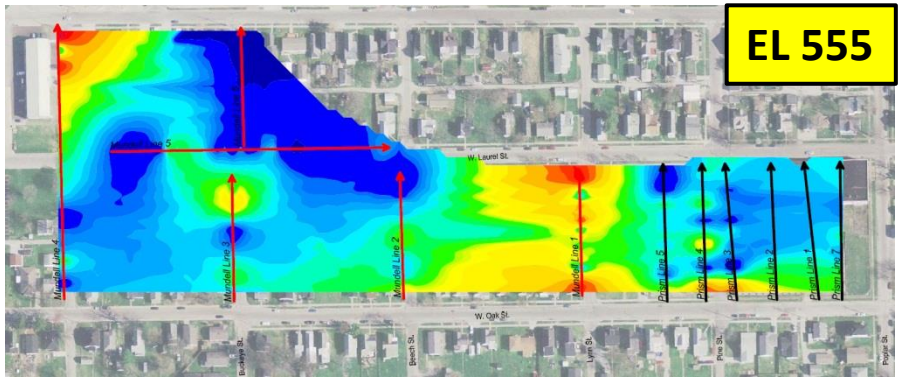


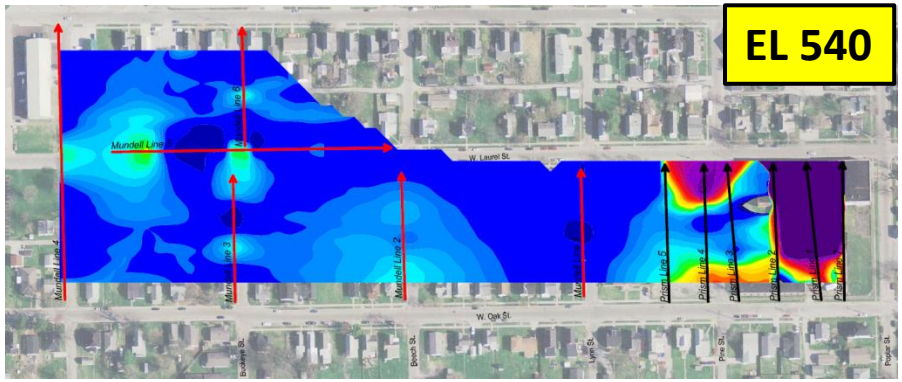




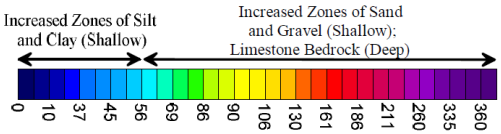




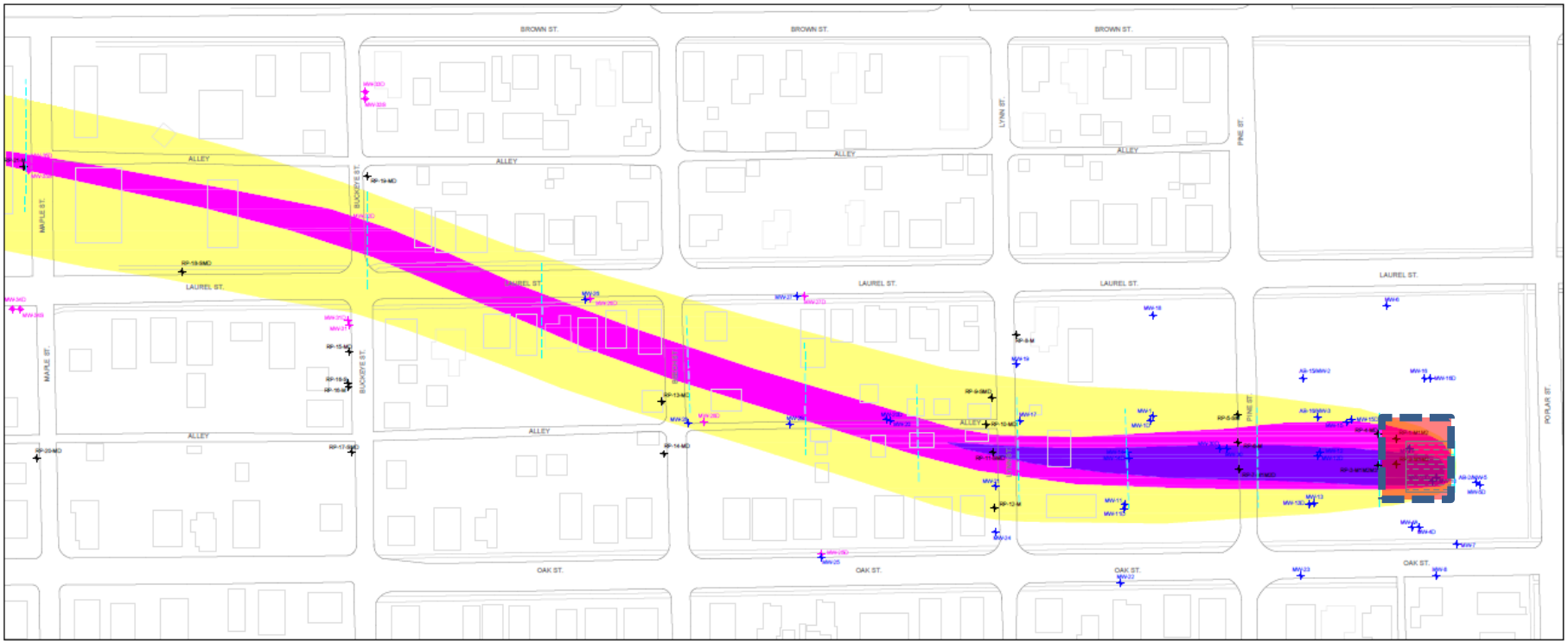




Resistivity (Ohm-meters)



Resistivity Slice Maps



LEGEND

MW-32 Mundell Monitoring Well Location

RP-8-M Mundell Remediation Progress Monitoring Piezometer Location

MW-18 Astbury Monitoring Well Location

Buildings

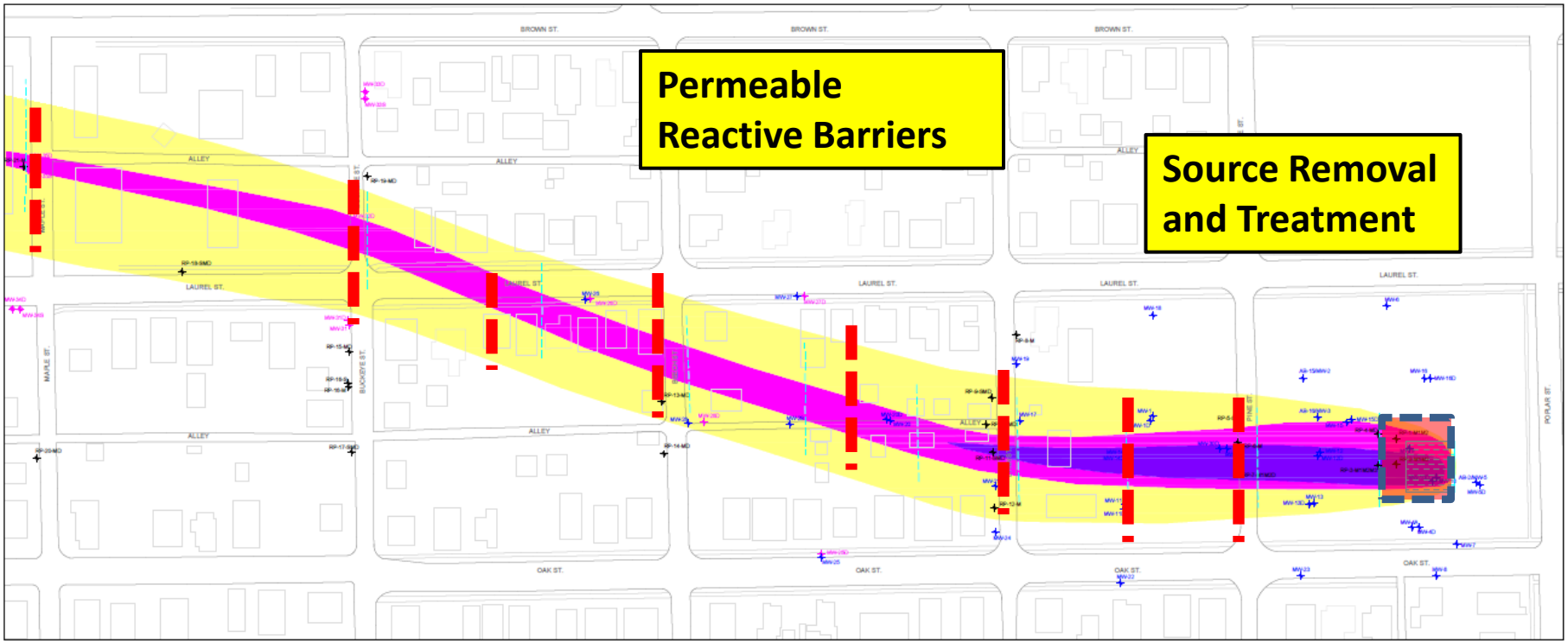
Approximate plume delineation of 50 ug/L of total chlorinated VOCs

Approximate plume delineation of 500 ug/L of total chlorinated VOCs

Approximate plume delineation of 5,000 ug/L of total chlorinated VOCs

0' 30' 60' 120'

Chlorinated Plume Delineation



LEGEND

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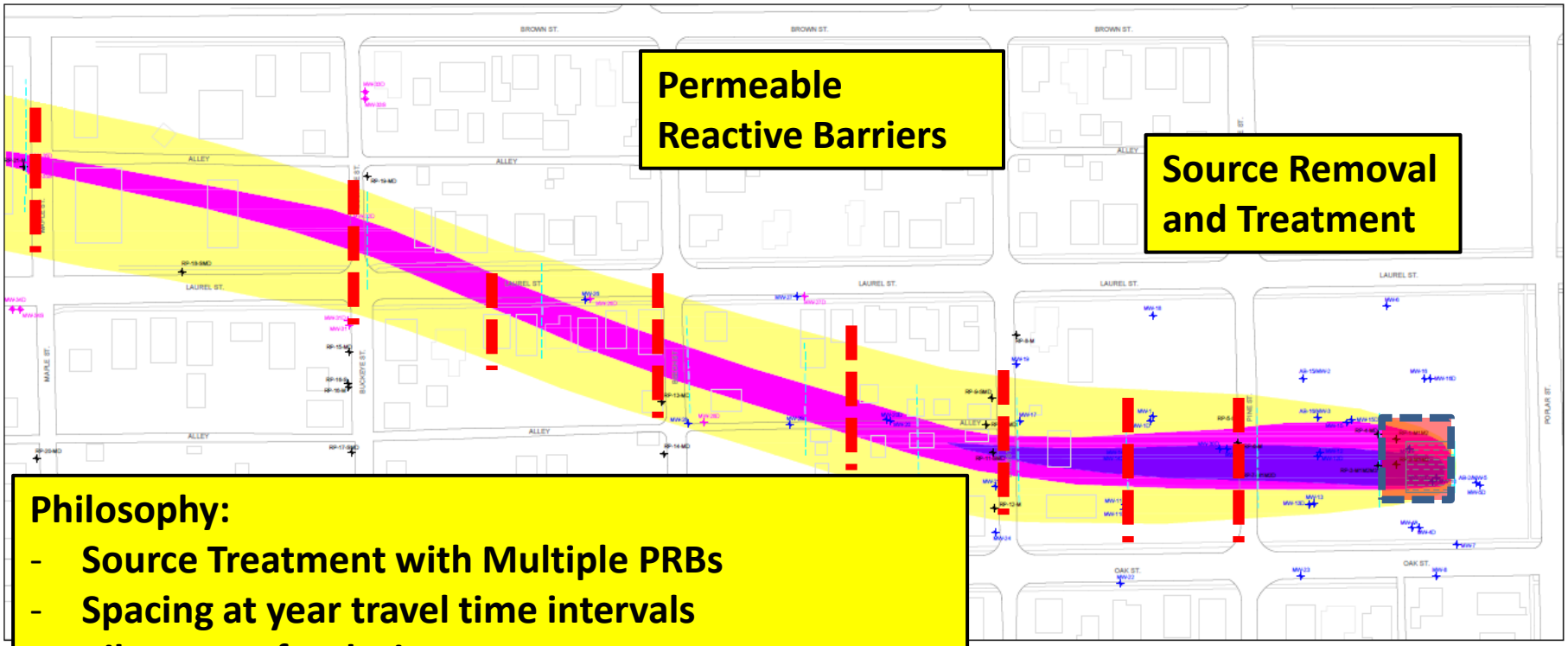
Approximate plume delineation of 50 ug/L of total chlorinated VOCs

Approximate plume delineation of 500 ug/L of total chlorinated VOCs

Approximate plume delineation of 5,000 ug/L of total chlorinated VOCs

0' 30' 60' 120'

Remediation of Chlorinated Plume



Philosophy:

- **Source Treatment with Multiple PRBs**
- **Spacing at year travel time intervals**
- **Pilot test – for design**
- **Monitor – Observational approach**

MW-32 Mundell Monitoring Well Location

RP-8-M Mundell Remediation Progress Monitoring Piezometer Location

MW-18 Astbury Monitoring Well Location

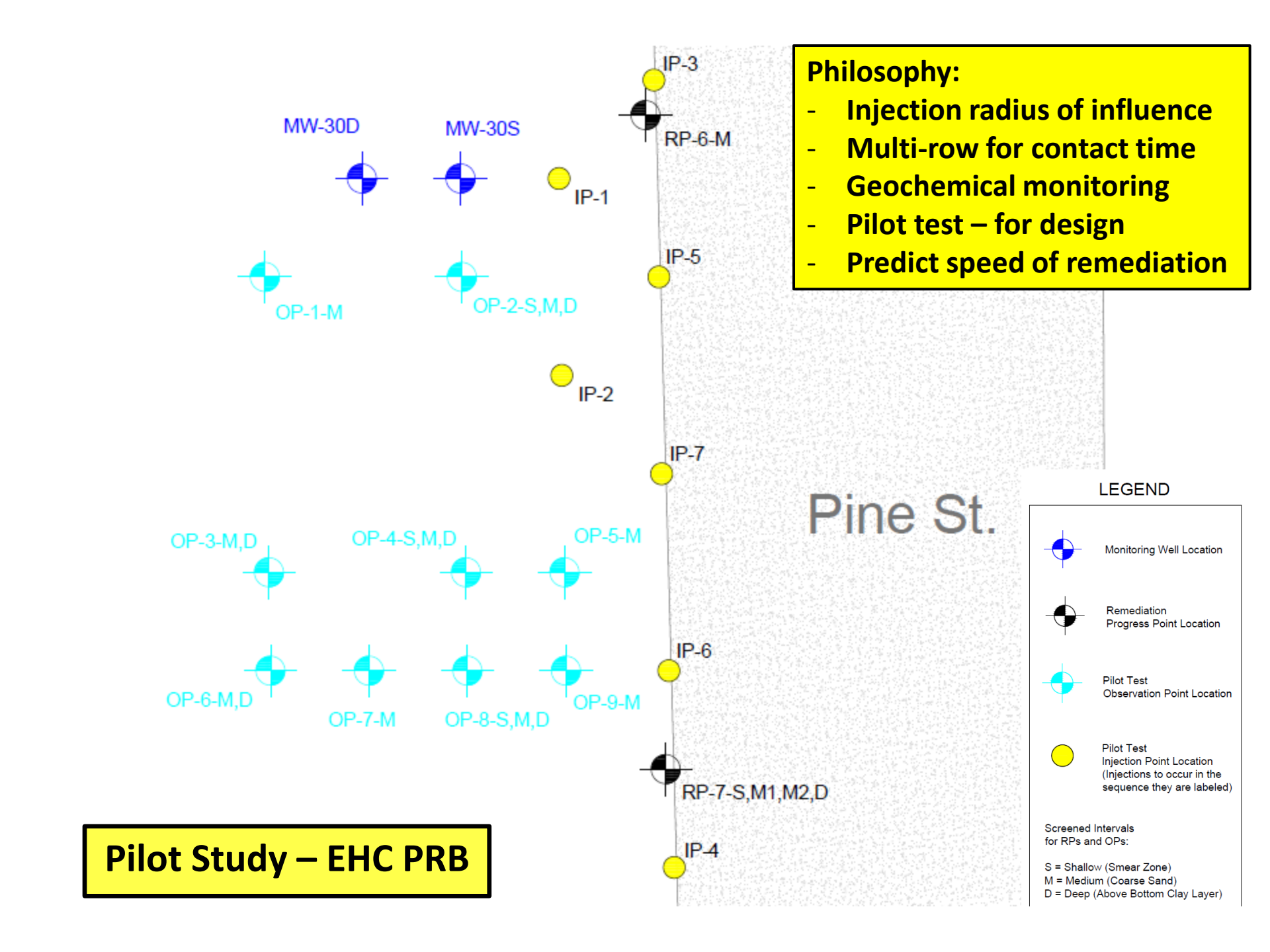
Buildings

Approximate plume delineation of 50 ug/L of total chlorinated VOCs

Approximate plume delineation of 500 ug/L of total chlorinated VOCs

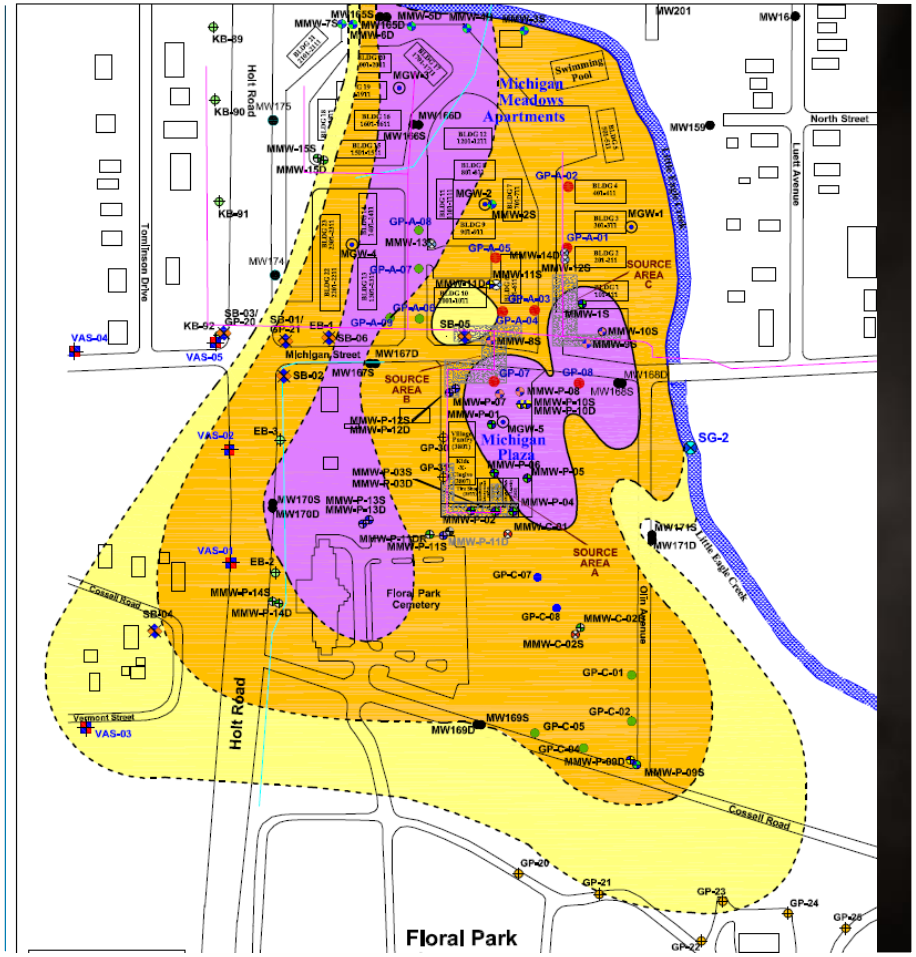
Approximate plume delineation of 5,000 ug/L of total chlorinated VOCs

Remediation of Chlorinated Plume


Philosophy:
- Injection radius of influence
- Multi-row for contact time
- Geochemical monitoring
- Pilot test – for design
- Predict speed of remediation
IP-3
RP-6-M
MW-30D
MW-30S
IP-1
IP-5
OP-1-M
OP-2-S,M,D
IP-2
IP-7
Pine St.
OP-3-M,D
OP-4-S,M,D
OP-5-M
IP-6
OP-6-M,D
OP-7-M
OP-8-S,M,D
OP-9-M
RP-7-S,M1,M2,D
IP-4
LEGEND
Monitoring Well Location
Remediation Progress Point Location
Pilot Test Observation Point Location
Pilot Test Injection Point Location (Injections to occur in the sequence they are labeled)
Screened Intervals for RPs and OPs:
S = Shallow (Smear Zone)
M = Medium (Coarse Sand)
D = Deep (Above Bottom Clay Layer)
Pilot Study – EHC PRB


emGrout

Lessons Learned



- Most PRB failures are from a lack of subsurface data collection prior to final design
- Wrong location, thickness and depth of PRB.
- PRB material under-designed for chemical concentrations

THANKS!


Mundell
Consulting Professionals
for the Earth and the Environment