Vertex Environmental Solutions

Soil Variability Implications For In-Situ Programs

RemTech 2008

October 17, 2008

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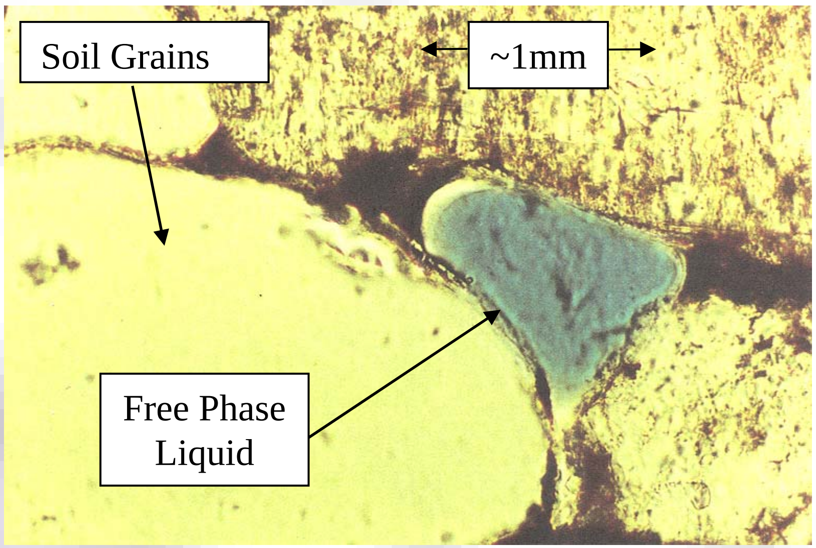
VERTEX

Outline



- The Big Picture
  - Background
  - In-Situ vs Excavation
  - Understanding Your Site
- Soil Variability Examples
  - Mass Calculations
- Case Studies
- Questions

Background - Vertex

- Environmental Contracting
- Specialize in technically challenging sites
  - Injection (>350), DNAPL
- Clients are consultants
- Typical Consultant Roles
  - Phase II ESA
- Typical Vertex Roles
  - Remedial Design
  - Remediation (bench, full-scale)
- Issue: Data collection

In-Situ vs Excavation

- Data Collection
  - Soil remediation (excavation)
    - 100% of affected area removed
    - soil variability doesn't play a role
  - Groundwater or in-situ remediation
    - need good understanding of distribution and mass of COCs
- Why choose in-situ?
  - non-disruptive to operating facility
  - Treatment of inaccessible soil (under structures or located at depth)
  - lower cost, distributed costs
- Is in-situ being used?

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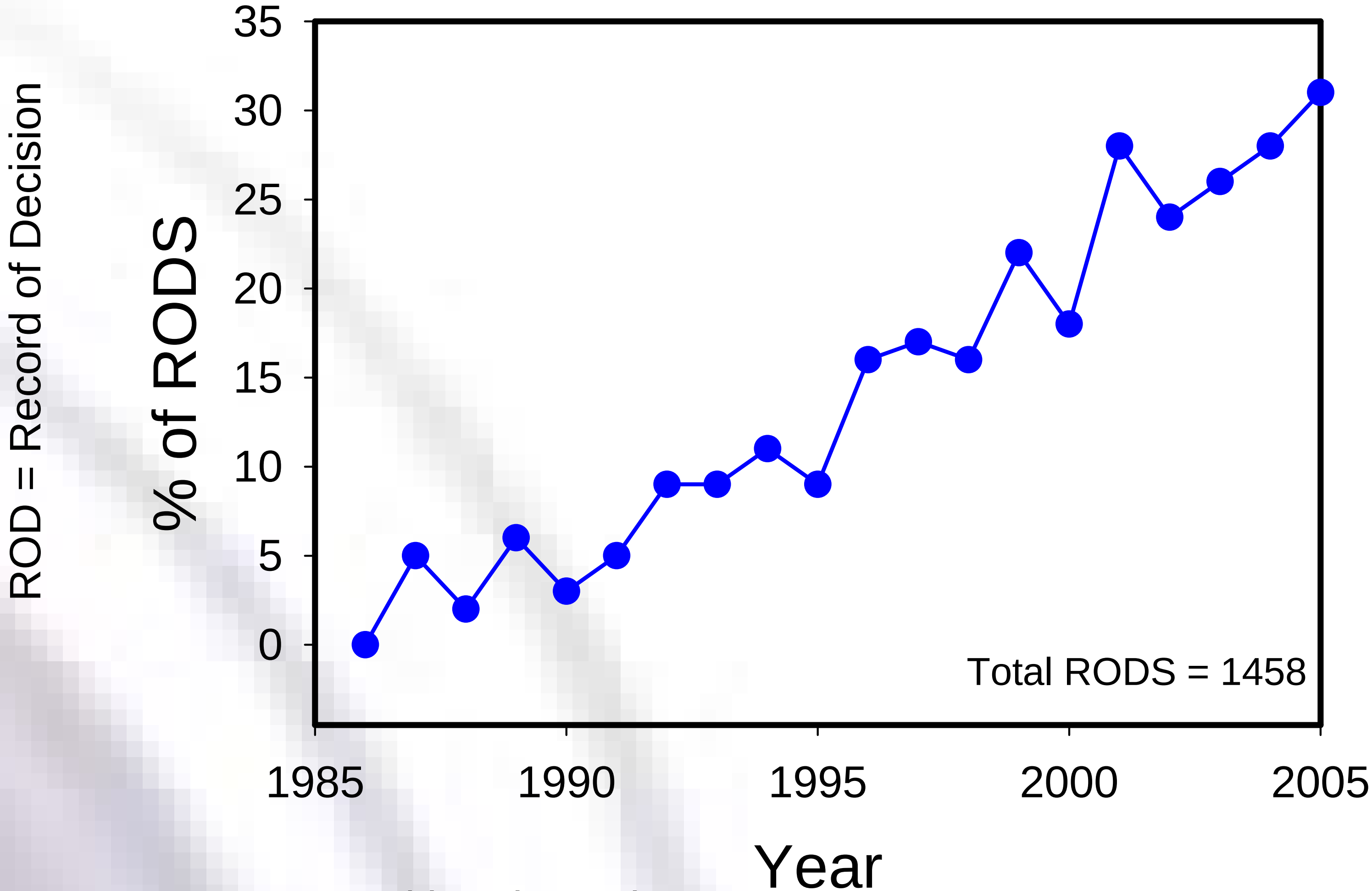
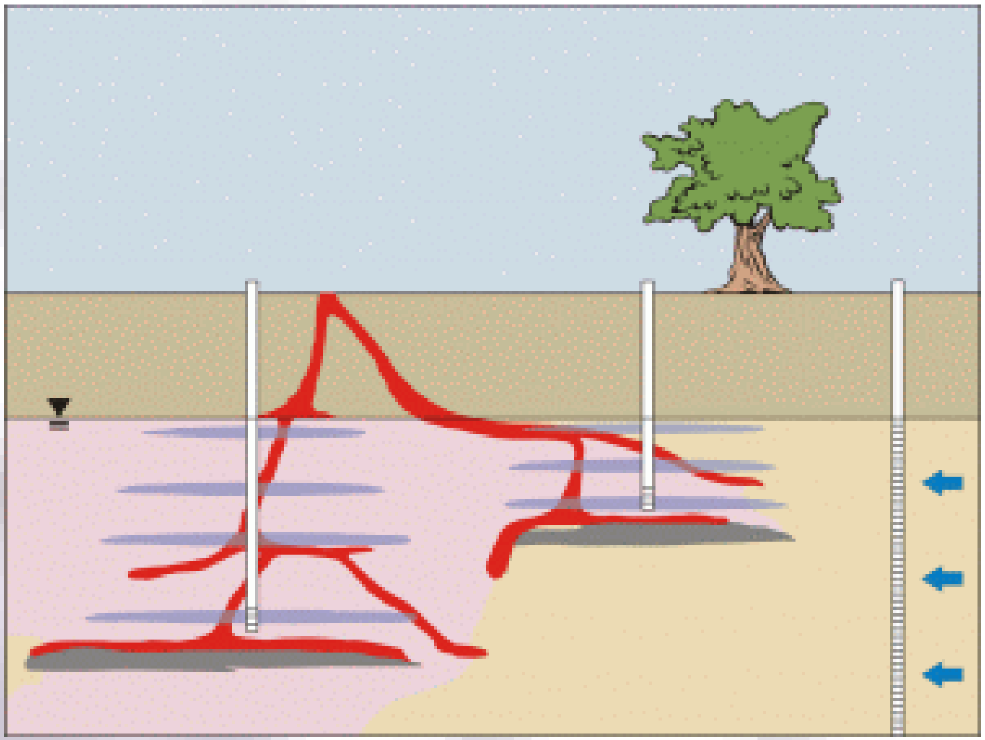
In-Situ: Market Trend



- U.S.EPA Document (dated 2007)
  - "Treatment Technologies for Site Cleanup: Annual Status Report"
  - Information associated with National Priorities List (NPL) sites

Understanding Your Site



How Can In-Situ Fail?

- Geology
- Contaminants
  - Distribution
  - Concentration
  - Fate
  - Contaminant Mass
- Anthropogenic
  - Sewers, sumps

Soil Variability

- CFB Borden Research Site
- 3 m by 3 m cell constructed
- 231 L PCE release in June 1990
  - Known volume of contamination
  - Injected at average rate of 8 L/hr (29 hrs)
  - One month: no more DNAPL movement
- 2 months after release – soil cores

- Data presented by B. Kueper et al, Ground Water, 1993

Probable PCE Distribution

- Short circuiting down Multilevel 3
- 3 soil cores: 2.5 m cores, 5 cm sample interval
- PCE: <100 mg/kg to 90,900 mg/kg (9%)
- PCE varied 1,000 times over distance <0.5 m

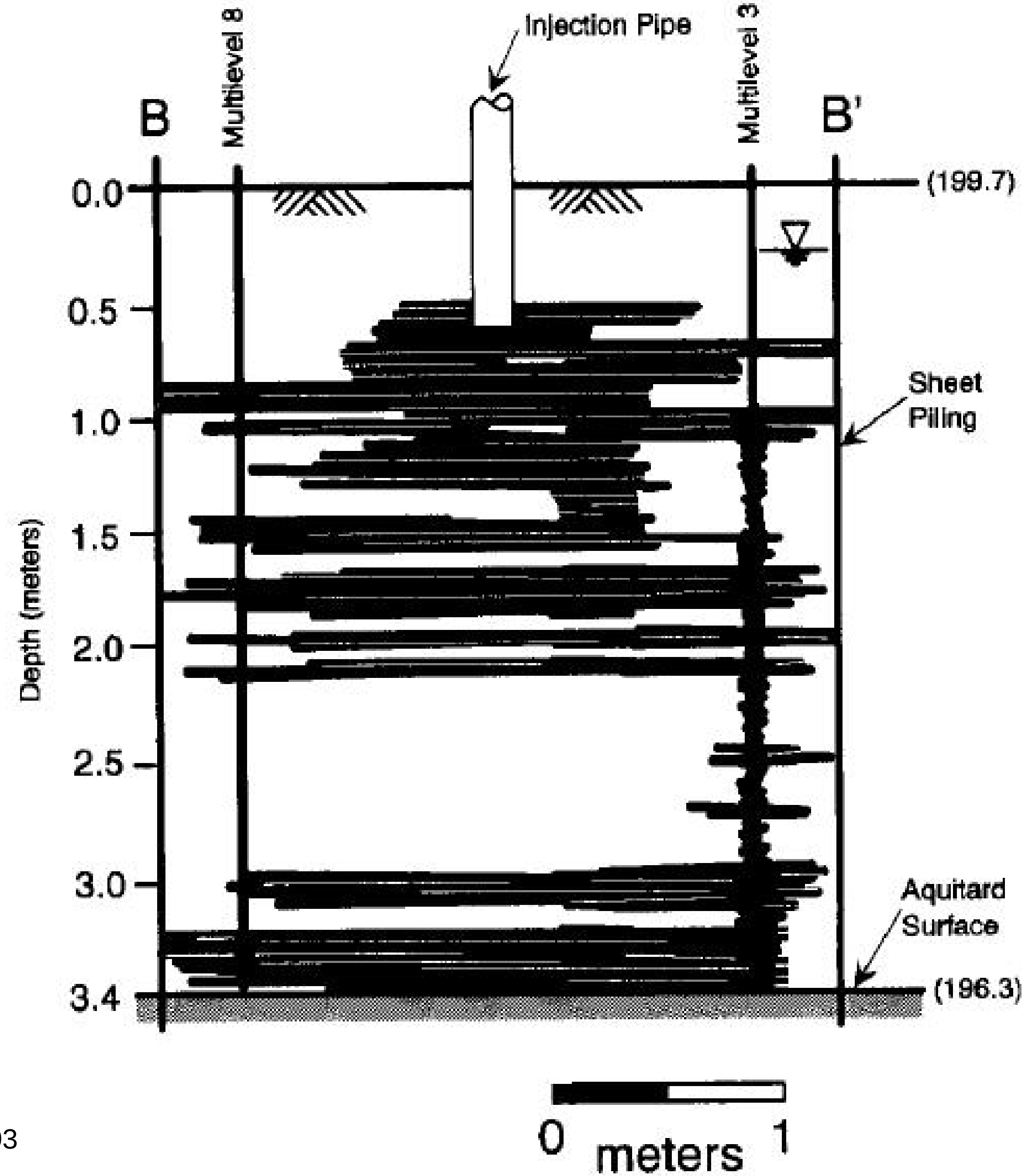


Figure 10: Kueper et al, Ground Water, 1993

Soil Variability

- Stan Feenstra analyzed data*
  - Core 1 (5 cm intervals): 49 soil samples
- 2 Scenarios
  - Scenario 1: 0.50 m sample interval (~standard)
  - Scenario 2: 1.25 m sample interval (~Geoprobe)
- Randomly selected 5 cm cores:
  - 0.50 m interval: 5 samples
  - 1.25 m interval: 2 samples
- Ran the simulation 5,000 times

* Stan Feenstra, Environmental & Engineering Geoscience, Feb 2003

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Soil Variability

Sample Interval	PCE Average	Minimum Average	Maximum Average
0.05 m	12,700 mg/kg	n/a	n/a
0.50 m	10,800 mg/kg	890 mg/kg	43,400 mg/kg
1.25 m	6,500 mg/kg	510 mg/kg	66,400 mg/kg

- Feenstra: “variability of chemical concentrations…can introduce very substantial uncertainty”
- Can this happen at a “real” site?

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Soil Variability

- Vertex Site (TCE)
  - 2 different sampling intervals

BH	Soil Samples Submitted	PID Range (ppm)
MW107	2	<5 to 80
MW305	10	<5 (all)

- Wells about 10 m apart in “TCE source area”
- Overall PIDs low

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Soil Variability

MW107 Sample Depth	MW107 TCE Conc (mg/kg)	MW305 Sample Depth	MW305 TCE Conc (mg/kg)
		0.75 m	<0.005
		1.35 m	0.04
2.00	<0.005	1.65 m	1.8
		2.25 m	43
		2.85 m	41
3.75	4.1	3.90 m	23
		4.30 m	29
		5.65 m	0.15
		6.50 m	<0.005
		7.20 m	<0.005

MW107 gw = 10,000 ug/L TCE

MW305 gw = 11,000 ug/L TCE

Mass Calculation

- 3 x 3 cell data*
- Assumptions / Calculations
  - 231 L PCE
  - 1.6 g/cm^3 PCE density
  - 370 kg PCE
  - 9 m^2 with PCE detected over 2.7 m
  - Volume of Soil = 24 m^3
  - Soil Density = 1.8 MT/m^3
  - Soil Mass = 44 MT

* Kueper et al, Ground Water, 1993

Mass Calculation

Description	Ave PCE Conc (mg/kg)	Total PCE (kg)	% of Actual
231 L PCE	-	370	100%
5 cm*: ave	12,700	555	150%
0.50 m*: ave	10,800	472	128%
1.25 m*: ave	6,500	284	77%
0.50 m*: min	890	39	11%
0.50 m*: max	43,400	1,898	514%
1.25 m*: min	510	22	6%
1.25 m*: max	66,400	2,904	786%

* Sample interval and average PCE concentrations from Feenstra (2003), data from Kueper (Ground Water, 1993)

Oxidant Calculation

- How does Mass Calculation affect in-situ?
- Stoichiometric relationship
  - TCE and Permanganate

$2\ \mathbf{KMnO_4} + \mathbf{C_2HCl_3} \rightarrow 2\ CO_2 + 2\ MnO_2 + 2\ K^+ + H^+ + 3\ Cl^-$

Compound	Mass of $KMnO_4$ Required per g of Compound
PCE	1.3 g
TCE	2.4 g
DCE	4.4 g
VC	8.4 g

- Direct relationship to oxidant

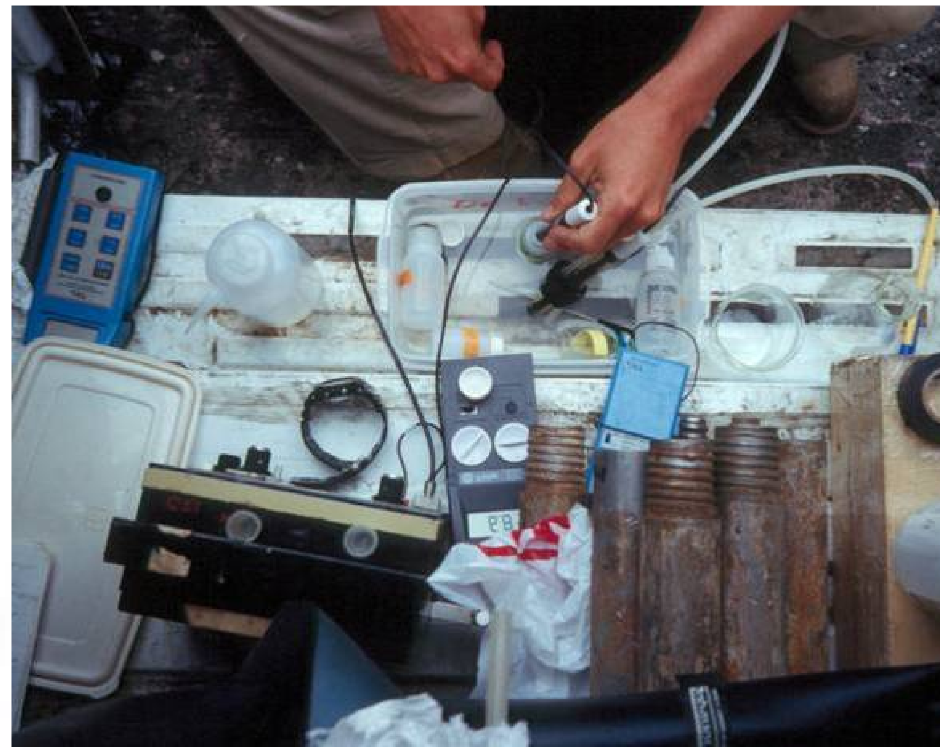
Mass Calculation

Description	Total VOC (kg)	$KMnO_4$ Required (kg) If PCE	$KMnO_4$ Required (kg) If VC
231 L PCE	370	470	3,100
5 cm*: ave	555	710	4,700
1.25 m*: min	22	28	190
1.25 m*: max	2,904	3,700	24,500

Does not include allowance for reactions with subsurface

Data Collection

- How Much?
- Understand CoCs
- Understand SOD
- Hydrogeology
- Geochemistry



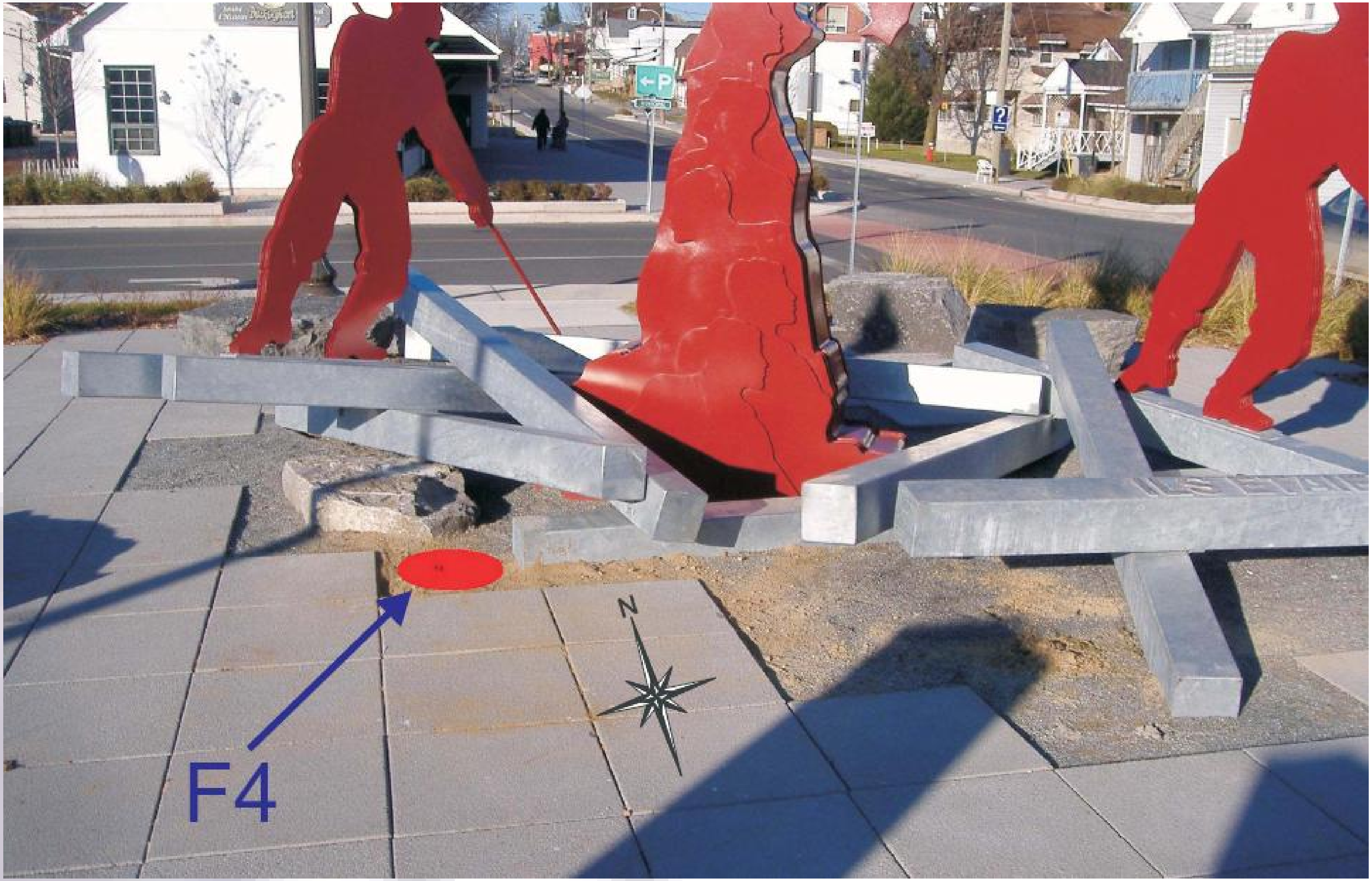
Case Studies

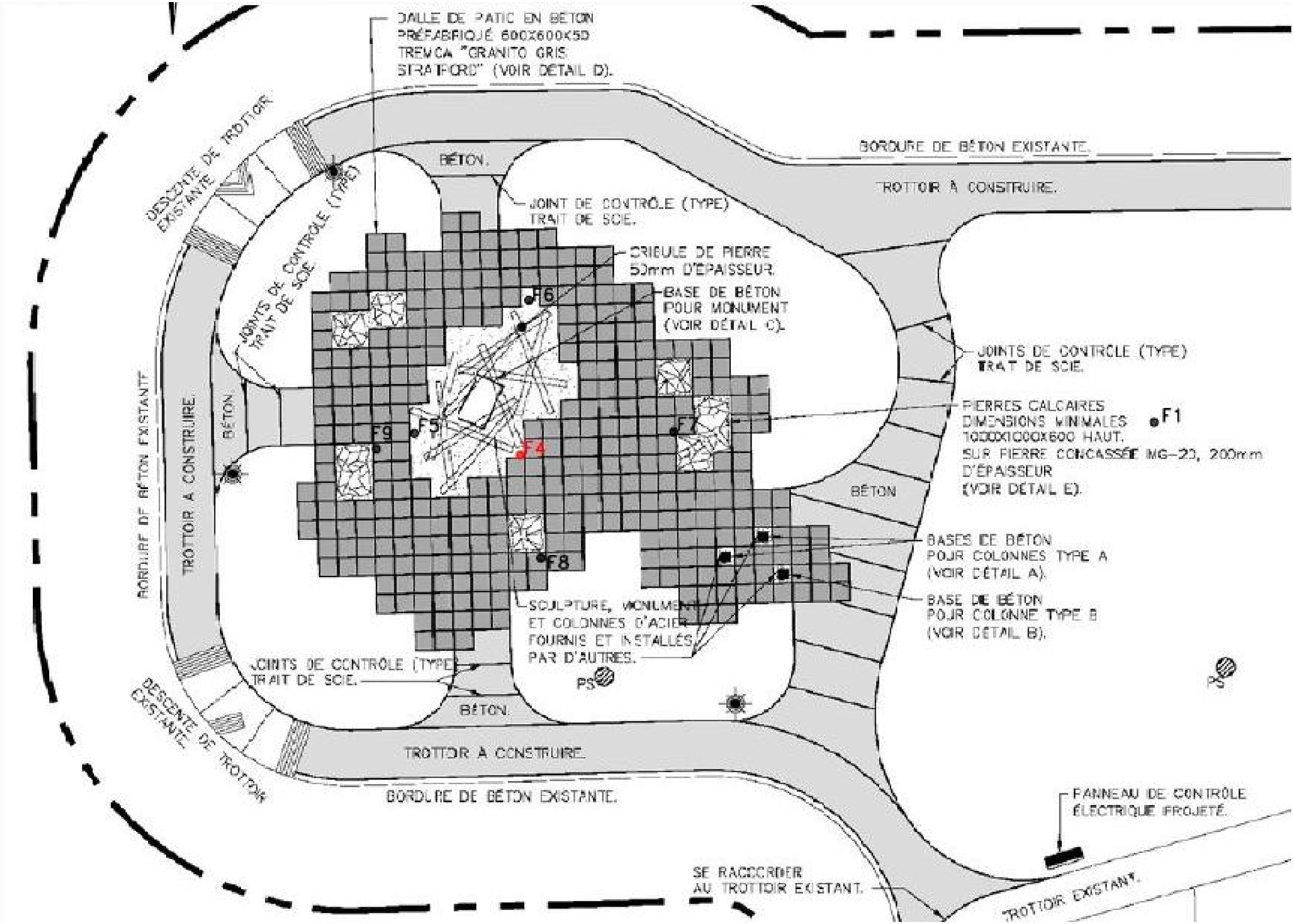
Case Study #1 - Statue

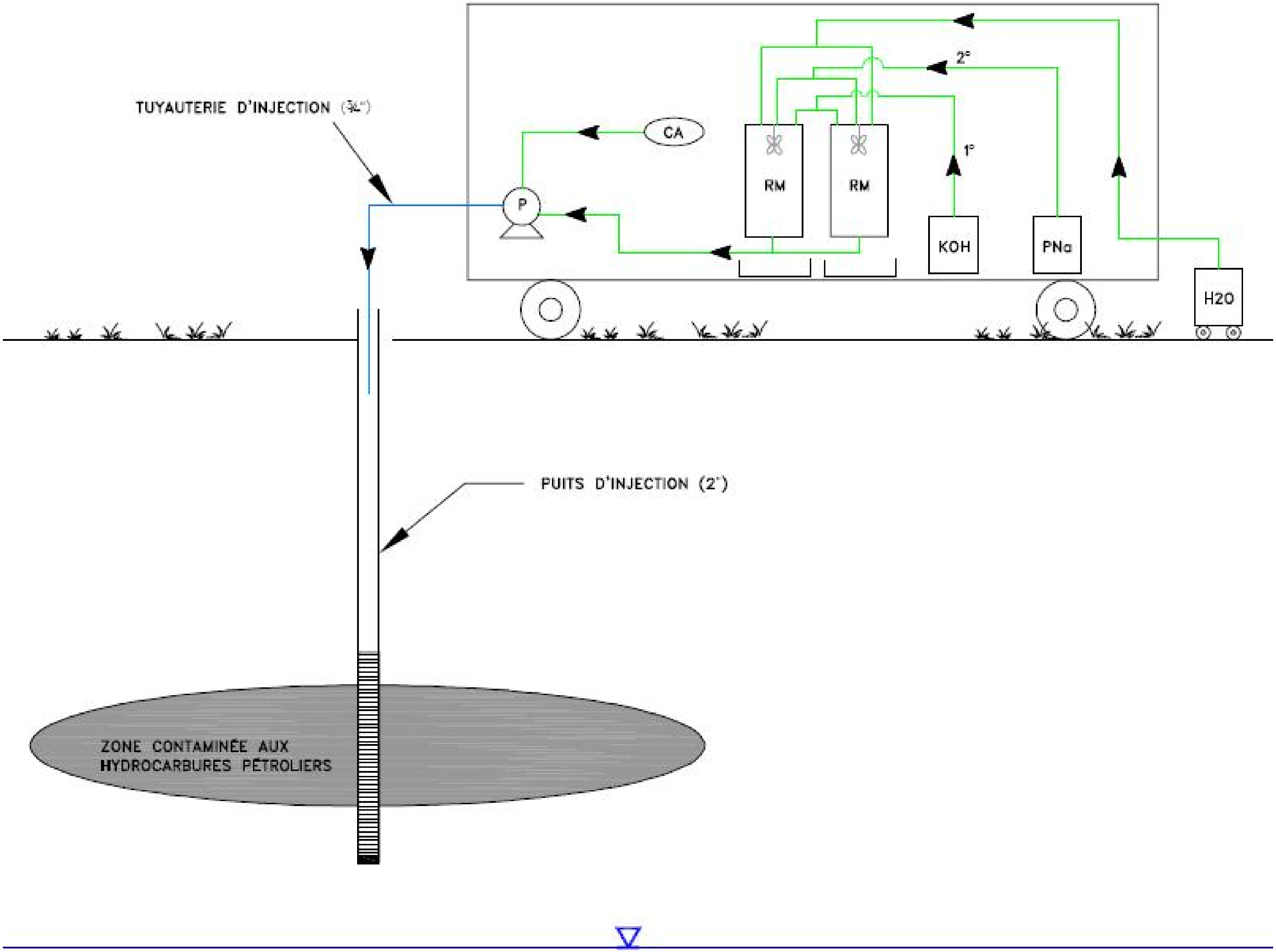
- Statue located in Quebec
- PHC identified beneath statue
- Fragile construction & high political value
- In-Situ remediation was requested
  - injection wells
- PHC (C10-C50) – 6,100 mg/kg
- PHC (C10-C50) criteria – 3,500 mg/kg
- Oxidant injected every 3 weeks for 3 events (Week 0, Week 3, Week 6)
- Sampled Week 12

VERTEX

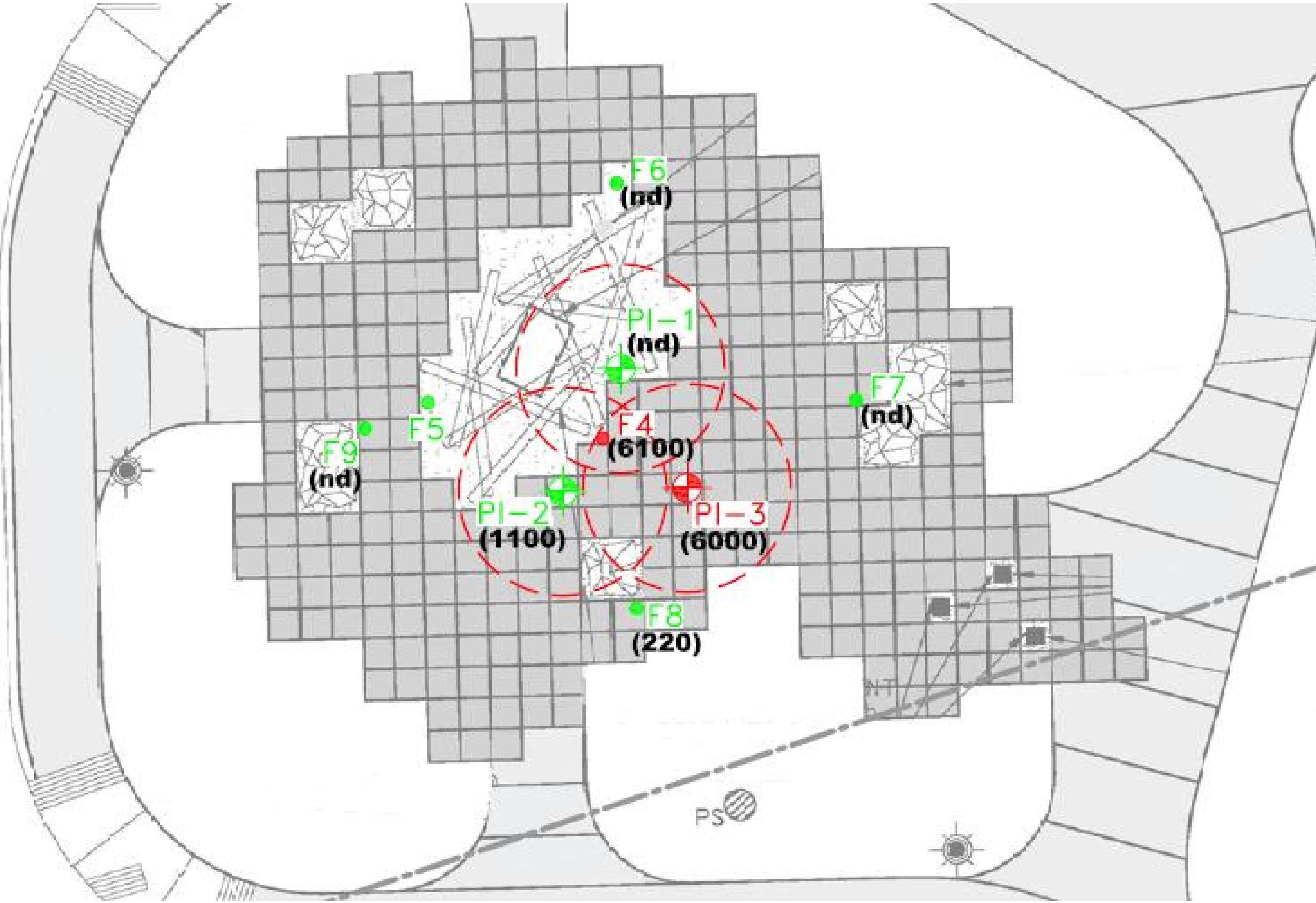
Case Study #1 - Statue



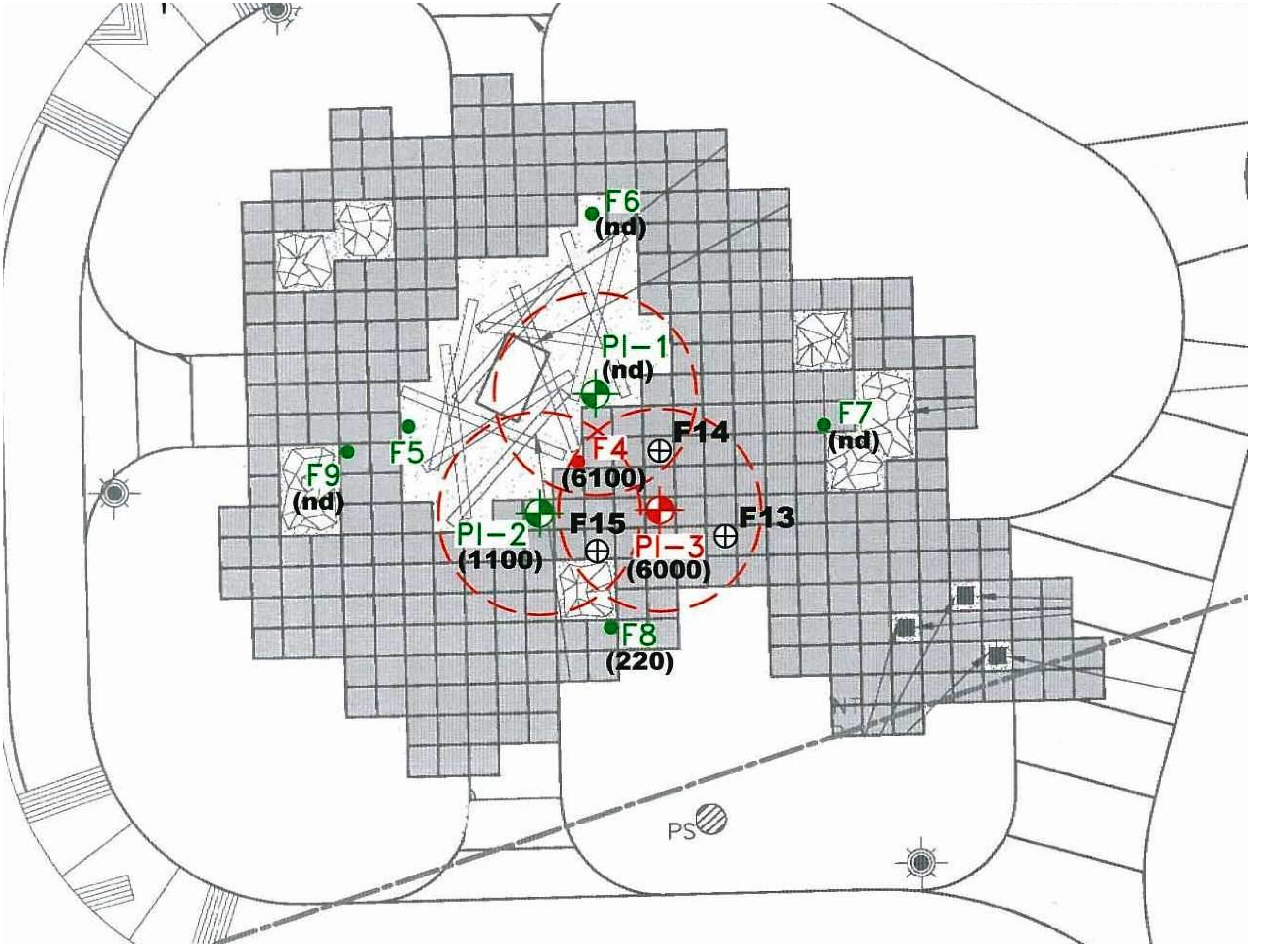

DALLE DE PATIO EN BÉTON
PRÉFABRIQUÉ 600X600X50
TREMCA "GRANITO GRIS
STRATFORD" (VOIR DÉTAIL D).
BÉTON.
JOINT DE CONTRÔLE (TYPE)
TRAIT DE SCIE.
BORDURE DE BÉTON EXISTANTE.
TROTTOIR À CONSTRUIRE.
DESCENTE DE TROTTOIR EXISTANTE
JOINTS DE CONTROLE (TYPE)
TRAIT DE SCIE
CRIBLURE DE PIERRE
50mm D'ÉPAISSEUR.
BASE DE BÉTON
POUR MONUMENT
(VOIR DÉTAIL C).
F6
JOINTS DE CONTRÔLE (TYPE)
TRAIT DE SCIE.
BÉTON.
BORDURE DE BÉTON EXISTANTE
TROTTOIR À CONSTRUIRE.
F9
F5
F4
F7
PIERRES CALCAIRES
DIMENSIONS MINIMALES
1000X1000X600 HAUT.
SUR PIERRE CONCASSÉE MG-20, 200mm
D'ÉPAISSEUR
(VOIR DÉTAIL E).
F1
BÉTON
F8
BASES DE BÉTON
POUR COLONNES TYPE A
(VOIR DÉTAIL A).
BASE DE BÉTON
POUR COLONNE TYPE B
(VOIR DÉTAIL B).
SCULPTURE, MONUMENT
ET COLONNES D'ACIER
FOURNIS ET INSTALLÉS
PAR D'AUTRES.
JOINTS DE CONTRÔLE (TYPE)
TRAIT DE SCIE.
PS
BÉTON.
DESCENTE DE TROTTOIR EXISTANTE
TROTTOIR À CONSTRUIRE.
BORDURE DE BÉTON EXISTANTE.
PANNEAU DE CONTRÔLE
ÉLECTRIQUE PROJETÉ.
SE RACCORDER
AU TROTTOIR EXISTANT.
TROTTOIR EXISTANT.



TUYAUTERIE D'INJECTION (3/4")
CA
P
RM
RM
2°
1°
KOH
PNa
H2O
PUITS D'INJECTION (2")
ZONE CONTAMINÉE AUX HYDROCARBURES PÉTROLIERS



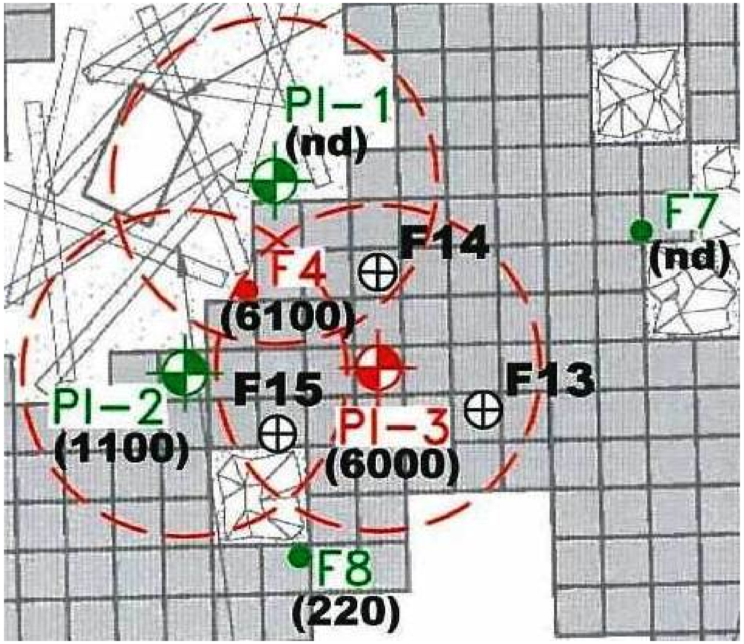
F6
(nd)
PI-1
(nd)
F7
(nd)
F5
F9
(nd)
F4
(6100)
PI-2
(1100)
PI-3
(6000)
F8
(220)
PS


F6
(nd)
PI−1
(nd)
F7
(nd)
F14
F5
F4
(6100)
F9
(nd)
F15
F13
PI−2
(1100)
PI−3
(6000)
F8
(220)
PS

Case Study #1 - Statue

Sampling Location	PHC Result	% Reduction	Location
F13	4,000 mg/kg	33%	South IW#3
F14	1,800 mg/kg	70%	Between 2 IWs
F15	1,500 mg/kg	75%	Between 2 IWs

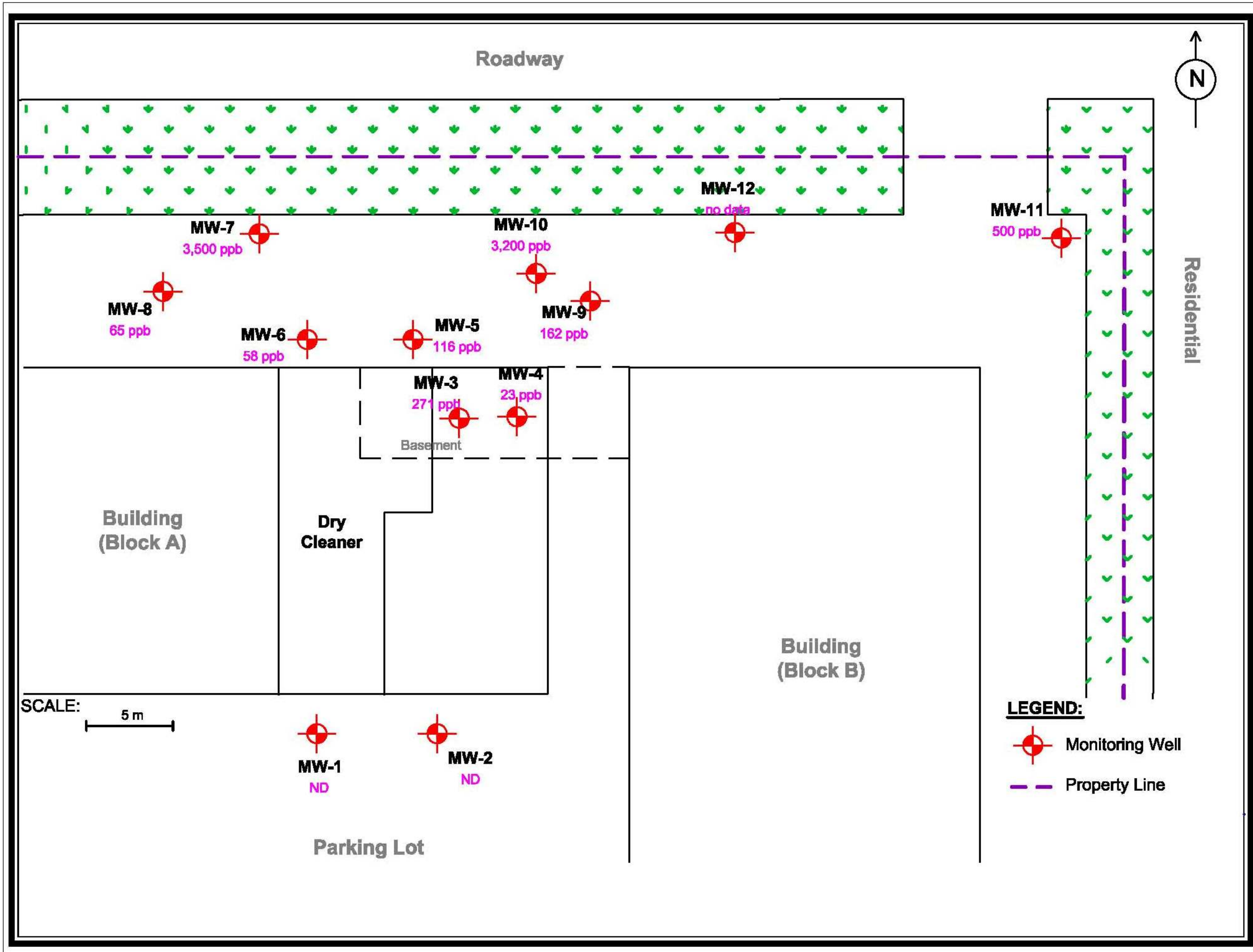
- Reductions noted, best results in vicinity of injection wells
- One result just over criteria, but far enough from statue that excavation is possible

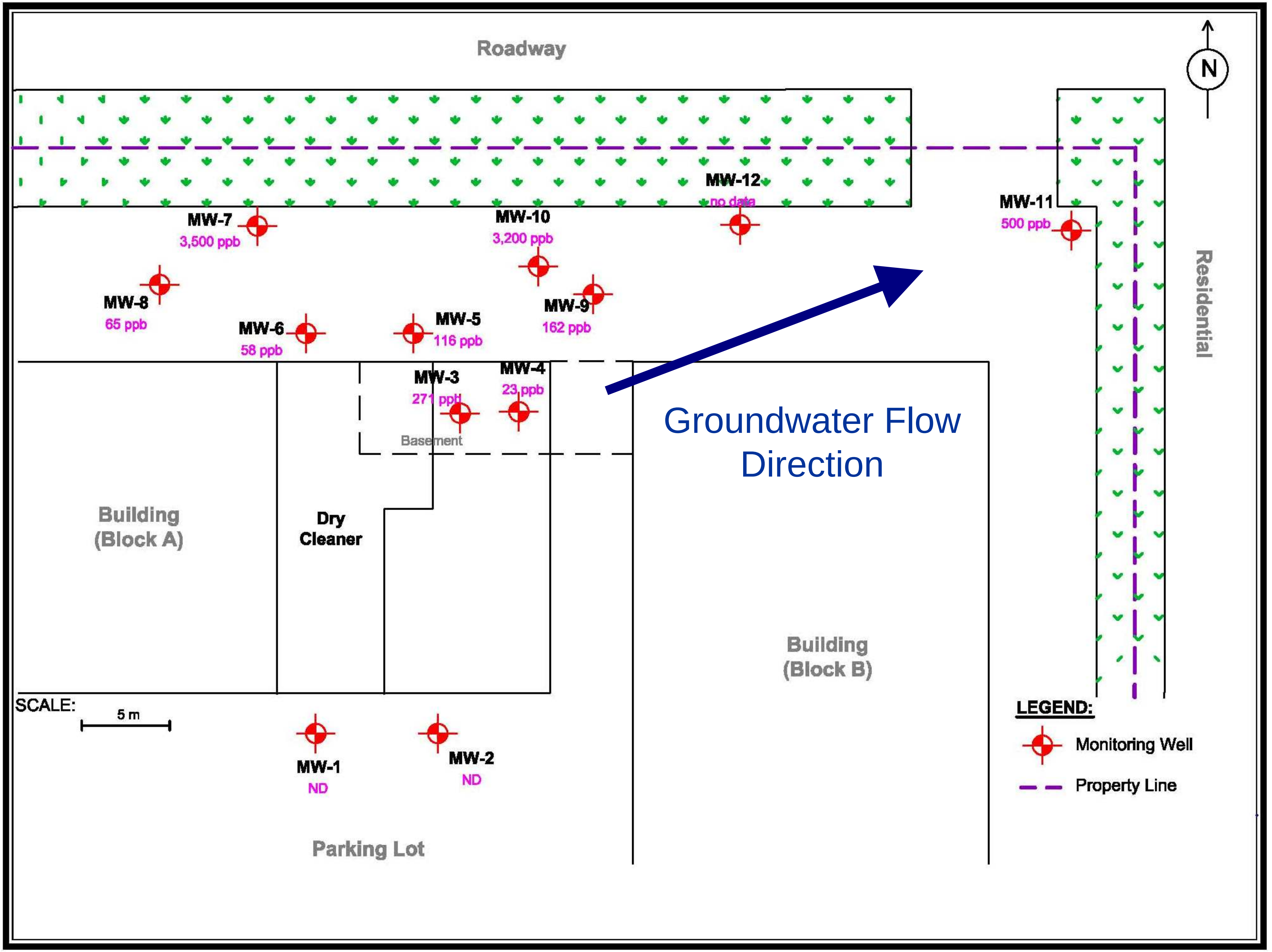


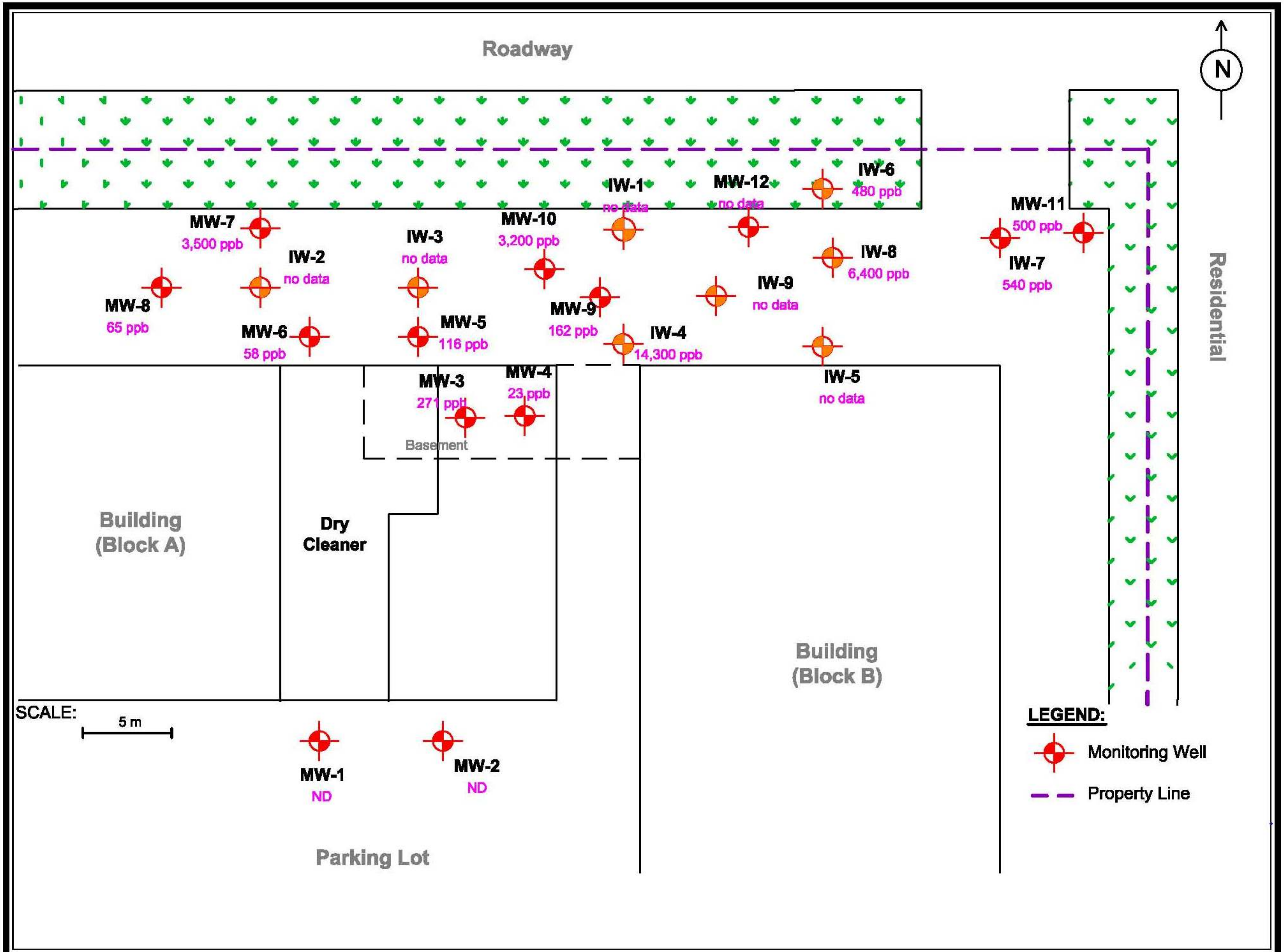
Case Study #2 - Dry Cleaner

- Dry cleaning Site
  - PCE stored in basement
- Environmental program
  - had to meet cash flow of mall
  - $ to delineation vs. $ to remediation
- Remediation before delineation?
  - VOCs likely migrating off-site
  - No source found
  - Restricted budget
- Permanent Injection Wells
  - Allowed sampling prior to injection

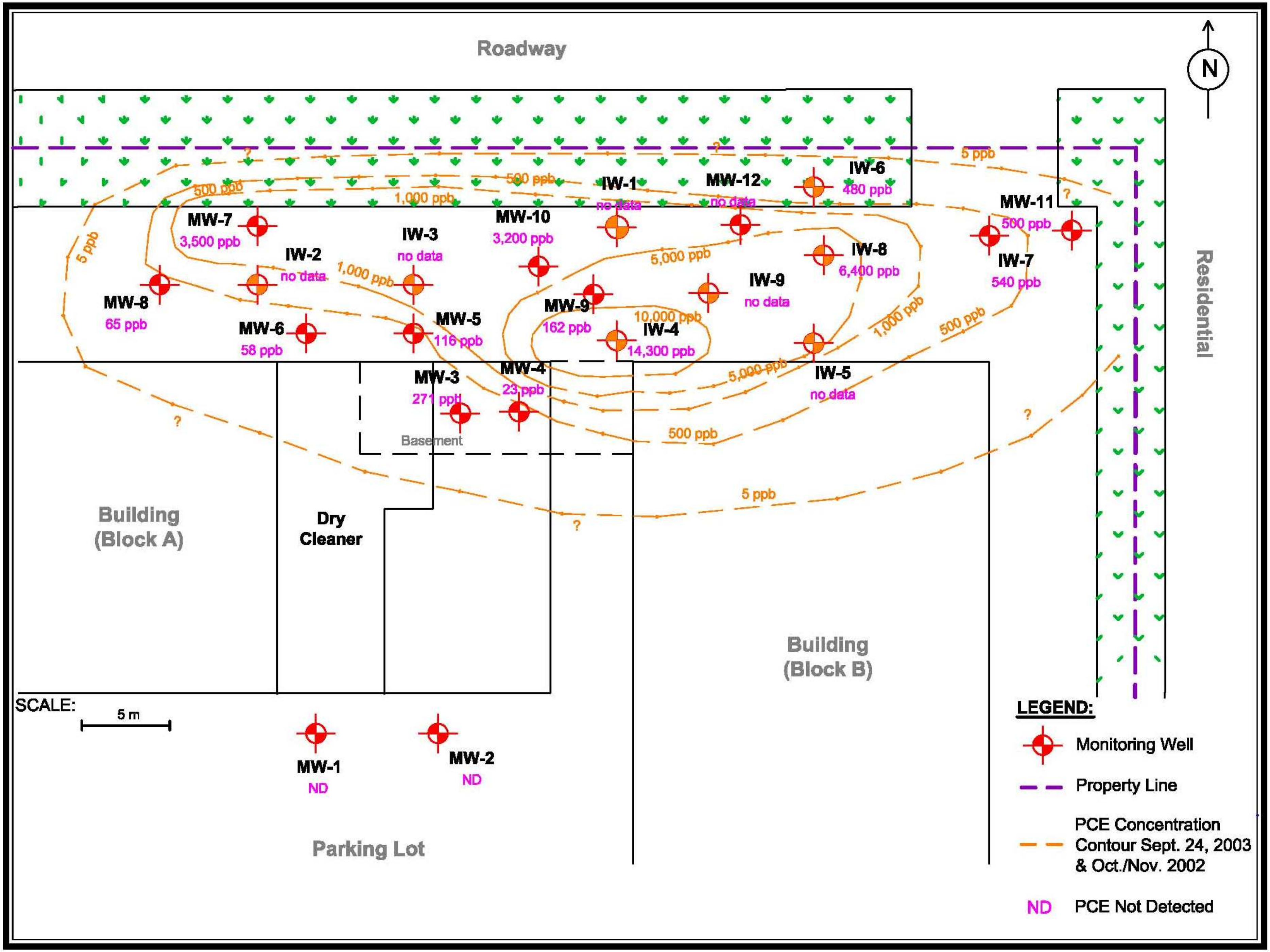
VERTEX


Roadway
N
Residential
MW-12
no data
MW-7
3,500 ppb
MW-10
3,200 ppb
MW-11
500 ppb
MW-8
65 ppb
MW-9
162 ppb
MW-6
58 ppb
MW-5
116 ppb
MW-3
271 ppb
MW-4
23 ppb
Basement
Building
(Block A)
Dry
Cleaner
Building
(Block B)
SCALE:
5 m
MW-1
ND
MW-2
ND
Parking Lot
LEGEND:
Monitoring Well
Property Line


Roadway
N
MW-12
no data
MW-11
500 ppb
MW-7
3,500 ppb
MW-10
3,200 ppb
MW-8
65 ppb
MW-9
162 ppb
MW-6
58 ppb
MW-5
116 ppb
MW-4
23 ppb
MW-3
271 ppb
Basement
Residential
Groundwater Flow Direction
Building (Block A)
Dry Cleaner
Building (Block B)
SCALE:
5 m
MW-1
ND
MW-2
ND
LEGEND:
Monitoring Well
Property Line
Parking Lot



Roadway
N
Residential
IW-6
480 ppb
IW-1
no data
MW-12
no data
MW-11
500 ppb
MW-7
3,500 ppb
MW-10
3,200 ppb
IW-3
no data
IW-2
no data
IW-8
6,400 ppb
IW-7
540 ppb
IW-9
no data
MW-8
65 ppb
MW-9
162 ppb
MW-6
58 ppb
MW-5
116 ppb
IW-4
14,300 ppb
IW-5
no data
MW-4
23 ppb
MW-3
271 ppb
Basement
Building
(Block A)
Dry
Cleaner
Building
(Block B)
SCALE:
5 m
MW-1
ND
MW-2
ND
Parking Lot
LEGEND:
Monitoring Well
Property Line

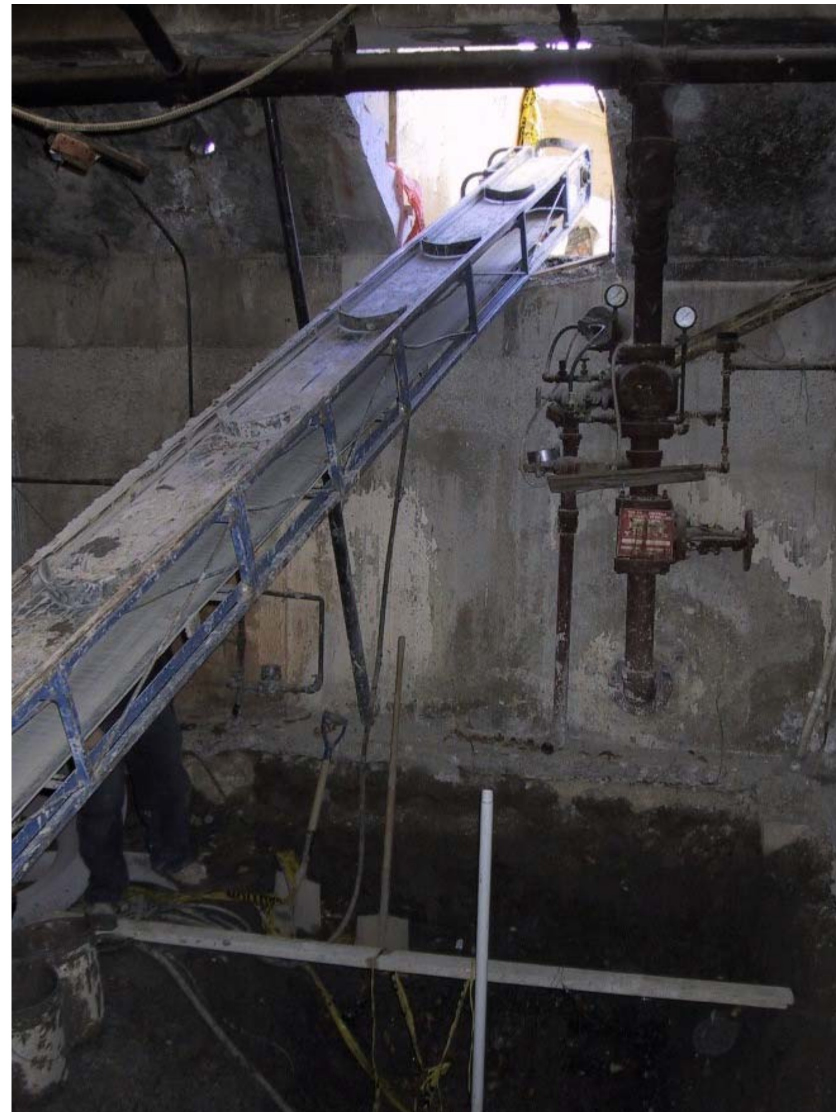


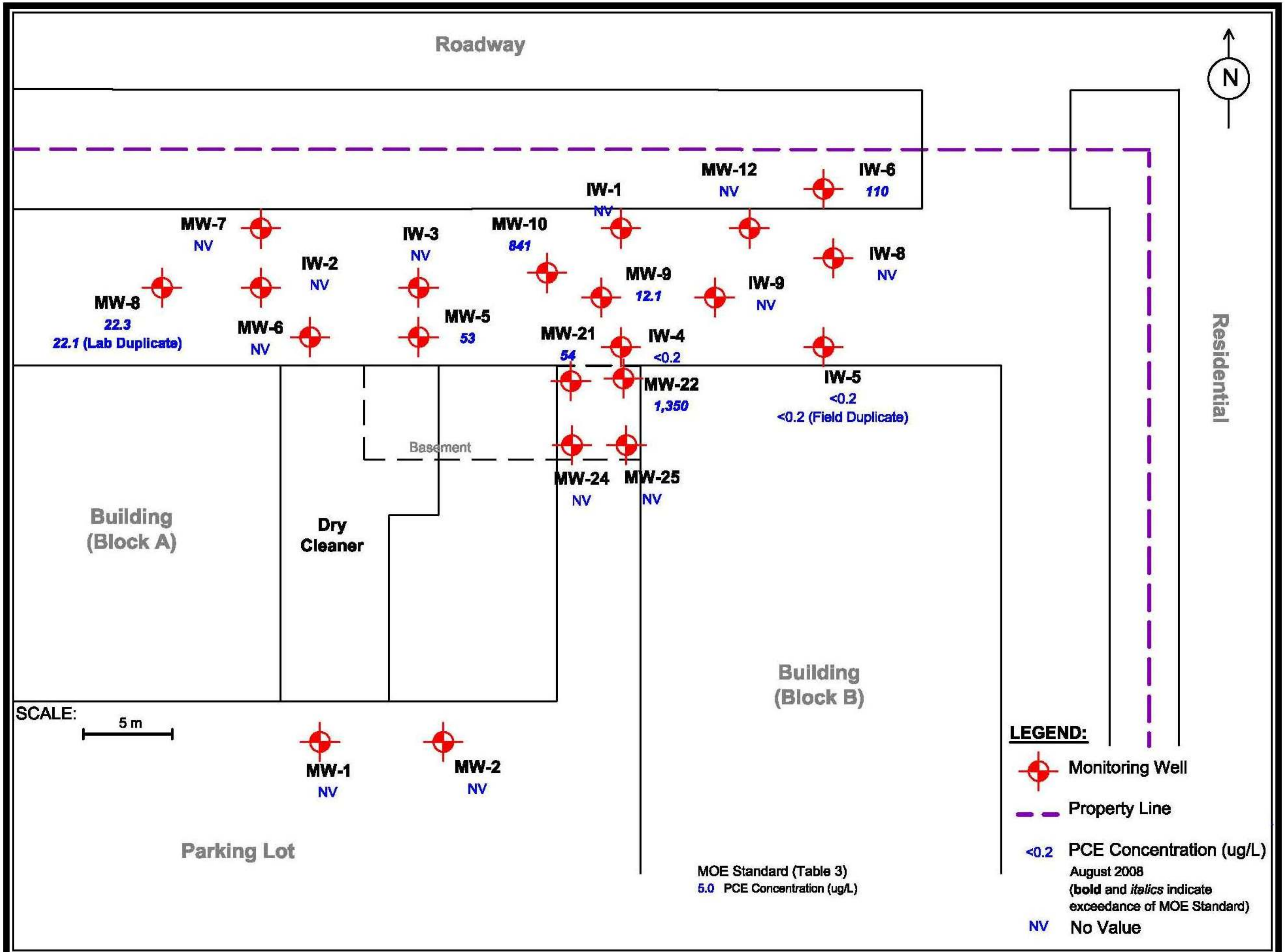
Roadway
N
Residential
5 ppb
500 ppb
1,000 ppb
5,000 ppb
10,000 ppb
?
IW-1
no data
MW-12
no data
IW-6
480 ppb
MW-11
500 ppb
MW-7
3,500 ppb
IW-3
no data
MW-10
3,200 ppb
IW-2
no data
IW-8
6,400 ppb
IW-7
540 ppb
IW-9
no data
MW-8
65 ppb
MW-9
162 ppb
MW-6
58 ppb
MW-5
116 ppb
IW-4
14,300 ppb
IW-5
no data
MW-3
271 ppb
MW-4
23 ppb
Basement
Building
(Block A)
Dry
Cleaner
Building
(Block B)
SCALE:
5 m
MW-1
ND
MW-2
ND
Parking Lot
LEGEND:
Monitoring Well
Property Line
PCE Concentration
Contour Sept. 24, 2003
& Oct./Nov. 2002
ND PCE Not Detected

Case Study #2 - Dry Cleaner

- Significant Findings:
  - IW4: PCE=14,300 ppb (source?)
- Injection was completed
  - plume control, mitigate VOC migration off property
- Second interior room was investigated
  - Soil 150 mg/kg PCE
  - Groundwater 15,000 ug/L PCE
- Source Zone excavation recommended
  - Oxidant direct placed, horizontal wells

Case Study #2 - Dry Cleaner





Roadway
N
Residential
MW-12
NV
IW-6
110
IW-1
NV
MW-7
NV
MW-10
841
IW-3
NV
IW-8
NV
IW-2
NV
MW-9
12.1
IW-9
NV
MW-8
22.3
22.1 (Lab Duplicate)
MW-6
NV
MW-5
53
MW-21
54
IW-4
<0.2
MW-22
1,350
IW-5
<0.2
<0.2 (Field Duplicate)
Basement
MW-24
NV
MW-25
NV
Building (Block A)
Dry Cleaner
Building (Block B)
SCALE:
5 m
MW-1
NV
MW-2
NV
Parking Lot
MOE Standard (Table 3)
5.0 PCE Concentration (ug/L)
LEGEND:
Monitoring Well
Property Line
<0.2 PCE Concentration (ug/L)
August 2008
(bold and italics indicate exceedance of MOE Standard)
NV No Value

Case Study #2 - Dry Cleaner

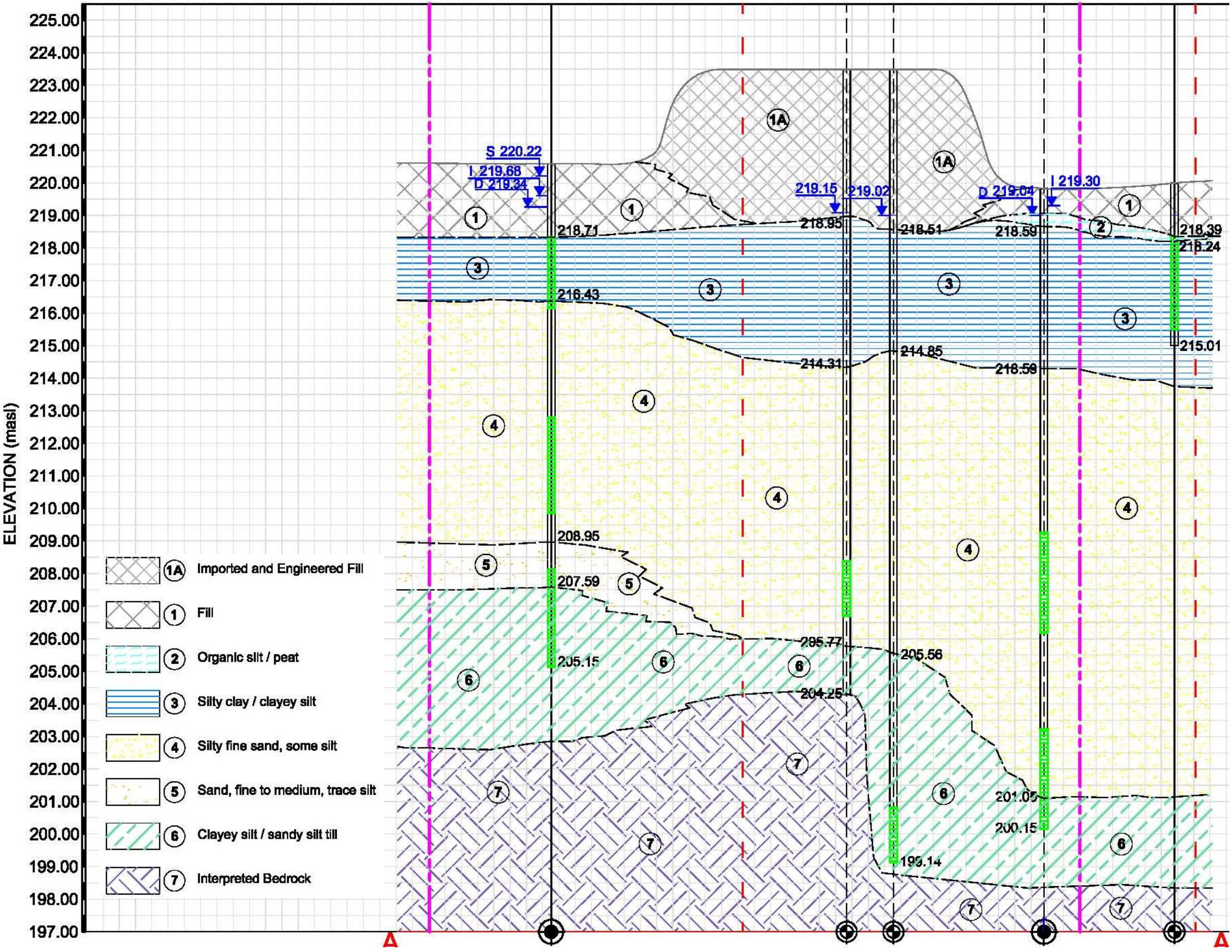
Sampling Location	PCE initial (ug/L)	PCE 2008 (ug/L)	Percent Decrease
Source	15,000	1,350	91%
4 m from Source	14,300	<0.2	100%
8 m from Source	3,200	841	74%
Property Boundary	500	110	78%

- Remediation before full delineation – feasible?
  - May result in long term remediation
  - Finite budget put to best use
- Client has to be flexible

VERTEX

Case Study #3 - Free Product

- Large redevelopment Site
- Sparse delineation
- Risk Assessment
  - Reductions in VOC concentrations required
- High VOC concentrations at one location
  - 100,000 ug/L TCE and breakdown products
- Injection proposed
- Permanent injection wells
  - sampled first

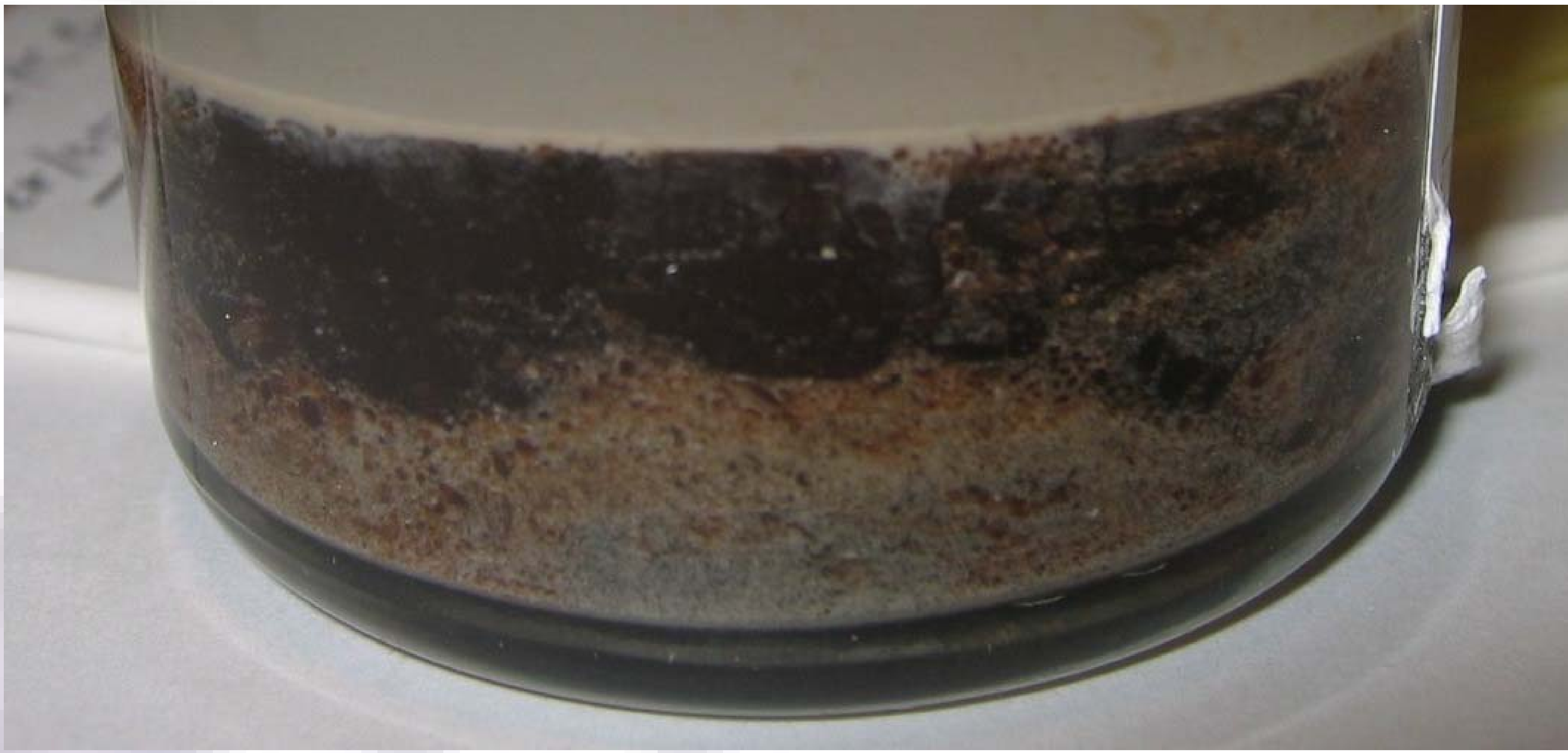


ELEVATION (masl)
225.00
224.00
223.00
222.00
221.00
220.00
219.00
218.00
217.00
216.00
215.00
214.00
213.00
212.00
211.00
210.00
209.00
208.00
207.00
206.00
205.00
204.00
203.00
202.00
201.00
200.00
199.00
198.00
197.00
S 220.22
I 219.68
D 219.34
219.15
219.02
D 219.04
I 219.30
218.71
218.95
218.51
218.59
218.39
218.24
216.43
215.01
214.31
214.85
218.59
208.95
207.59
205.15
205.77
205.56
204.25
201.05
200.15
199.14
1A Imported and Engineered Fill
1 Fill
2 Organic silt / peat
3 Silty clay / clayey silt
4 Silty fine sand, some silt
5 Sand, fine to medium, trace silt
6 Clayey silt / sandy silt till
7 Interpreted Bedrock

Case Study #3 - Free Product

Geology – highly variable, varved clay/sand, flowing sand

Case Study #3 - Free Product



Pure Phase DNAPL in Soil

Case Study #3 - Free Product

Pure Phase DNAPL purged from Well

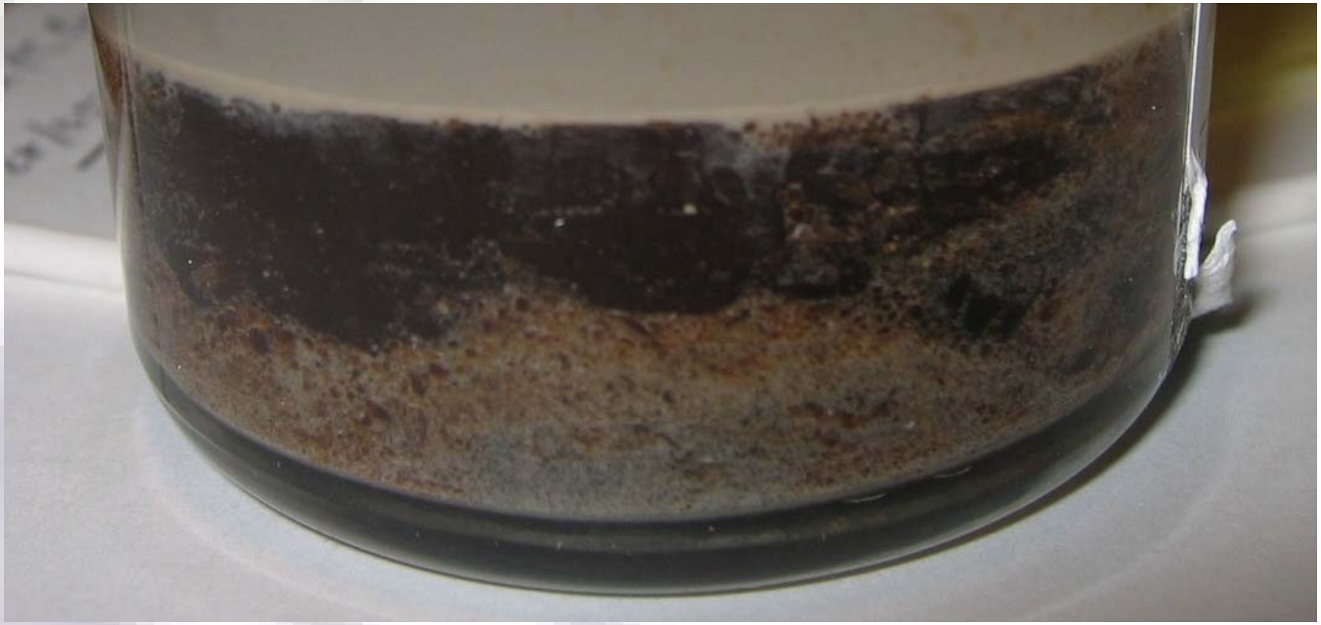
Case Study #3 - Free Product

- VOC Groundwater
  - 2,300,000 ug/L TCE
  - 1,500,000 ug/L TCE
  - Solubility = 1,000,000 ug/L
- Hand purge DNAPL, free product returned
- Vacuum Extract DNAPL
- If no DNAPL, then oxidation

Case Study #3 - Free Product

Case Study #3 - Free Product

- DNAPL persists after vacuum test
  - Will be constant source of groundwater contamination
- Vertex recommends against in-situ oxidation
- Re-development has yet to occur, need a solution



Closing

- Soil Variability
  - Important to gain an understanding for in-situ
  - Drastically affects contaminant mass calculations
  - Affects oxidant/reductant mass calculations
- Approach
  - Delineation up front
  - Remediation
  - Adapt to new data

Questions?

- Acknowledgements
  - Bernard Kueper & Stanley Feentra
  - Rick McGregor, Vertex
  - Humoud Al-Utaibi, Aramco

Thank You for Your Time

VERTEX

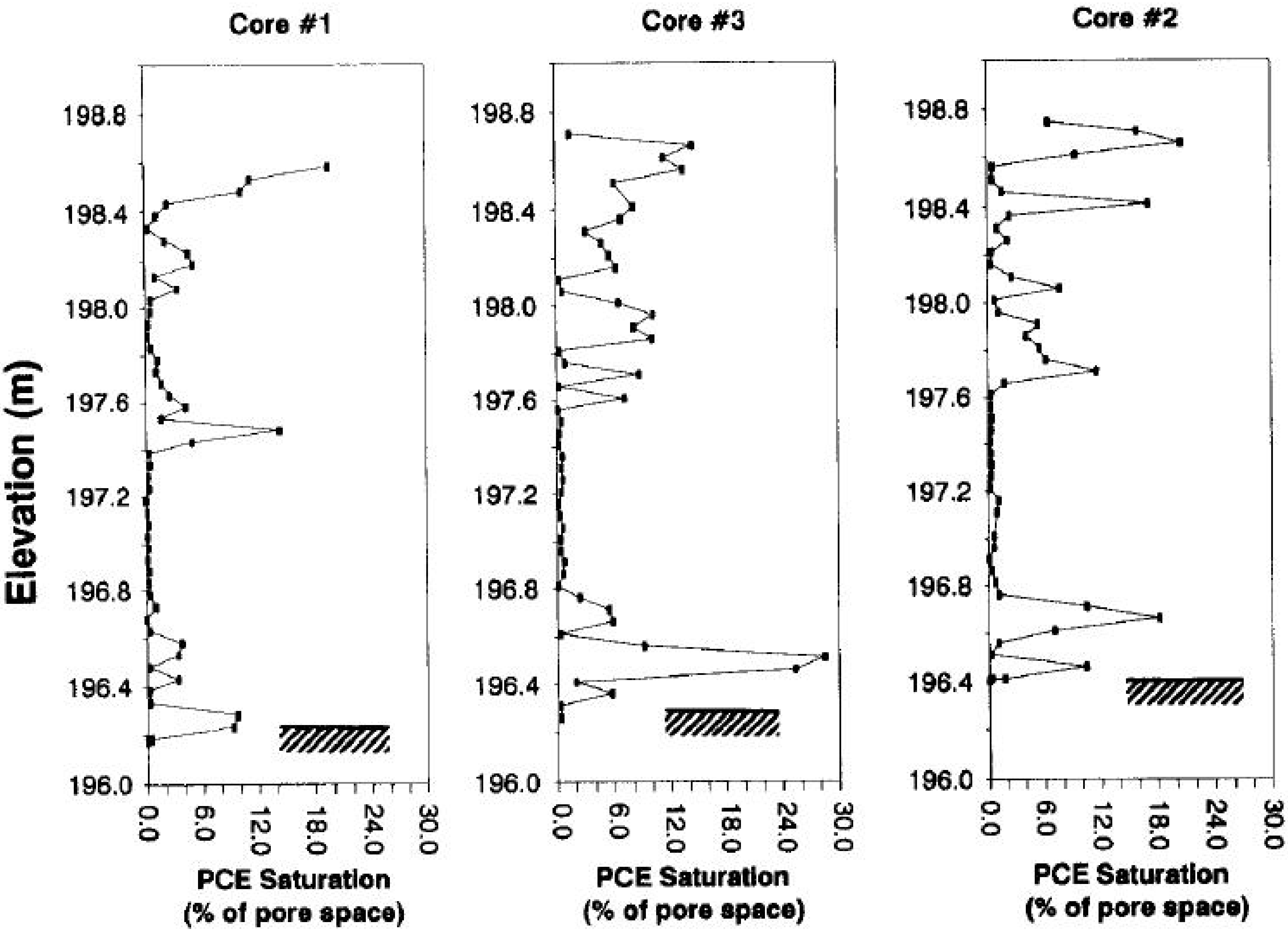


Figure 8: Kueper et al, Ground Water, 1993

Mass Calculation

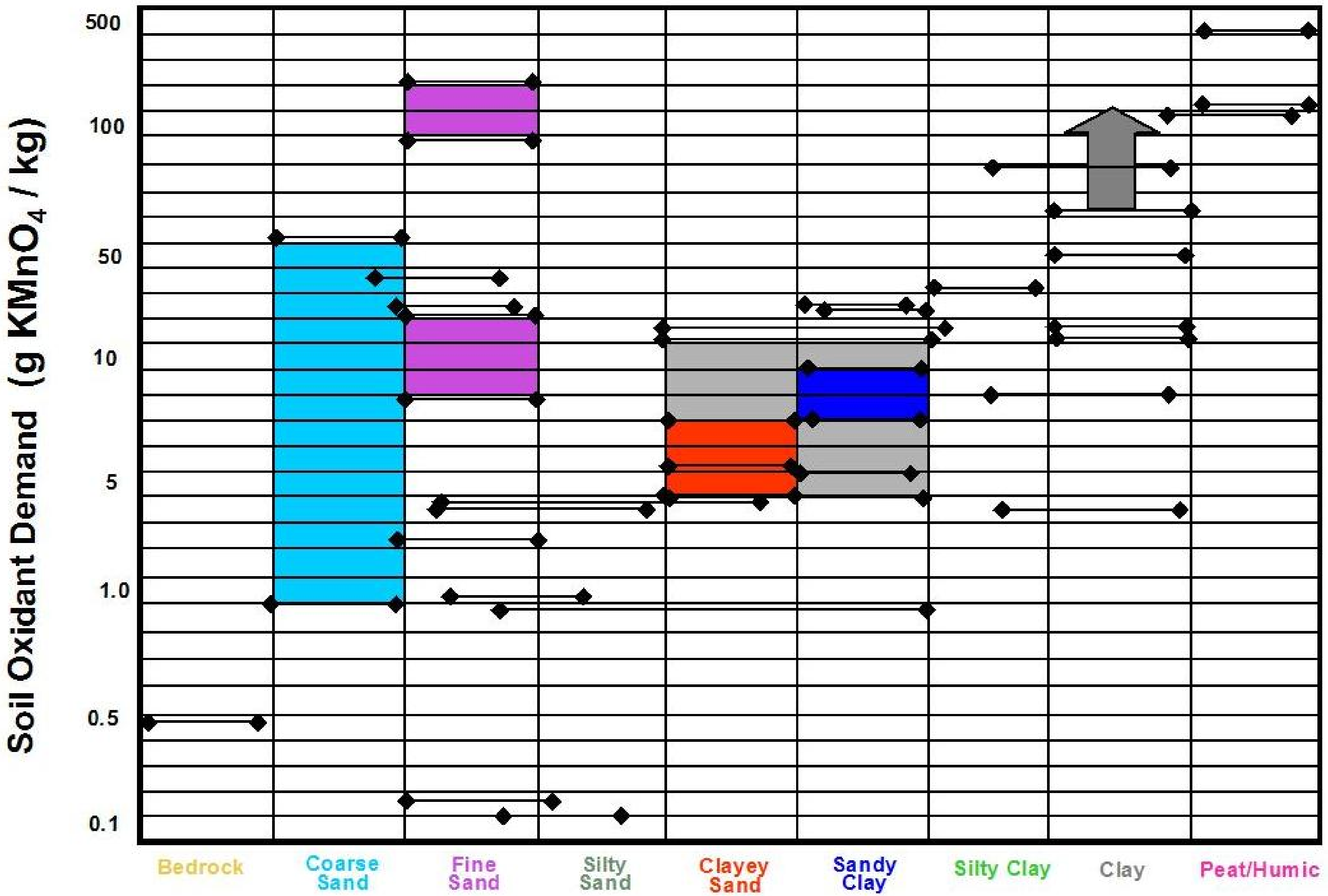
- Techniques
  - Professional interpretation
  - Simple program - kriging
  - Modeling program / Finite Element Analysis
- Professional Interpretation
  - Maximum concentration across Site
  - Linear decrease to known “clean” areas
  - Interpretation of “source” vs plume
  - Soil vs Groundwater vs Free Product
- Approach
  - client driven
  - personal choice

Soil Oxidant Demand

- Quantity of oxidant consumed by soil
- SODs
  - 24 hour
  - 3 day
  - 7 day
- SOD is different for each oxidant
- Questions about how to apply SOD

Soil Oxidant Demand (SOD)

(adapted from Shaw E & I presentation - 2003)



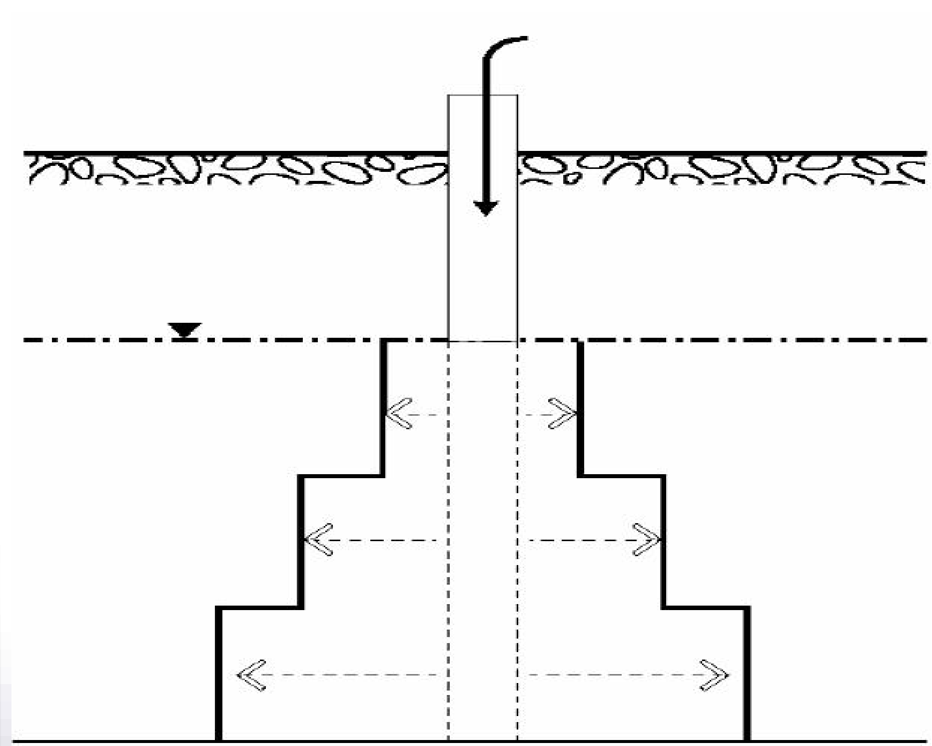
Soil Oxidant Demand

- Wide range of SODs
- Typical range for Vertex (permanganate)
  - 1 g/kg low
  - 10+ g/kg high
- How much $KMnO_4$ for 3 x 3 cell (44 MT)?
  - Low (1 g/kg): 44 kg
  - High (10 g/kg): 440 kg
  - Very High (100 g/kg): 4,400 kg

Oxidant Delivery Options

- Direct Push

- Bottom Up



Source – ITRC (2005)

Oxidant Delivery Options

- Horizontal Wells

- Direct Placement