Vertex Environmental Inc.

High Resolution Characterization of Petroleum Hydrocarbons

SMART Remediation Seminar 2013

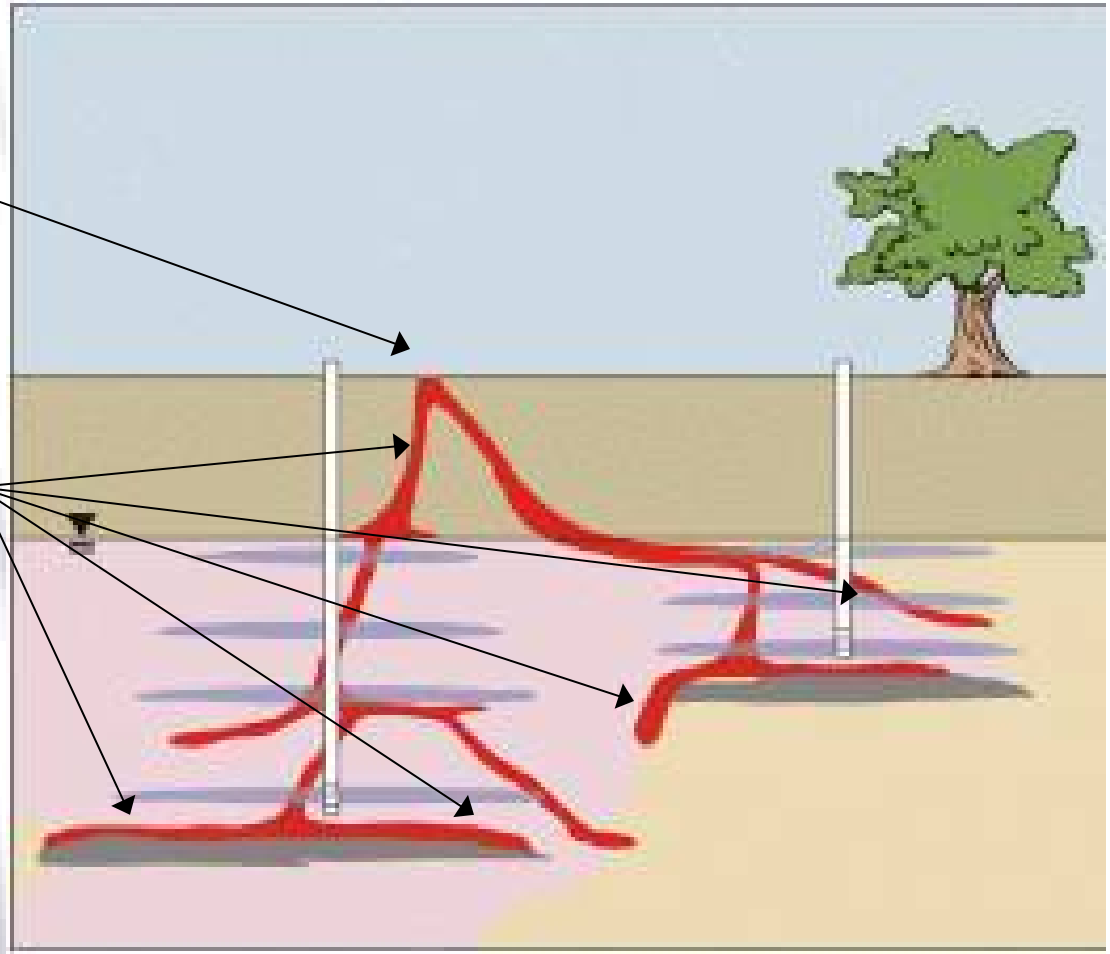
Bruce Tunnicliffe

Subsurface Impacts

Subsurface Impacts

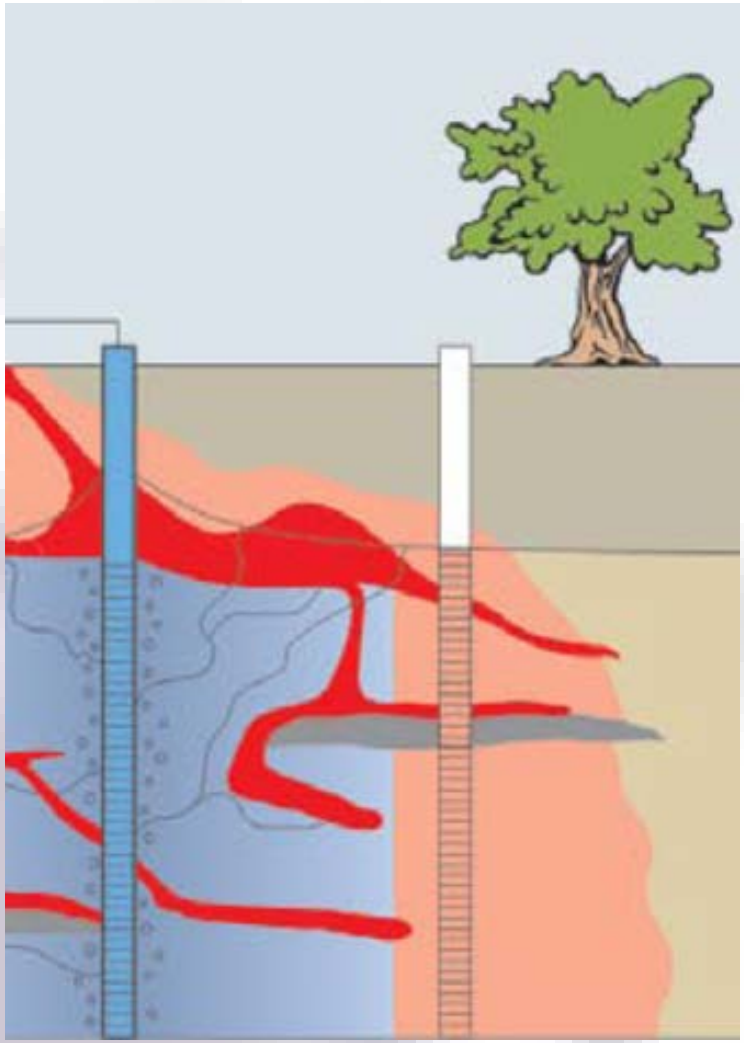
Surface Release

Subsurface Contamination



Source: EPA, 2010

Overview



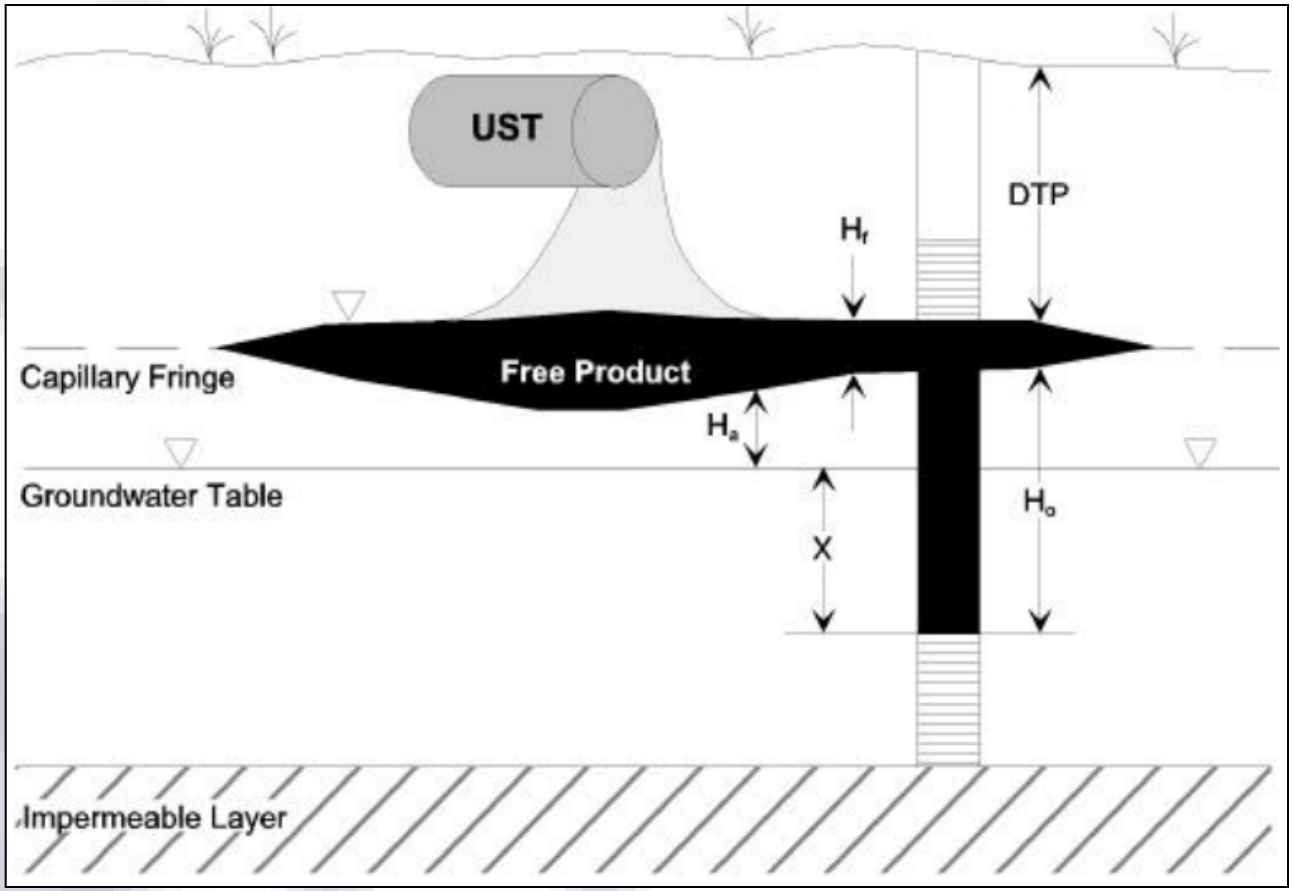
- Background
  - Vertex Background
  - Subsurface Impacts
- Contaminant Characterization
  - Laser Induced Fluorescence
  - Membrane Interface Probe
  - Data Visualization
- Case Study
- Questions

Vertex Background

- Bruce Tunnicliffe
  - Masters of Engineering – University of Waterloo
  - In-Situ Remediation (permanganate & bedrock)
- Vertex Environmental
  - Environmental Contracting
  - High Resolution Characterization
  - Remediation and injection services
    - Remedial Design
    - Implementation (bench, pilot, full-scale)

Subsurface Impacts

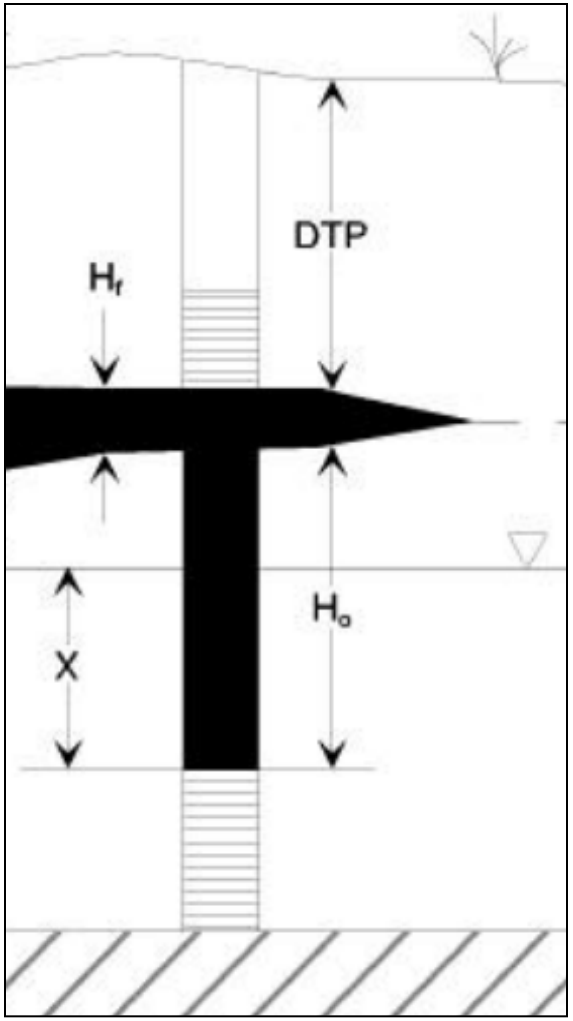
Is there a difference between <u>contaminant distribution</u> in the subsurface and <u>site measurements</u> we collect?



Source: EPA (1996)

Free Product Delineation

- Install MW
- Collect a NAPL measurement
- Estimate NAPL thickness in aquifer
  - Various Techniques:
    - Method of de Pastrovich (1979)
    - Method of Hall, et al. (1984)
    - Method of Ballestero et al. (1994)
    - Method of Schiegg. (1985)
    - Method of Lenhard and Parker (1990)
  - Uncertainties associated with:
    - single NAPL measurement
    - assumptions in models
    - geology, NAPL distribution



Source – EPA (1996)

Free Product Delineation

- Experiment in EPA document:
  - Diesel spill in a column containing a MW
  - Five “spills”, same volume
  - Thickness in MW ranged from 6 cm to 84 cm
- Using EPA estimation methods:

Data from: EPA Guide for State Regulators – How to Effectively Recover Free Product at Leaking Underground Storage Tank Sites (Sept 1996).

EPA Method	Avg. Product in MW (cm)	Predicted Product Thickness in Formation (cm)
Ballestero	6	
Pastrovich	6	
Schiegg	6	
Hall	6	
Lenhard & Parker	6	
Lenhard & Parker	84	

VERTEX

Free Product Delineation

- Experiment in EPA document:
  - Diesel spill in a column containing a MW
  - Five “spills”, same volume
  - Thickness in MW ranged from 6 cm to 84 cm
- Using EPA estimation methods:

Data from: EPA Guide for State Regulators – How to Effectively Recover Free Product at Leaking Underground Storage Tank Sites (Sept 1996).

EPA Method	Avg. Product in MW (cm)	Predicted Product Thickness in Formation (cm)
Ballestero	6	0.2
Pastrovich	6	1.2
Schiegg	6	2.4
Hall	6	4.8
Lenhard & Parker	6	7.5
Lenhard & Parker	84	105

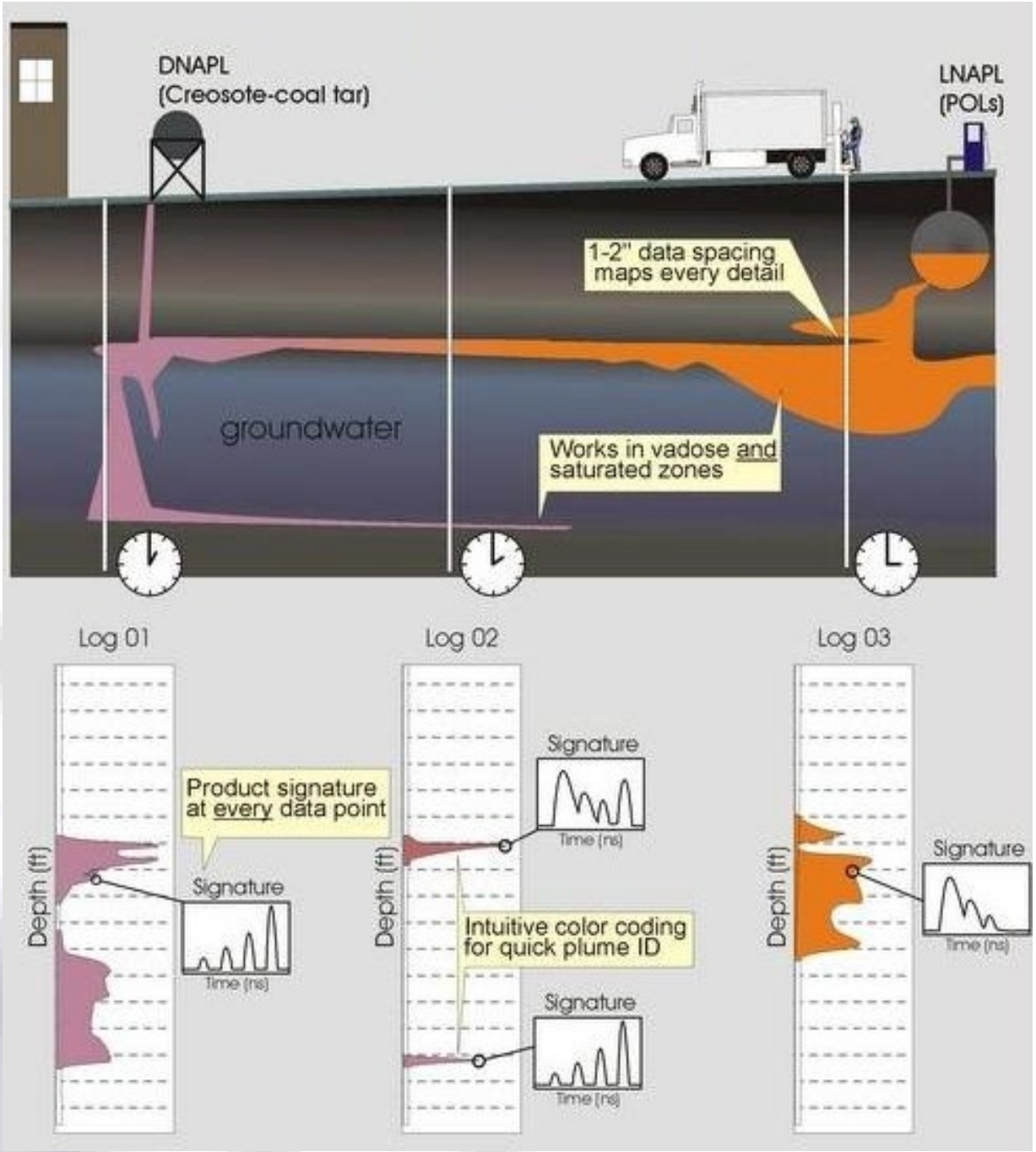
0.2 cm to 105 cm thickness = 525 times difference

VERTEX

Contaminant Characterization

- Current Approach to define NAPL and dissolved phase:
  - Monitoring Wells
- Innovative Approach:
  - Rapid, Real-Time High Resolution

VERTEX



Source:
Dakota Web Site

VERTEX

Laser Induced Fluorescence

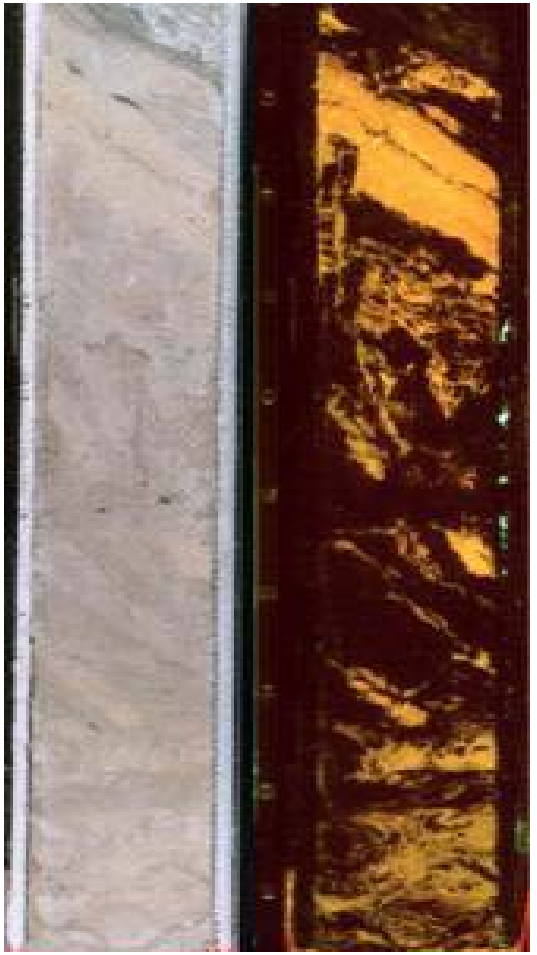
for Pure Phase Contamination, LNAPL

VERTEX

Laser Induced Fluorescence

- Developed in early 1990s
  - US Army Corps of Engineers
- UVOST (Ultra Violet Optical Screening Tool)
- Light-based (ultraviolet)
- Equipment
  - Direct push (Geoprobe)
  - Fibre optic cable
  - Sapphire window

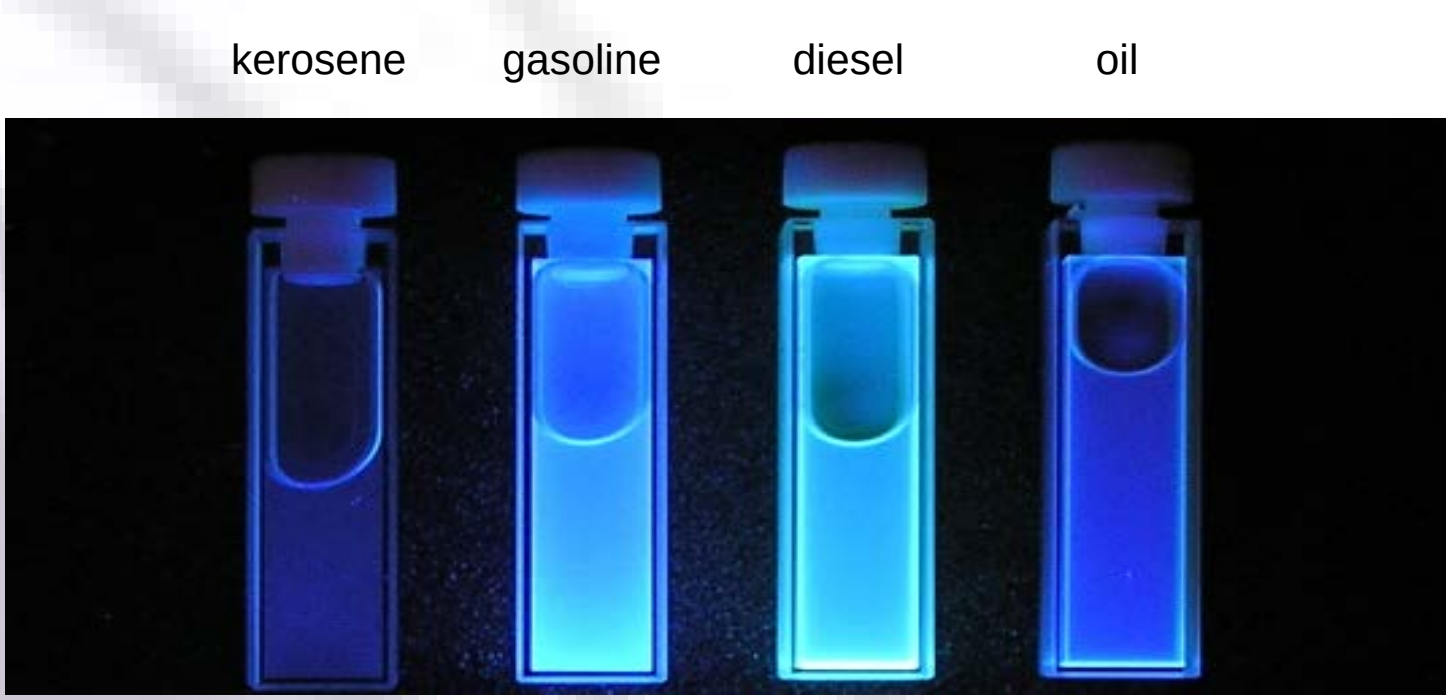
Laser Induced Fluorescence



visible fluorescence

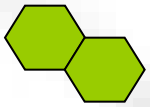
Laser Induced Fluorescence

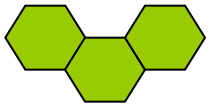
- Spectroscopy – molecules absorb light (gain energy) and then emit light (lose energy = fluoresce)
- Aromatic molecules (PAHs) readily absorb and emit light



Laser Induced Fluorescence

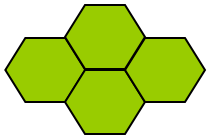
naphthalene

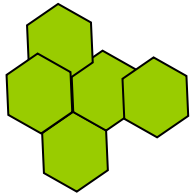




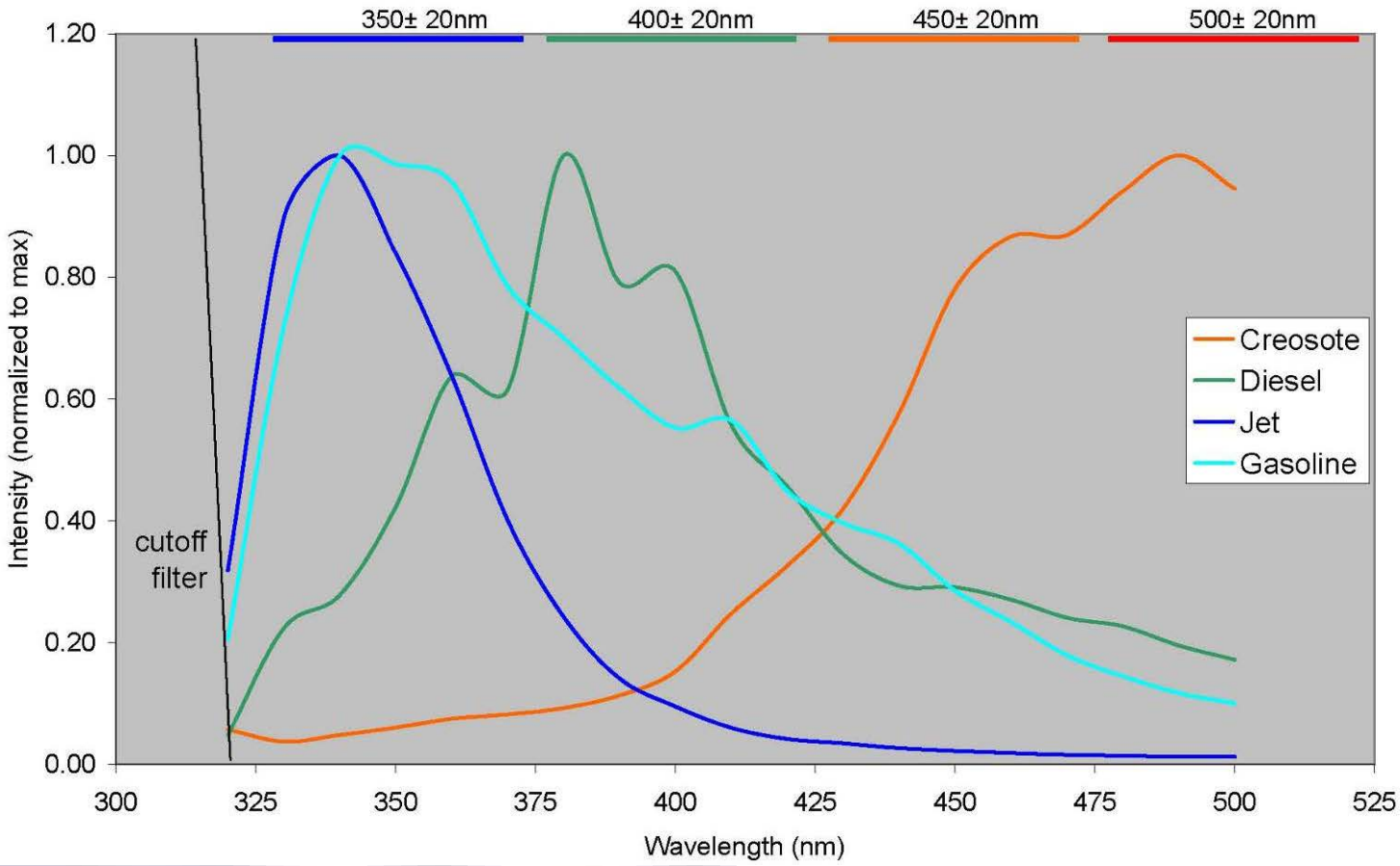
phenanthrene

pyrene



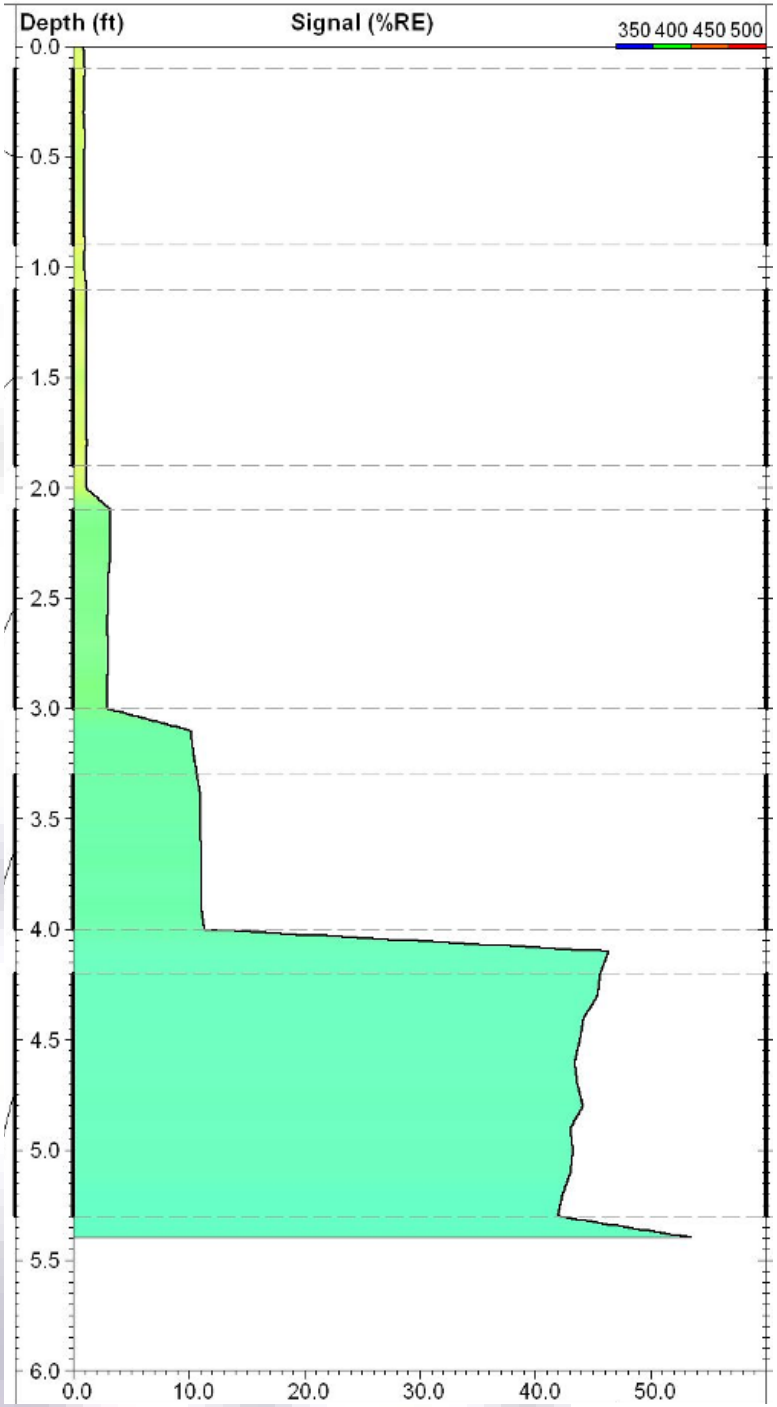


benzo[e]pyrene



VERTEX

Gasoline



Clean Sand

350 ppm

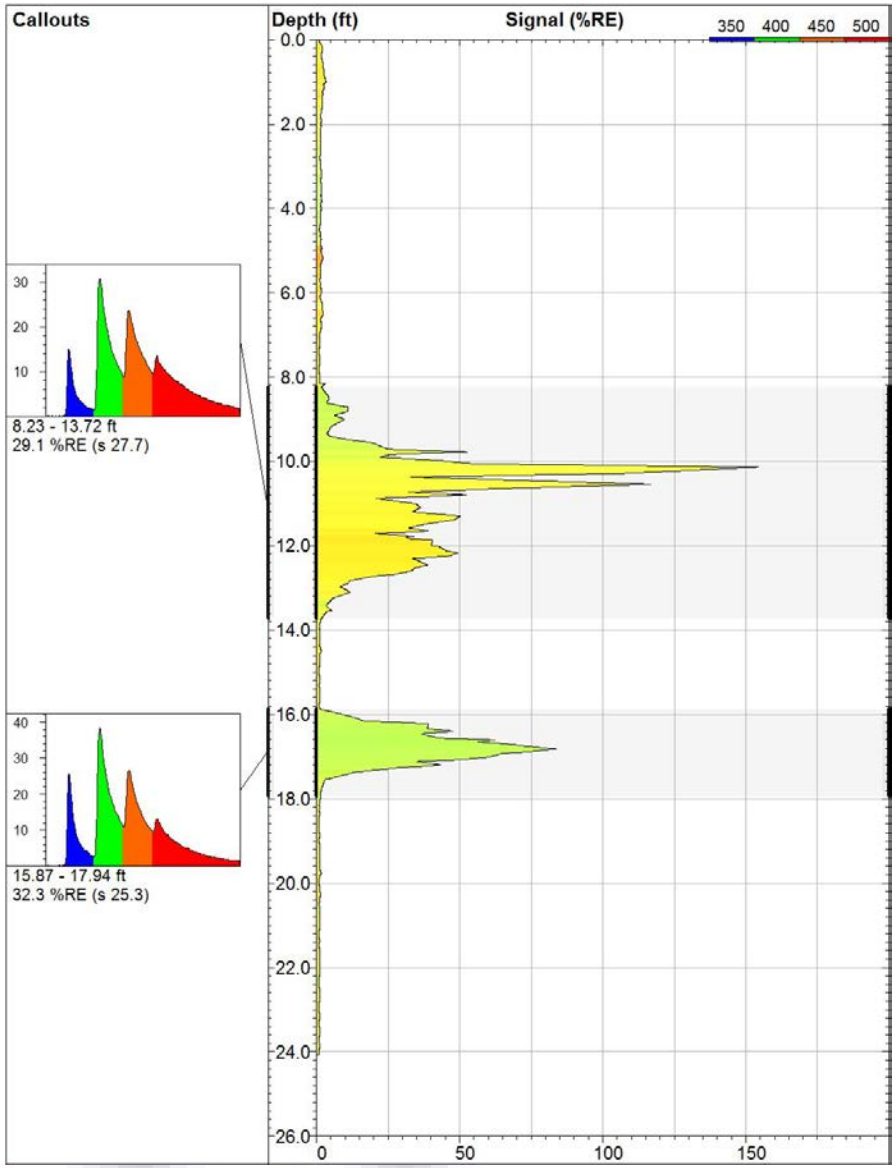
1,100 ppm

10,000 ppm

84,000 ppm

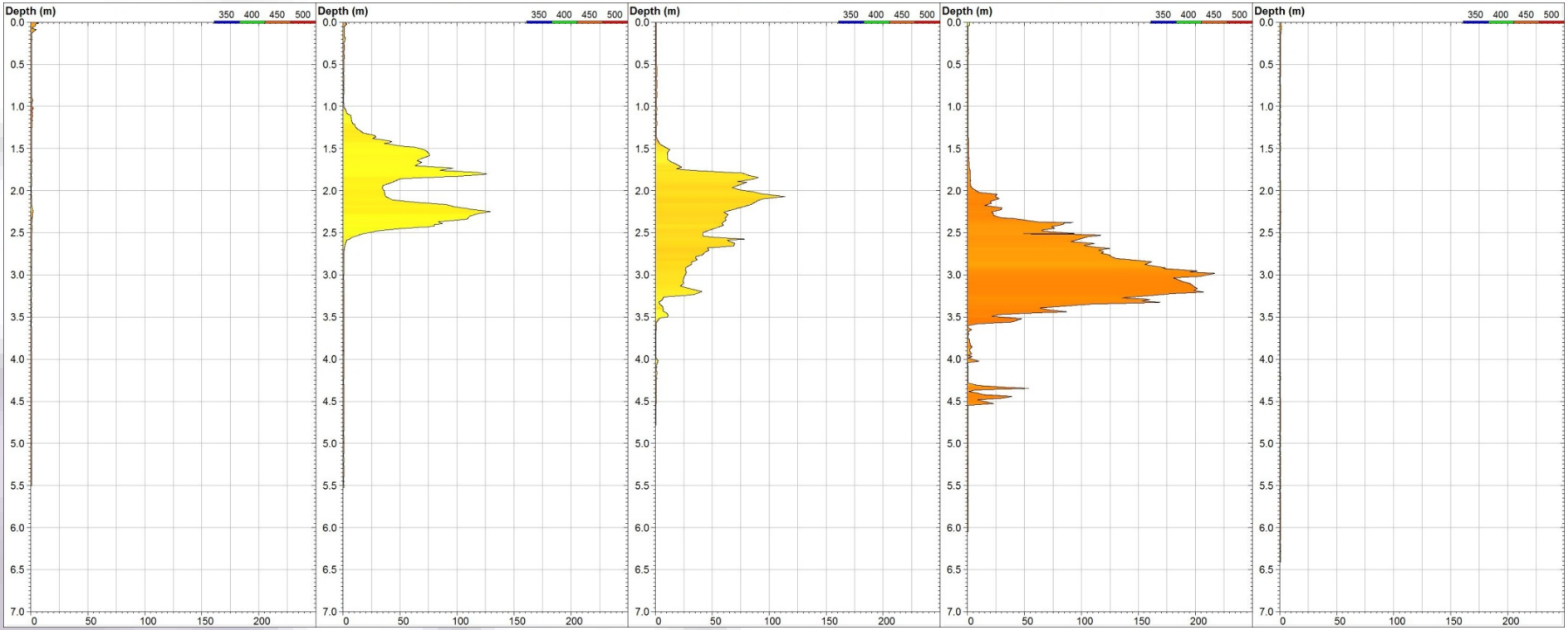
VERTEX

Example LIF Output



VERTEX

Example LIF Output



Cross Section of LIF Points

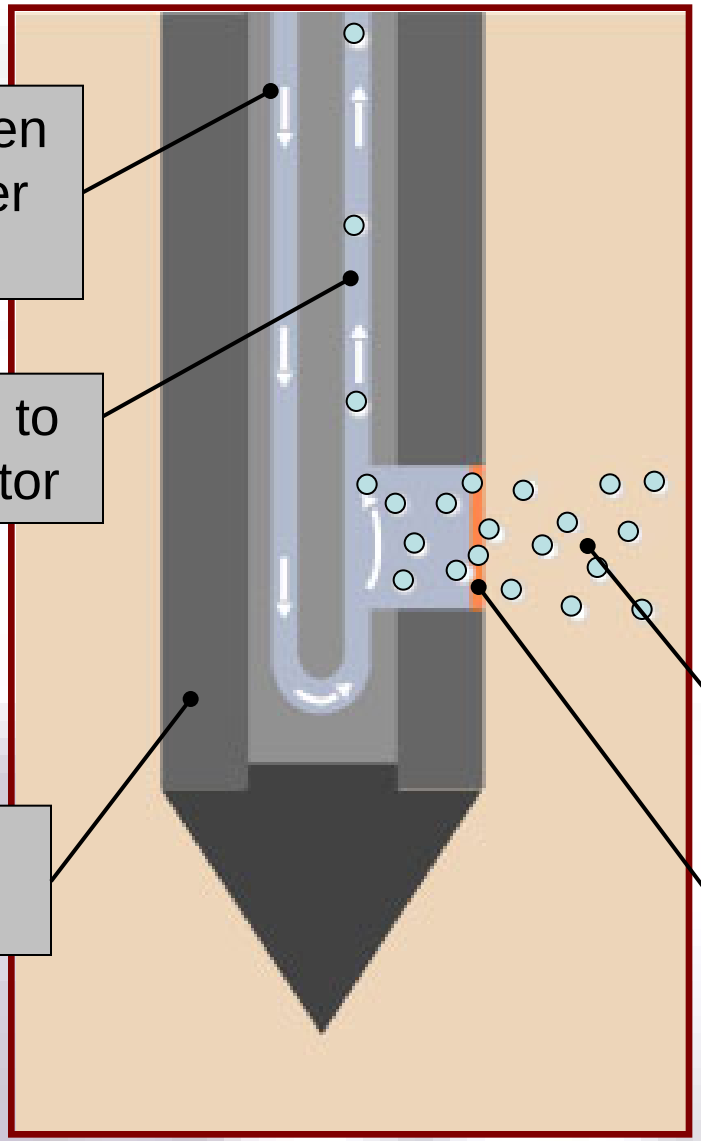
VERTEX

Membrane Interface Probe

for Dissolved Phase Contamination

VERTEX

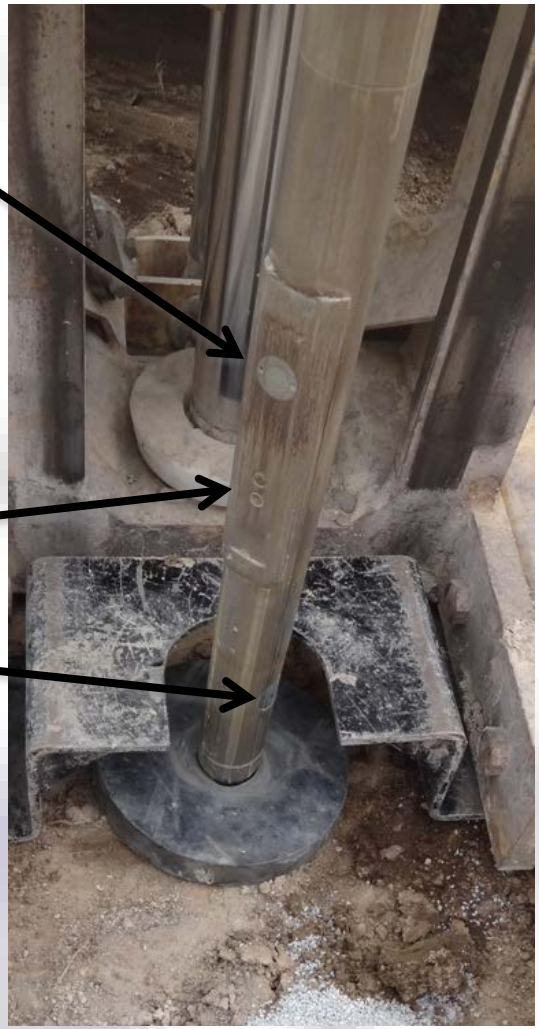
Membrane Interface Probe



<u>Dissolved Phase</u>:

- Depth
- Relative conc.
- Lithology (soil)

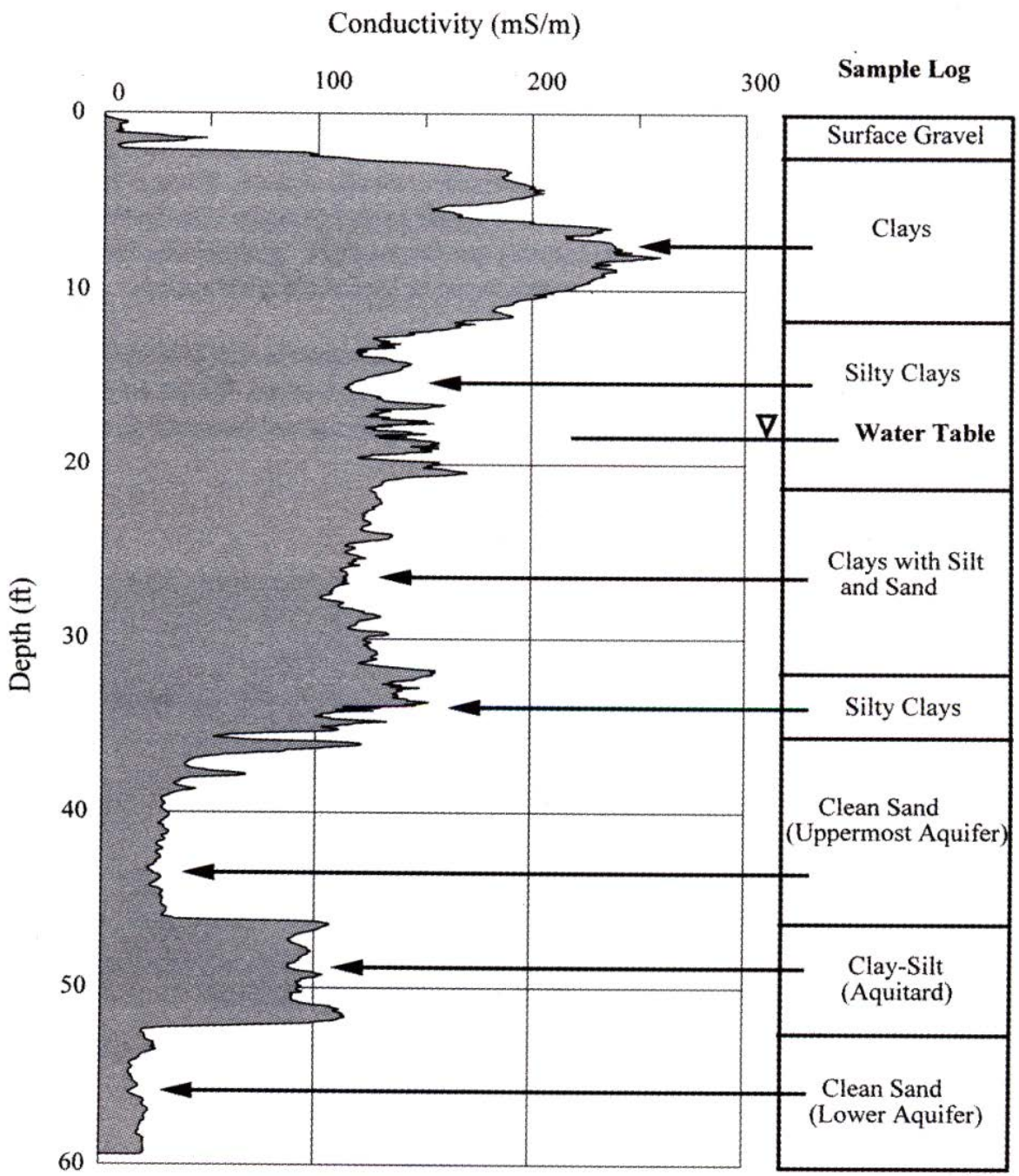
Membrane Interface Probe



Membrane Interface Probe

- Three detectors installed in the Gas Chromatograph:
  - Photoionization Detector (PID)
  - Flame Ionization Detector (FID)
  - Halogen Specific Detector (XSD)

- Detection of many common contaminants :
  - Petroleum Hydrocarbons (PHCs)
  - Chlorinated Solvents (TCE, PCE, TCA, etc…)

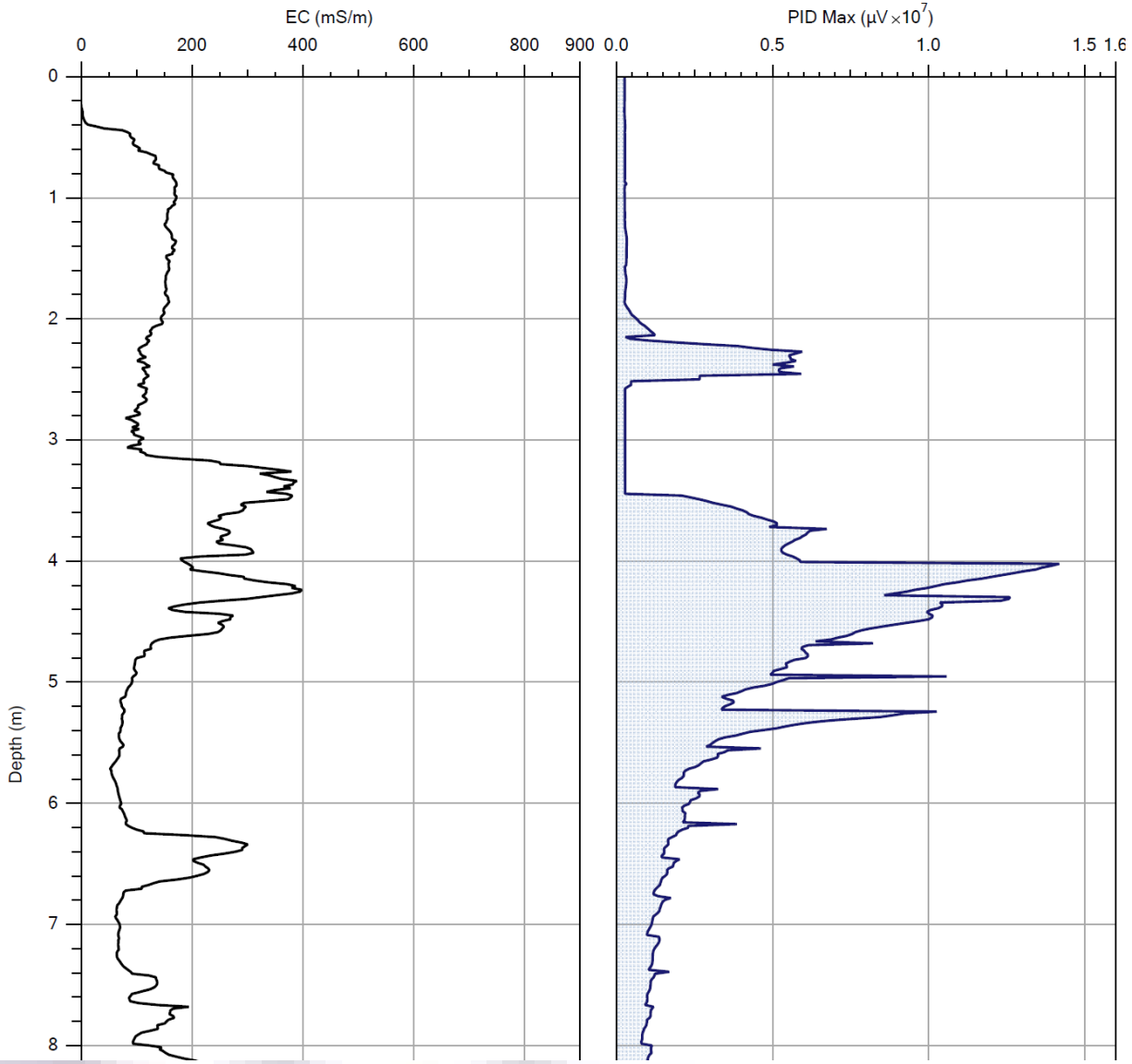


Electrical Conductivity (EC)

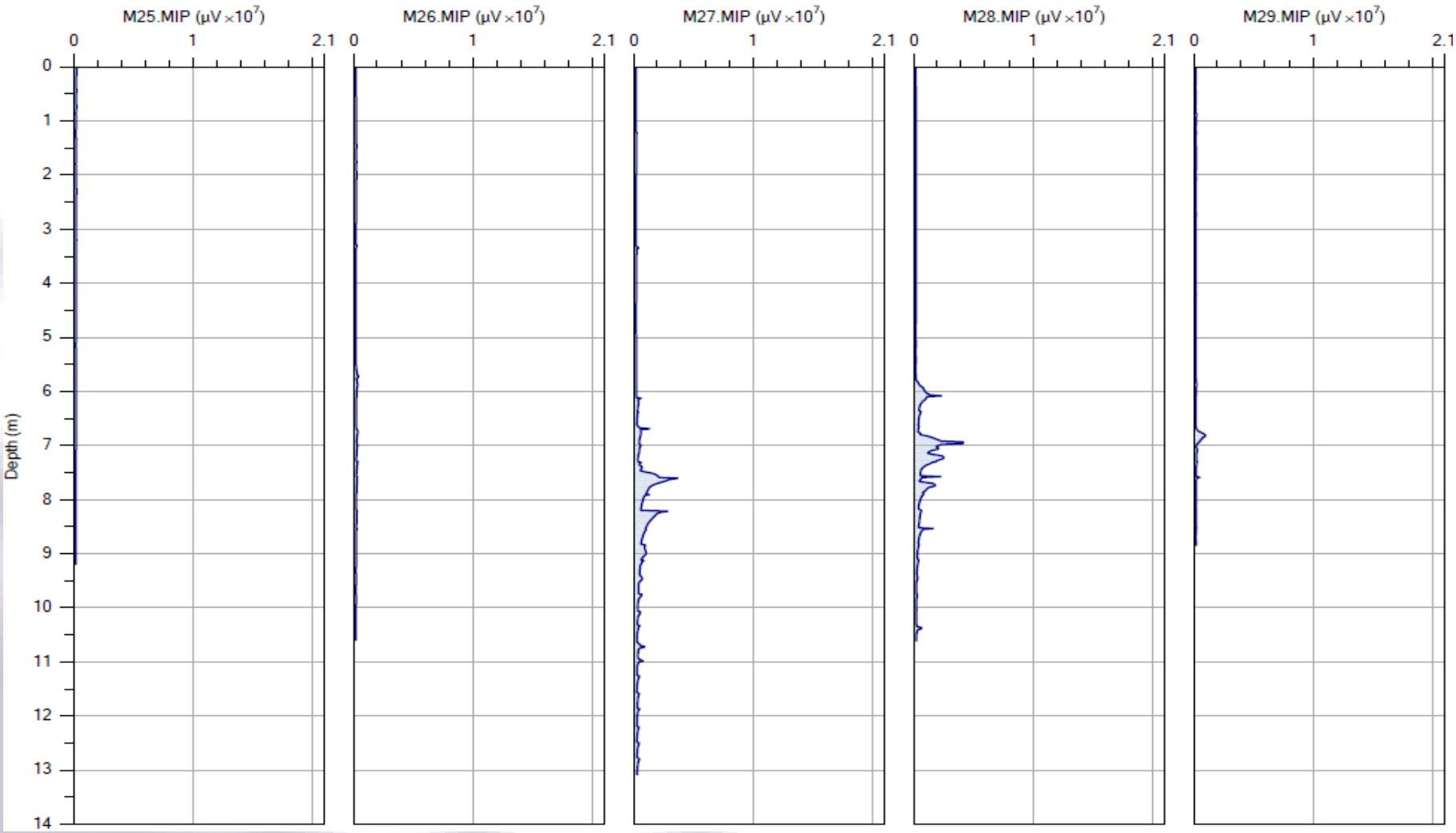
- used as soil classification tool
- Smaller grain sizes have a relatively high conductivity

VERTEX

Example MIP Output



Example MIP Output



Cross Section of MIP Points

Contaminant Characterization

- Current Approach:
  - 24 m daily rate (4 x 6 m MWs)
  - 4 Data points (NAPL or dissolved)
- Advanced Characterization:
  - Rapid, Real-Time High Resolution
  - 90 m LIF daily rate x 1 cm resolution = 9,000 data points
  - 60 m MIP daily rate x 30 cm resolution = 200 data points

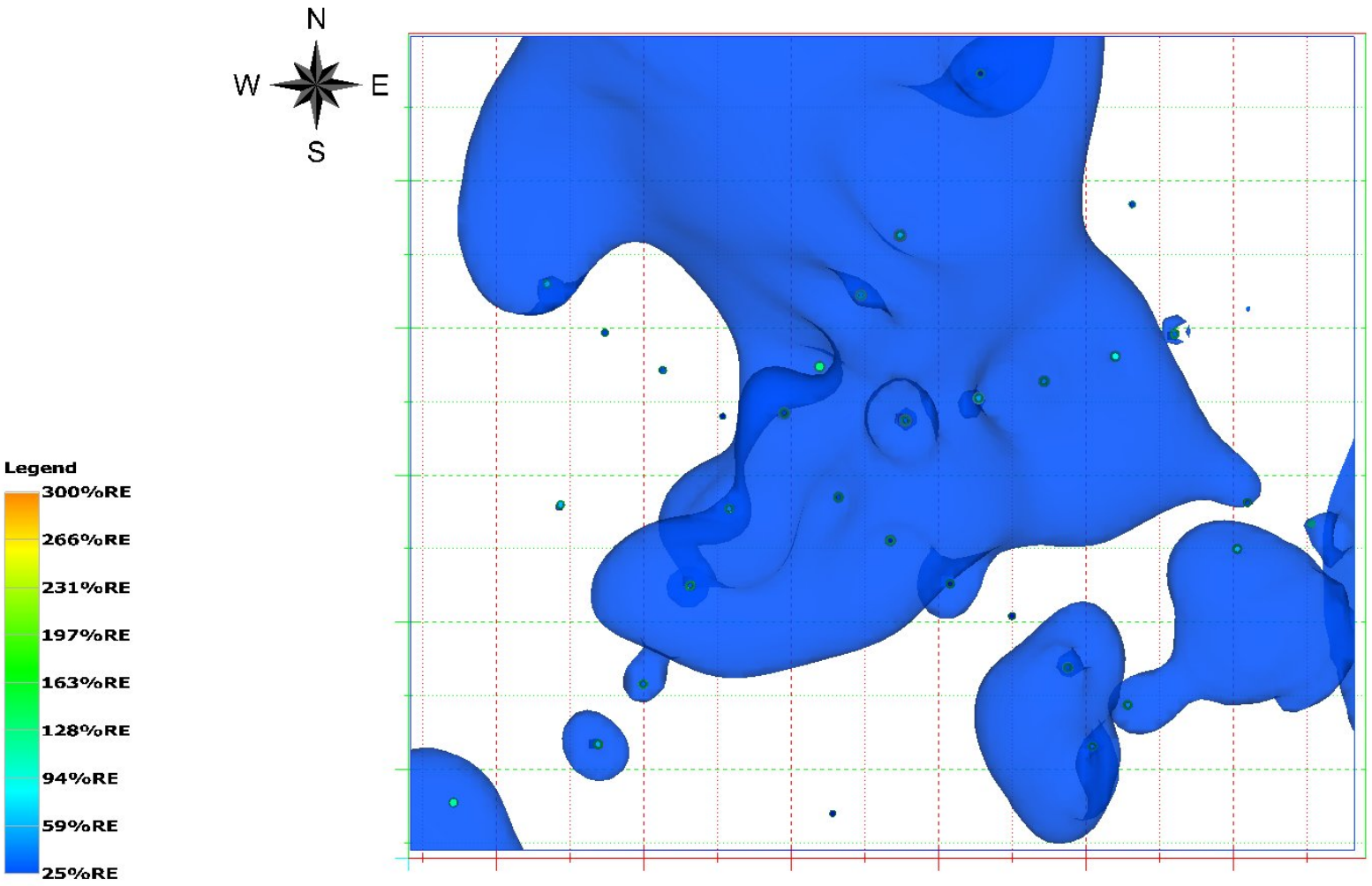
VERTEX

Contaminant Characterization

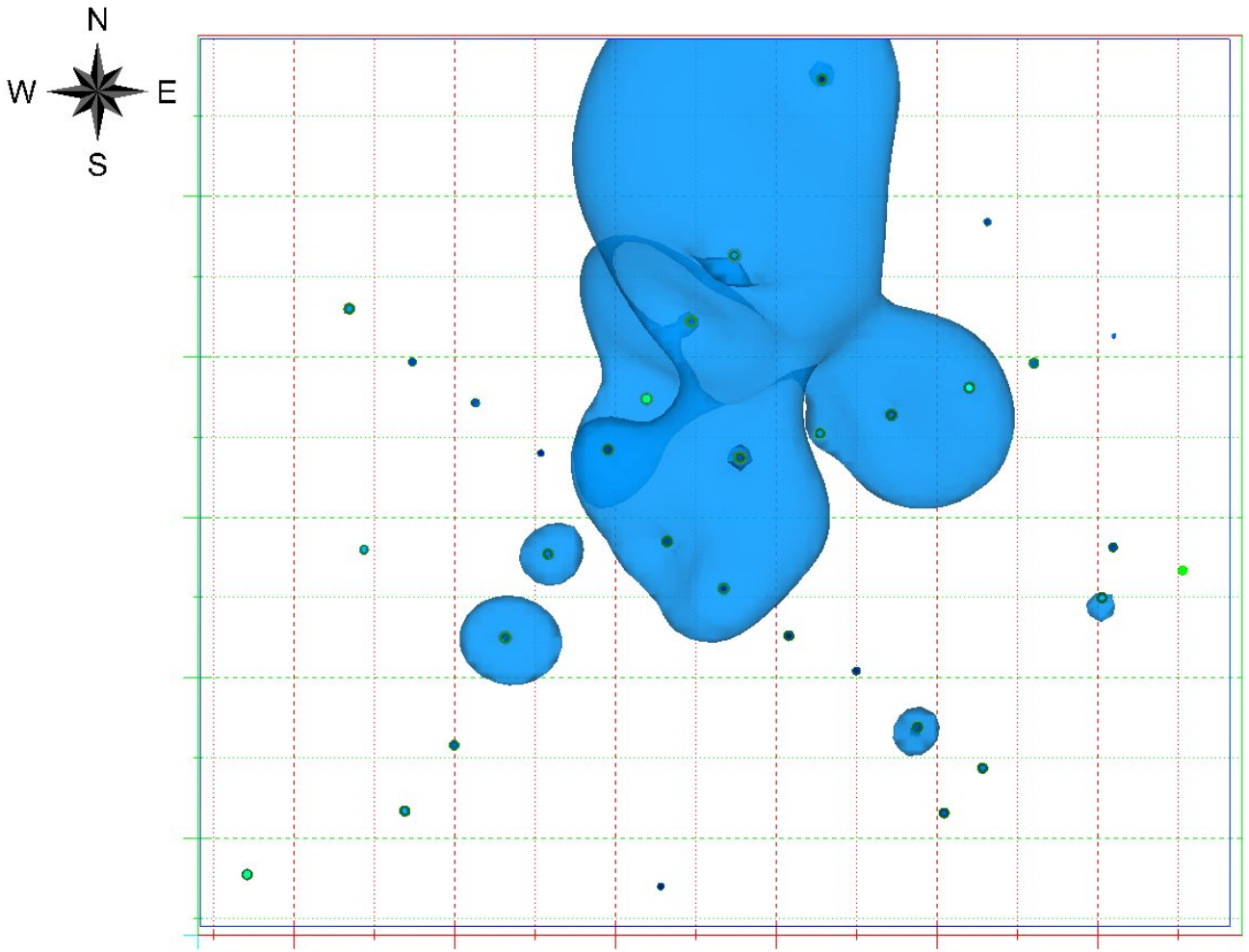
- **Visualization of High Resolution Data**
  - For NAPL or Dissolved-Phase

VERTEX

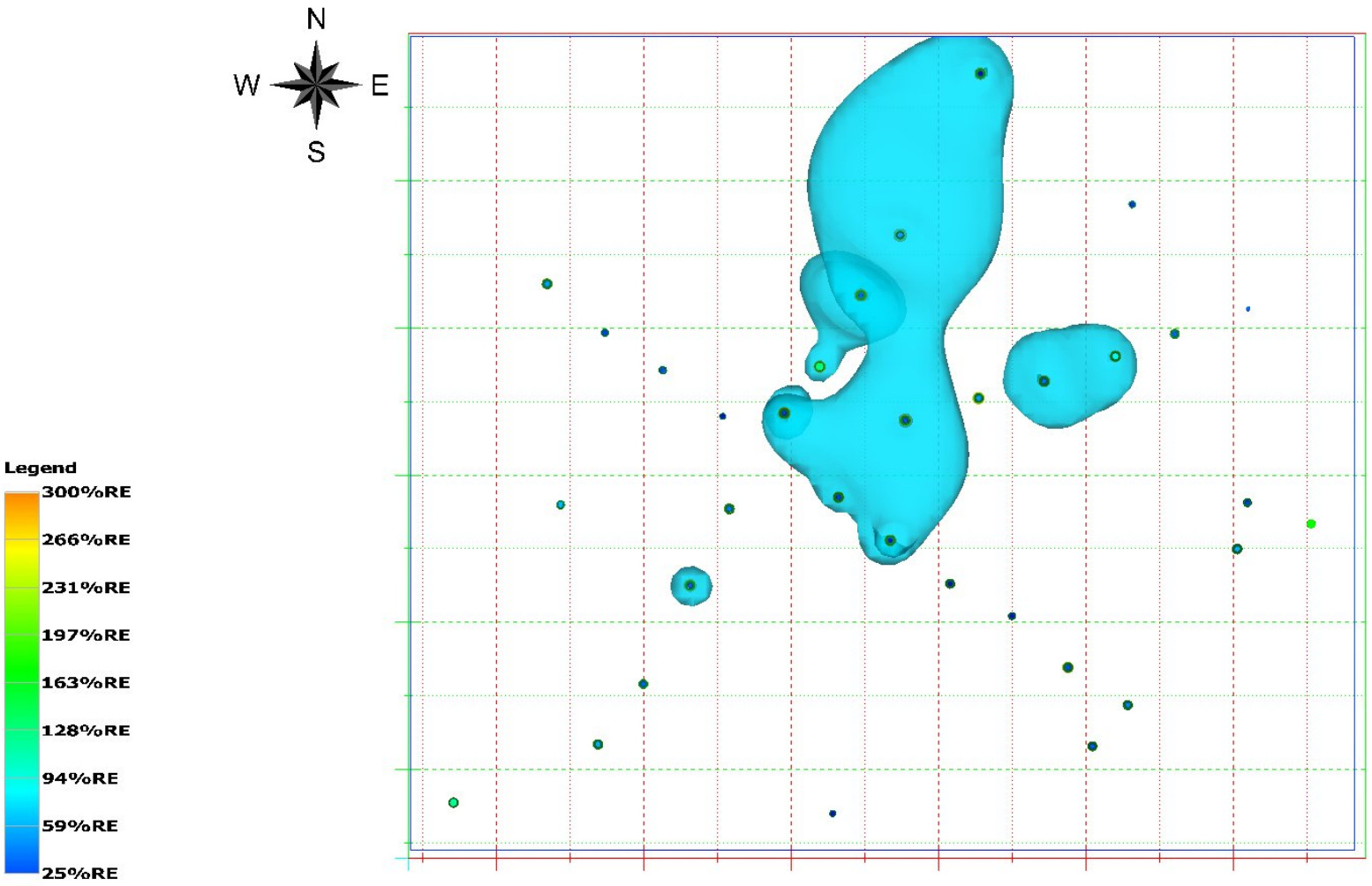
Characterization – Visualization



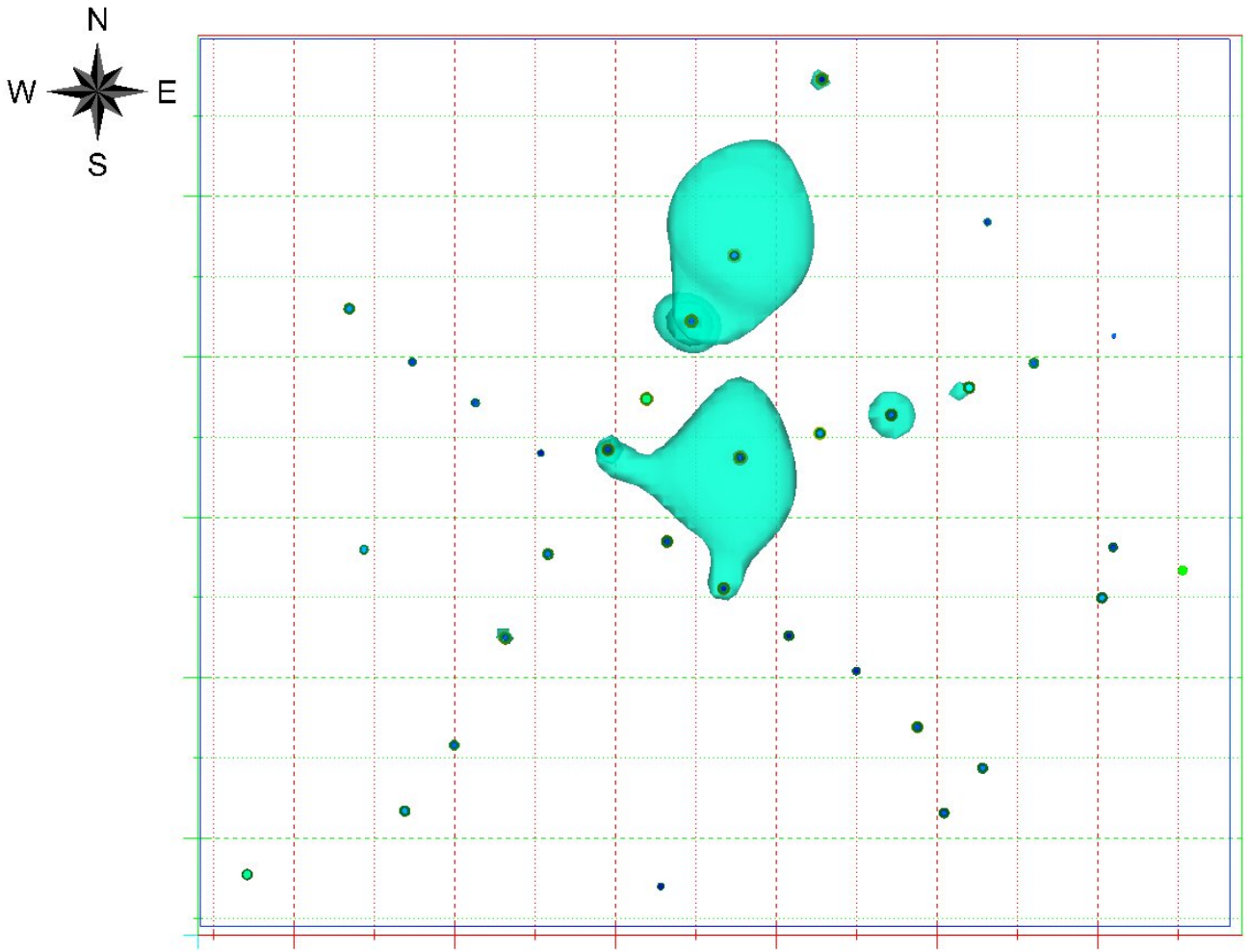
Characterization – Visualization



Characterization – Visualization

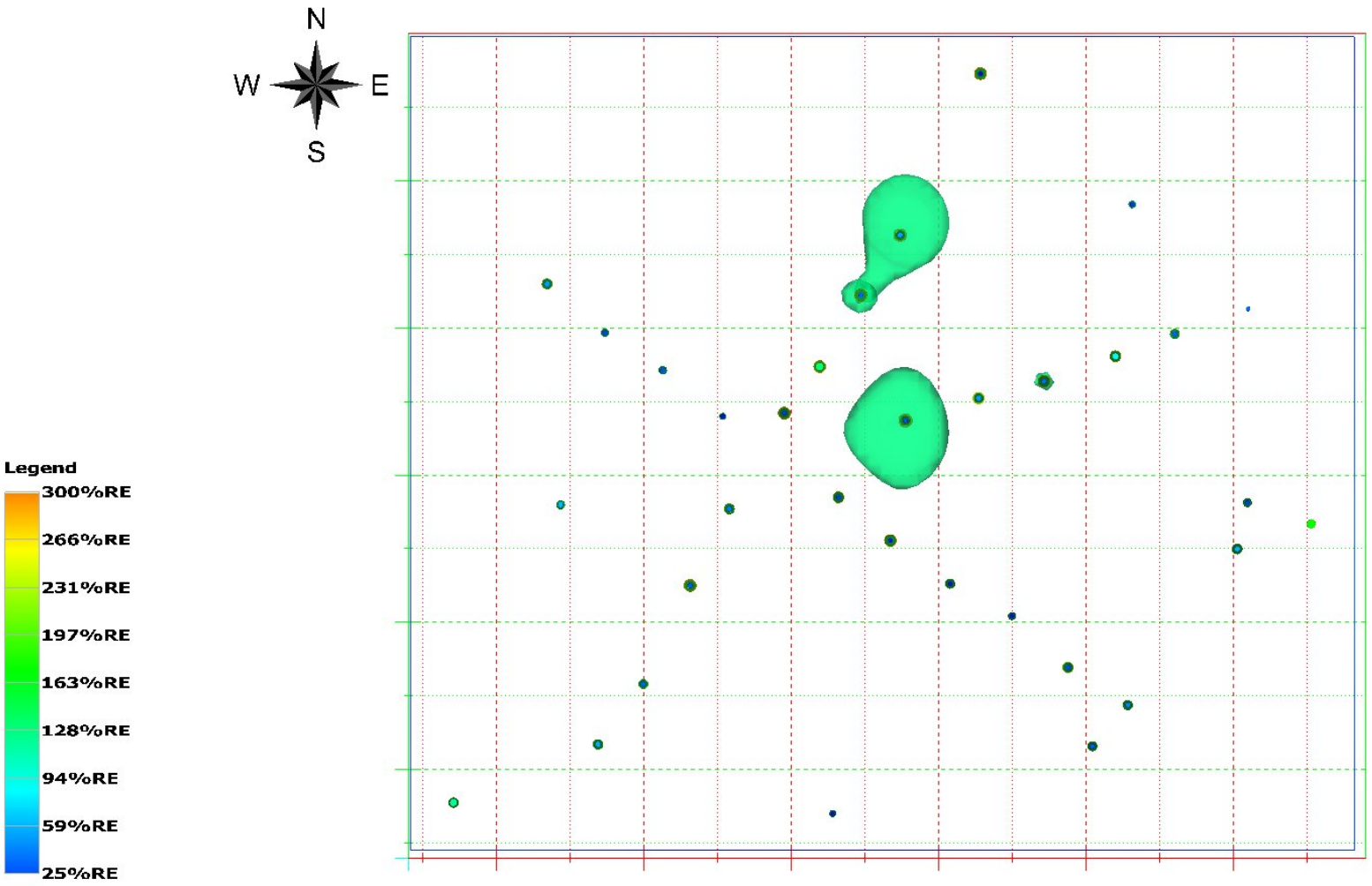


Characterization – Visualization

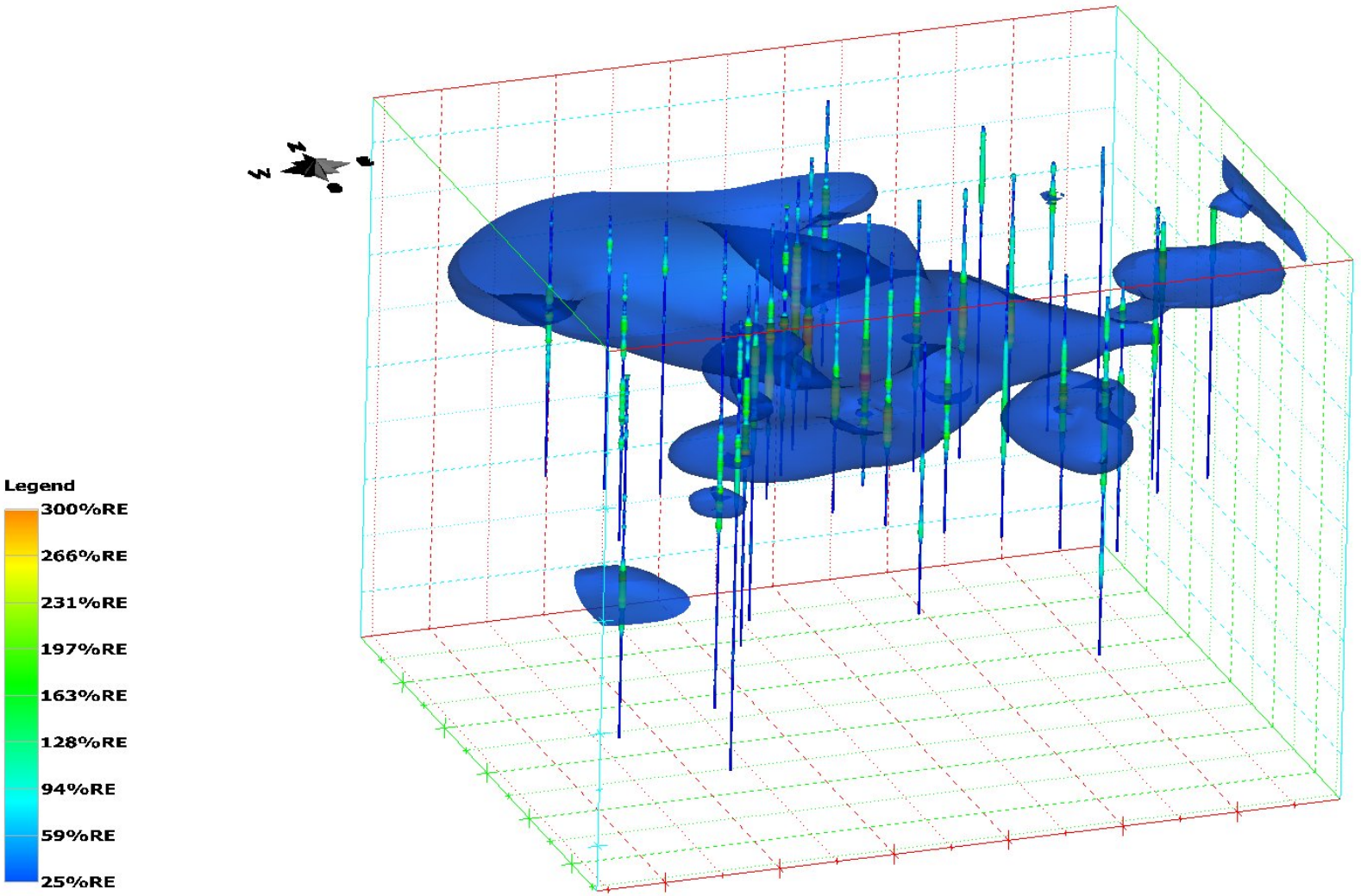


VERTEX

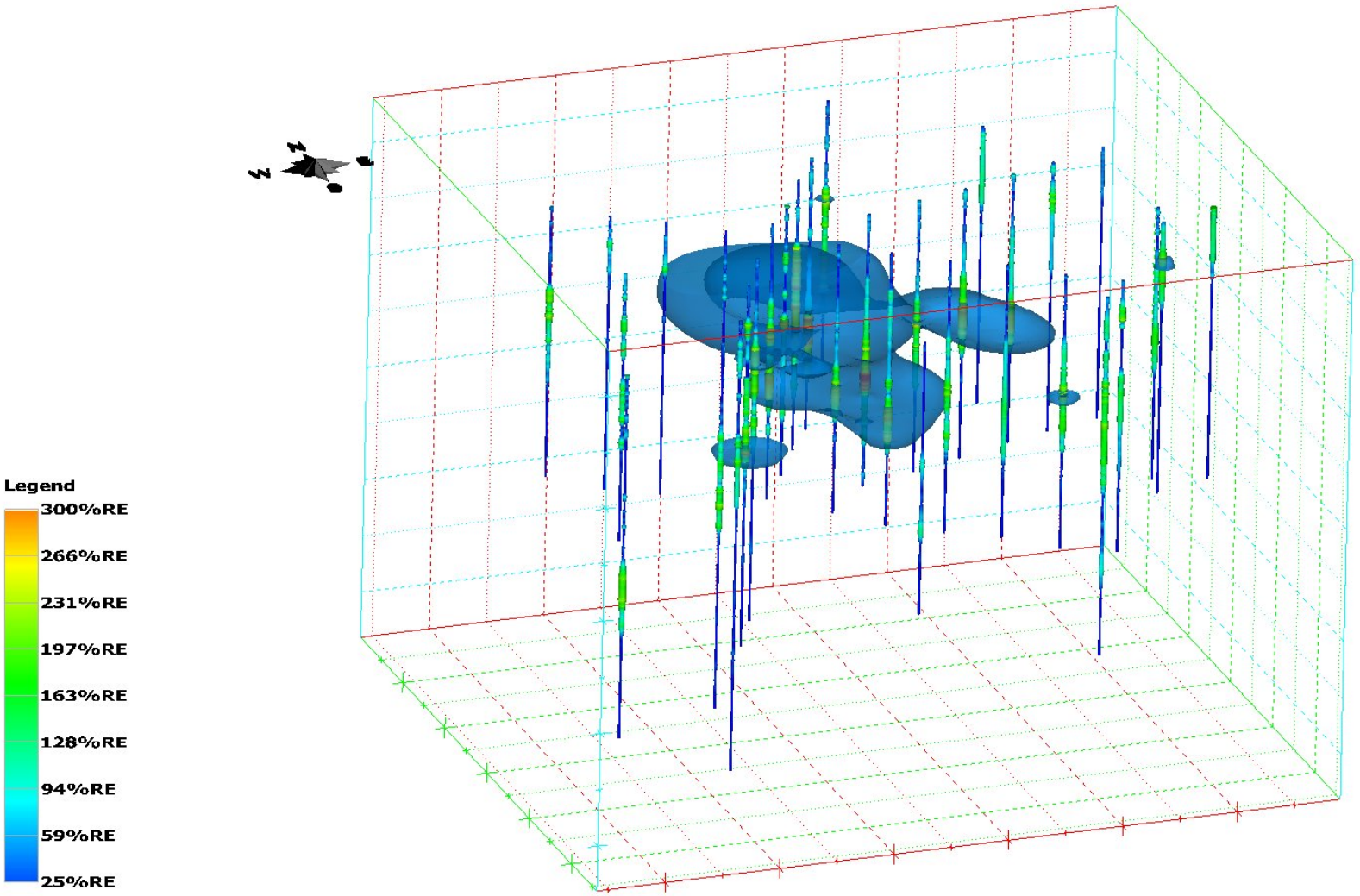
Characterization – Visualization



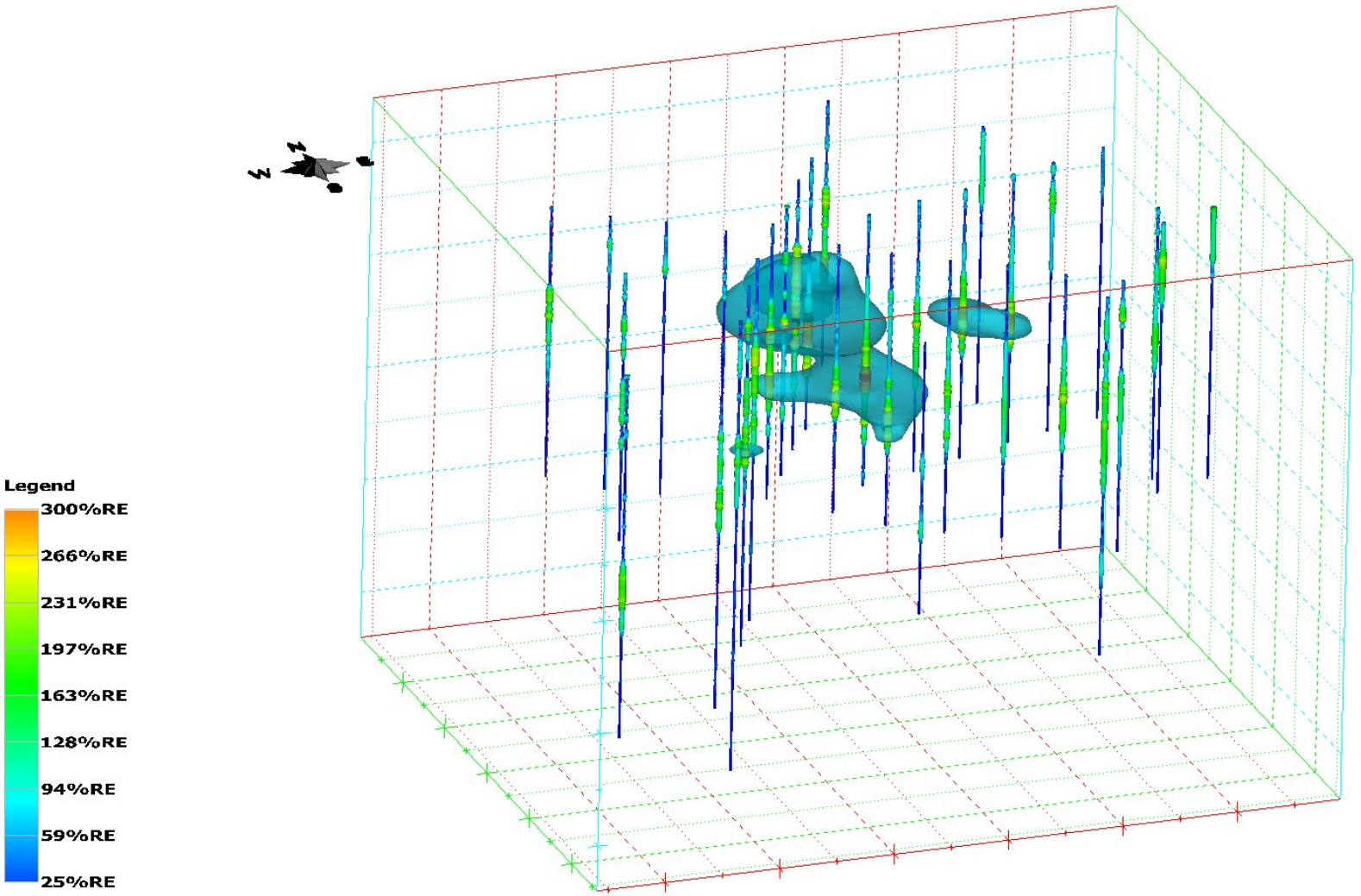
Characterization – Visualization



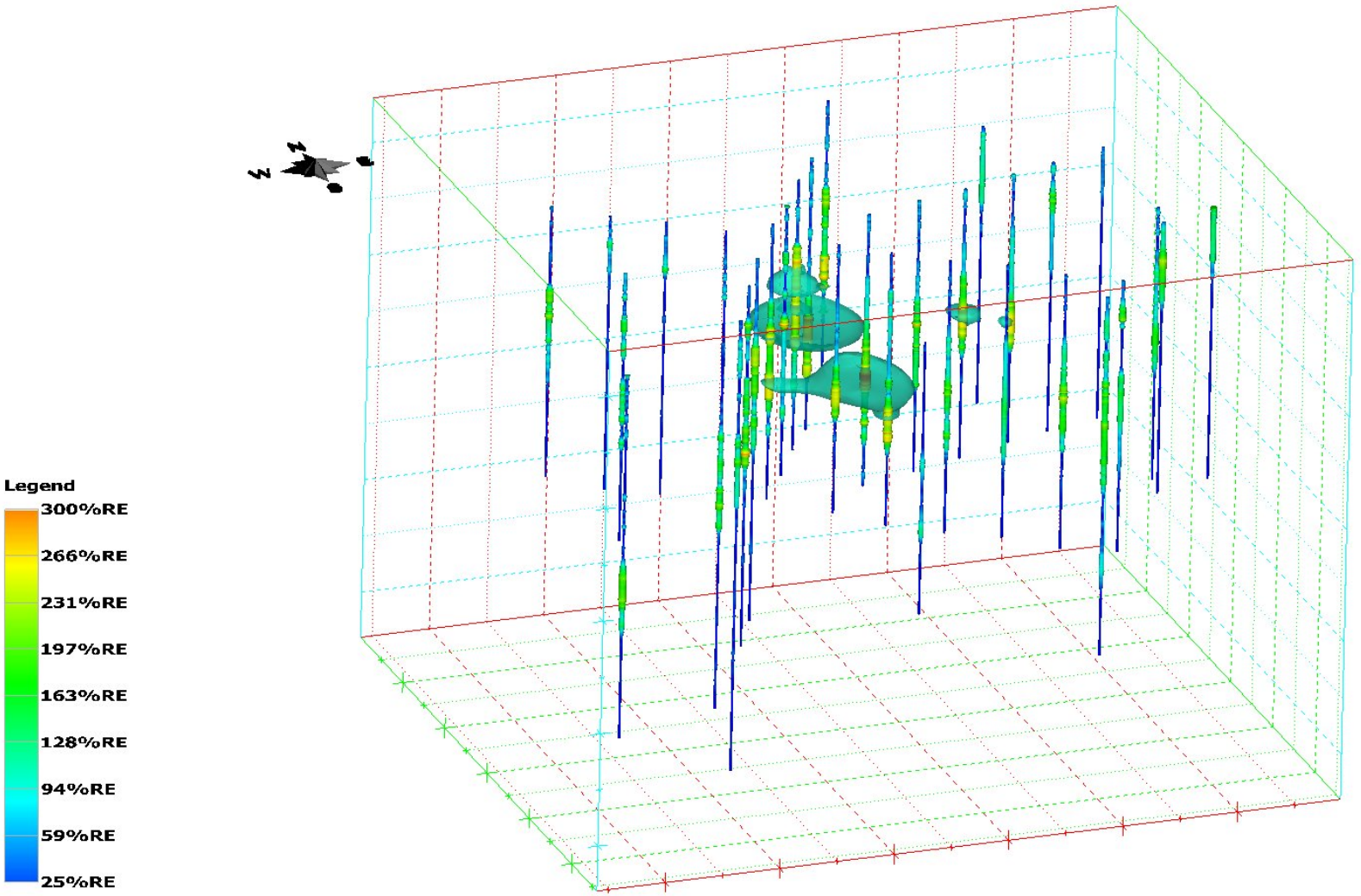
Characterization – Visualization



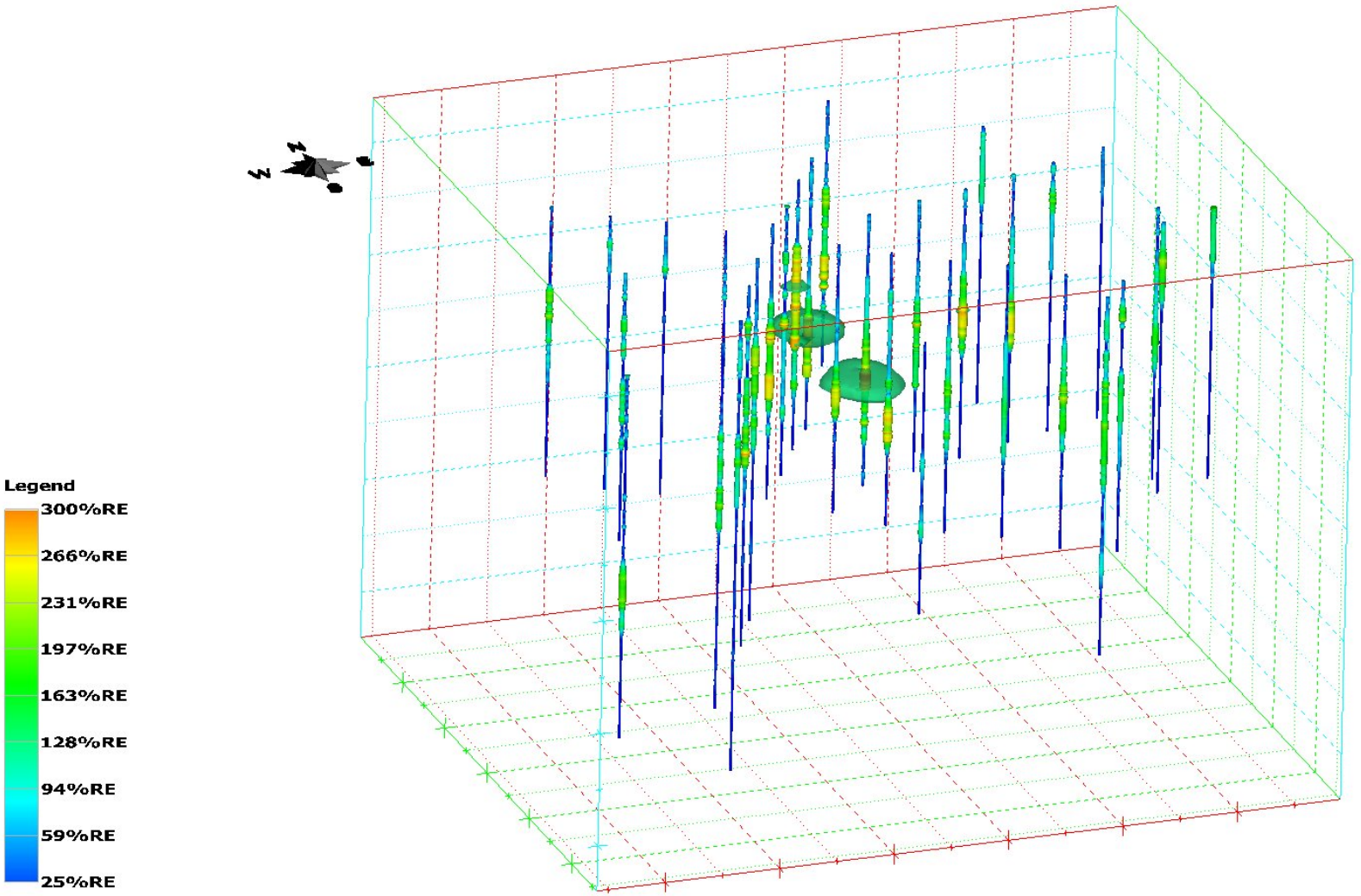
Characterization – Visualization



Characterization – Visualization



Characterization – Visualization

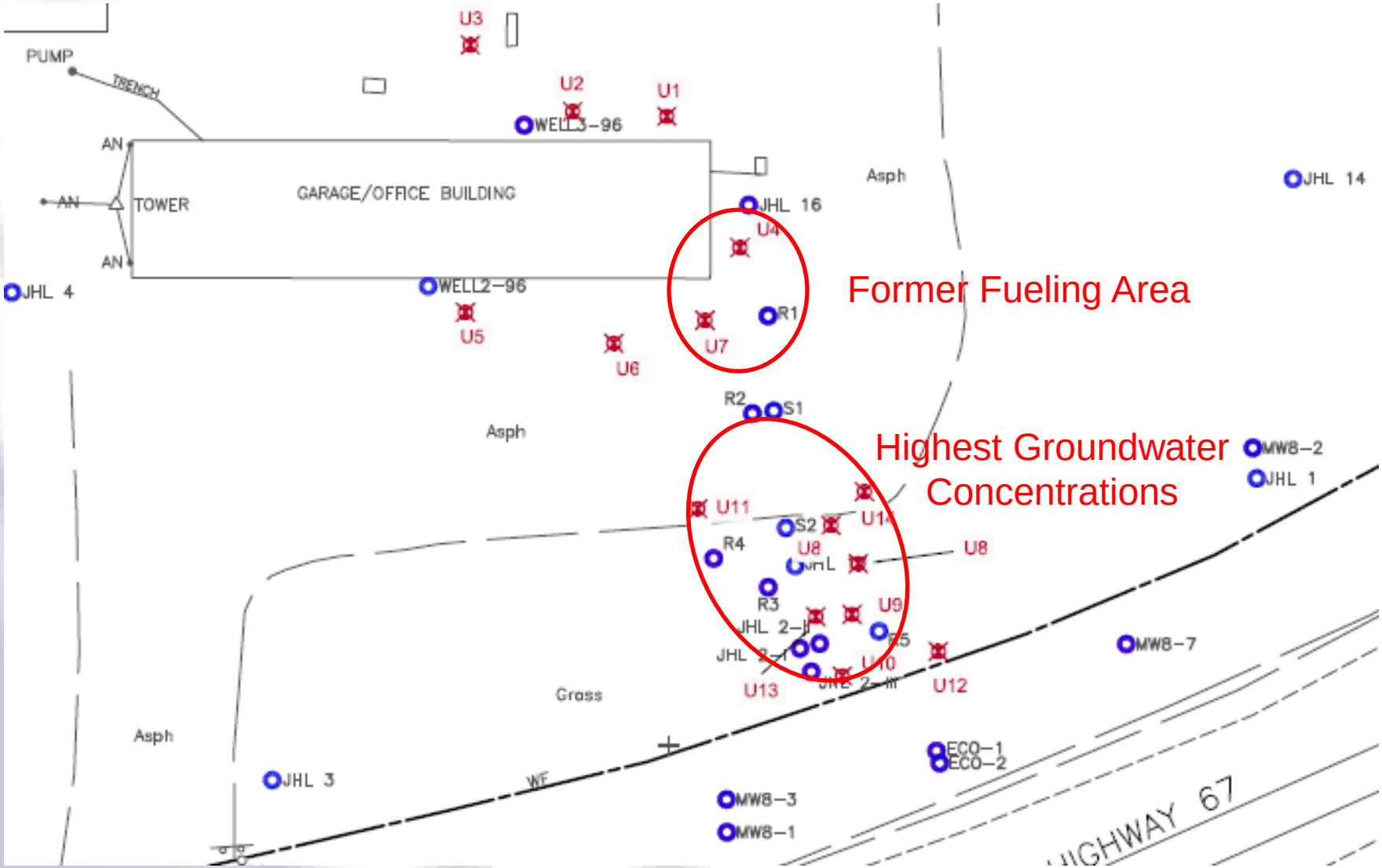


Characterization – Visualization

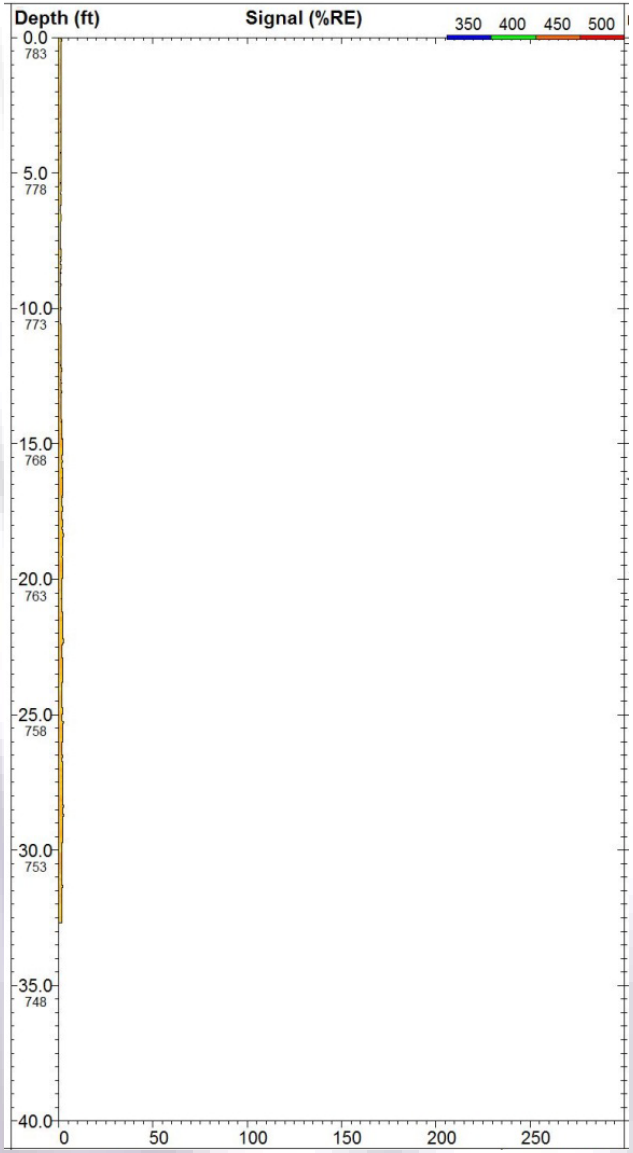
Case Study

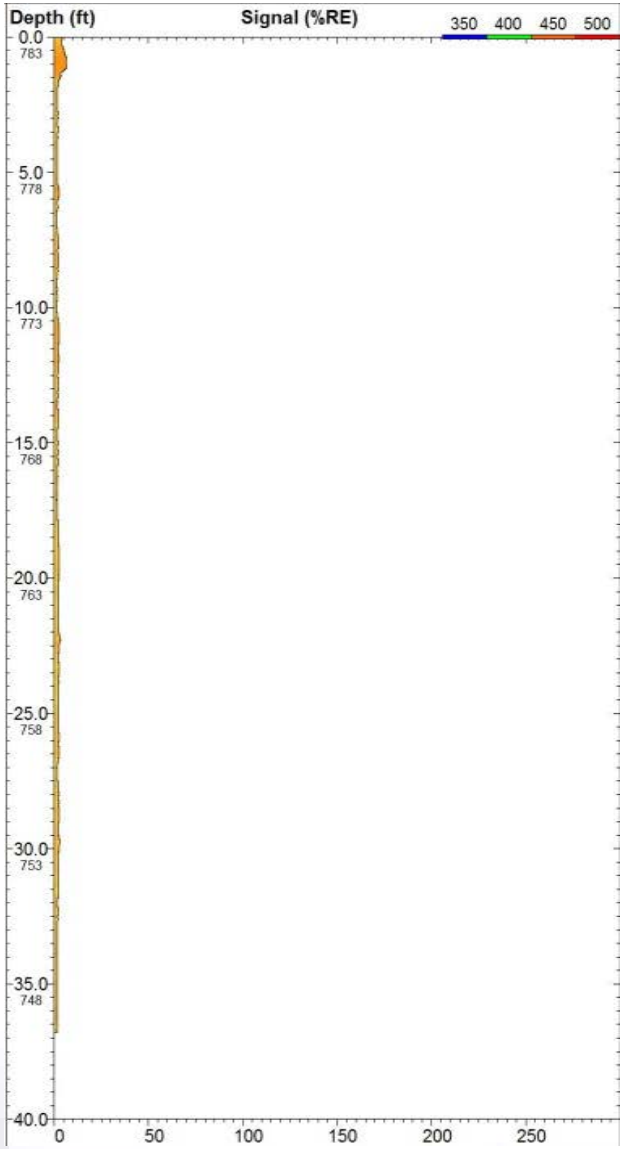
- Fueling ASTs / USTs at Site
  - 19,000 L of fuel lost to ground
- Excavation completed
  - Fire during dig
- Remediation system installed
  - After time: <1 cm of NAPL in wells
- ISCO (In-Situ Chemical Oxidation)
  - LIF to confirm no NAPL present
  - MIP to examine dissolved distribution

Case Study


U3
PUMP
TRENCH
U2
U1
WELL3-96
AN
AN
TOWER
GARAGE/OFFICE BUILDING
Asph
JHL 14
JHL 16
U4
JHL 4
WELL2-96
U5
R1
U7
U6
Former Fueling Area
R2
S1
Asph
Highest Groundwater Concentrations
MW8-2
JHL 1
U11
U14
S2
R4
U8
U8
R3
U9
JHL 2-J
JHL 2-I
S5
MW8-7
U10
U13
U12
Grass
Asph
ECO-1
ECO-2
JHL 3
WF
MW8-3
MW8-1
HIGHWAY 67

Case Study – LIF Results





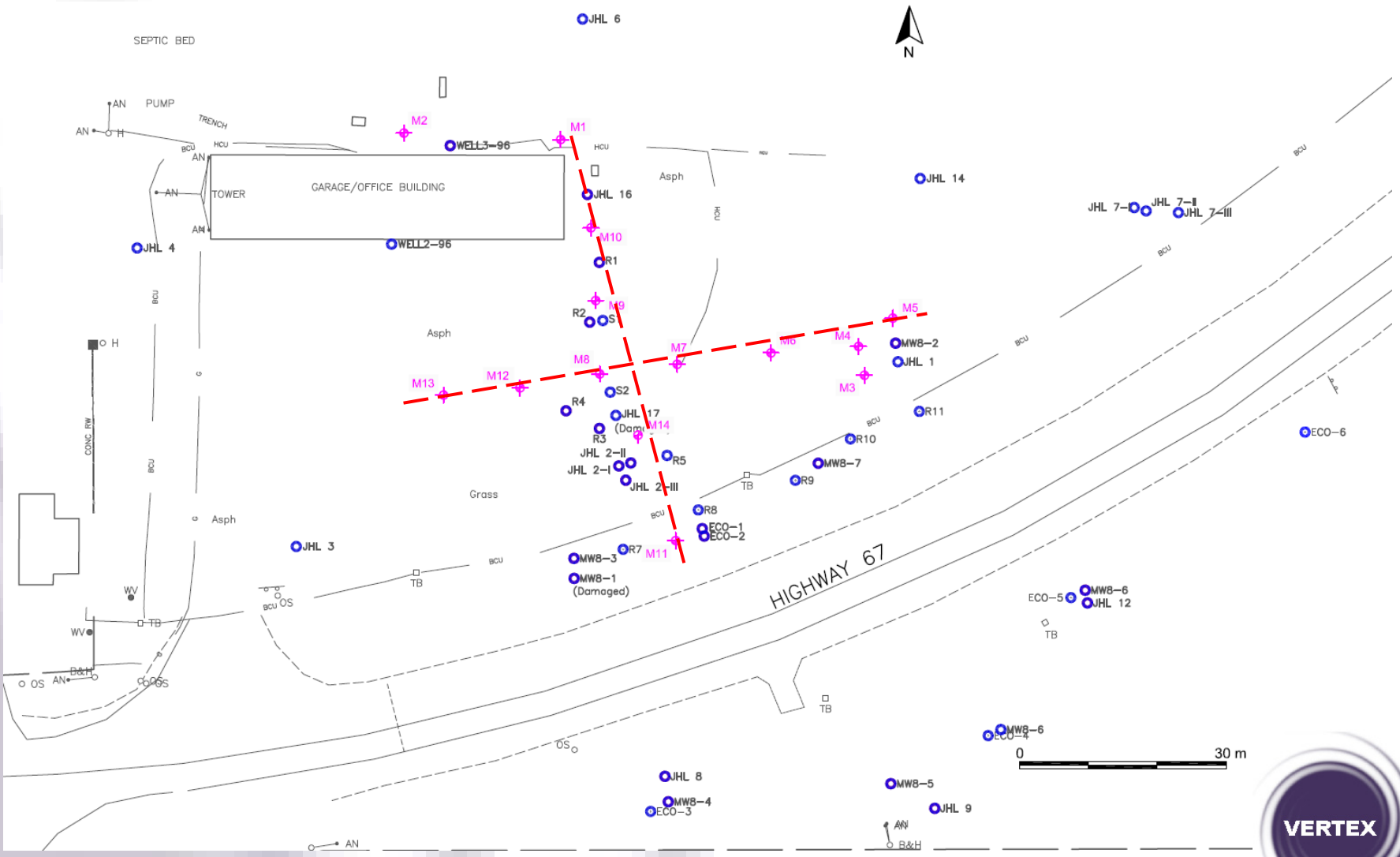
No NAPL detected

VERTEX

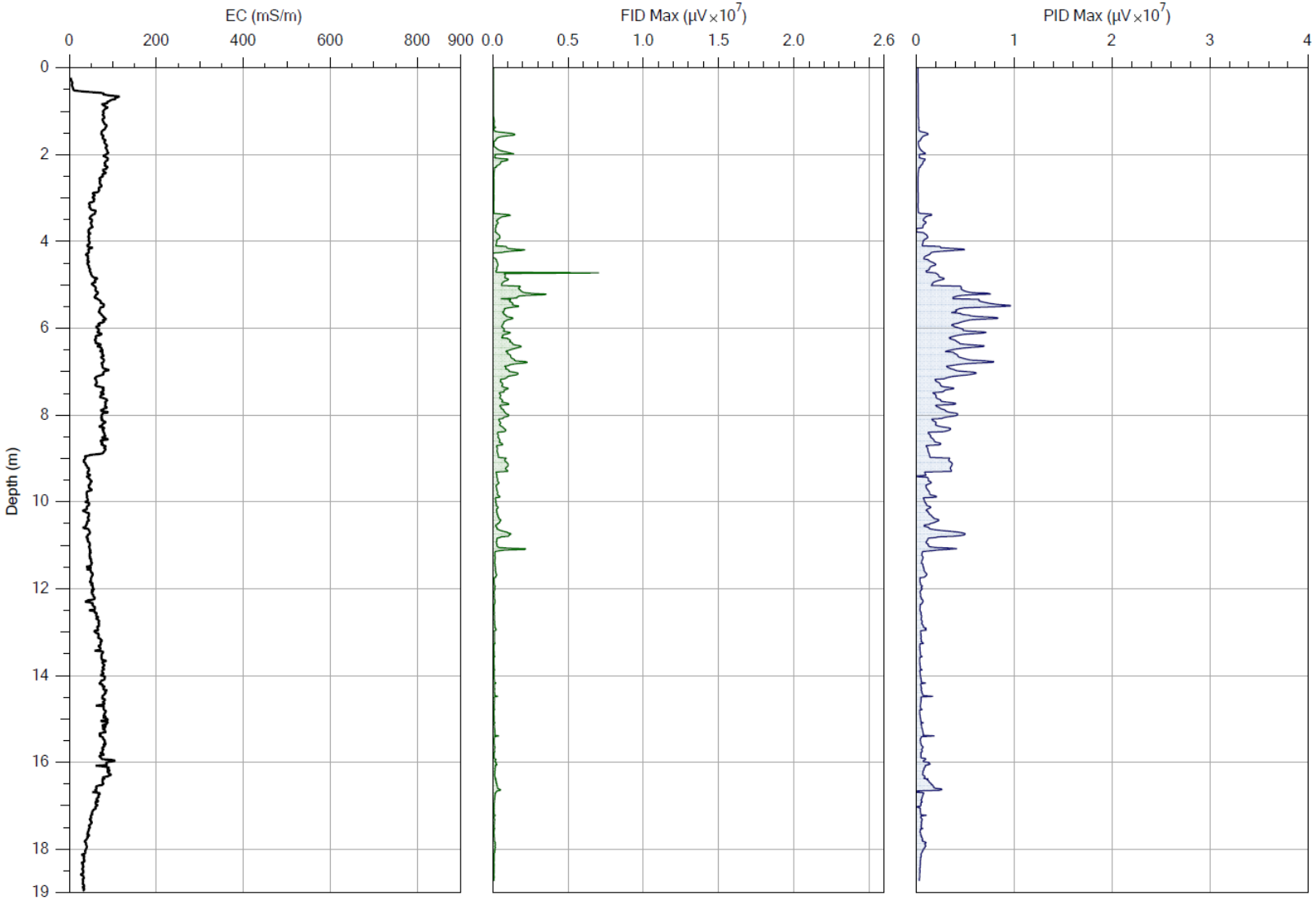
Case Study – Results

- No NAPL identified
  - ISCO could safely commence
- MIP delineation
  - Contract defined oxidant loading per vertical m
  - MIP - better define dissolved phase PHCs
  - Re-design injection to target vertical zones of highest dissolved phase contamination

MIP Investigation Round 1



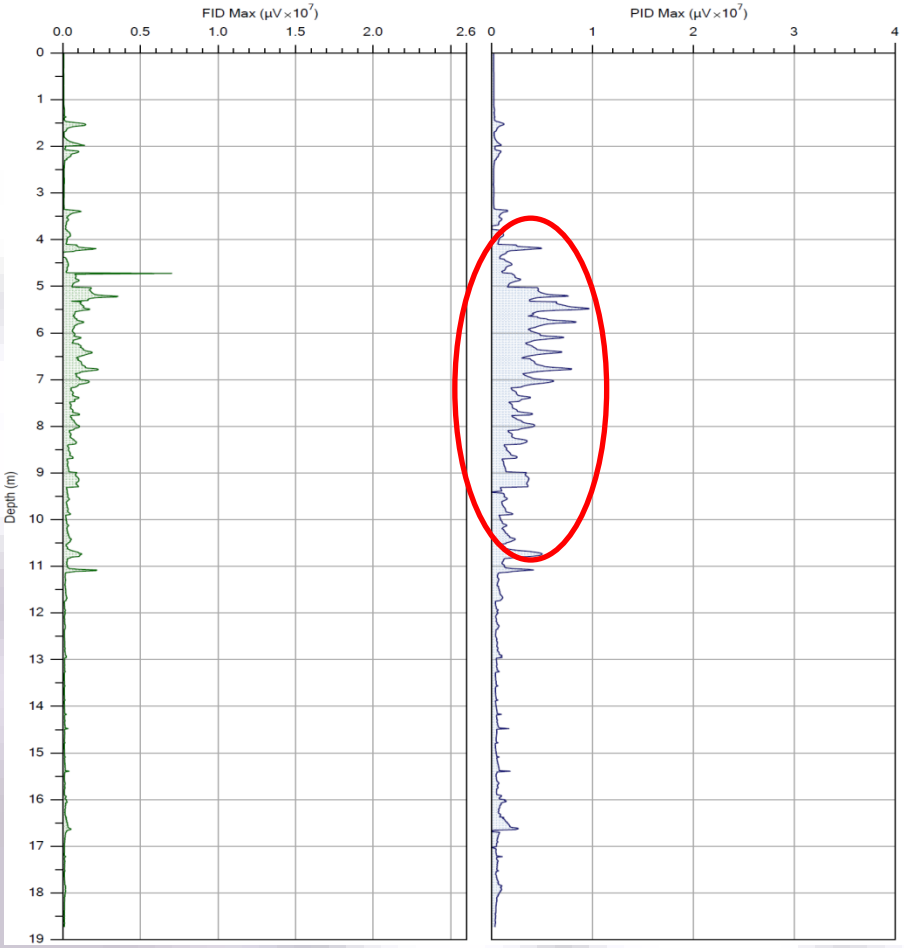
Case Study – MIP Results



Dissolved phase plume 3 m to 11 m below ground

VERTEX

Case Study - Oxidant Loading Rates



Original Design (kg/m)	Re-Design (kg/m)
0.0	0.0
29.6	38.0
	44.3
	31.7
	25.3
	19.0

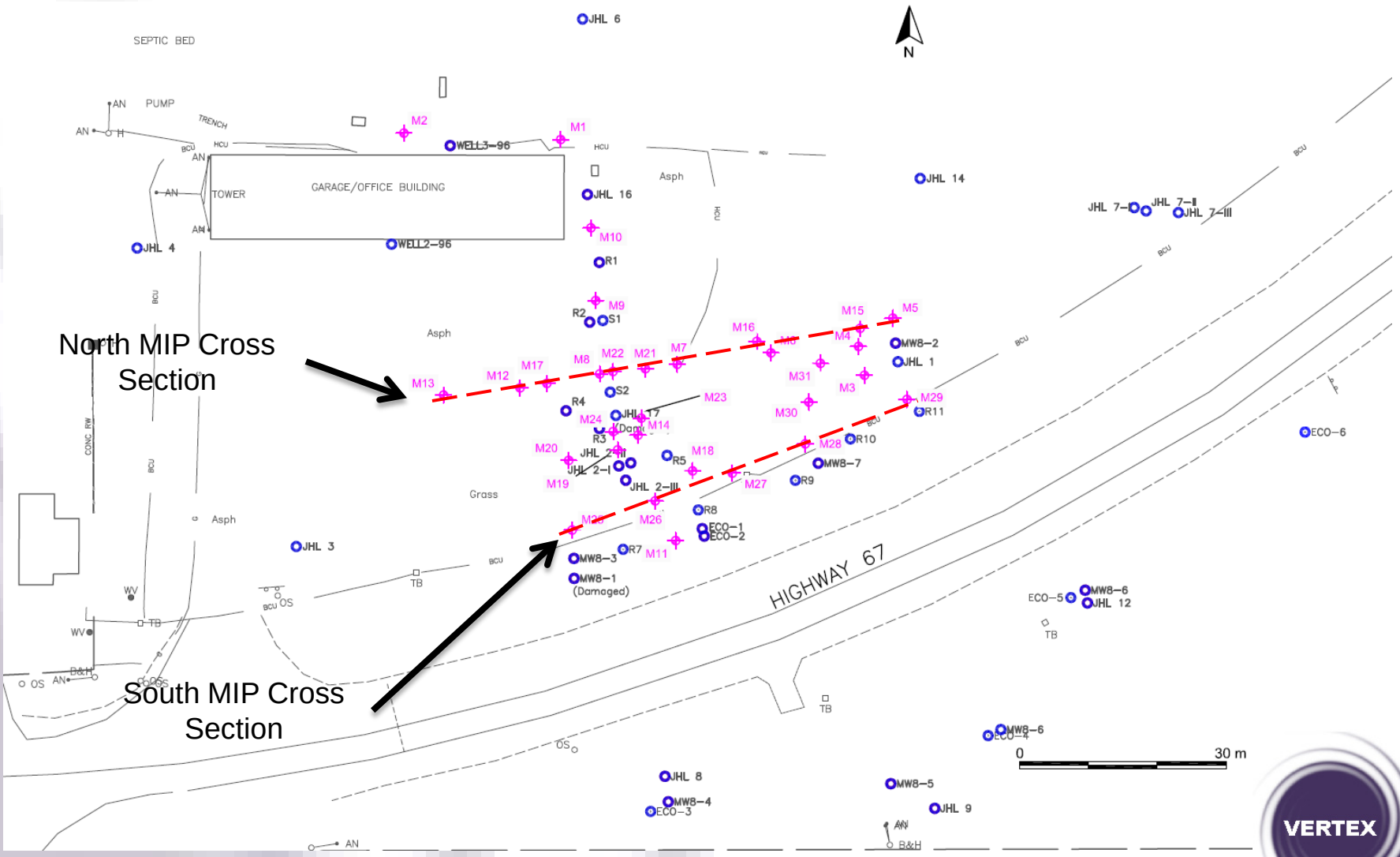
0 m

3 m

23 m

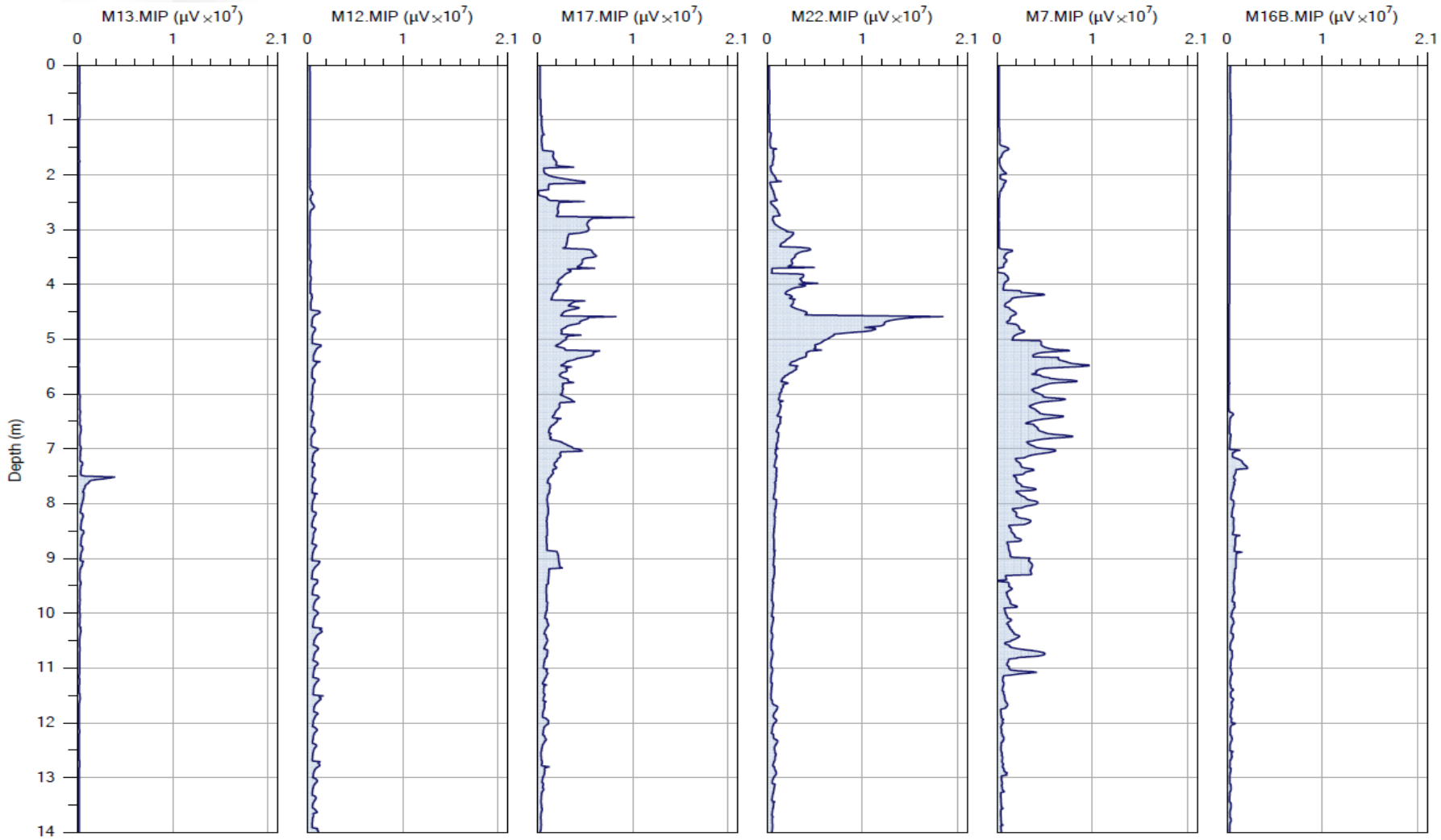
Original Design: Inject 29.6 kg/m from 3 m to 23 m bgs

MIP Investigation Round 1 & 2



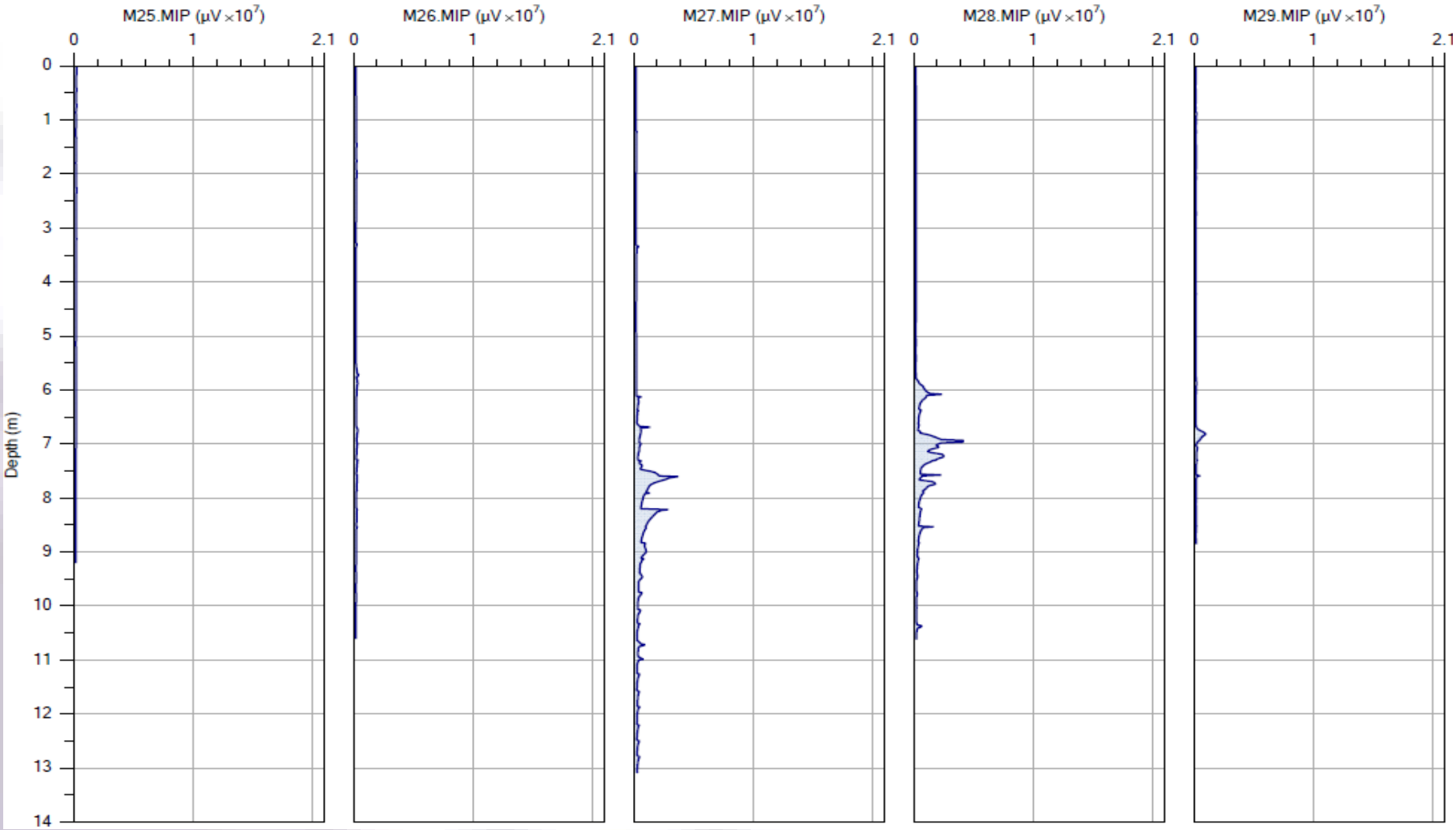
Case Study – MIP Results

North MIP Cross Section



Case Study – MIP Results

South MIP Cross Section



Case Study – MIP Results

MIP PID Results

Interim MIP sampling

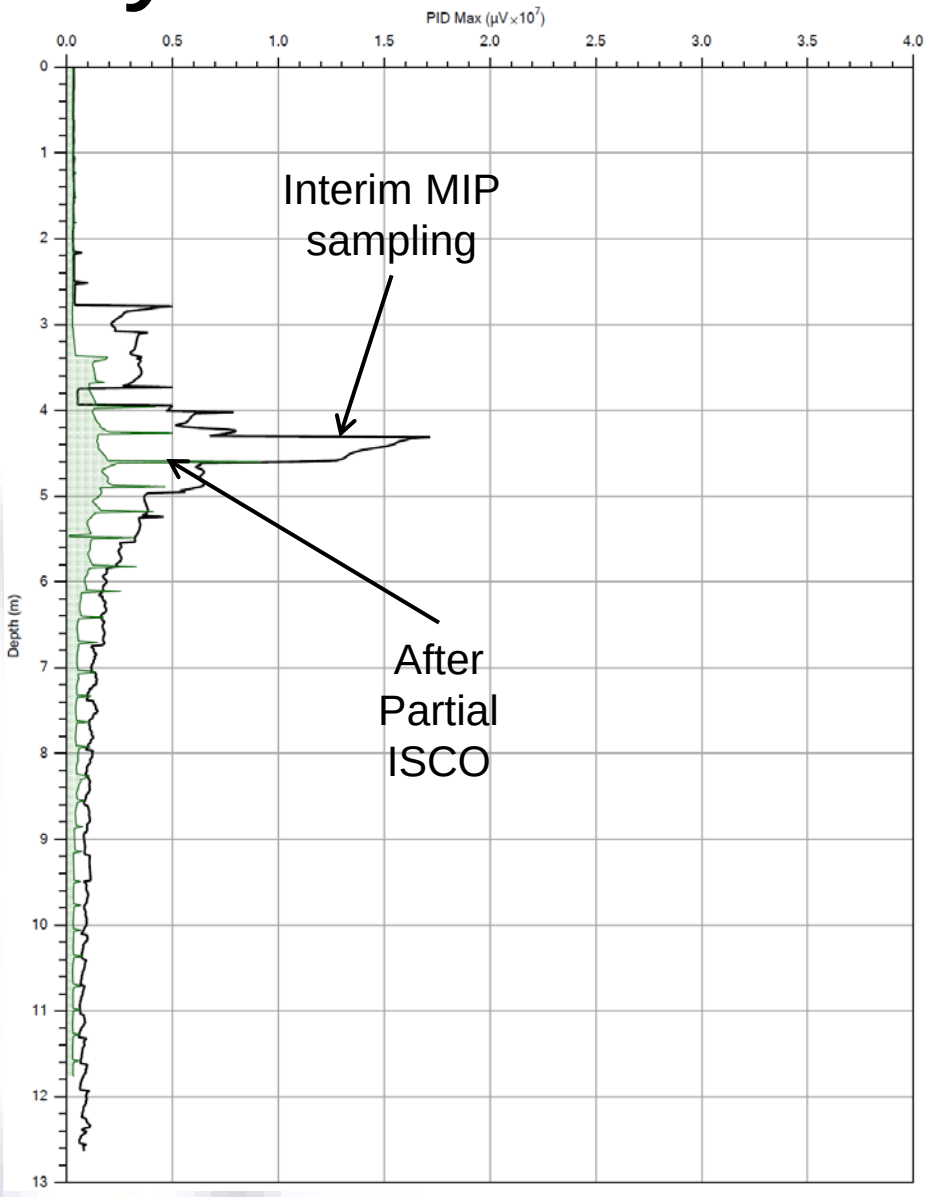
Fall 2011
Black Line

After Partial ISCO

Summer 2012
Green Line

Location

Core of Injection



Case Study – MIP Results

MIP PID Results

Interim MIP sampling

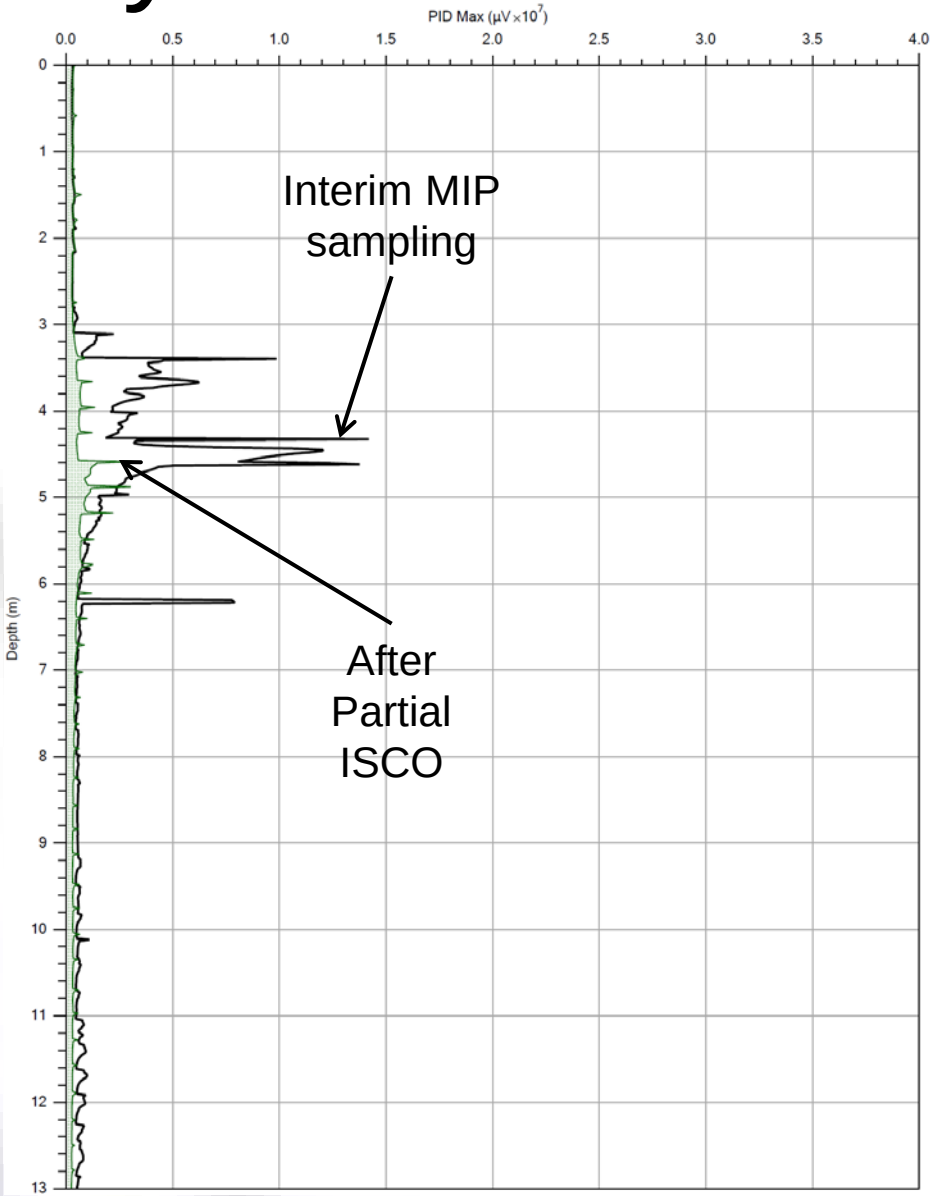
Fall 2011
Black Line

After Partial ISCO

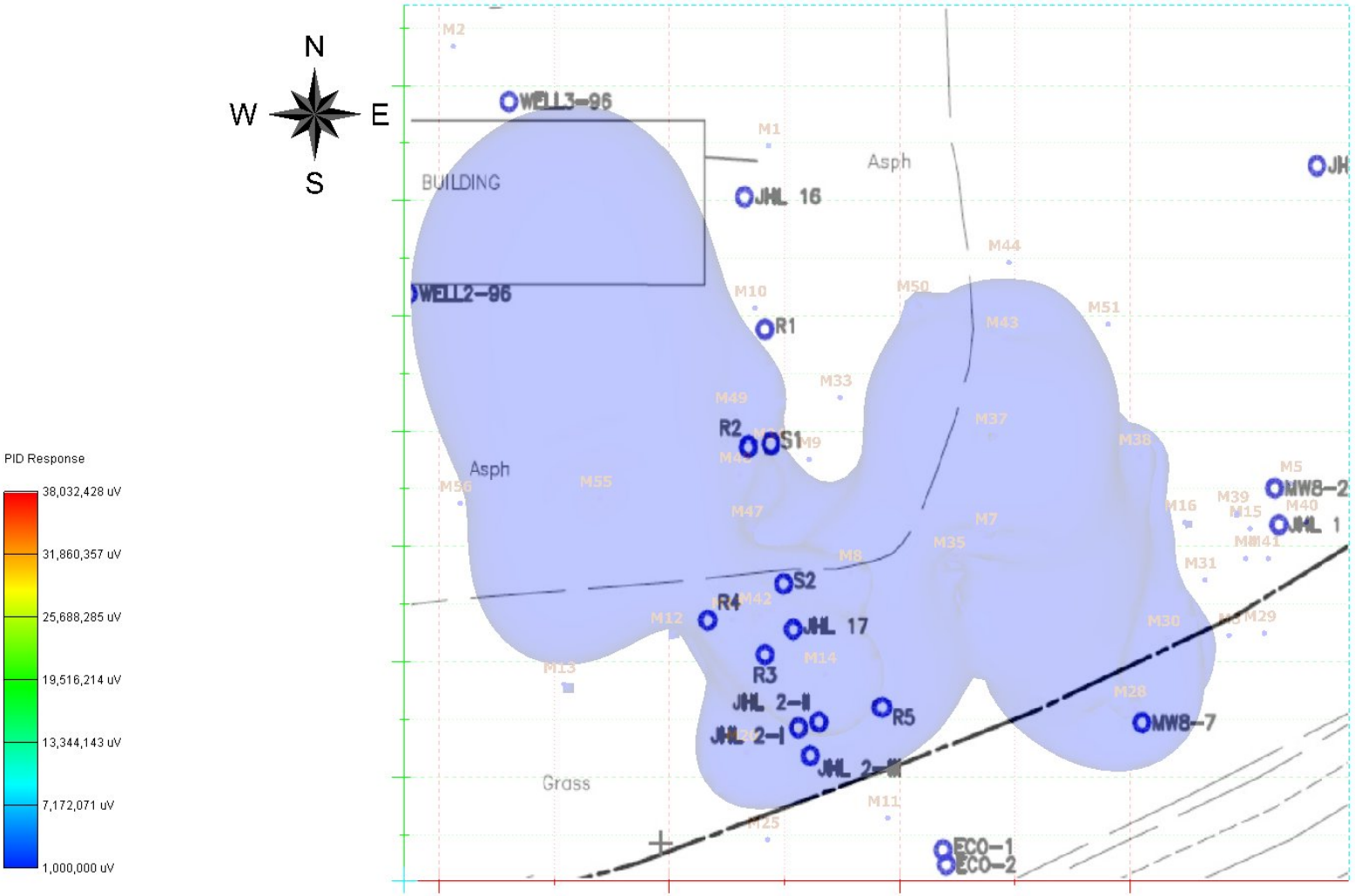
Summer 2012
Green Line

Location

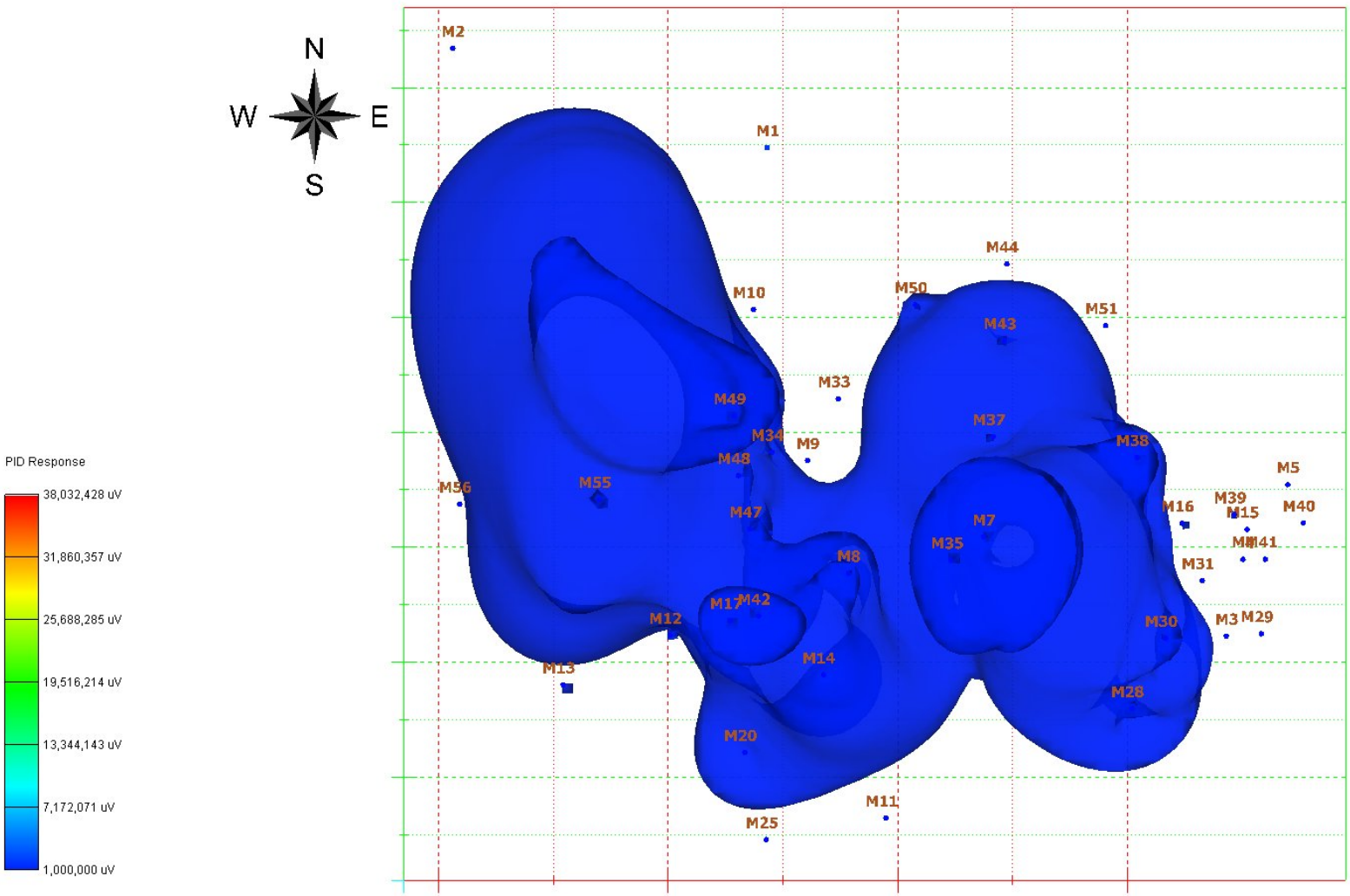
East Edge of the Core of Injection



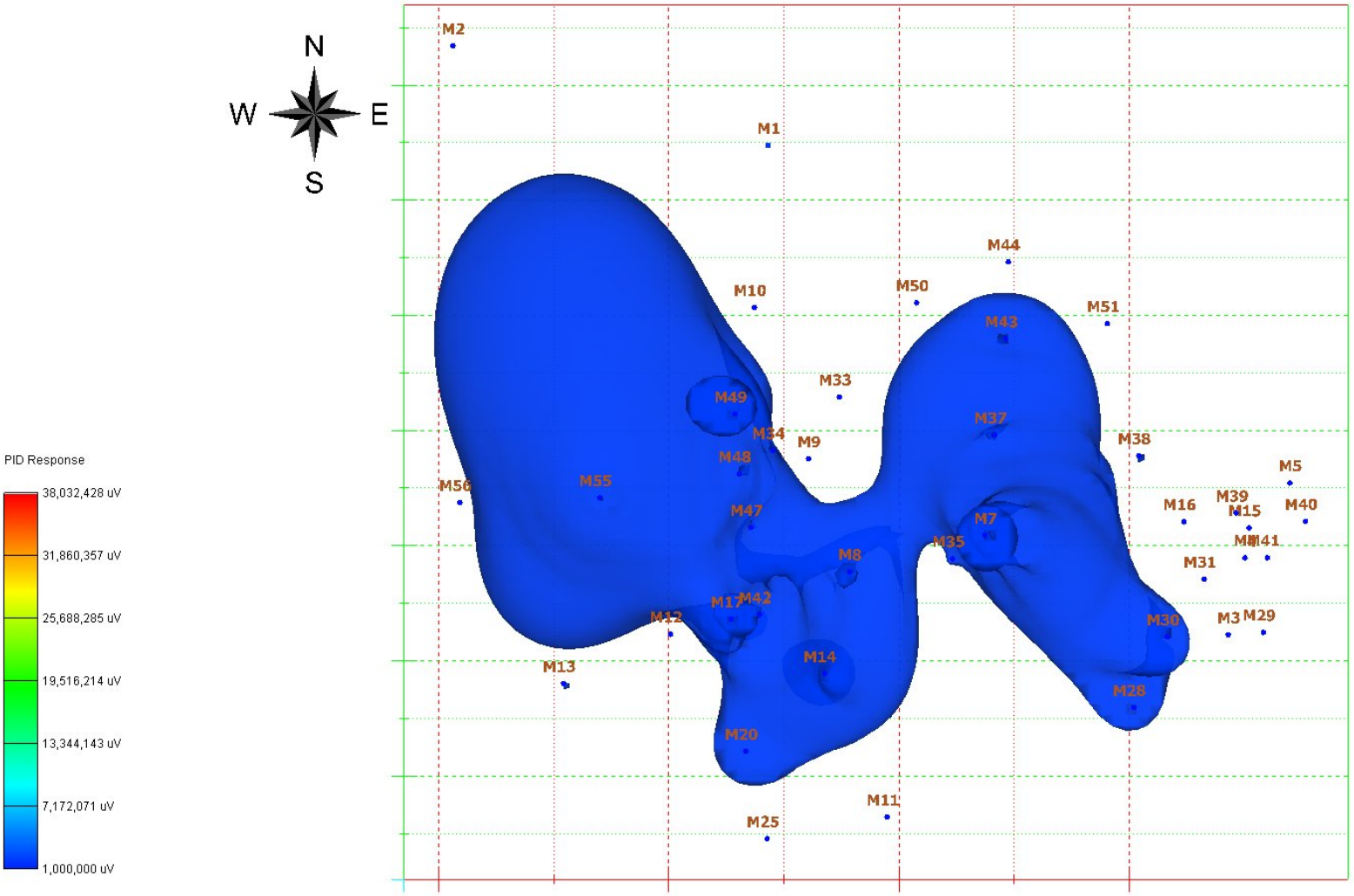
Characterization – Visualization



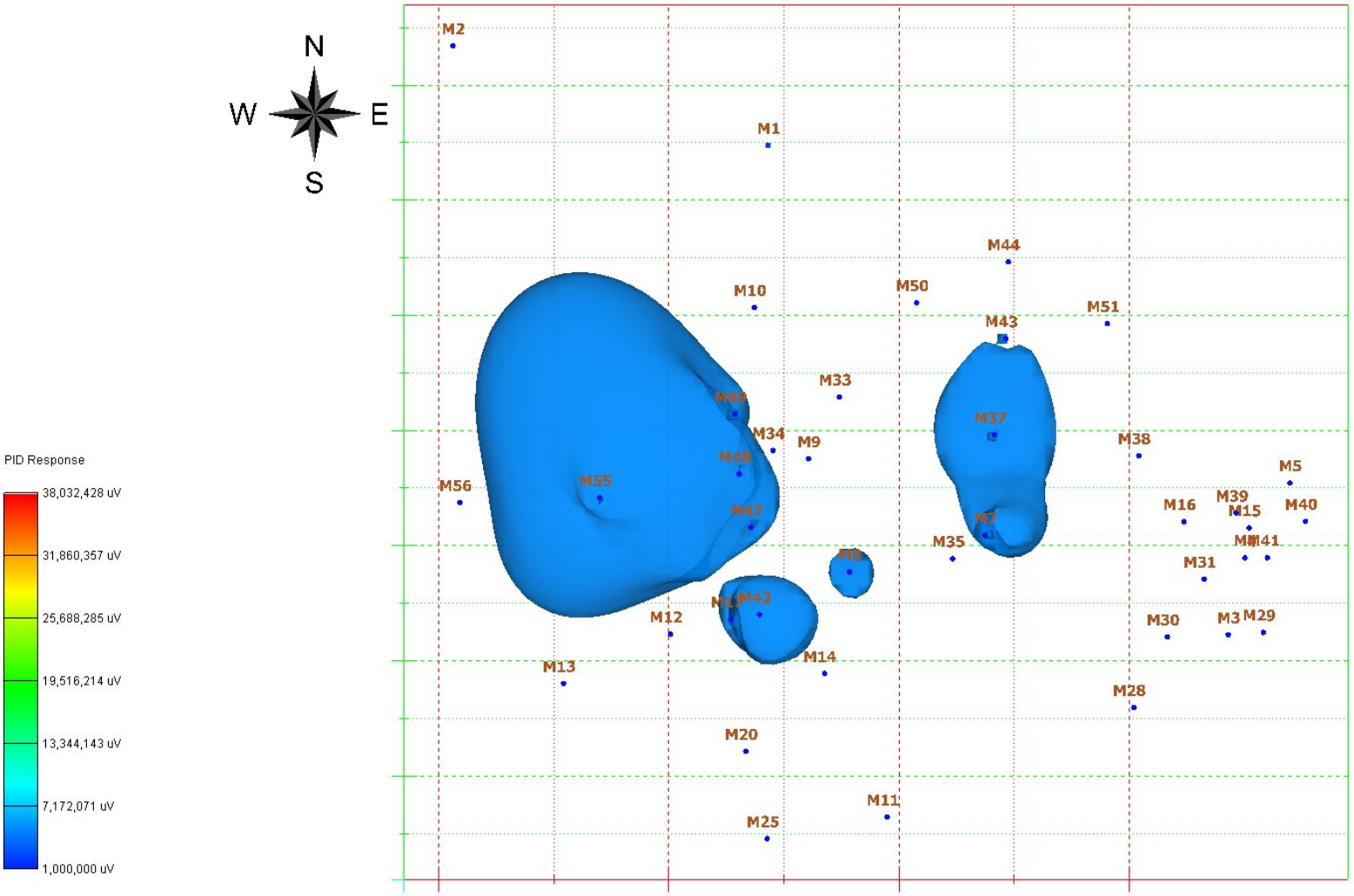
Characterization – Visualization



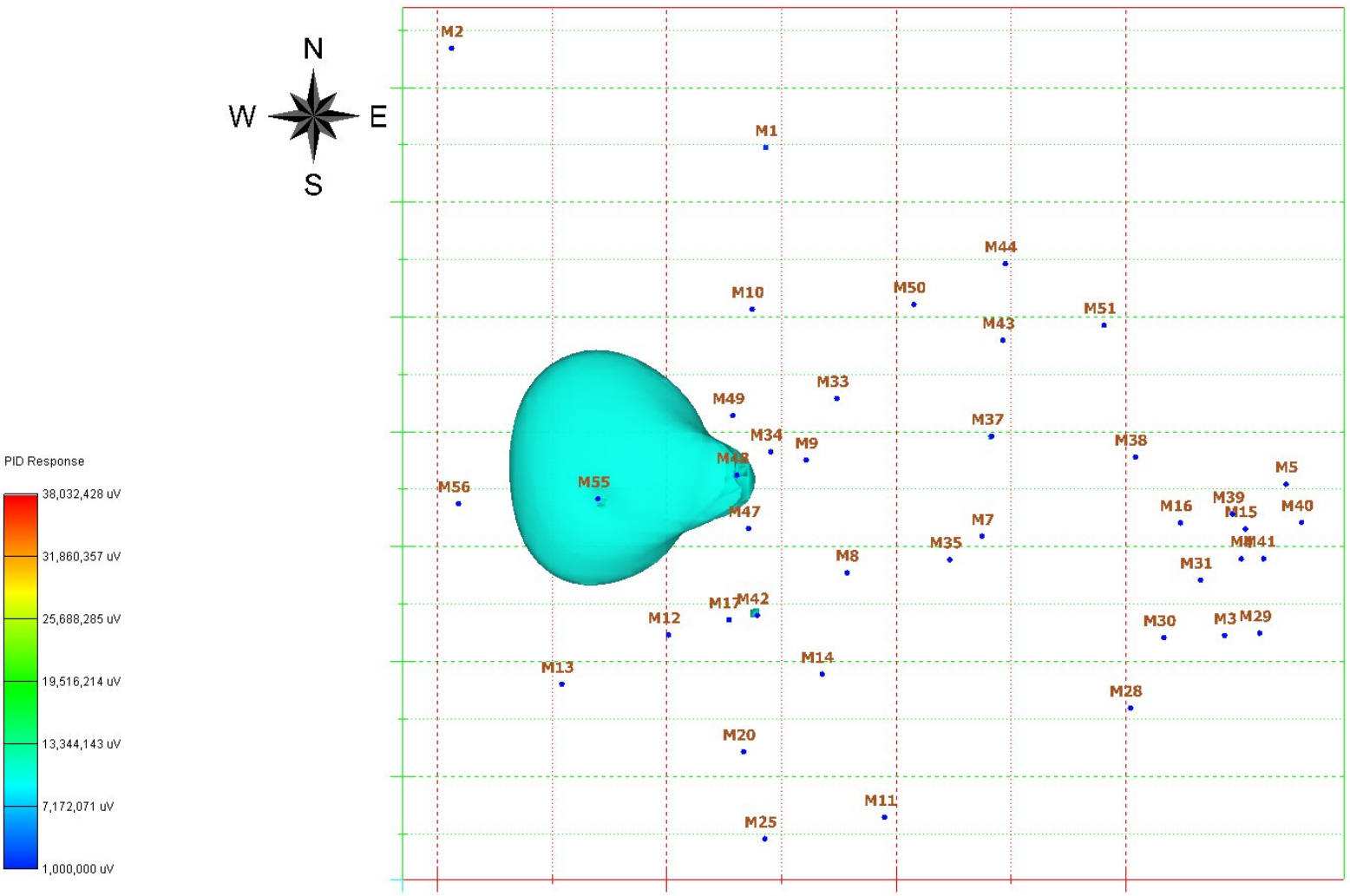
Characterization – Visualization



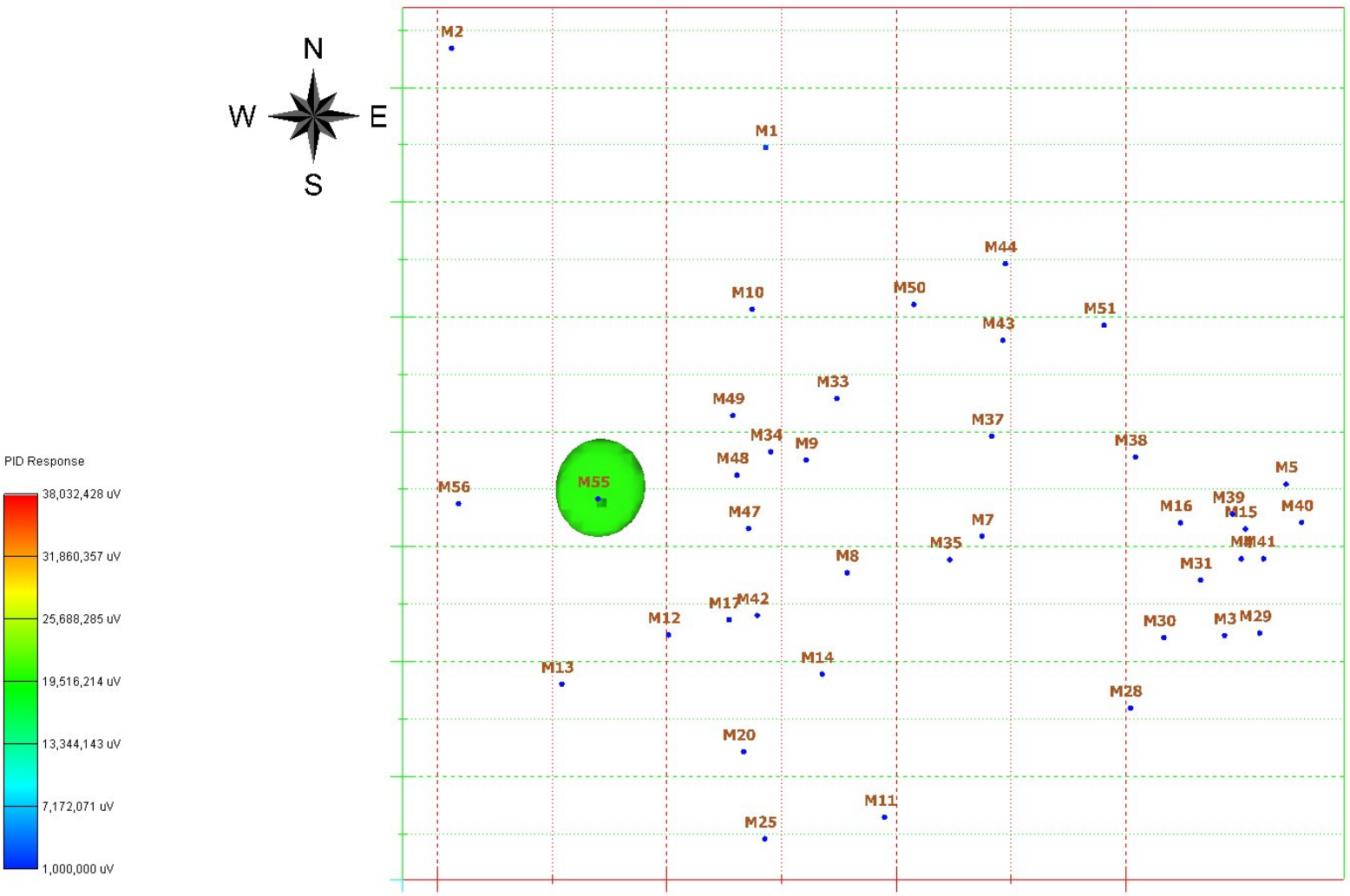
Characterization – Visualization



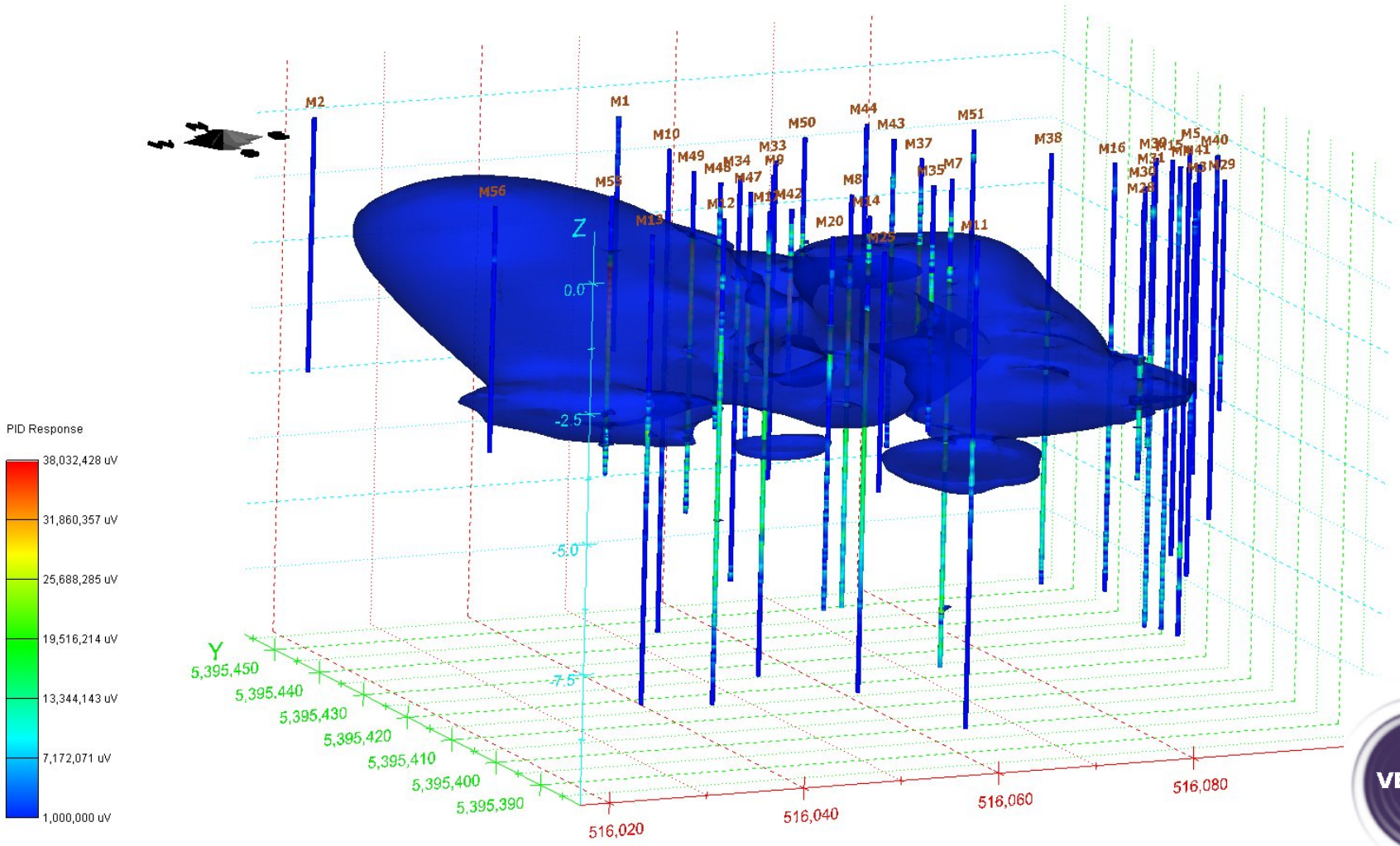
Characterization – Visualization



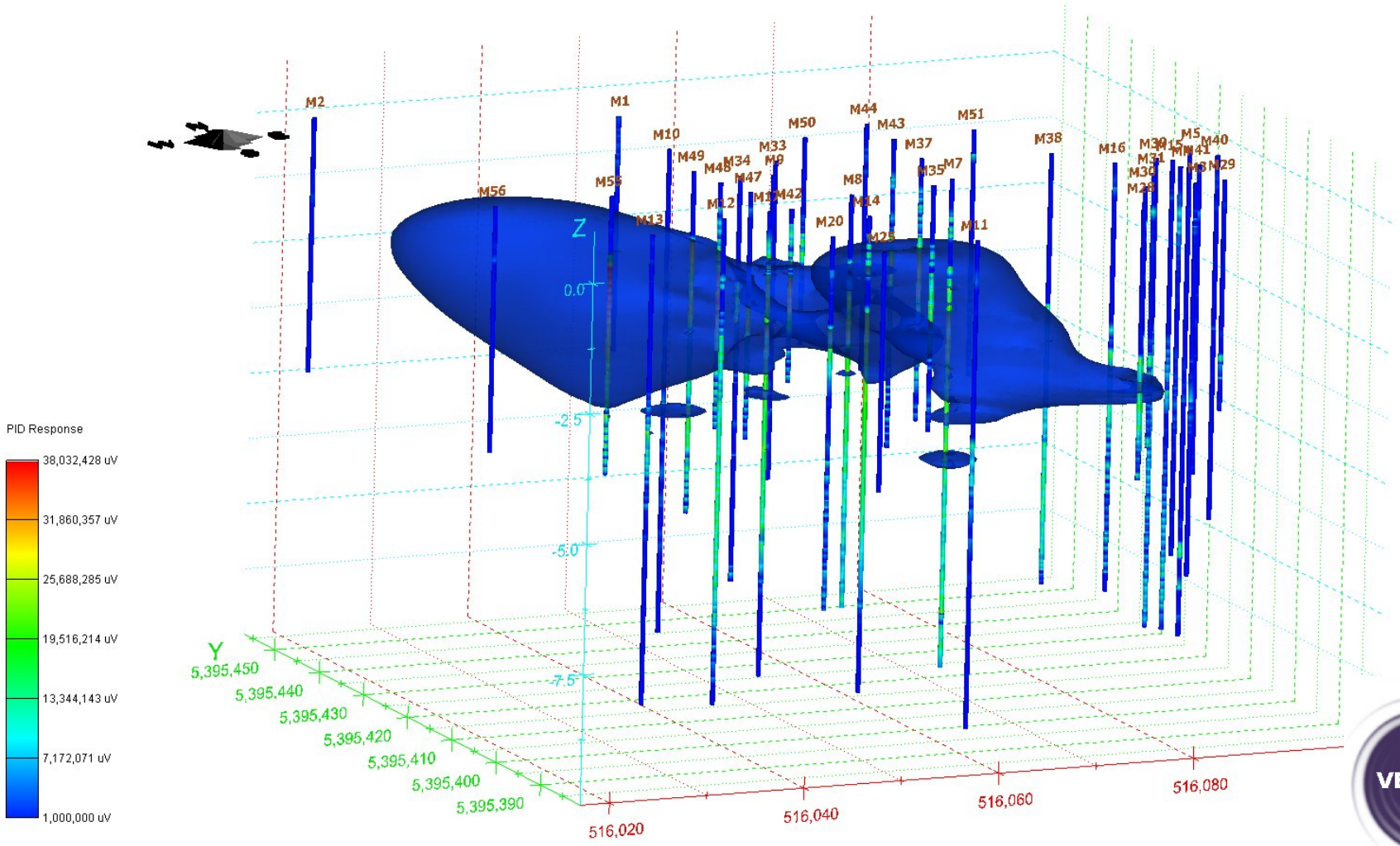
Characterization – Visualization



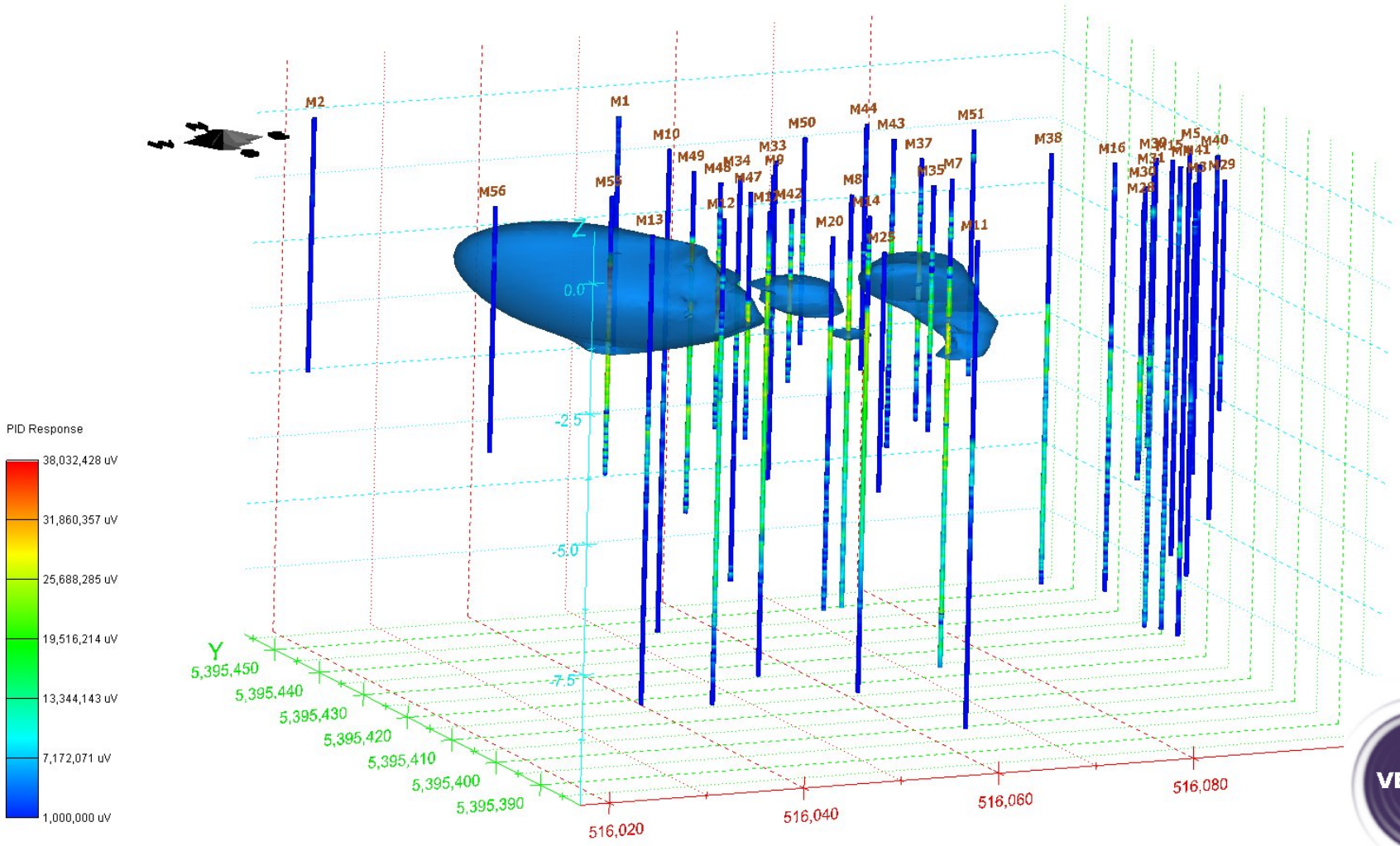
Characterization – Visualization



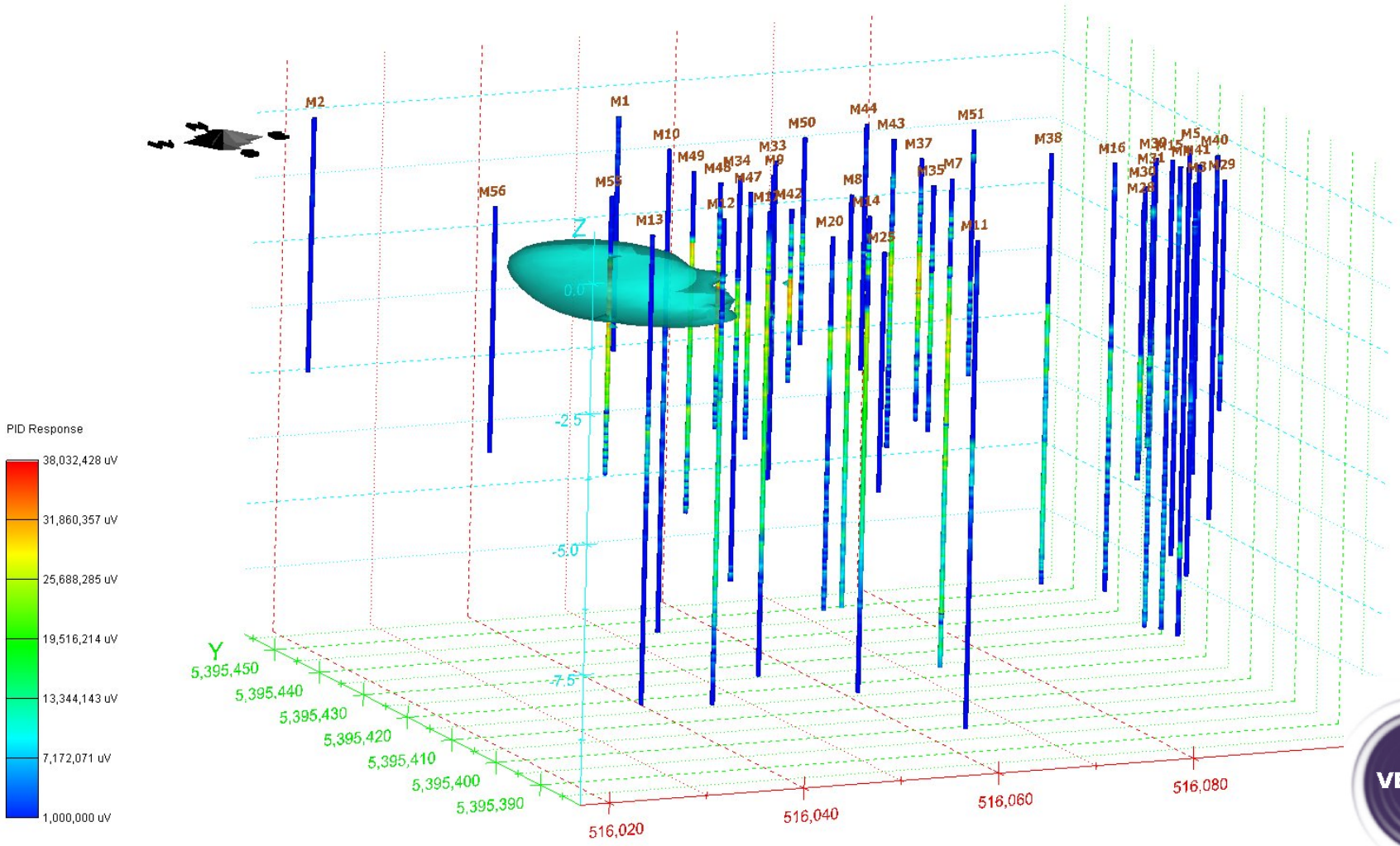
Characterization – Visualization



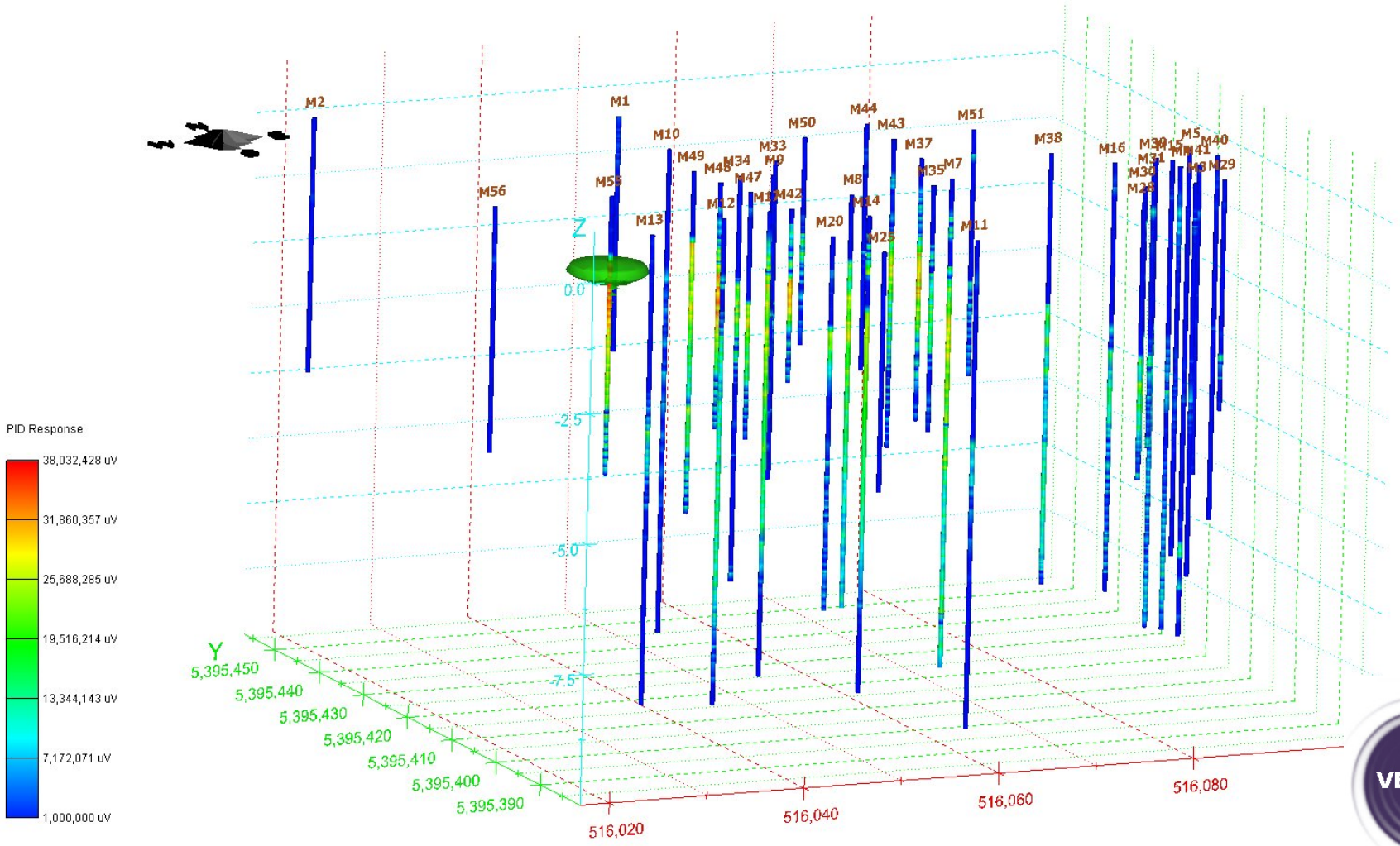
Characterization – Visualization

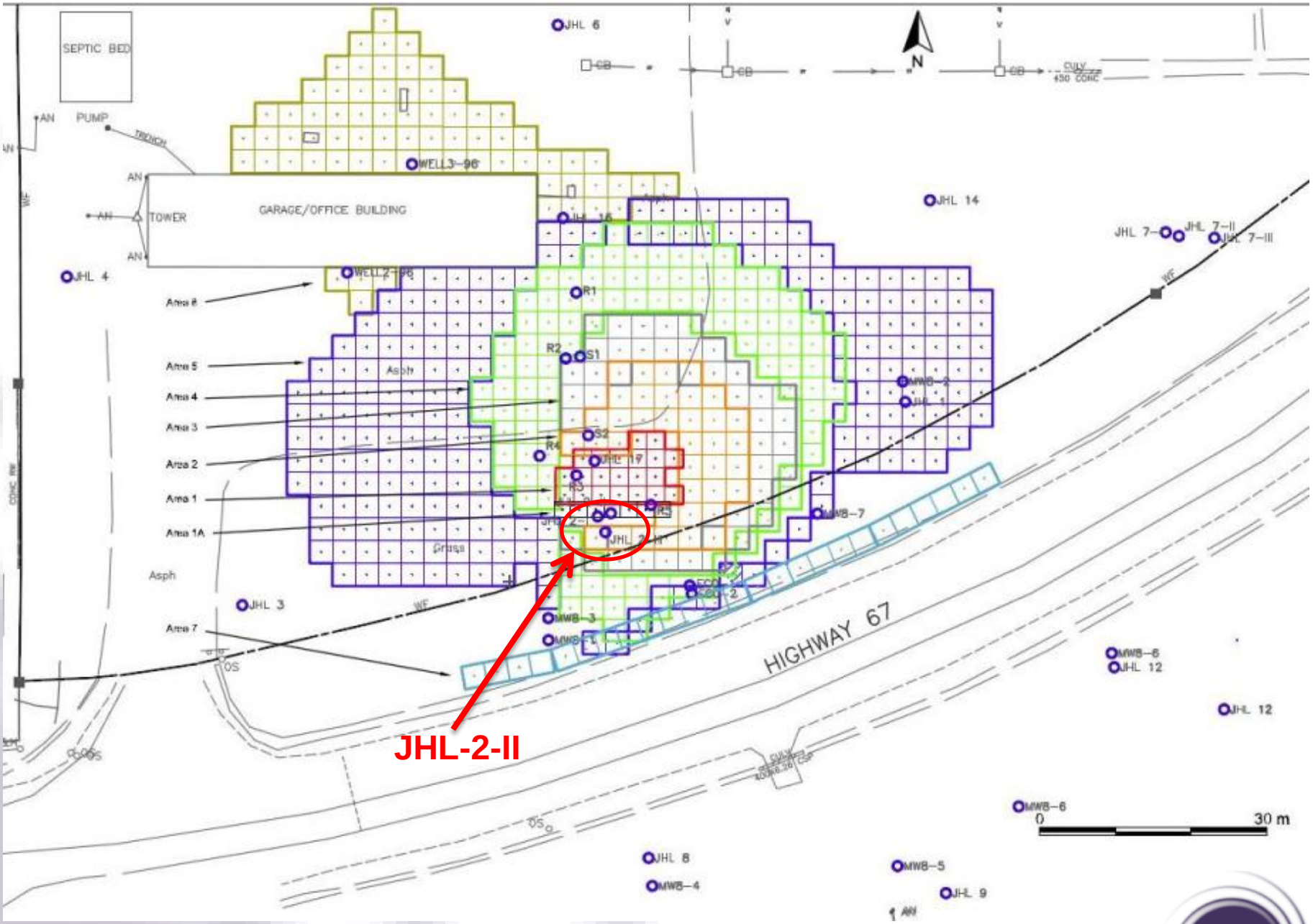


Characterization – Visualization

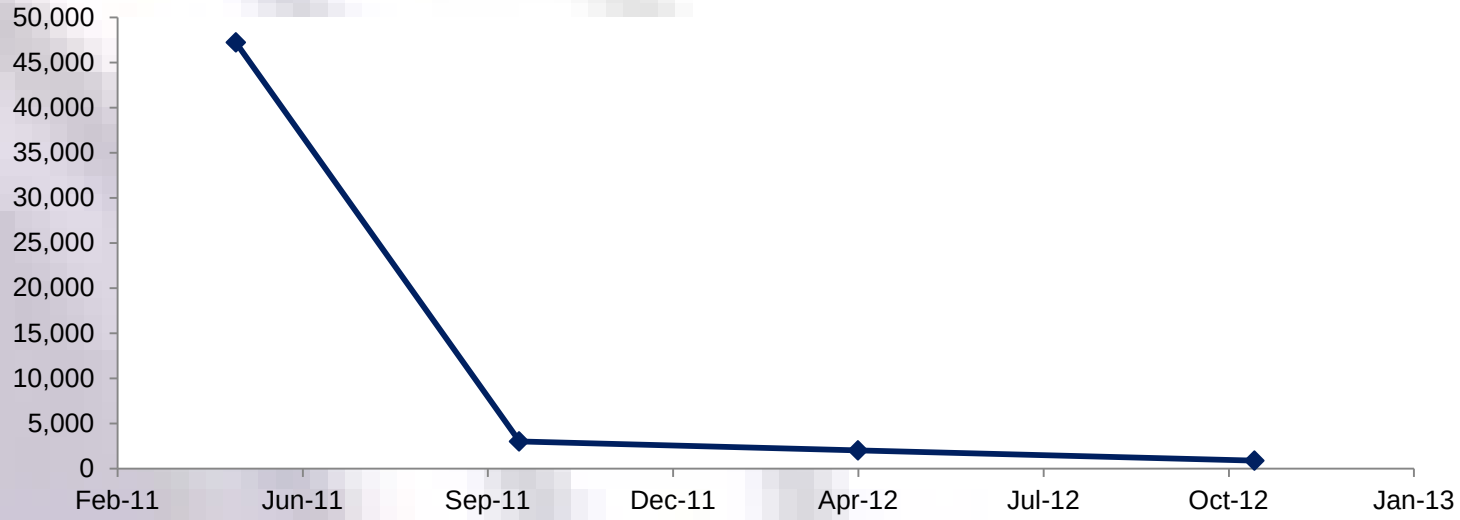


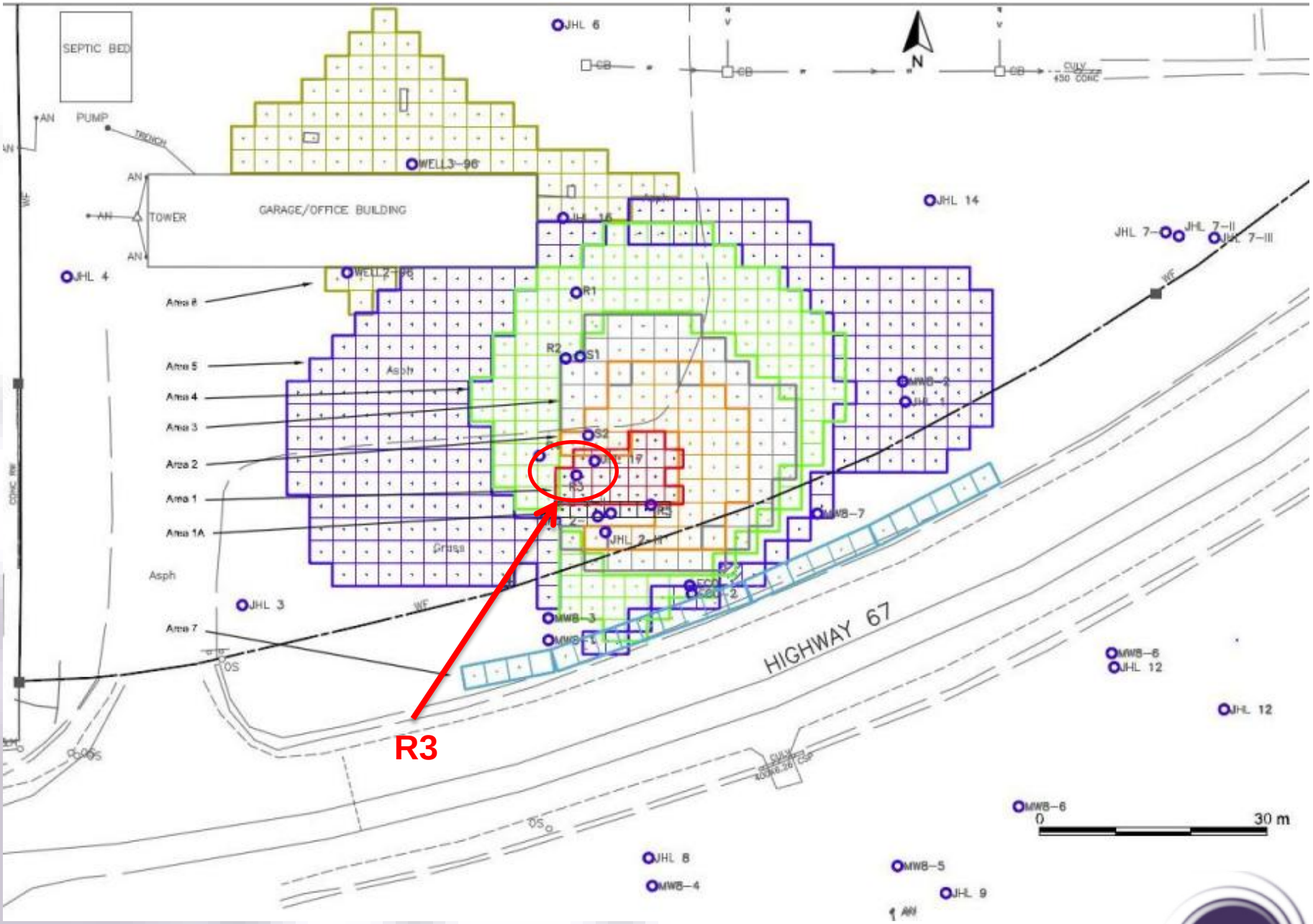
Characterization – Visualization



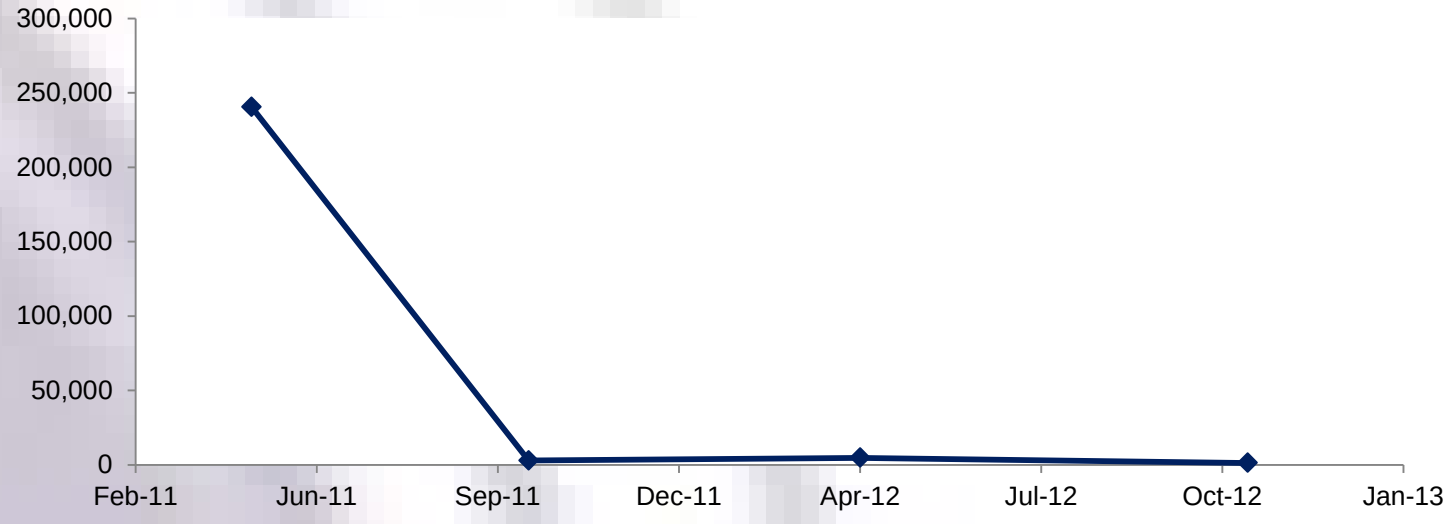

SEPTIC BED
PUMP
TRENCH
TOWER
GARAGE/OFFICE BUILDING
WELL3-96
WELL2-96
JHL 6
JHL 14
JHL 7-II
JHL 7-III
JHL 4
JHL 3
JHL 12
JHL 8
JHL 9
MWB-2
MWB-3
MWB-4
MWB-5
MWB-6
MWB-7
R1
R2
S1
S2
R4
R3
Area 8
Area 5
Area 4
Area 3
Area 2
Area 1
Area 1A
Area 7
Asph
Grass
HIGHWAY 67
JHL-2-II
N
0
30 m

PARAMETER	UNITS	MOE Groundwater Standards (1)	JHL2-II (11 m, 35 ft)				% Reduction
			May-11	Oct-11	Apr-12	Nov-12	
Benzene	ug/L	5.0	**9,500**	**1,100**	**450**	**60**	**99**
Ethylbenzene	ug/L	2.4	**690**	**46**	**300**	**14**	**98**
Toluene	ug/L	24	**9,100**	**780**	7	**130**	**99**
Xylenes (total)	ug/L	300	**2,900**	**1,100**	**410**	**160**	**94**
TPHg/d	ug/L	nv	-	-	-	-	-
PHC(F1-C6 to C10)	ug/L	750	**25,000**	<130	**850**	530	**98**
PHC(F2-C10 to C16)	ug/L	150	<100	<100	<100	<100	-
PHC(F3-C16 to C34)	ug/L	500	<100	<100	<100	<100	**-**
PHC(F4-C34 to C50)	ug/L	500	<100	<100	<100	<100	-
		Total	**47,190**	**3,026**	**2,017**	**894**	**98**

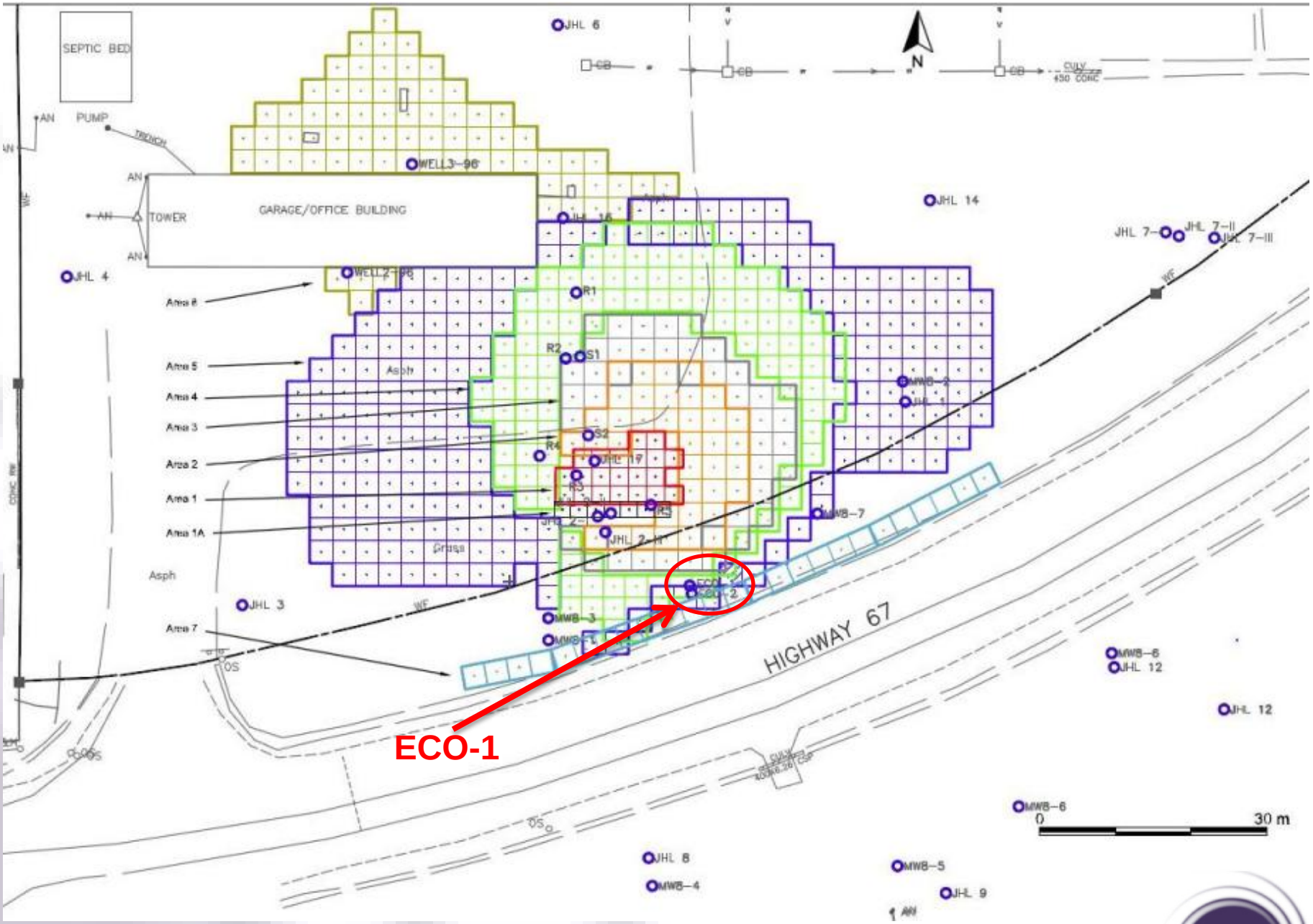



SEPTIC BED
PUMP
TRENCH
GARAGE/OFFICE BUILDING
TOWER
JHL 6
JHL 14
JHL 7
JHL 7-II
JHL 7-III
JHL 4
JHL 3
JHL 12
JHL 8
JHL 9
WELL3-96
WELL2-96
R1
R2
S1
S2
R3
MW8-2
MW8-7
MW8-3
MW8-6
MW8-5
MW8-4
Area 8
Area 5
Area 4
Area 3
Area 2
Area 1
Area 1A
Area 7
Asph
Grass
HIGHWAY 67
R3
0
30 m
VERTEX

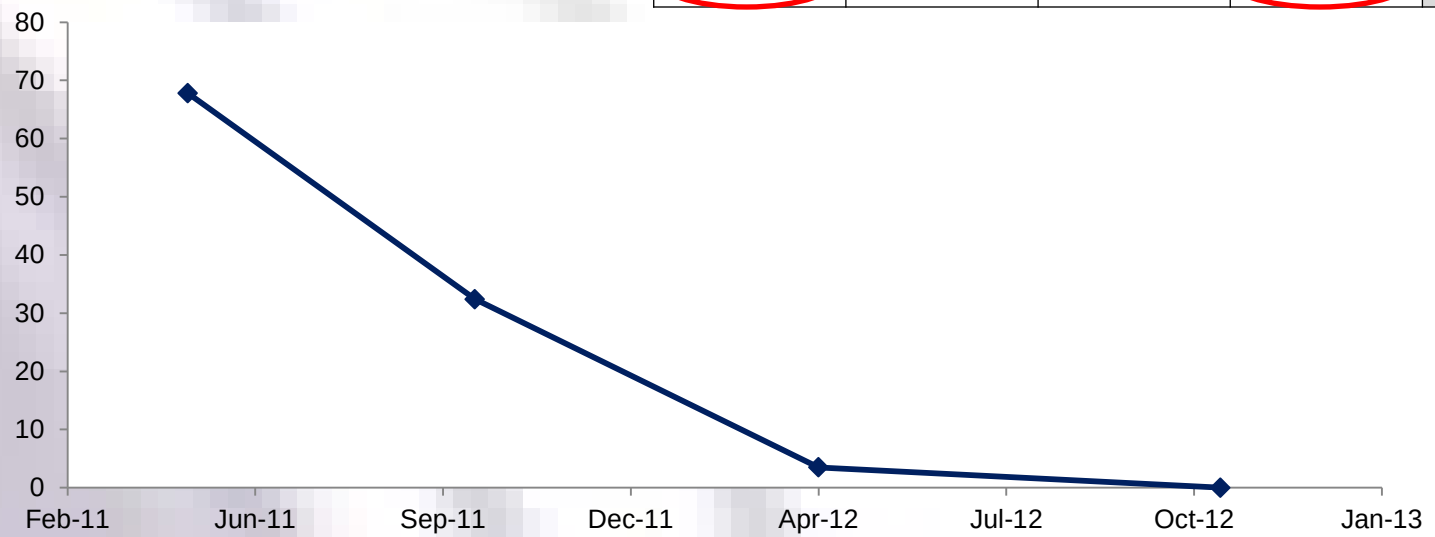
PARAMETER	UNITS	MOE Groundwater Standards (1)	R3				% Reduction
			May-11	Oct-11	Apr-12	Nov-12	
Benzene	ug/L	5.0	**2,100**	**170**	**540**	**150**	**93**
Ethylbenzene	ug/L	2.4	**2,300**	**<1.0**	**510**	**22**	**99**
Toluene	ug/L	24	**15,000**	**370**	**79**	**200**	**99**
Xylenes (total)	ug/L	300	**15,000**	**1,100**	**1,100**	200	**99**
TPHg/d	ug/L	nv	-	-	-	-	-
PHC(F1-C6 to C10)	ug/L	750	**140,000**	**1,100**	**2,400**	**770**	**99**
PHC(F2-C10 to C16)	ug/L	150	**61,000**	**160**	110	<100	**100**
PHC(F3-C16 to C34)	ug/L	500	**4,300**	<100	<100	<100	**-**
PHC(F4-C34 to C50)	ug/L	500	**790**	<100	<100	<100	-
		Total	**240,490**	**2,900**	**4,739**	**1,342**	**99**



VERTEX


SEPTIC BED
PUMP
TRENCH
GARAGE/OFFICE BUILDING
TOWER
WELL3-96
WELL2-96
JHL 6
JHL 14
JHL 7-I
JHL 7-II
JHL 7-III
JHL 4
JHL 3
JHL 12
JHL 8
JHL 9
MWB-2
MWB-3
MWB-4
MWB-5
MWB-6
MWB-7
R1
R2
R3
R4
S1
S2
Area 8
Area 5
Area 4
Area 3
Area 2
Area 1
Area 1A
Area 7
Asph
Grass
HIGHWAY 67
ECO-1
ECO-2
N
0
30 m
VERTEX

PARAMETER	UNITS	MOE Groundwater Standards (1)	ECO-1				% Reduction
			May-11	Oct-11	Apr-12	Nov-12	
Benzene	ug/L	5.0	**51**	**12**	**4**	<0.2	**100**
Ethylbenzene	ug/L	2.4	**8**	**5**	<0.20	<0.20	**98**
Toluene	ug/L	24	**3**	**7**	<0.20	<0.20	**93**
Xylenes (total)	ug/L	300	**6**	**8**	<0.40	<0.40	**93**
TPHg/d	ug/L	nv	-	-	-	-	-
PHC(F1-C6 to C10)	ug/L	750	<100	<25	<25	<25	-
PHC(F2-C10 to C16)	ug/L	150	<100	<100	<100	<100	-
PHC(F3-C16 to C34)	ug/L	500	<100	<100	<100	<100	-
PHC(F4-C34 to C50)	ug/L	500	<100	<100	<100	<100	-
		Total	**68**	**32**	**4**	**<0.40**	**100**



VERTEX

Case Study

- Average PHC groundwater mass reduction across Site = 96% to date
- Laser-Induced Fluorescence
  - safe commencement of ISCO
- Membrane Interface Probe
  - Fill in data gaps and ISCO re-design
- Intelligent use of Advanced Characterization tools resulted in excellent in-situ treatment

VERTEX

Closing

- Laser-Induced Fluorescence (LIF)
  - Define free phase (LNAPL)
- Membrane Interface Probe (MIP)
  - Define dissolved phase
- Both tools are quick, cost-effective and provide orders of magnitude more data than traditional techniques
- More data = better visualization

VERTEX

Questions?

Thank You for Your Time

Bruce Tunnicliffe
Vertex Environmental Inc.
(519) 653-8444 x304
(519) 249-9184 mobile
brucet@vertexenvironmental.ca

www.vertexenvironmental.ca