Introduction to 3-D Mapping Techniques

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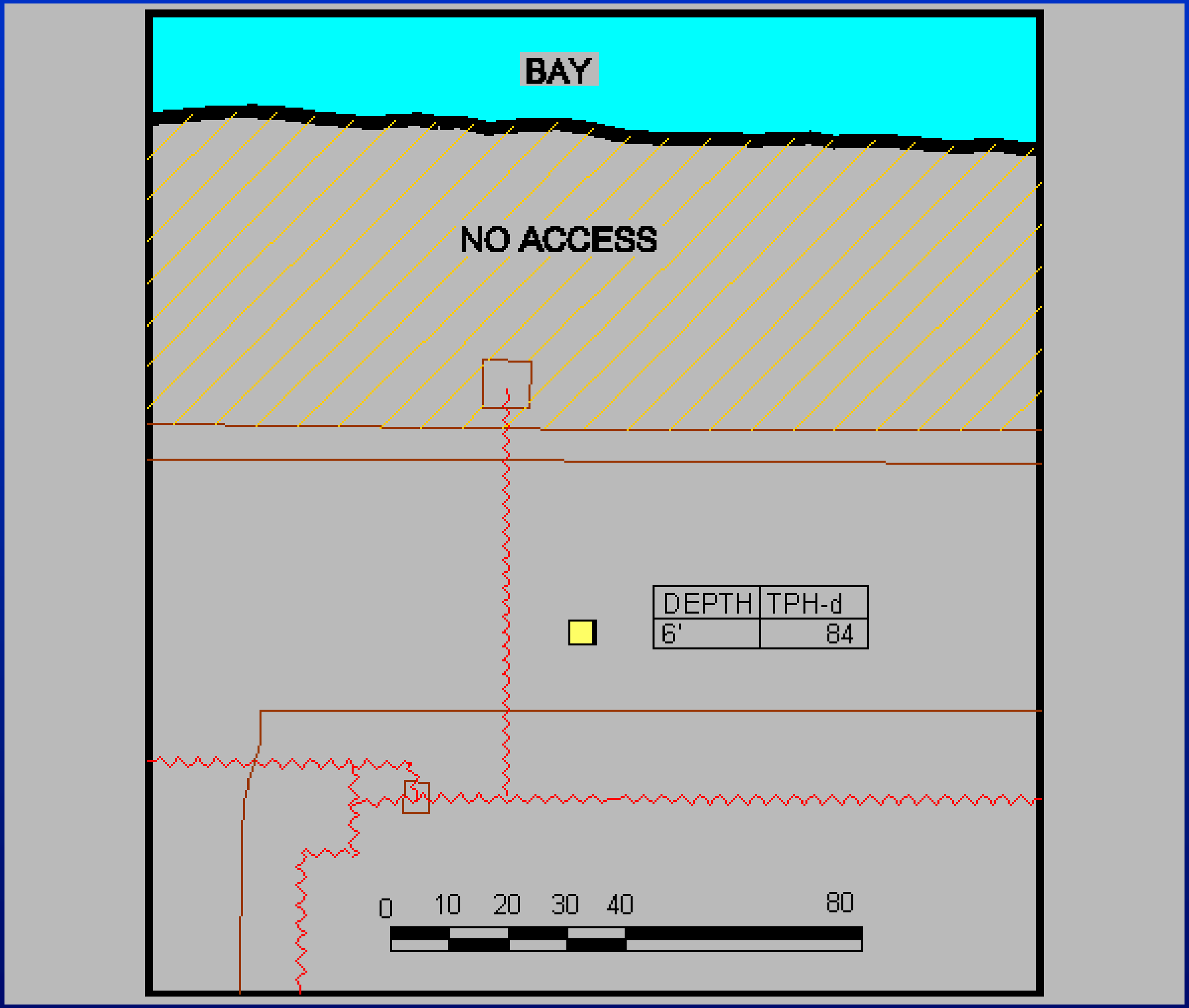
NAVFAC
Naval Facilities Engineering Command

Why Use 3-D Mapping Techniques?

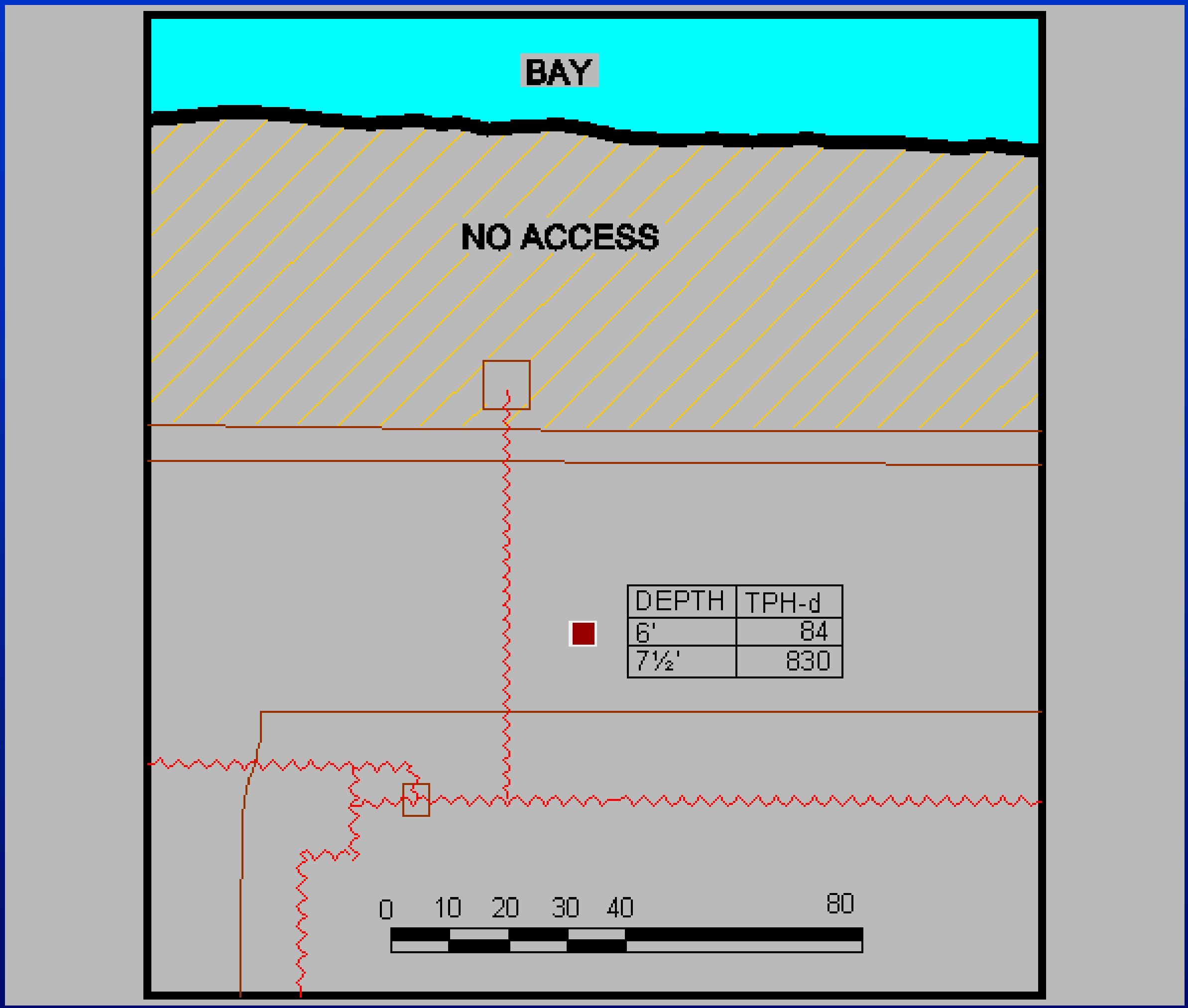
- Typical sampling plans have low sample density due to high analytical costs.



Fuel Pipeline Site, investigated by Navy PWC San Diego SCAPS, 1998

Low Sample Density Does Not Adequately Address Heterogeneity

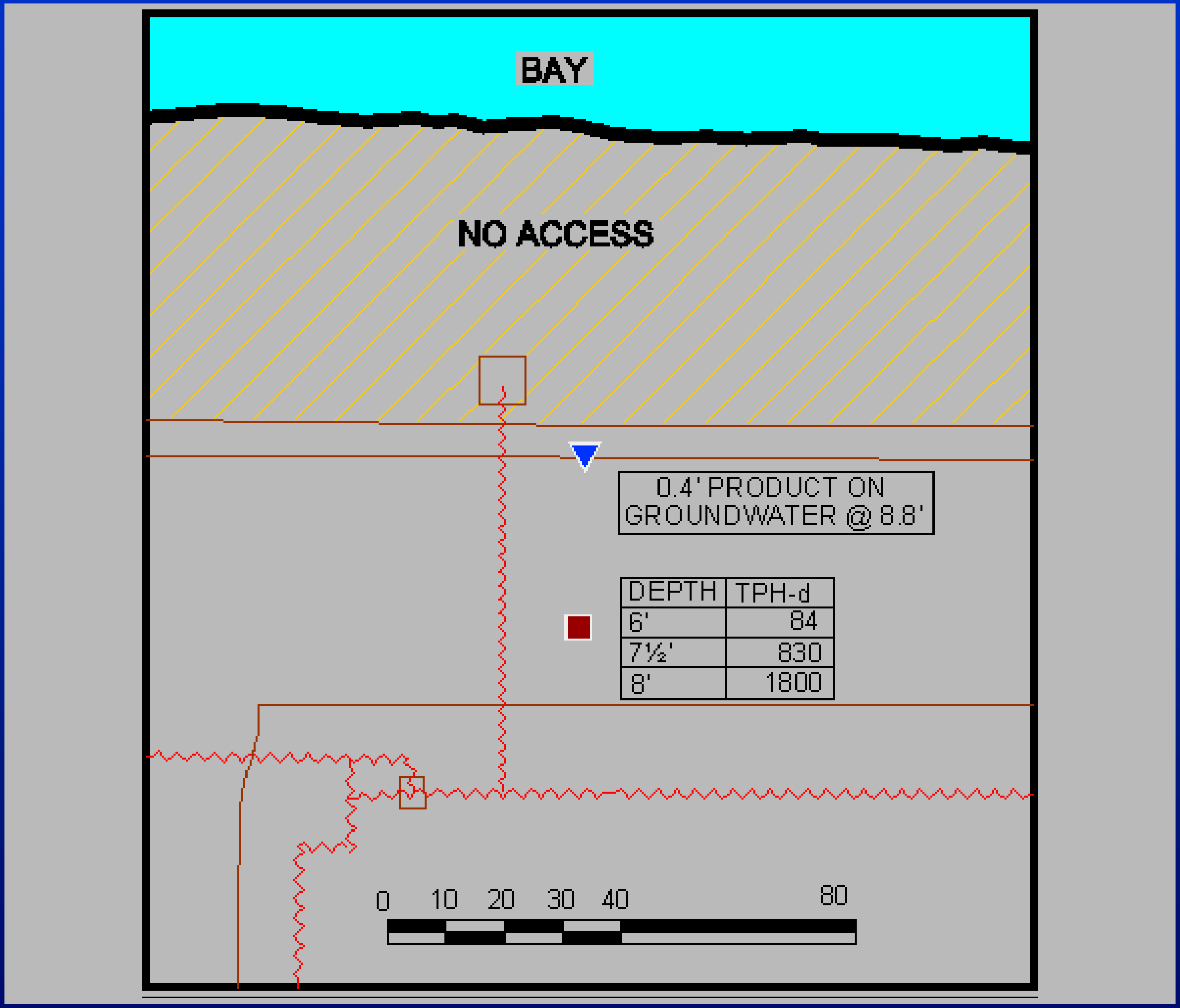
- In this case, a sample 18 inches deeper was significantly more contaminated.



Fuel Pipeline Site, investigated by Navy PWC San Diego SCAPS, 1998

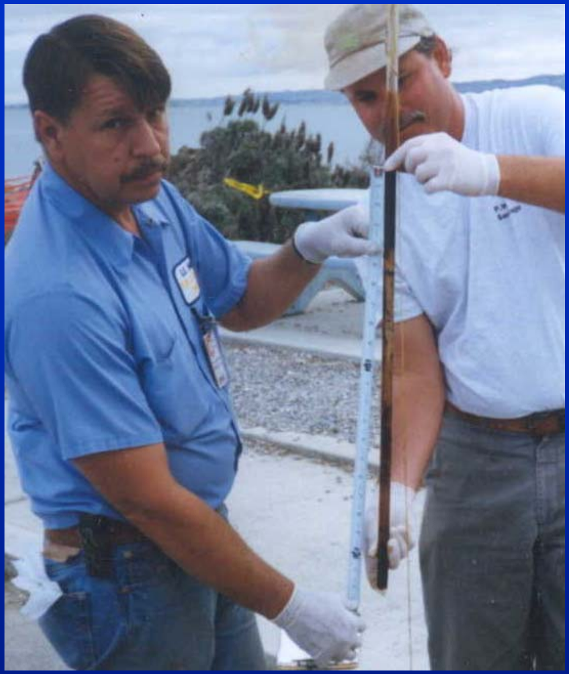
Discounting Heterogeneity Can Lead to an Inaccurate Conceptual Site Model

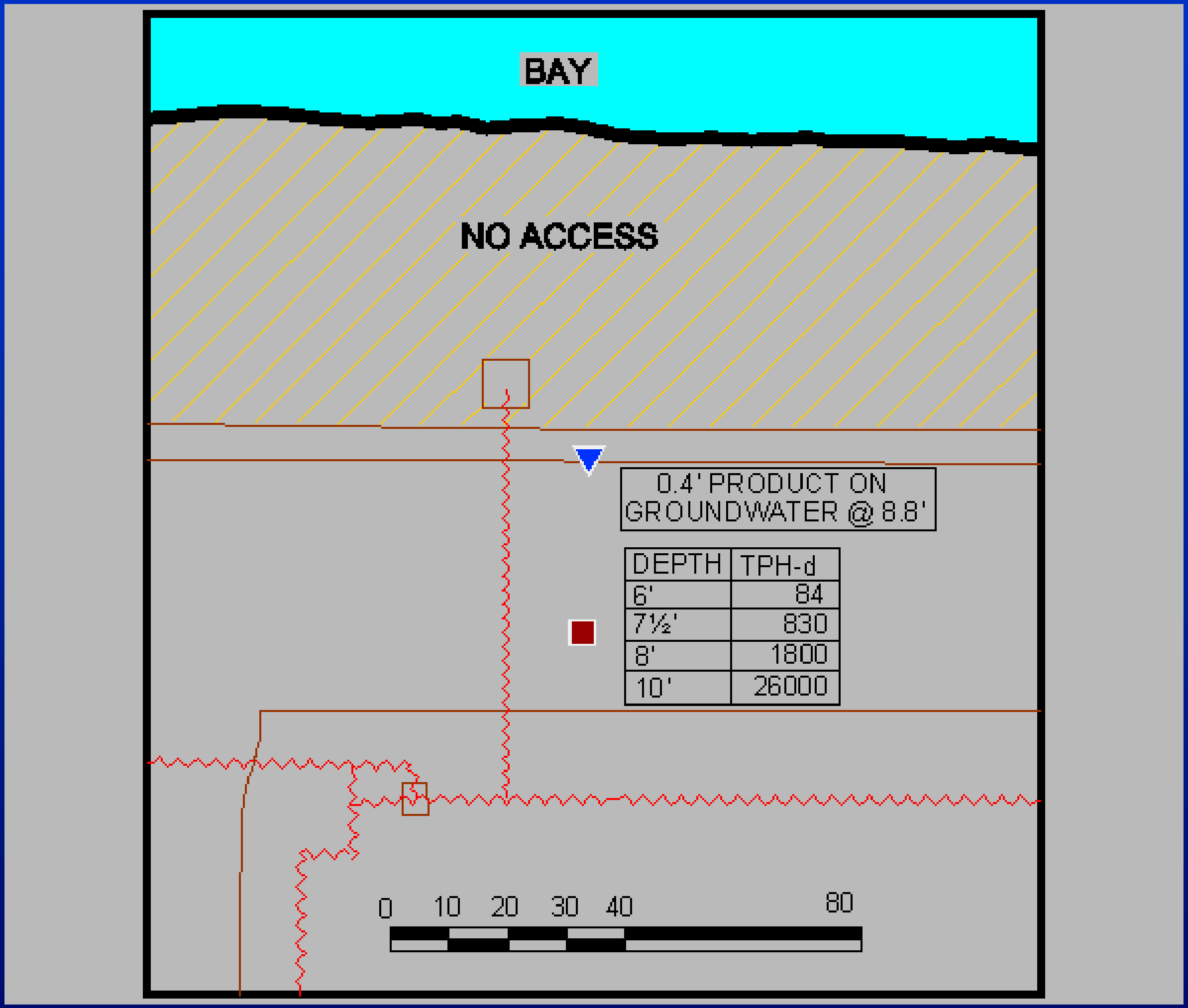
- Six more inches deeper, contamination more than doubled.
- Free product found 30 feet away.



Fuel Pipeline Site, investigated by Navy PWC San Diego SCAPS, 1998

An Inaccurate CSM Can Lead to Poor Decisions



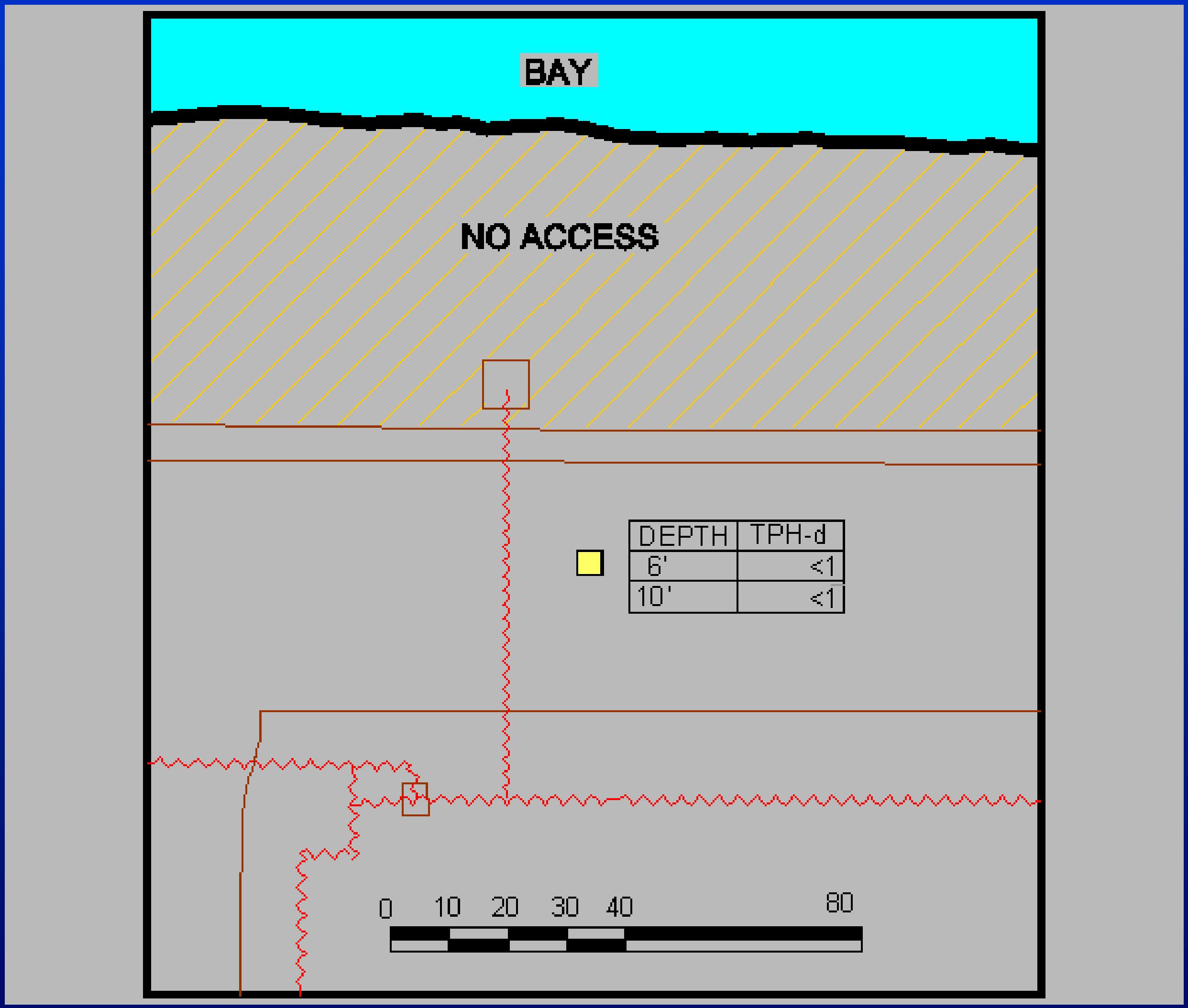


- Even higher levels of contamination 2 feet down.

Fuel Pipeline Site, investigated by Navy PWC San Diego SCAPS, 1998

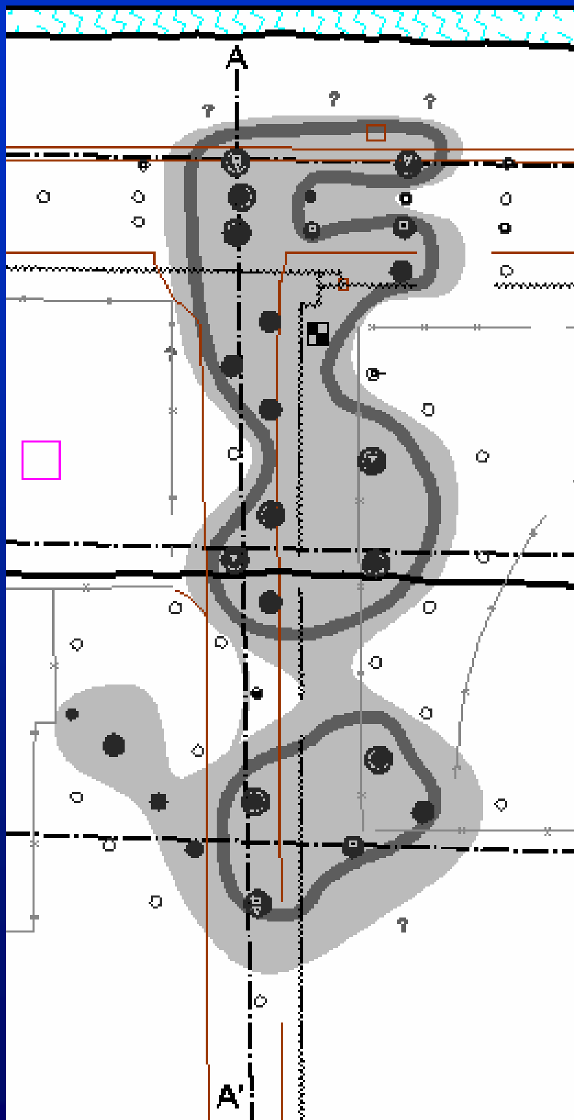
Without High Sample Density, Each Analytical Result Can Carry Too Much Decision Importance

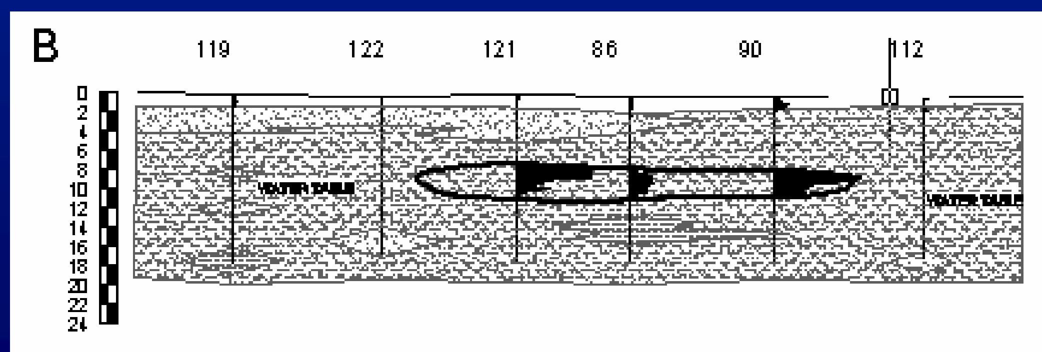
- Clean soil found in between contaminated sample locations.



Fuel Pipeline Site, investigated by Navy PWC San Diego SCAPS, 1998

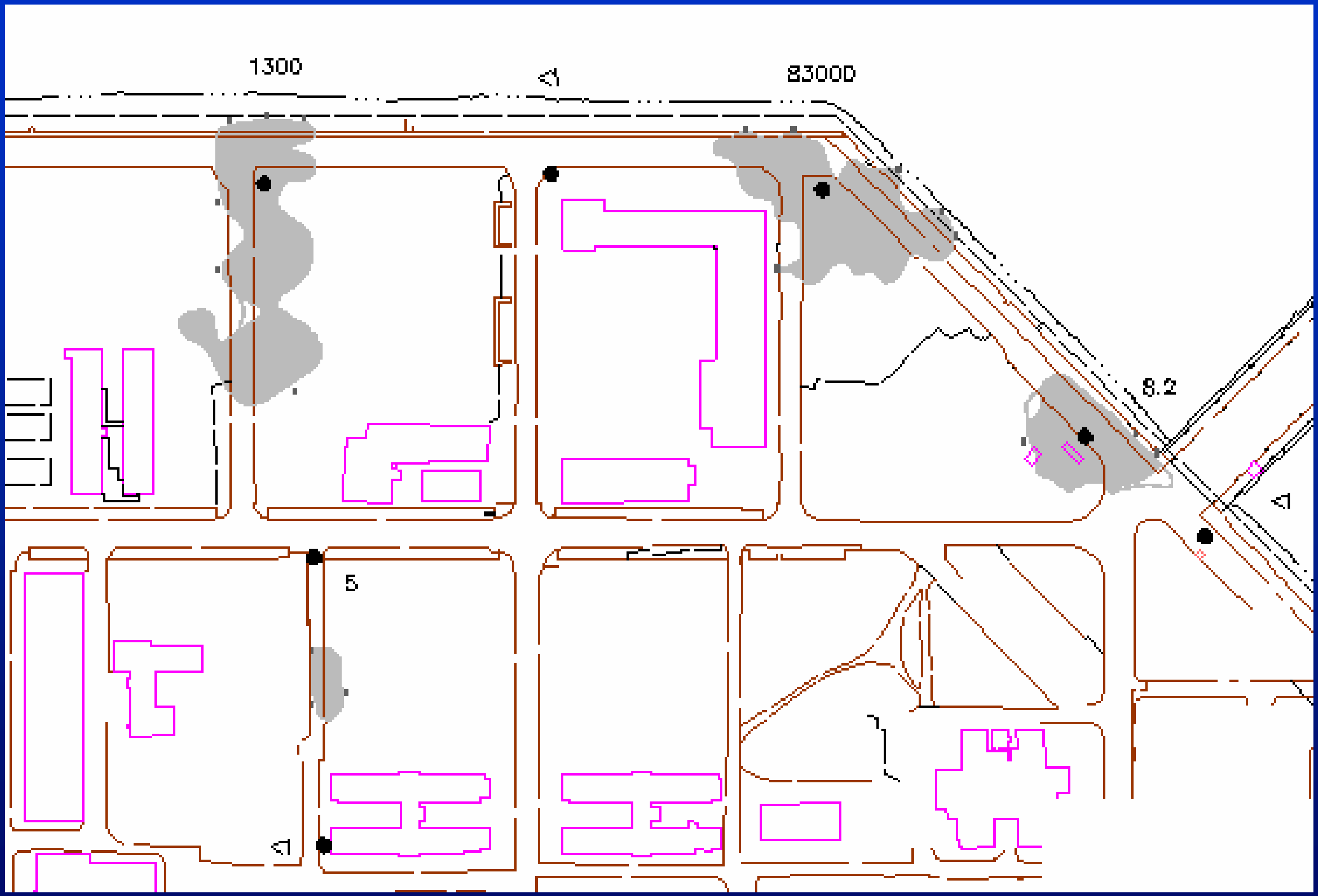
3-D Mapping Techniques Provide Detailed Characterization





Fuel Pipeline Site, investigated by Navy PWC San Diego SCAPS, 1998

Real-Time In-Place 3-D Mapping Tools Can Give More Data for the Dollar



Fuel Pipeline Site, investigated by Navy PWC San Diego SCAPS, 1998

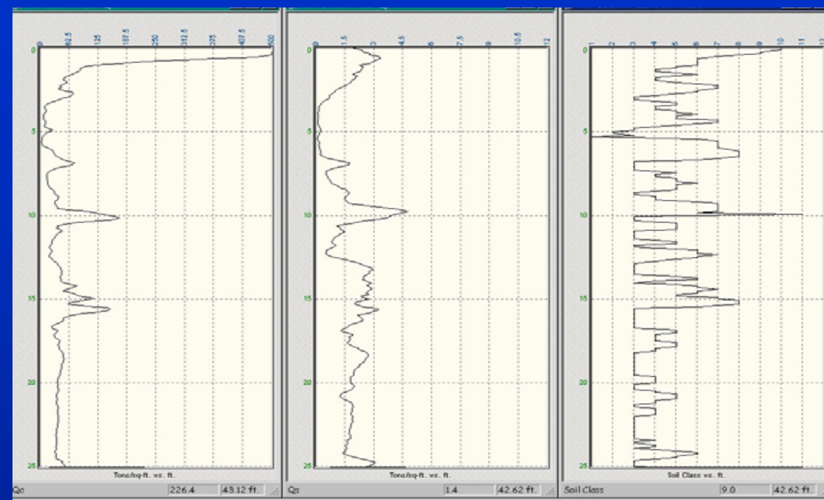
Using CPT Data to Field-Design a Small-Diameter Well

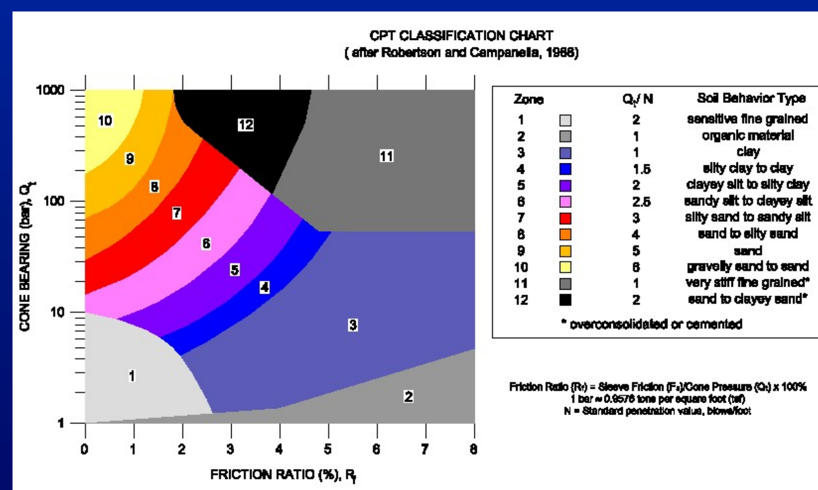
Before setting well:

- *Collected CPT data for stratigraphy*
- *Collected soil samples for contaminant data*
- *Set temporary piezometer*

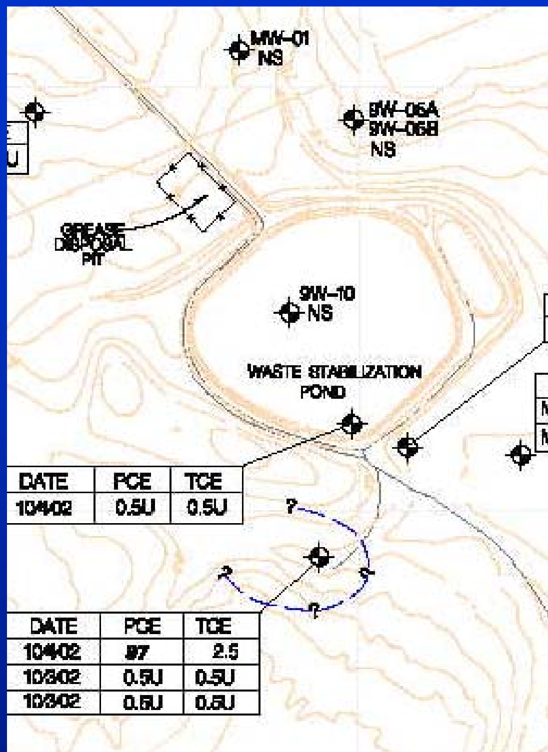
Cone Penetrometer Test

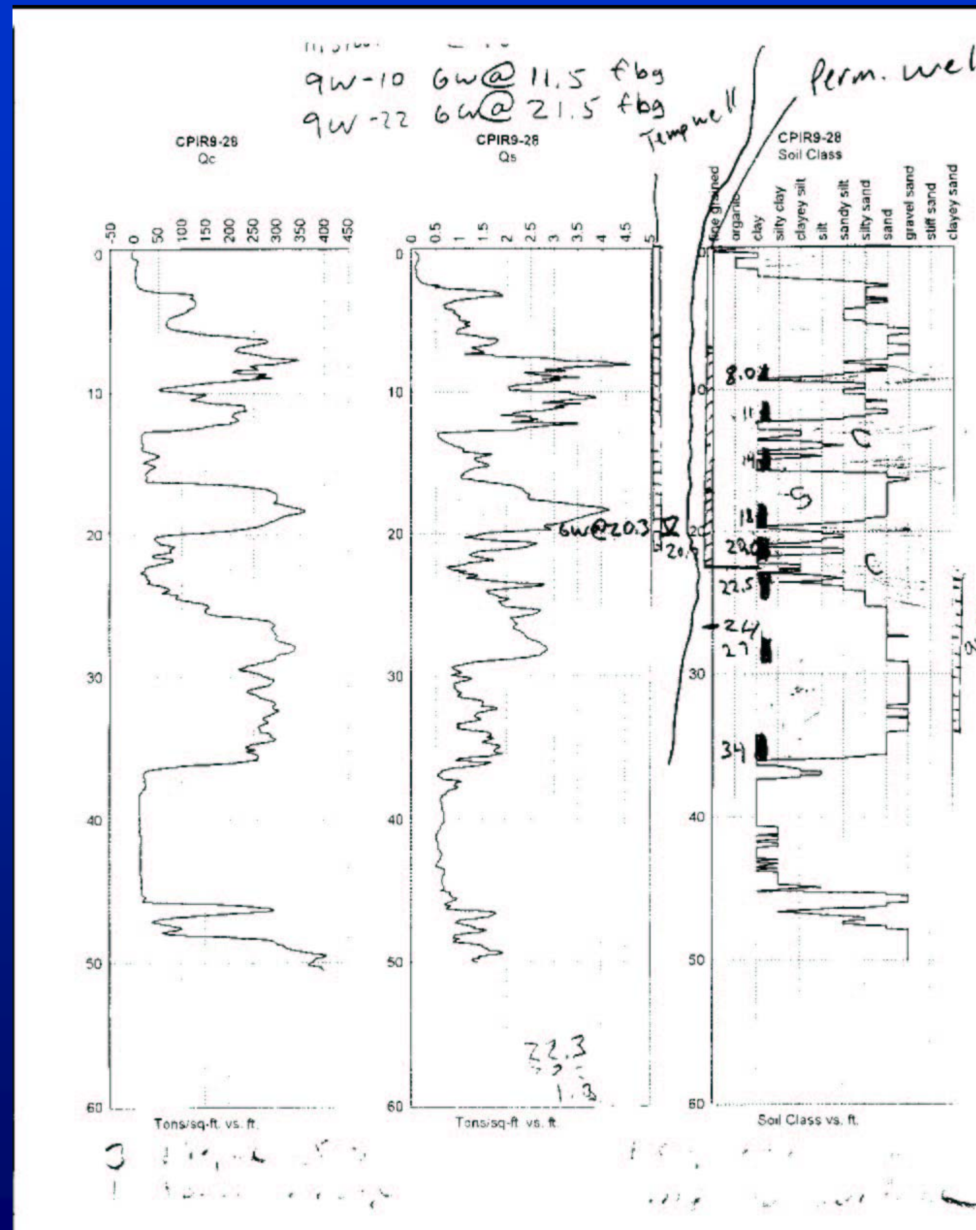
- Standard Cone Penetrometer (CPT) tip resistance and sleeve friction data are collected according to ASTM standards
- CPT data is analyzed by a neural net algorithm, and soil classifications are displayed in real time with the contaminant sensor data





Real-Time Data for Well Sampling Design





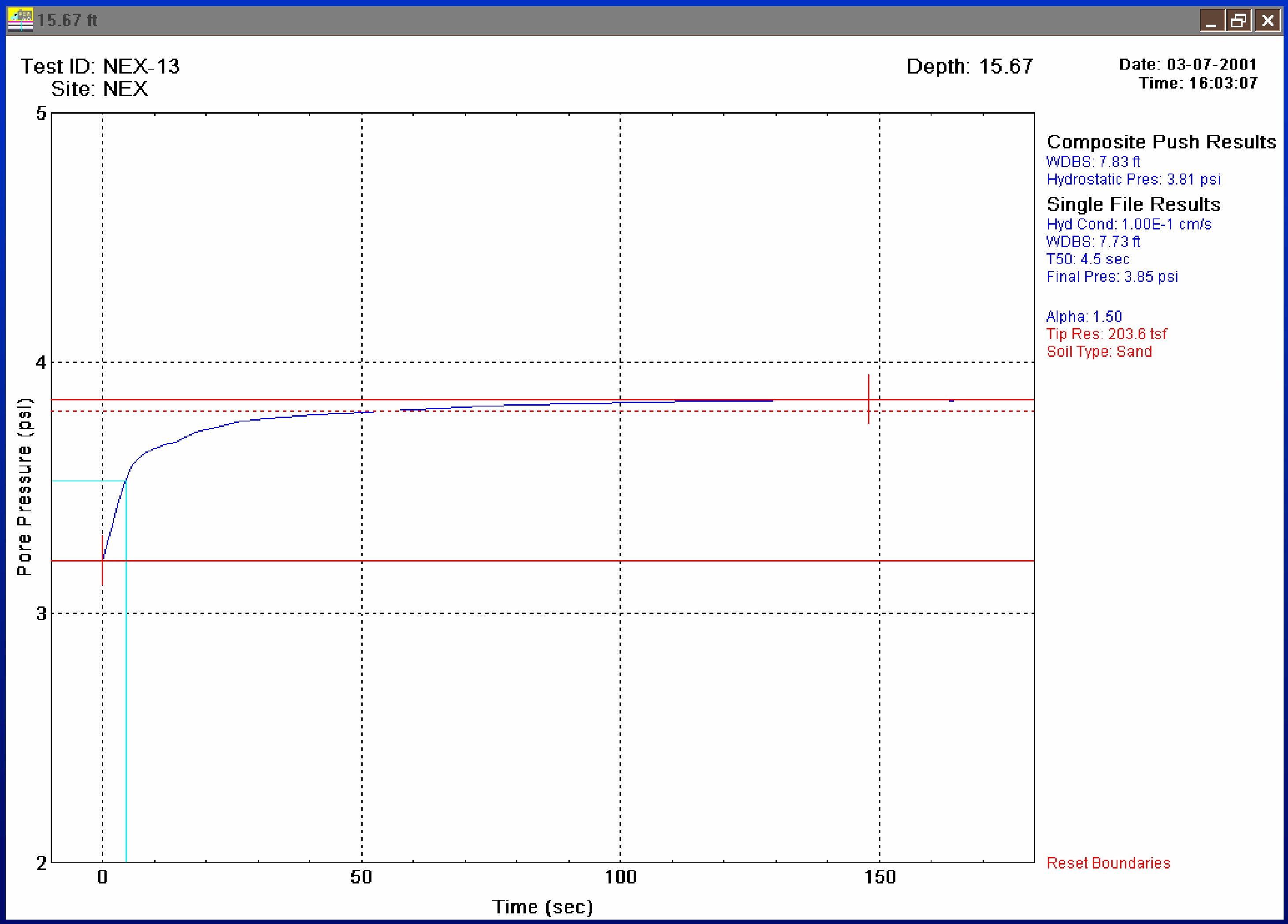
High Resolution Piezocone

Groundwater 3-D Mapping Tool

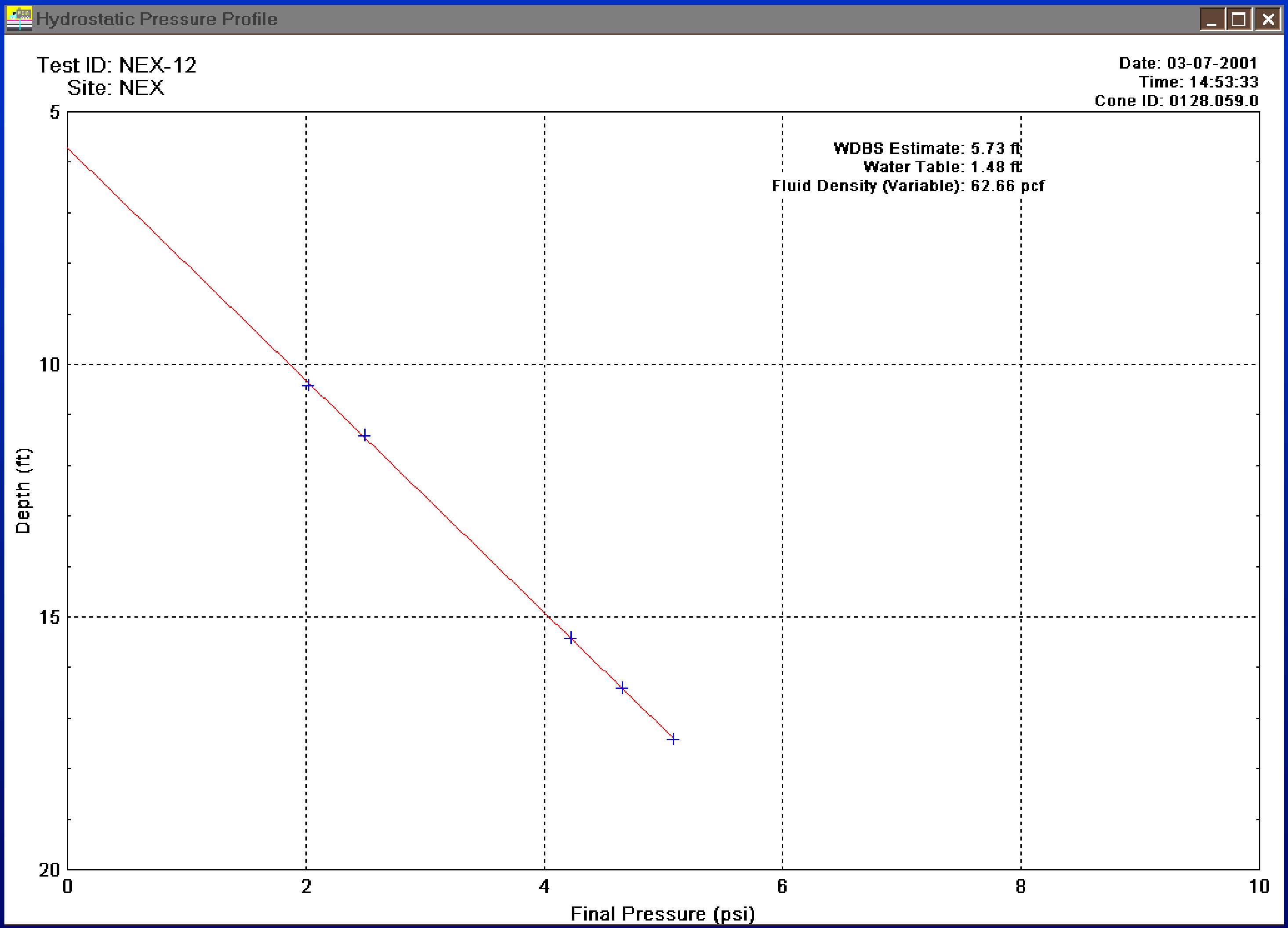
By Mark Kram, Naval Facilities Engineering Service Center

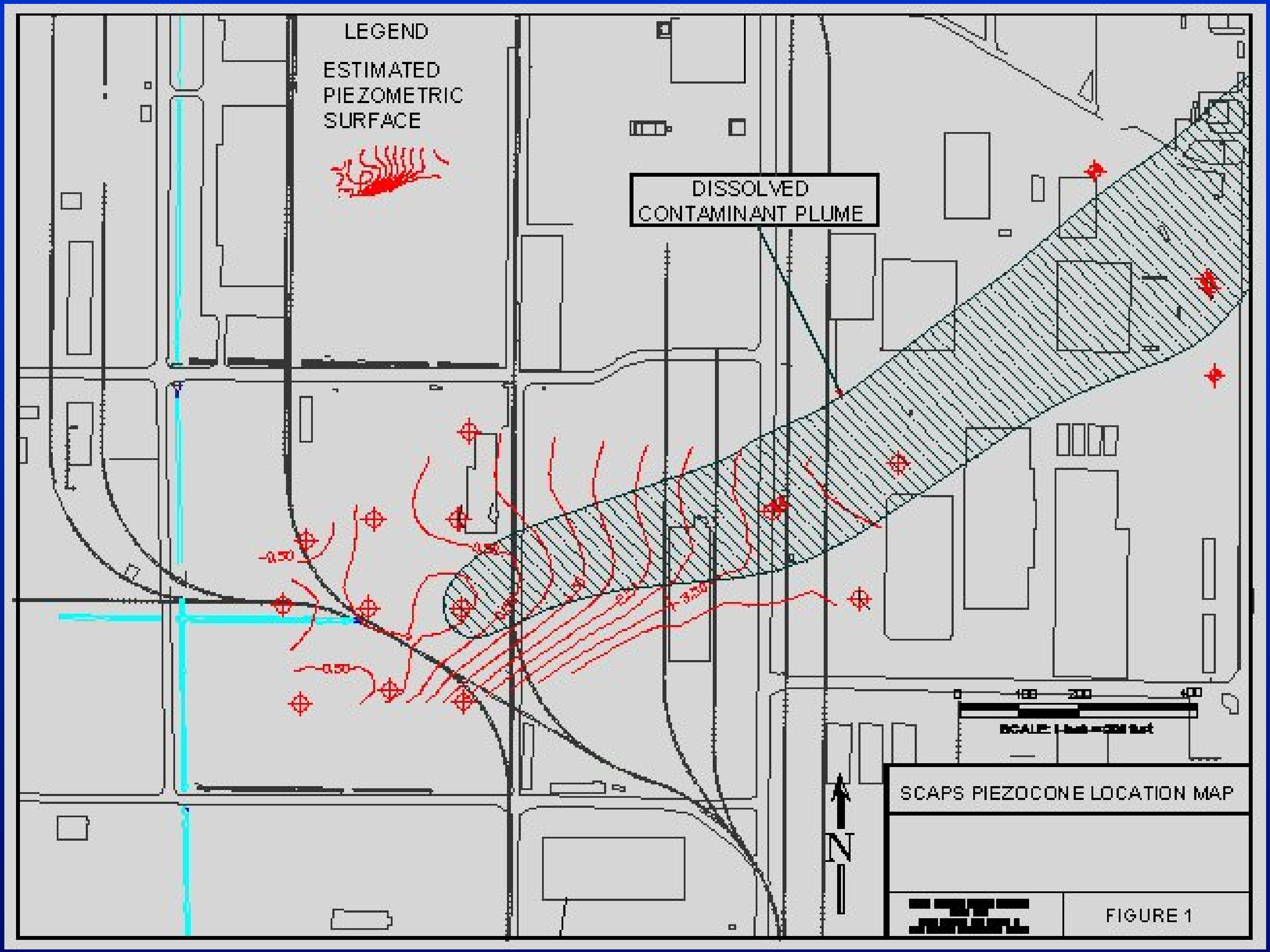
High resolution piezocone system and dissipation software developed by Naval Facilities Engineering Service Center

Pore Pressure Dissipation Curve at Discrete Depth

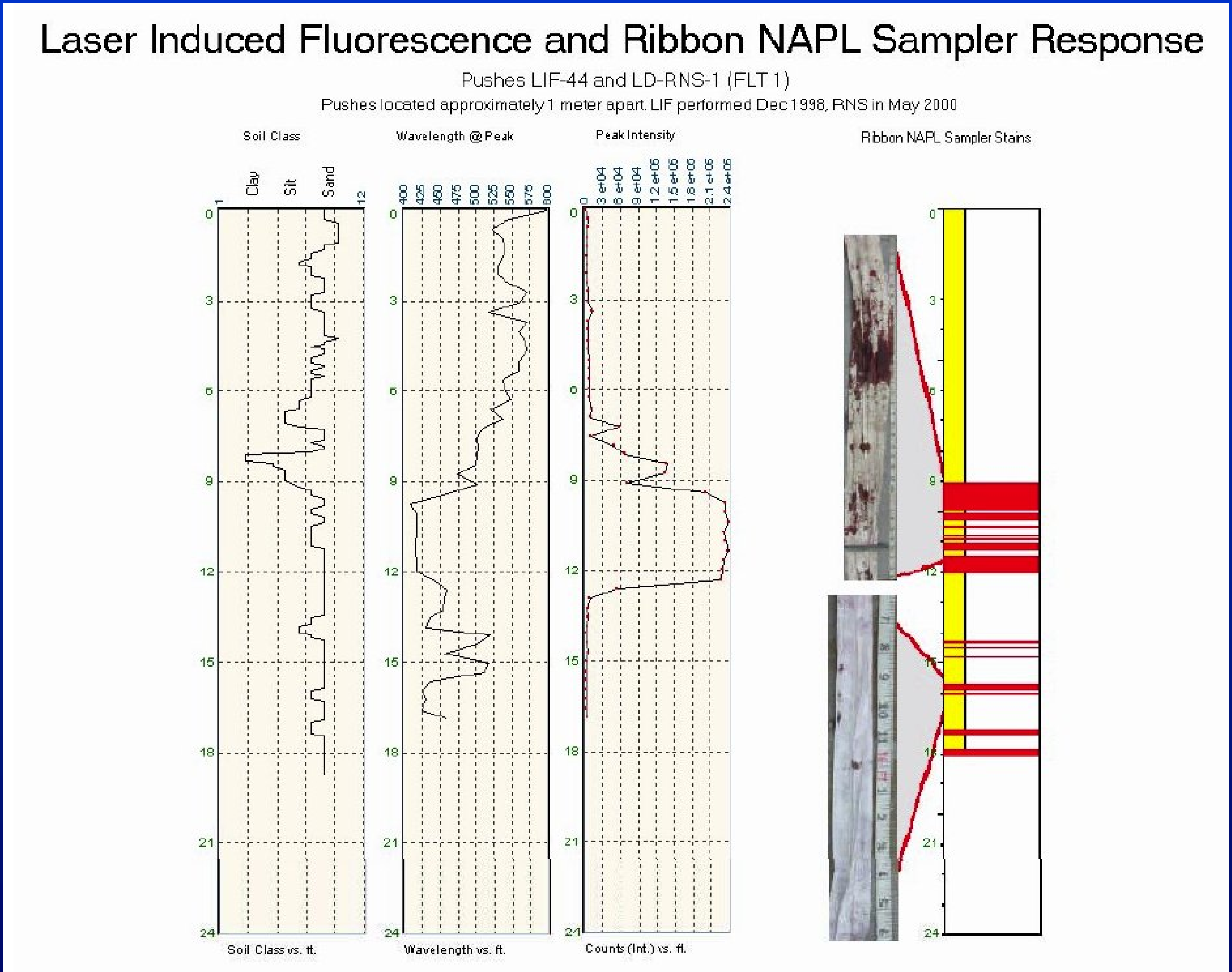


Depth to Groundwater Calculation Using Final Dissipation Pressures




LEGEND
ESTIMATED
PIEZOMETRIC
SURFACE
DISSOLVED
CONTAMINANT PLUME
-0.50
0
100
200
400
N
SCAPS PIEZOCONE LOCATION MAP
FIGURE 1

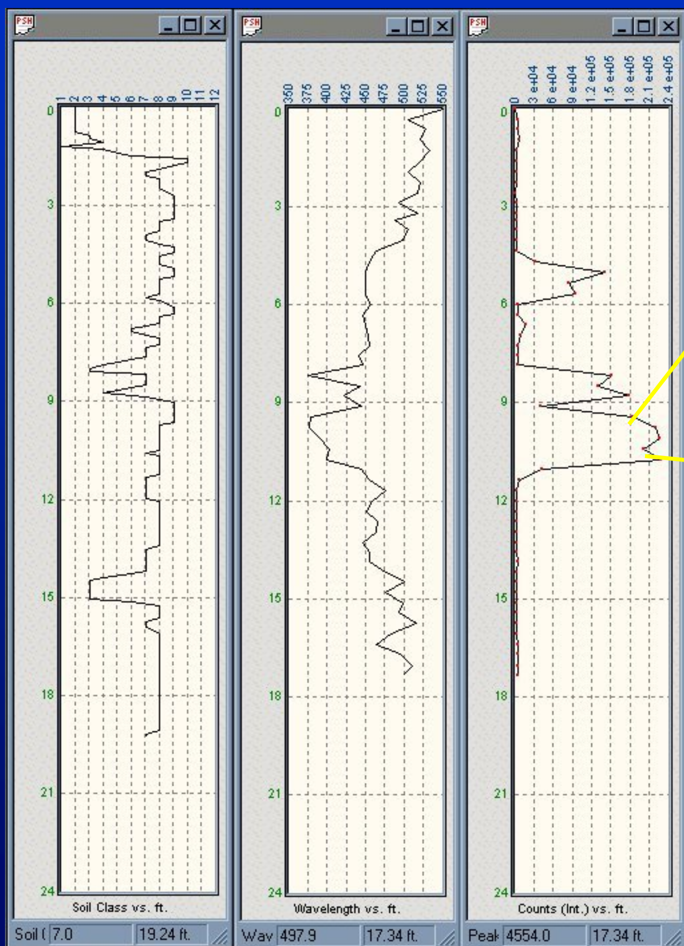
Continuous Logs for Contaminants



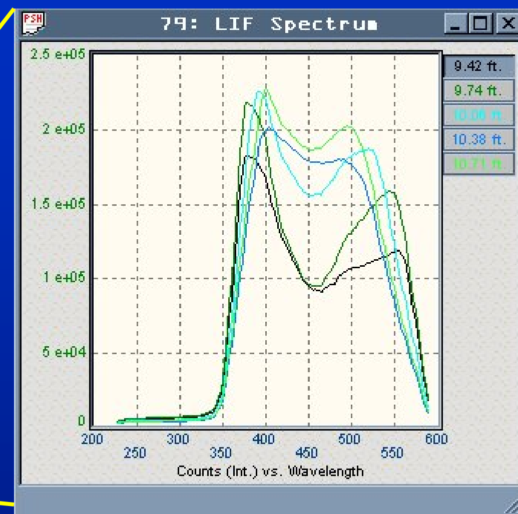
“Confirmation” Sampling and Small Scale Subsurface Heterogeneity

LIF Profiles

Soil *Wavelength* *Intensity*



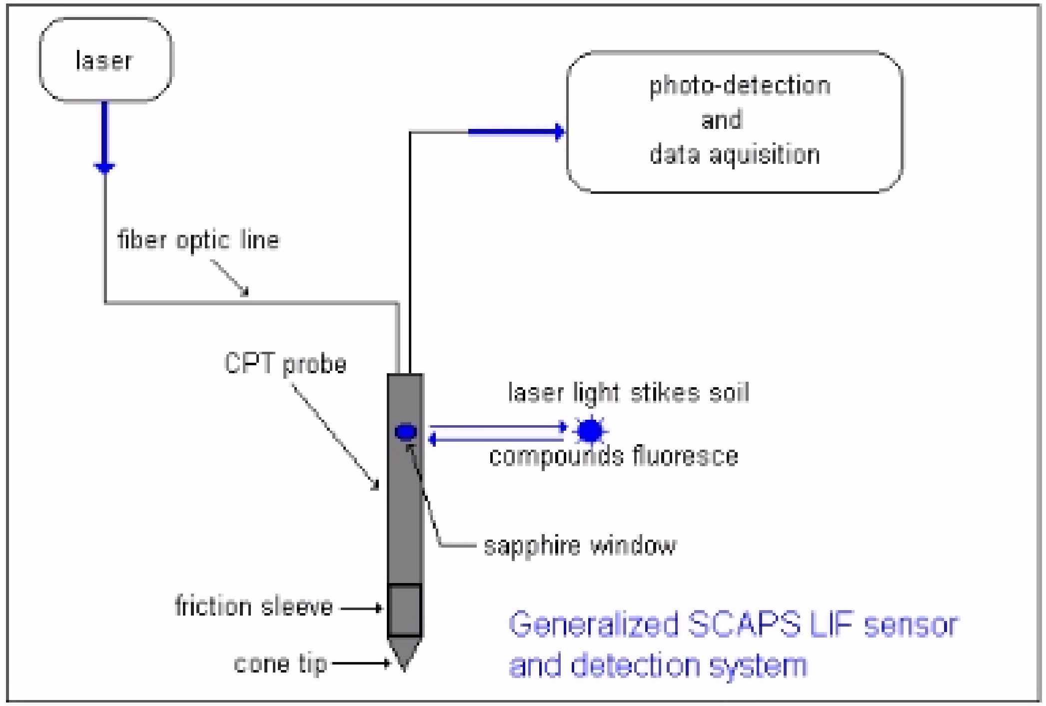
LIF Spectra

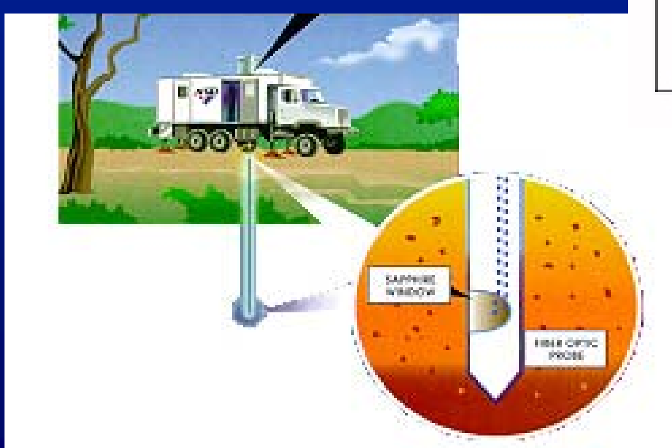


- *LIF suggests free product*
- *TPH-gas = 953 mg/kg*
- *TPH-diesel = 2,920 mg/kg*
- ***Fuel saturation of 6-inch sample tube = 28.9 %***

Petroleum Hydrocarbons
SCAPS Laser-Induced Fluorescence

- Laser Source: Ultraviolet (308 nm) Xenon Chloride Eximer laser
- Excites 2-ring and greater Polycyclic Aromatic Hydrocarbons





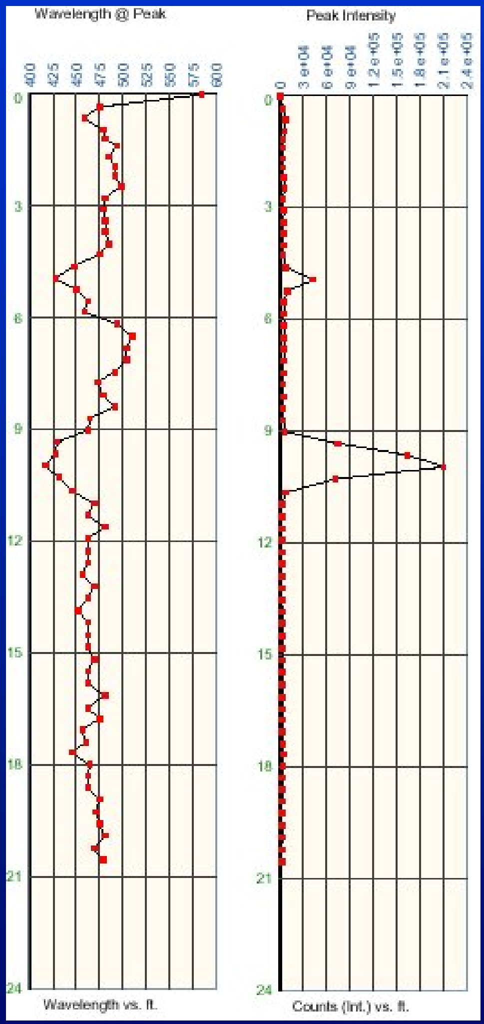
- LIF generally detects fuel concentrations greater than 100 ppm

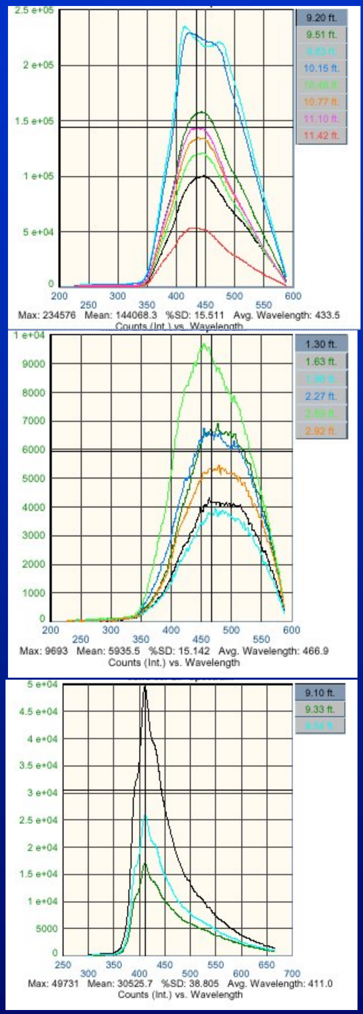
XeCl Laser Ultraviolet Light Source

LIF Data Interpretation

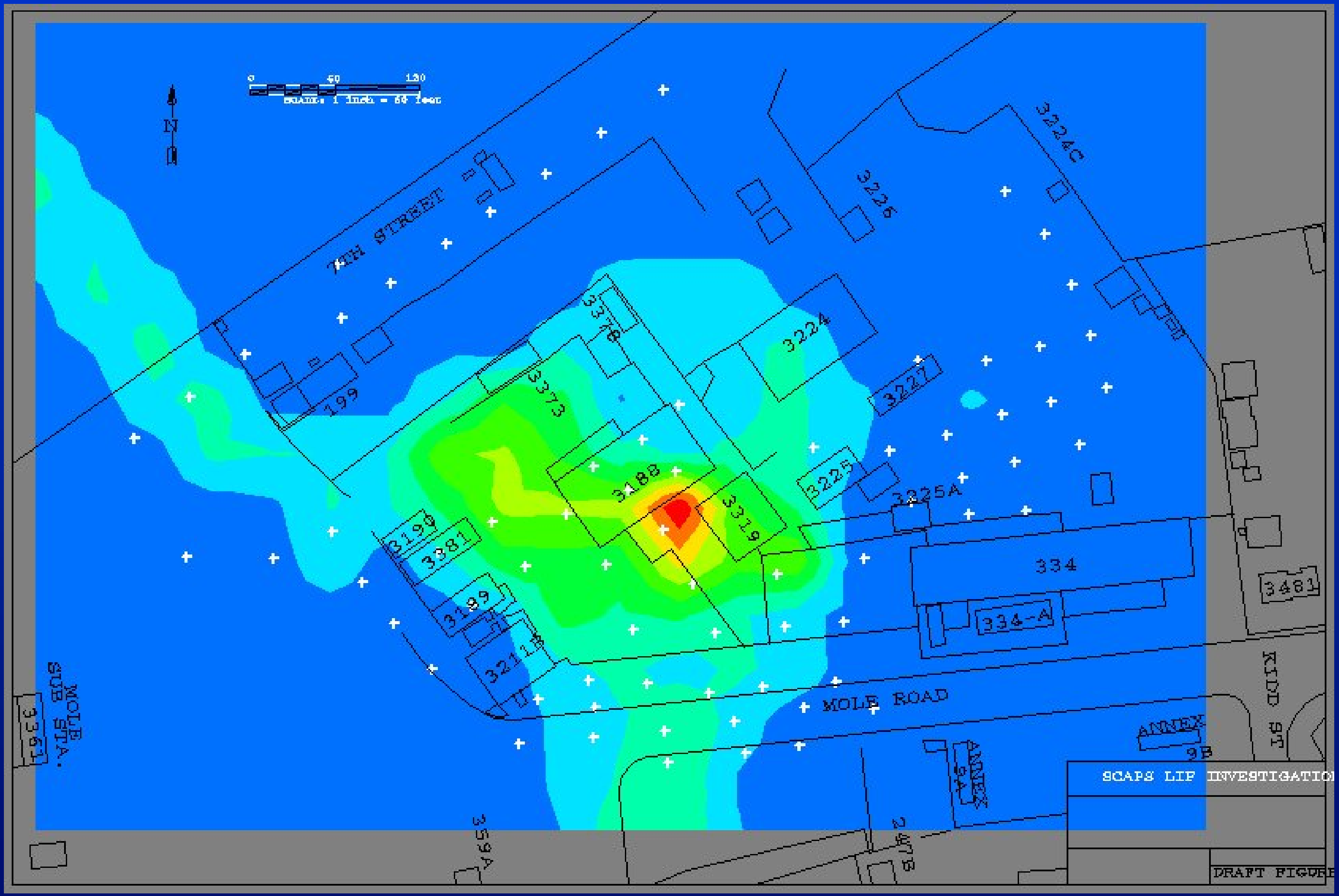
Factors to Evaluate Fuel Detection by LIF

- Increase in Fluorescence Intensity
- Corresponding Change in Fluorescence Wavelength
- Spectral Curve Shape Consistent with Fuel
- Significant Thickness of Interval
- Spatial Location Consistent with Expected Migration Patterns
- Comparison with Sample Analysis





Data Visualization

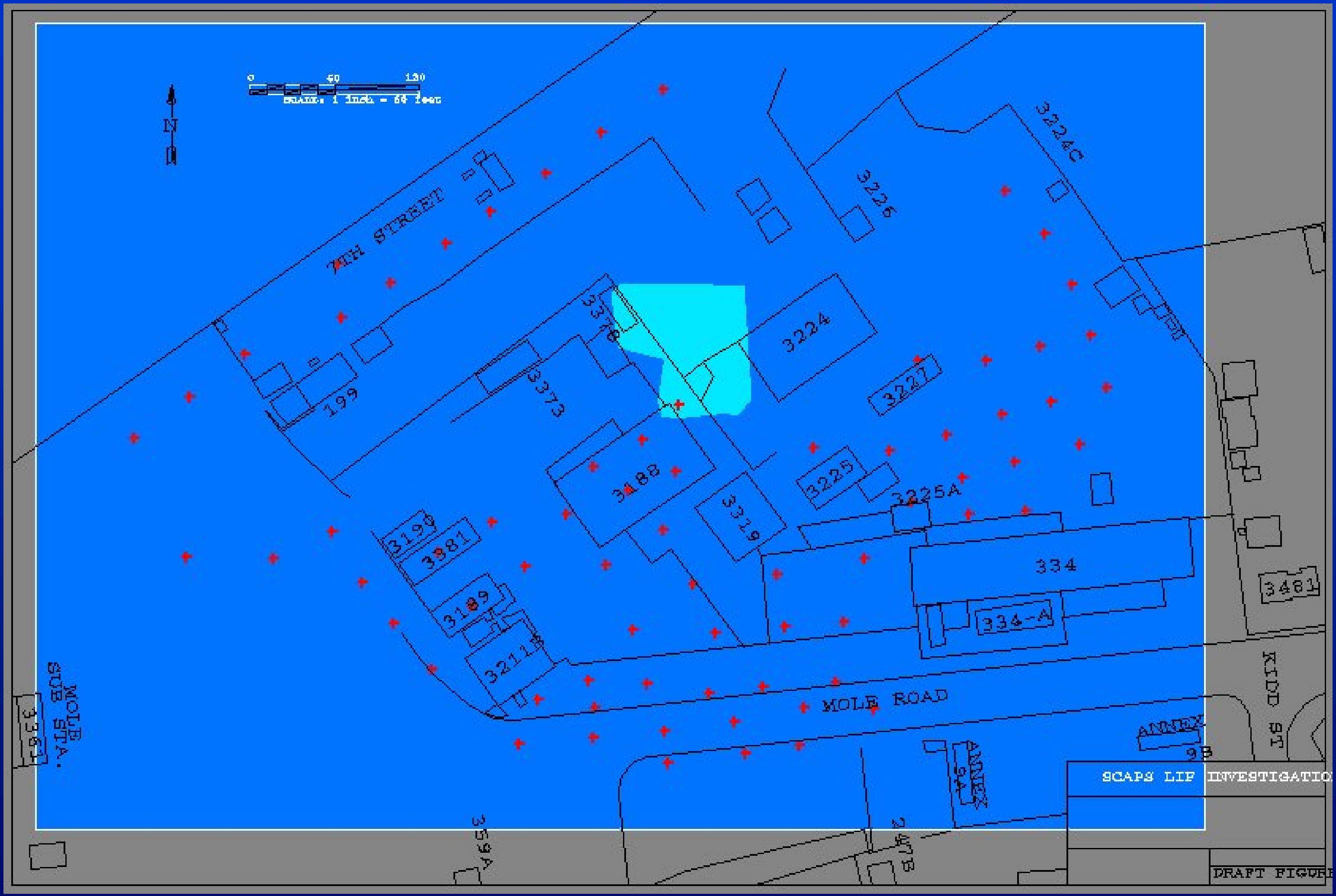


This figure depicts the sum of the interpolated fluorescence in vertical columns of a 3-d interpolation -- the combined fluorescence intensity and the thickness of the fluorescence interval. The “hot spot” has a thick zone of high fluorescence.

Elevation 10 ft (4 ft bgs)

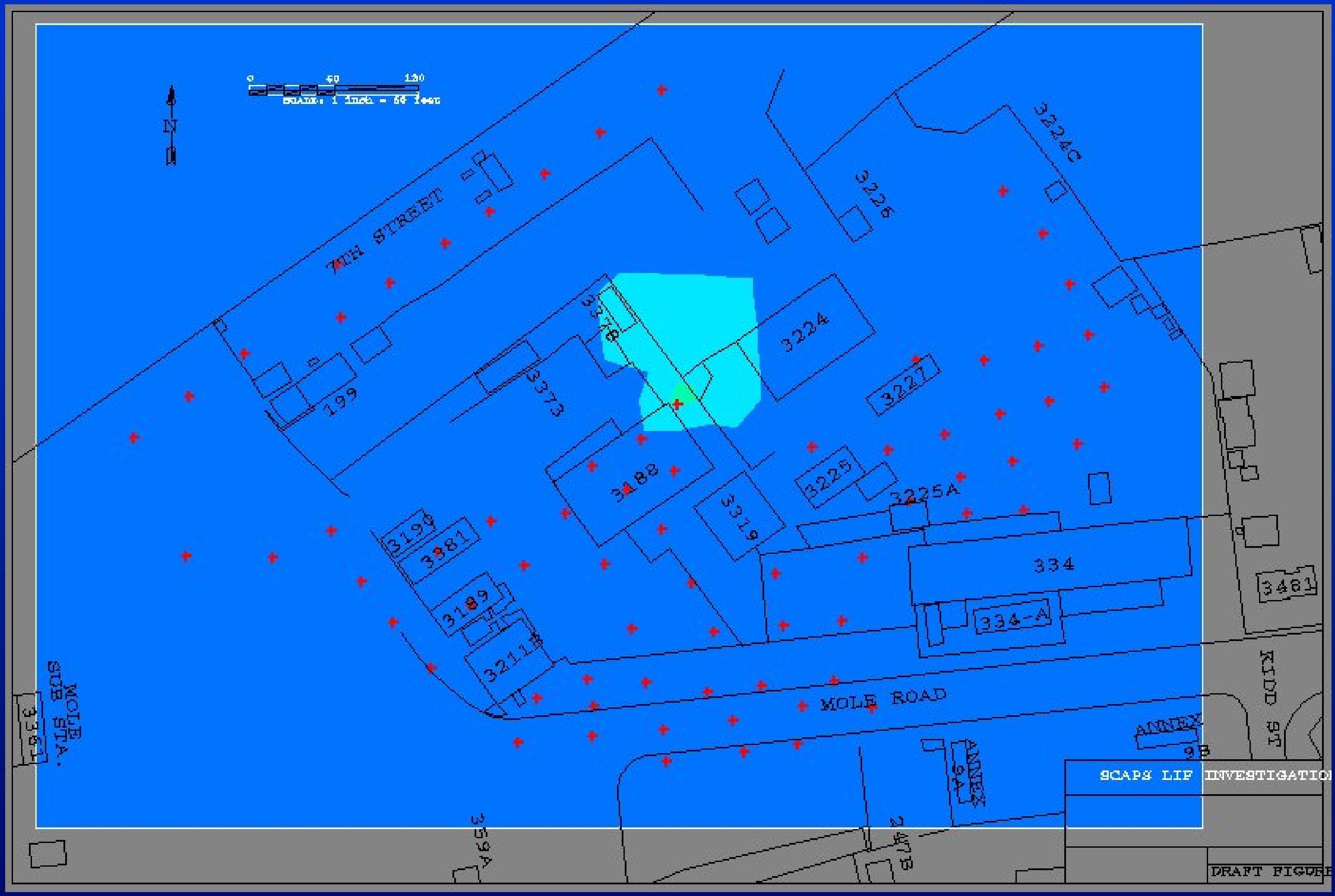
- This and the subsequent figures are cross-sections (both horizontal and vertical) from the 3-dimensional interpolations.

Elevation 9 ft (5 ft bgs)



- Most of the elevations were not surveyed -- approximate depths were adequate for the decisions.

Elevation 8 ft (6 ft bgs)

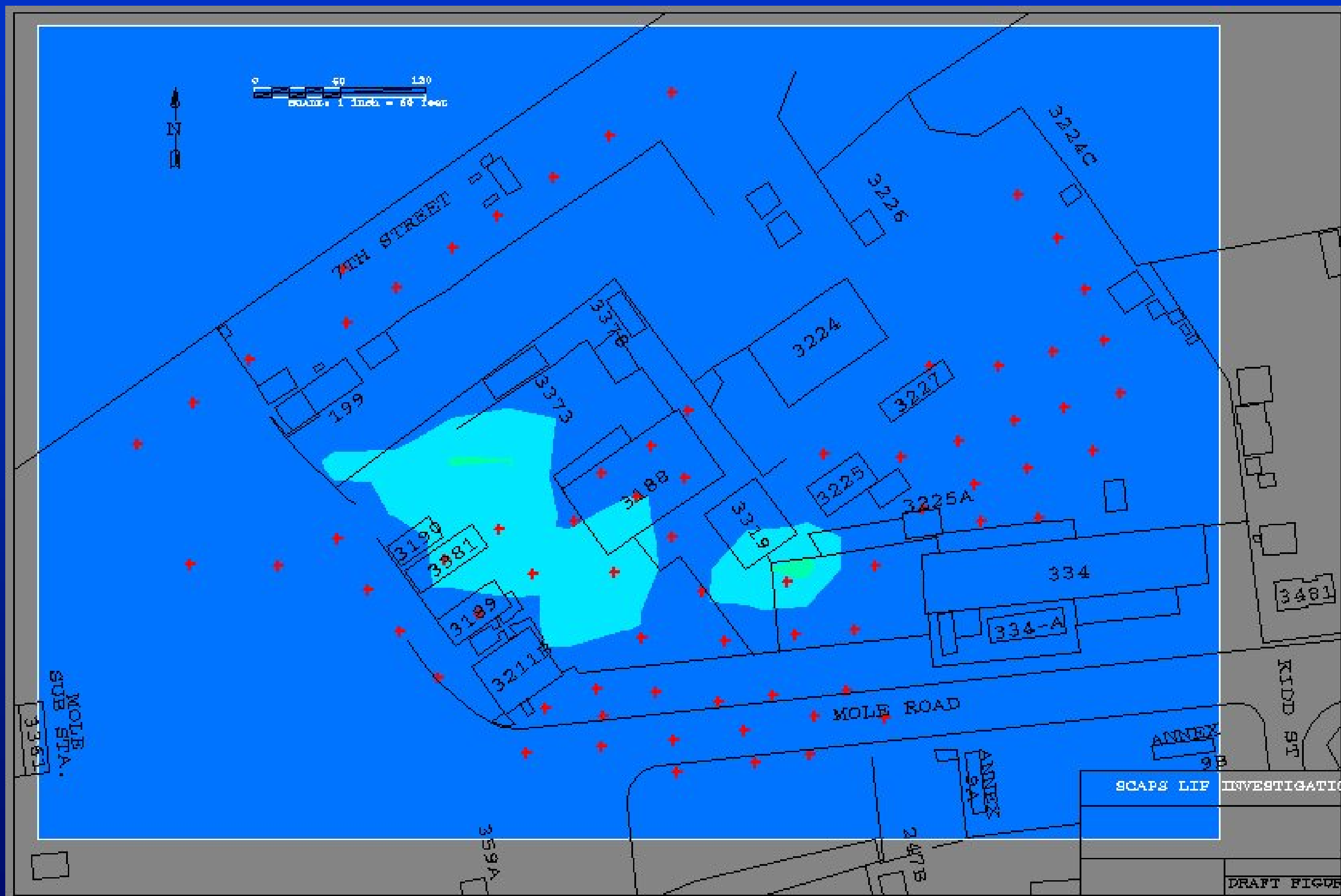


Elevation 7 ft (7 ft bgs)

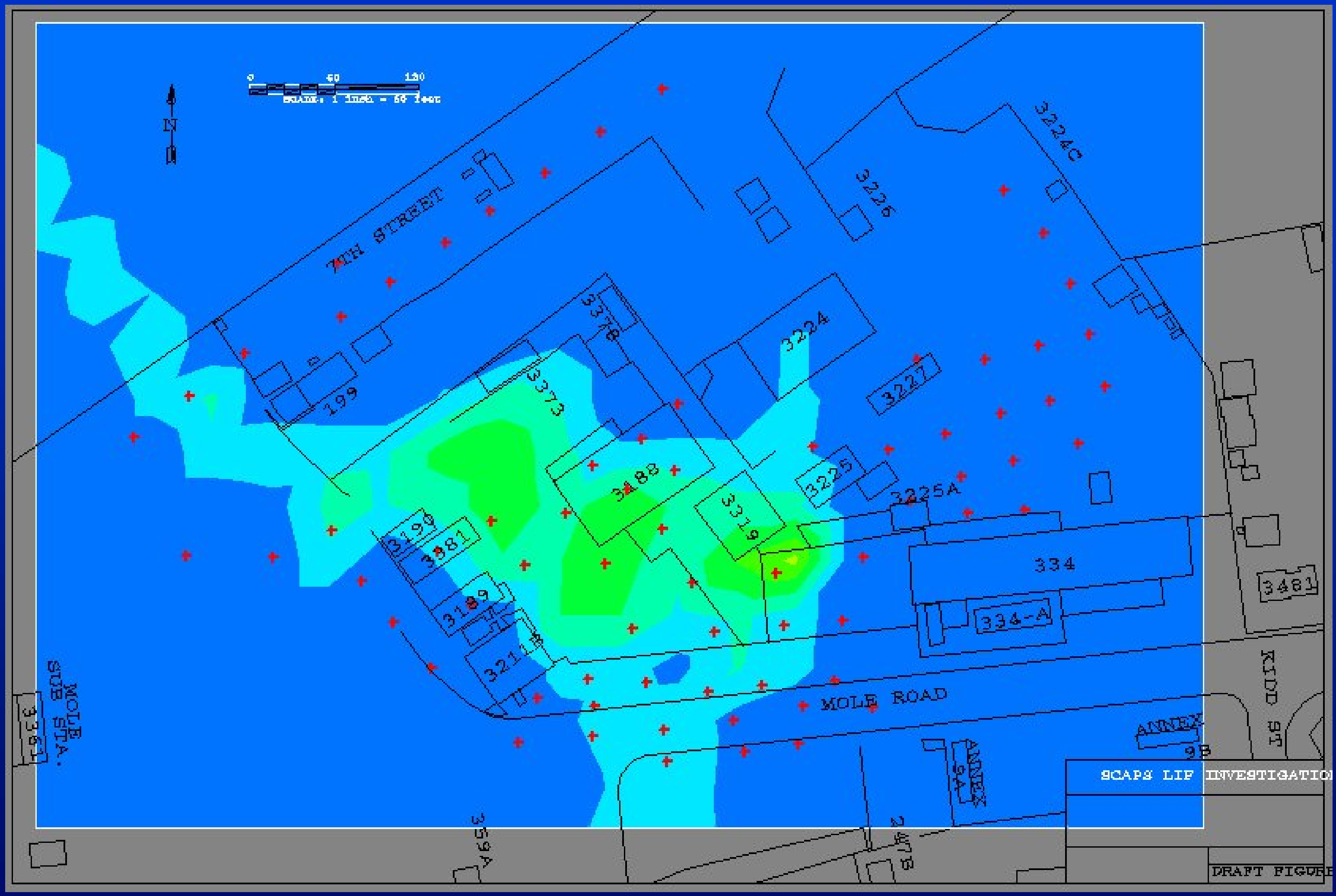
Elevation 6 ft (8 ft bgs)

Elevation 5 ft (9 ft bgs)

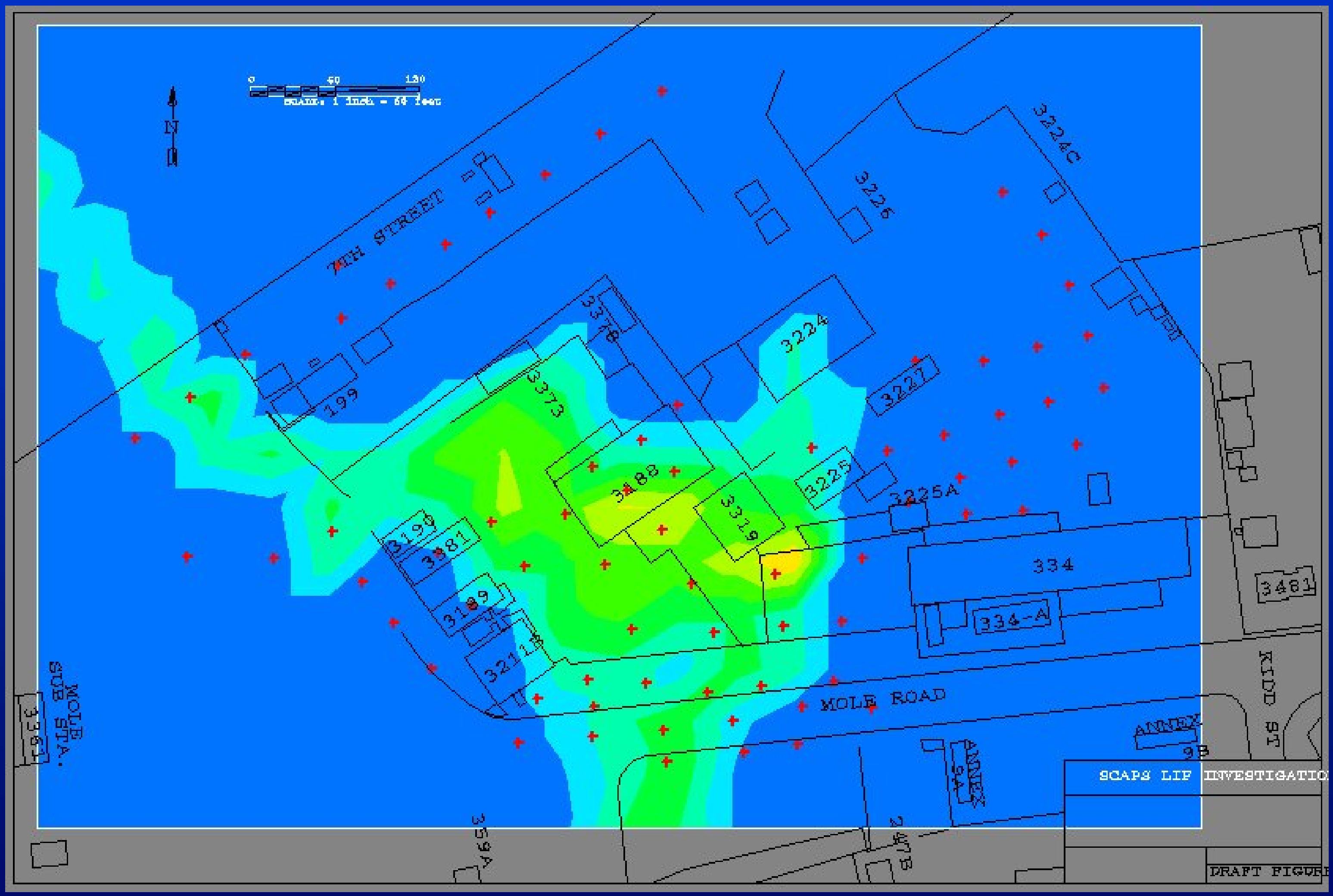
Elevation 4 ft (10 ft bgs)



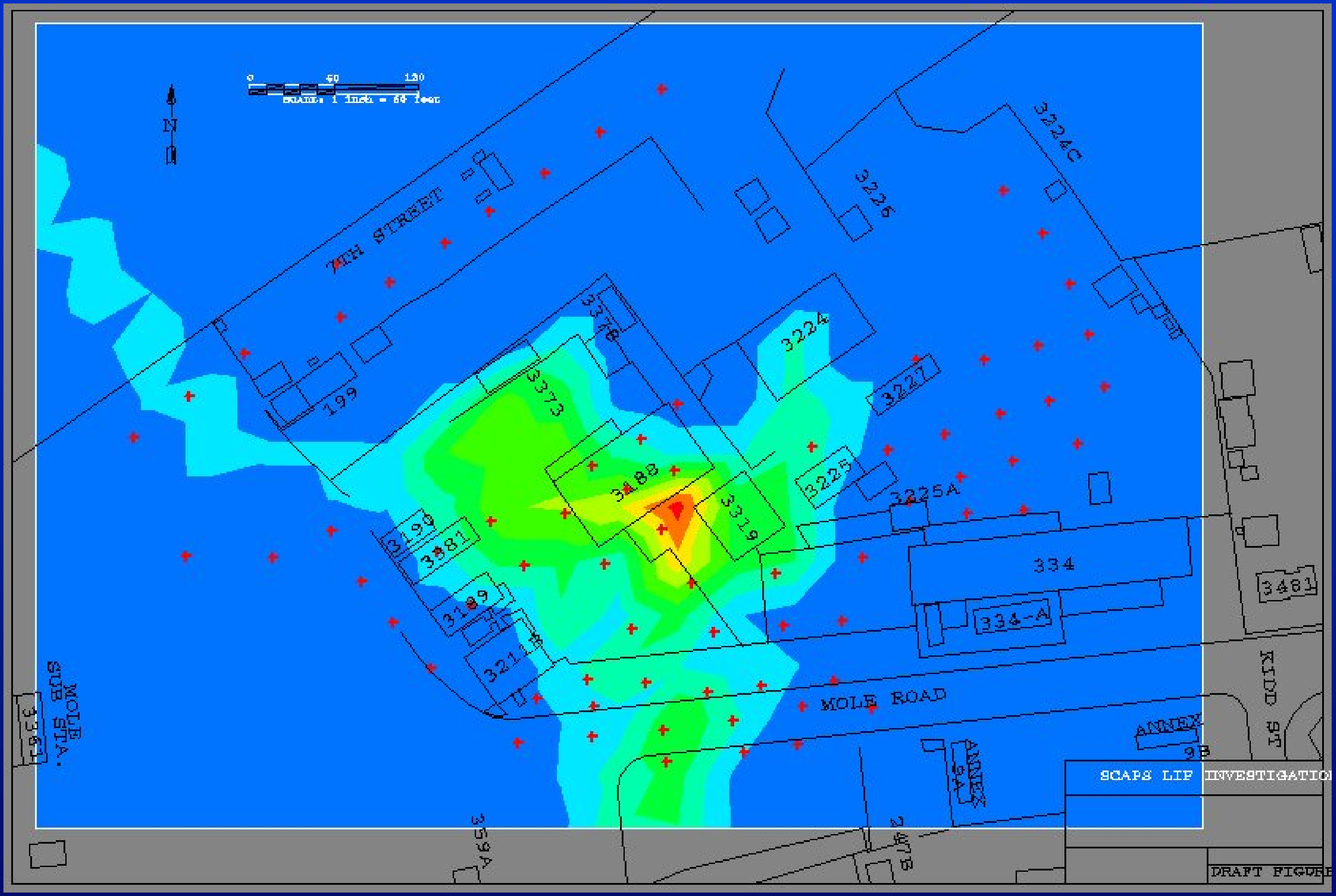
Elevation 3 ft (11 ft bgs)



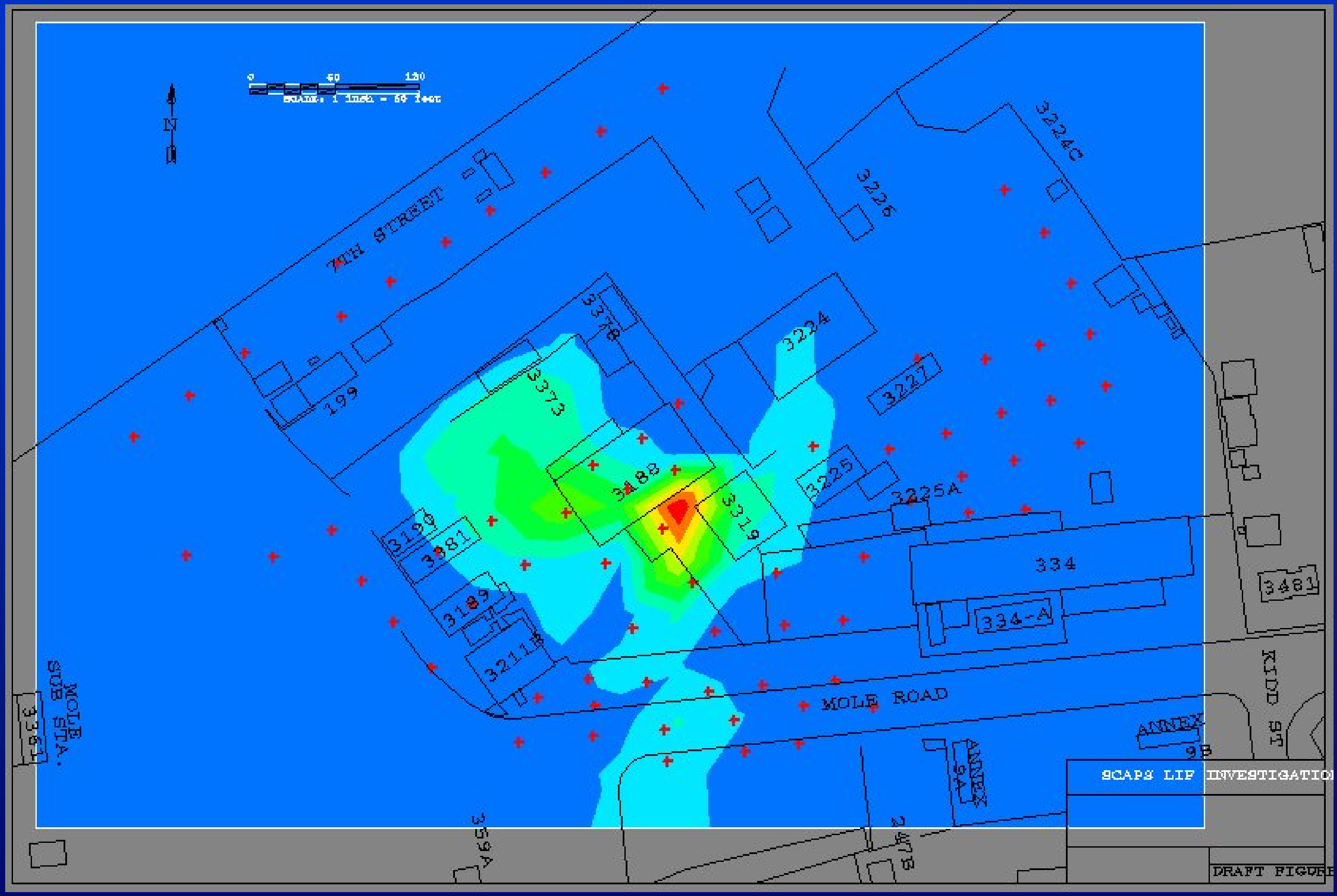
Elevation 2 ft (12 ft bgs)



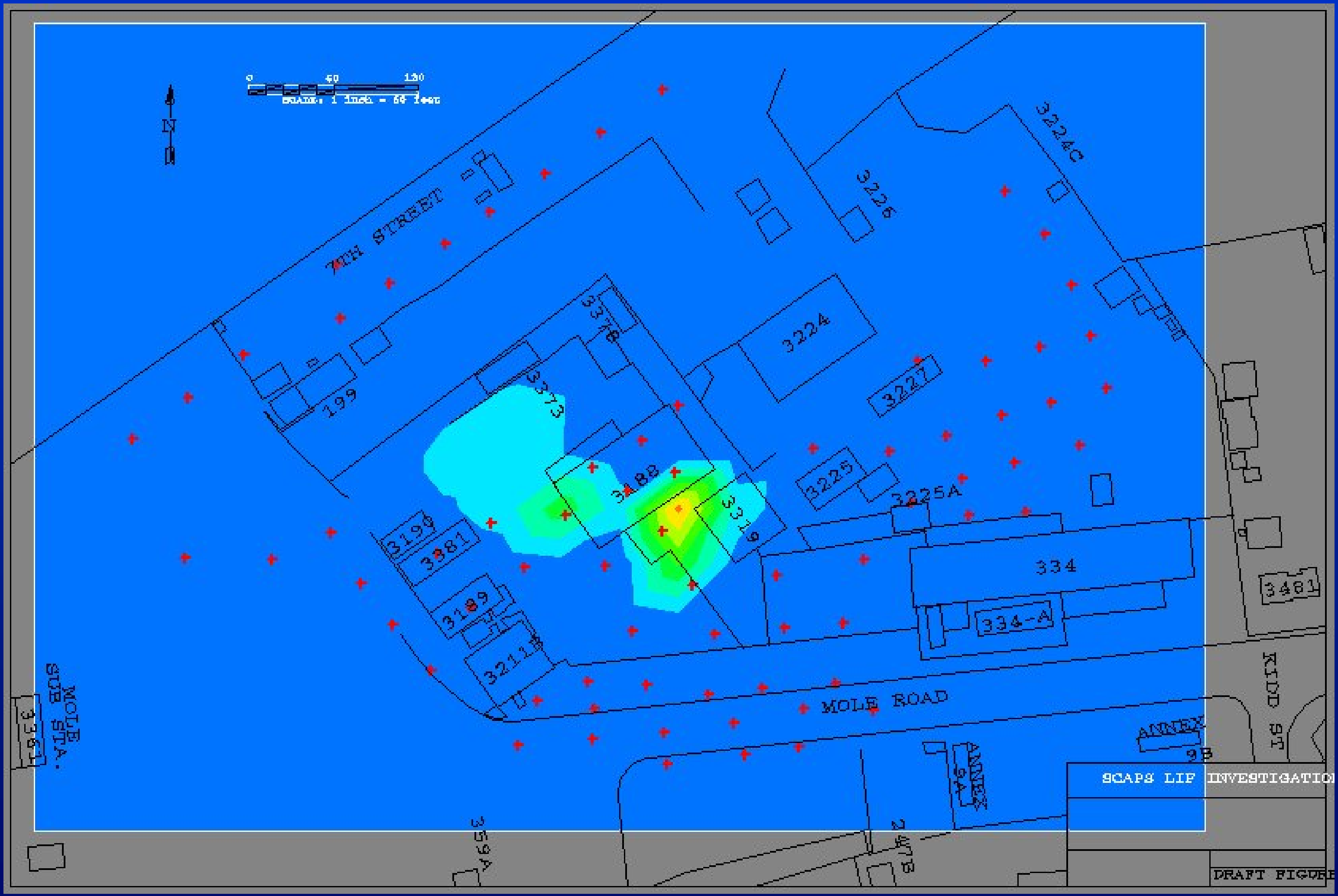
Elevation 1 ft (13 ft bgs)



Elevation 0 ft (14 ft bgs)

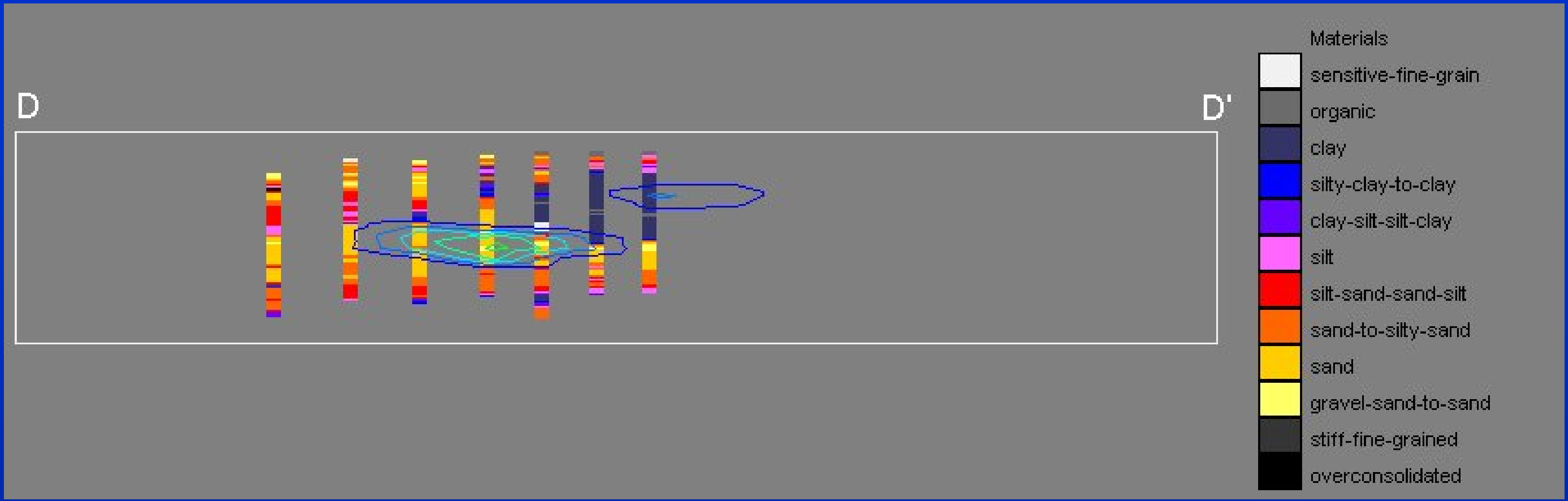


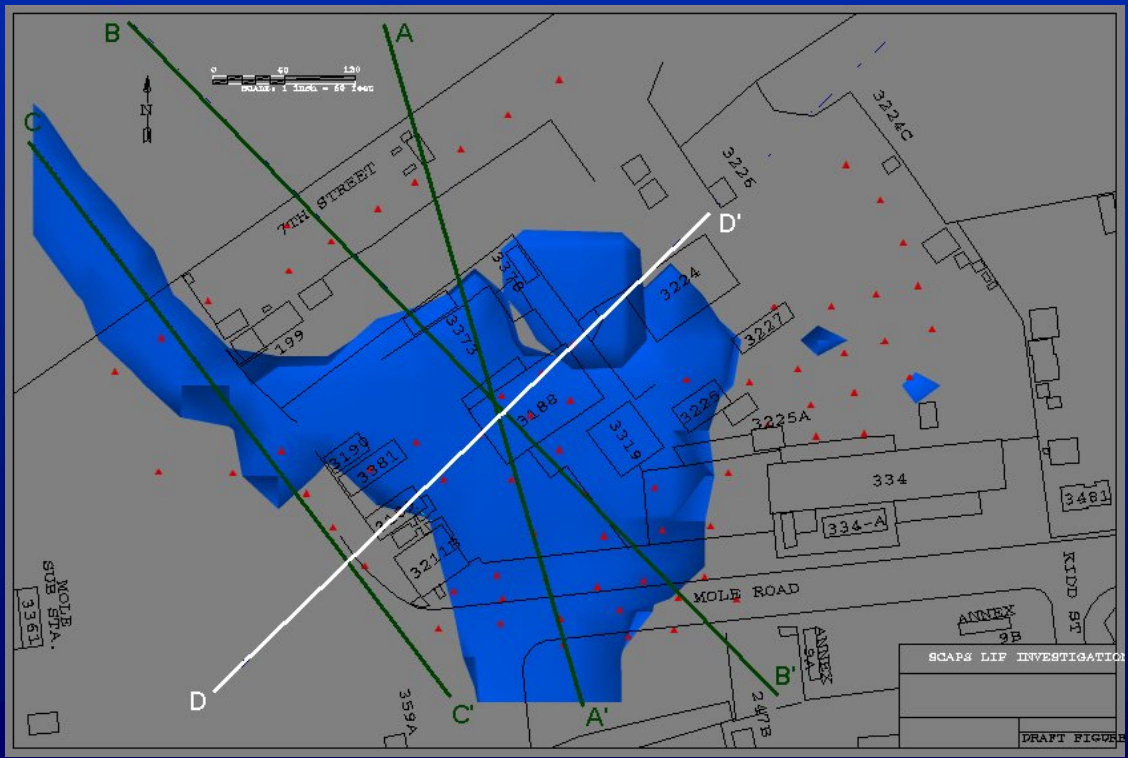
Elevation -1 ft (15 ft bgs)



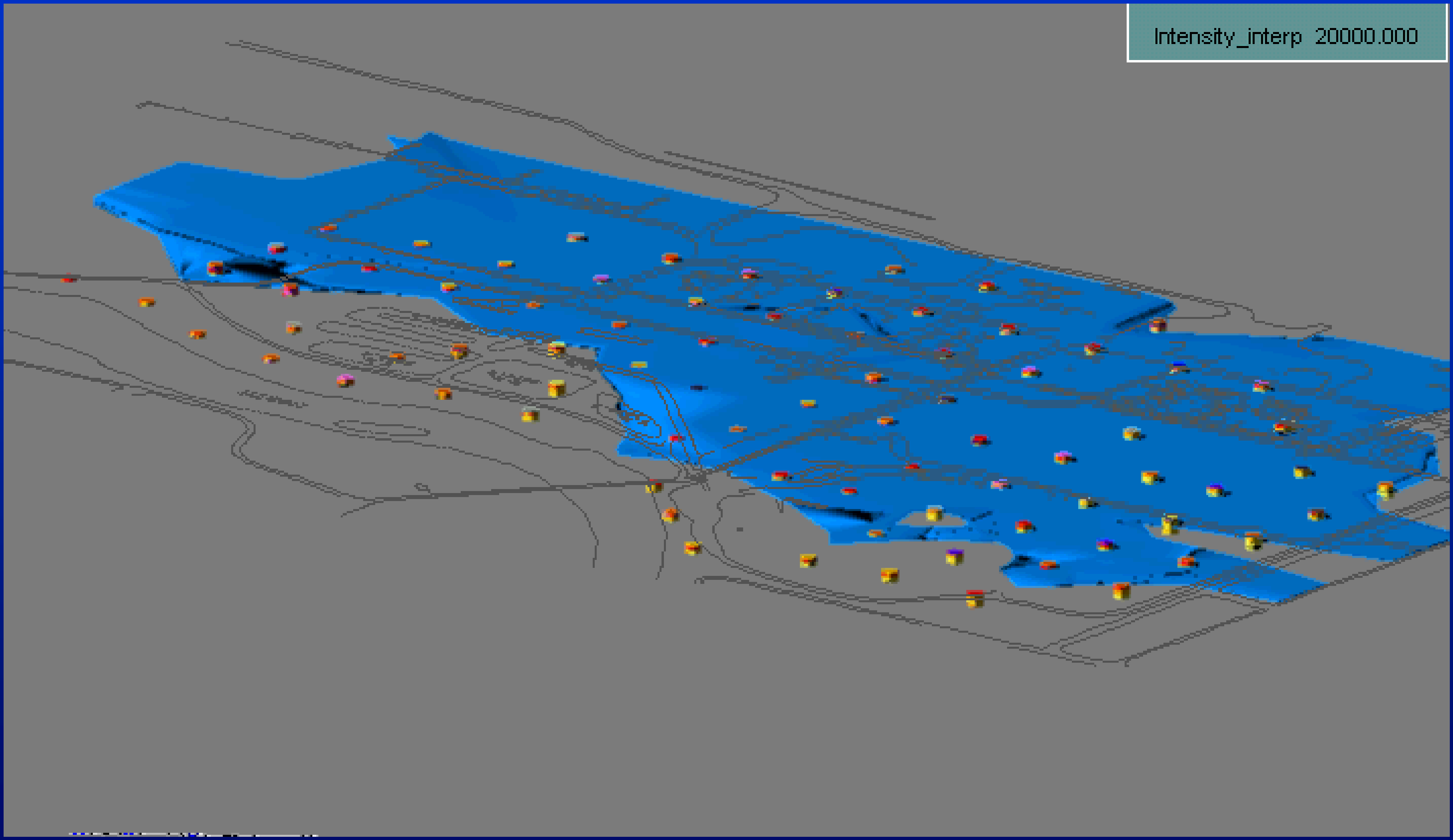
Elevation -2 ft (16 ft bgs)

Elevation -3 ft (17 ft bgs)


D
D'
Materials
sensitive-fine-grain
organic
clay
silty-clay-to-clay
clay-silt-silt-clay
silt
silt-sand-sand-silt
sand-to-silty-sand
sand
gravel-sand-to-sand
stiff-fine-grained
overconsolidated

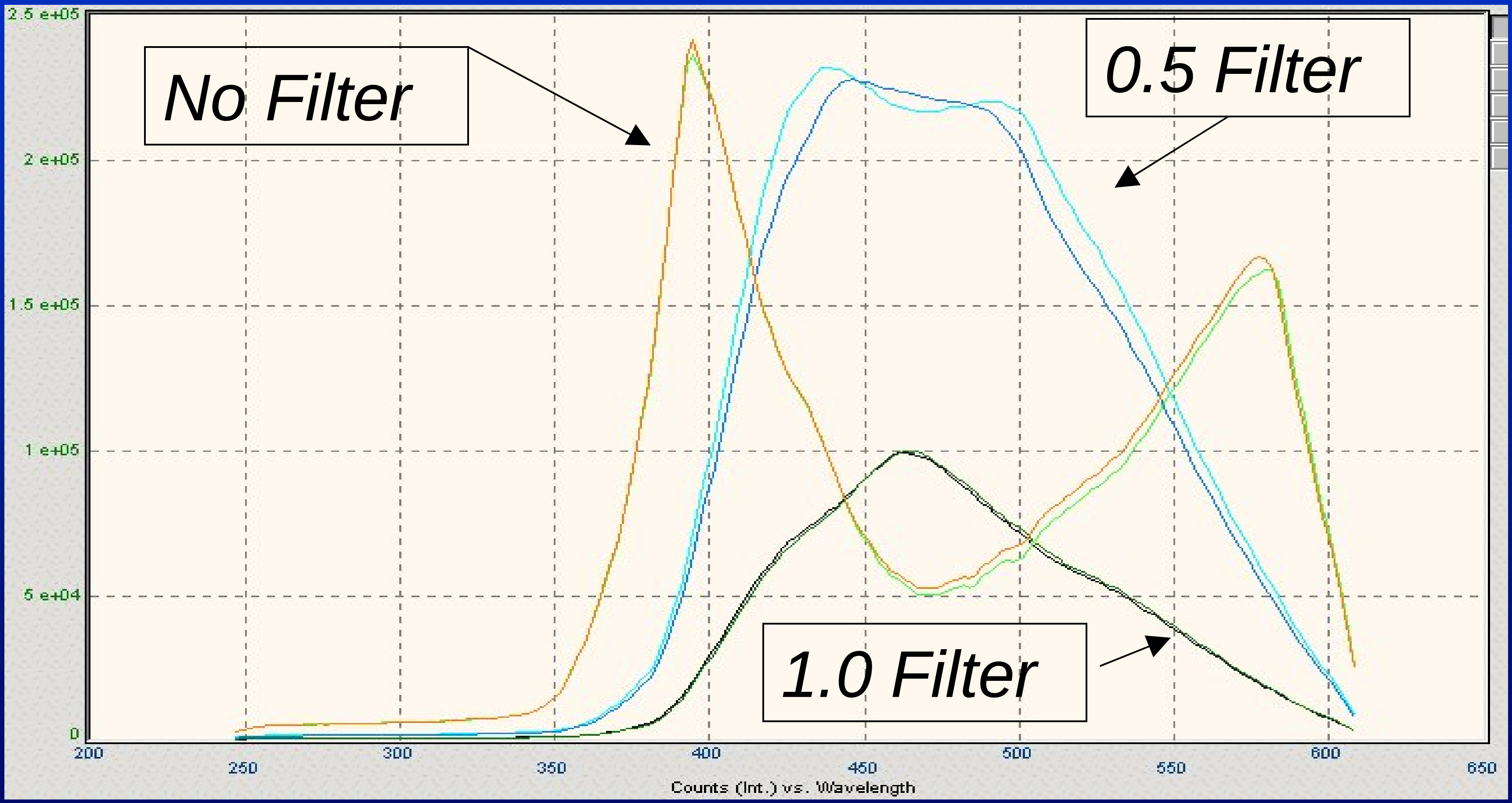

B
A
C
D'
D
C'
A'
B'
7TH STREET
MOLE ROAD
KIDD ST
MOLE SUB STA.
3361
199
3373
3376
3226
3224C
3224
3227
3188
3199
3381
3319
3225
3225A
334
334-A
3481
359A
247B
ANNEX 9B
ANNEX 9A
SCAPS LIF INVESTIGATION
DRAFT FIGURE

Example 2
Overall Fluorescence Intensity



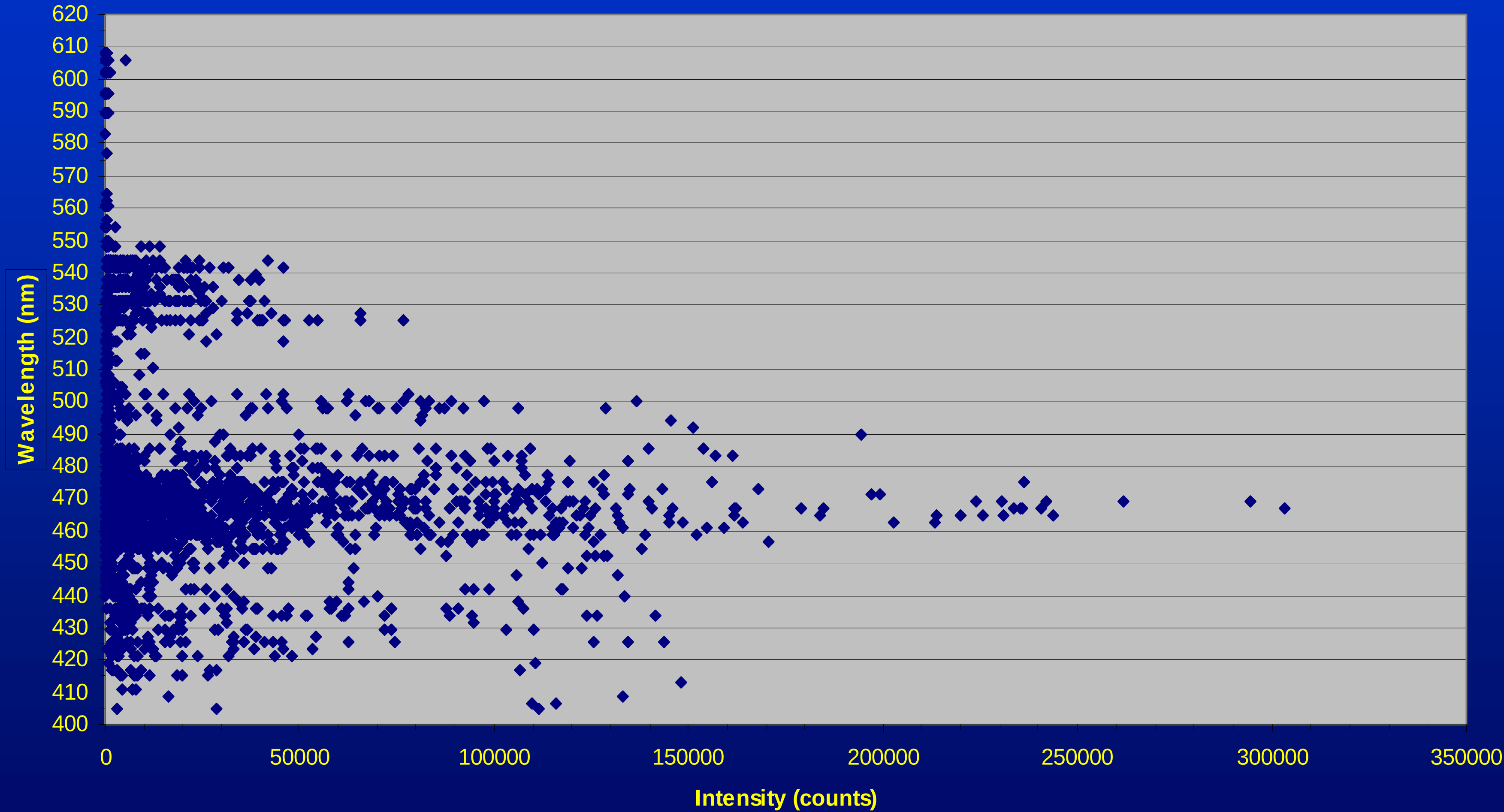
Using Fluorescence Wavelength to Distinguish Fuel Products

463 nm Wavelength Spectra (diesel)

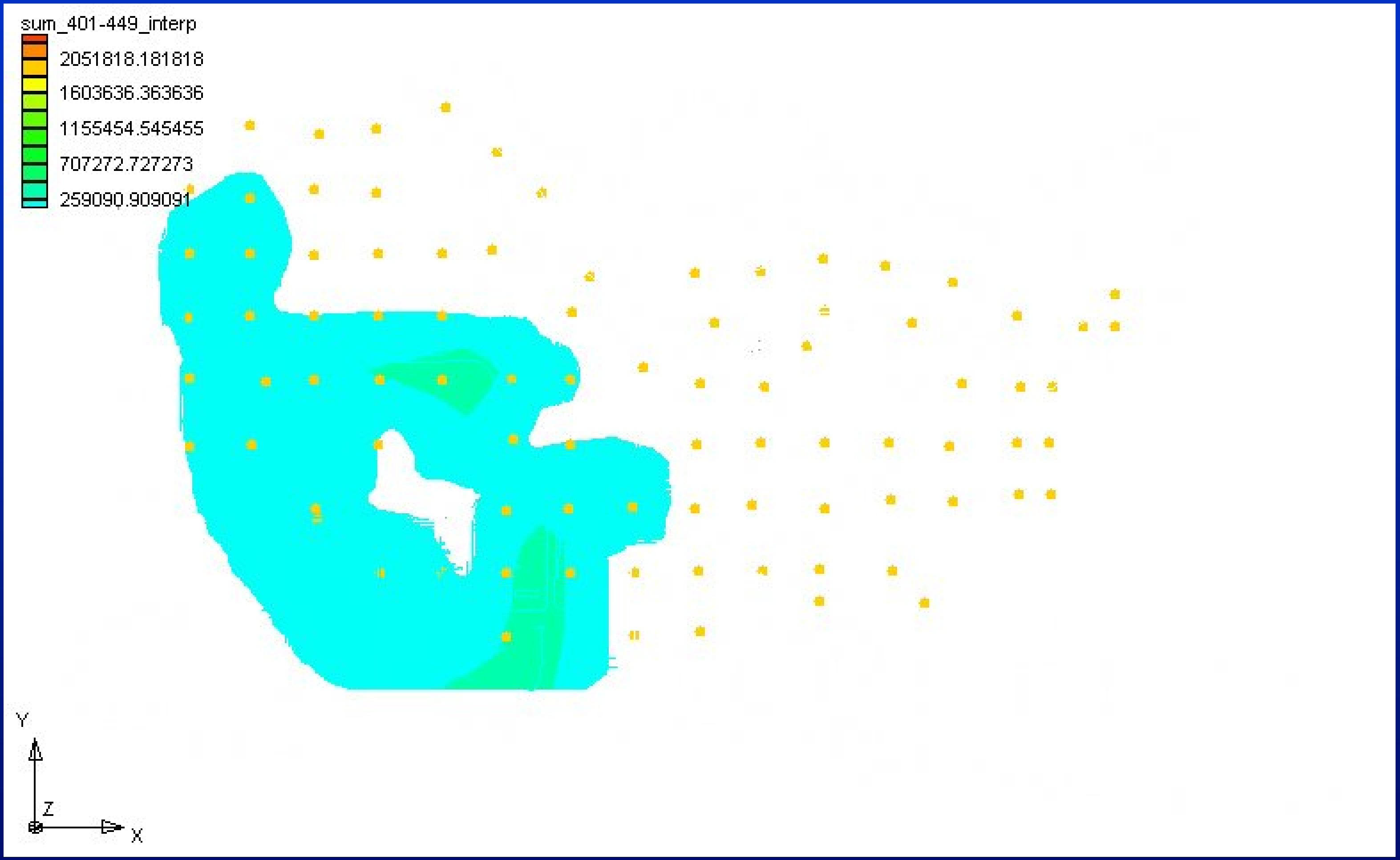


531 nm Wavelength Spectra (oil)

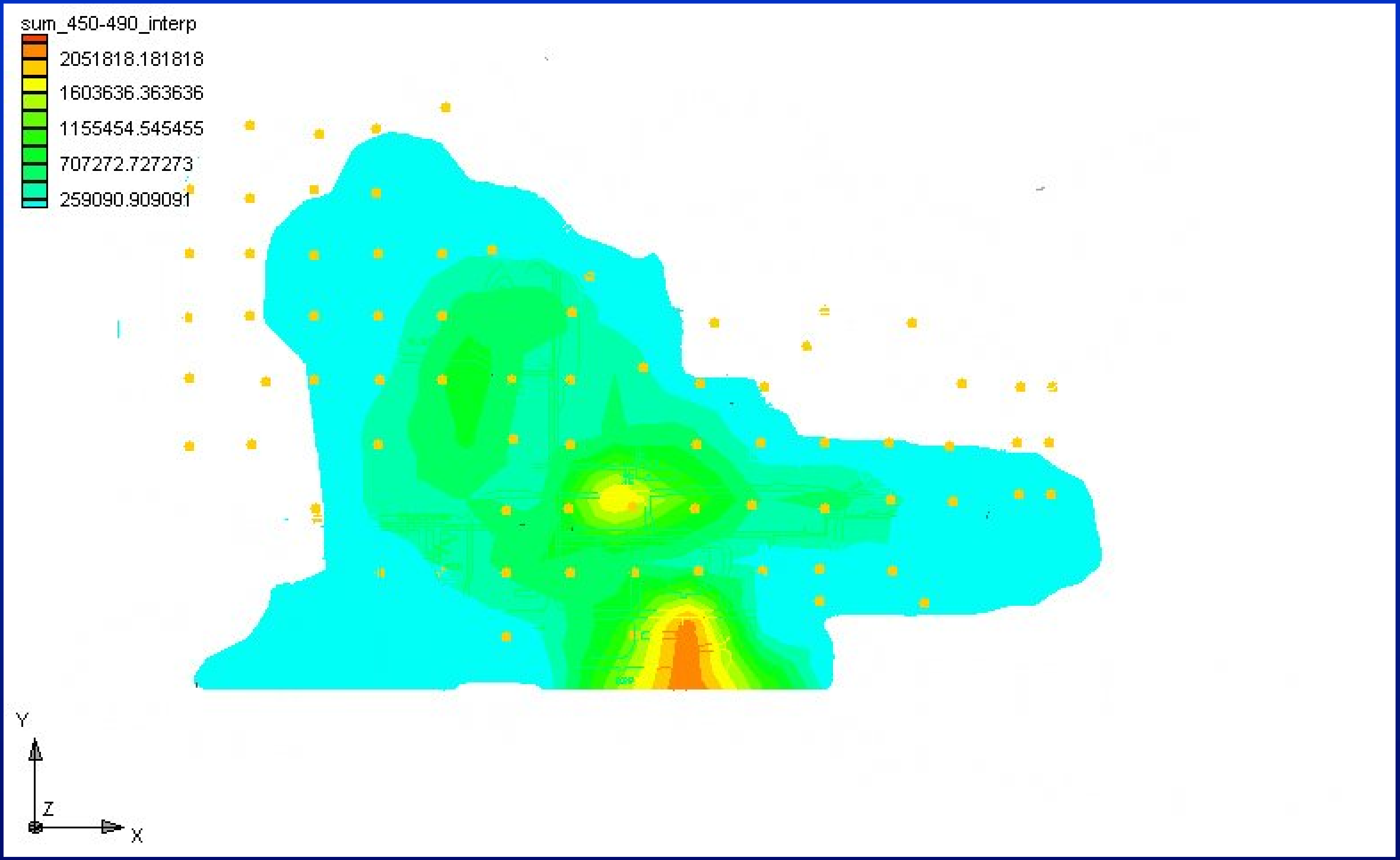
Fluorescence Intensity vs Wavelength
Pushes 001-080



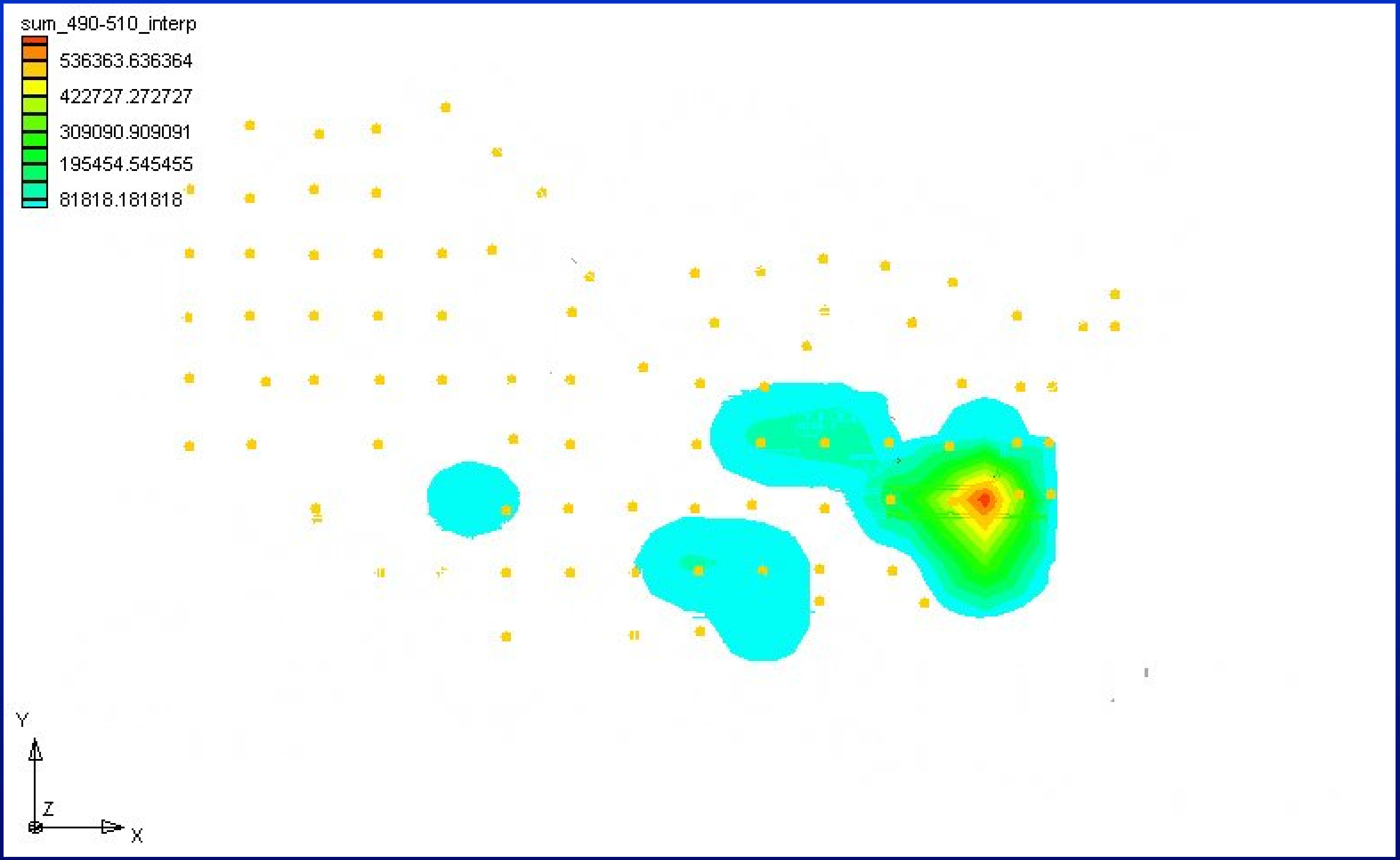
Gasoline (401 - 449 nm)



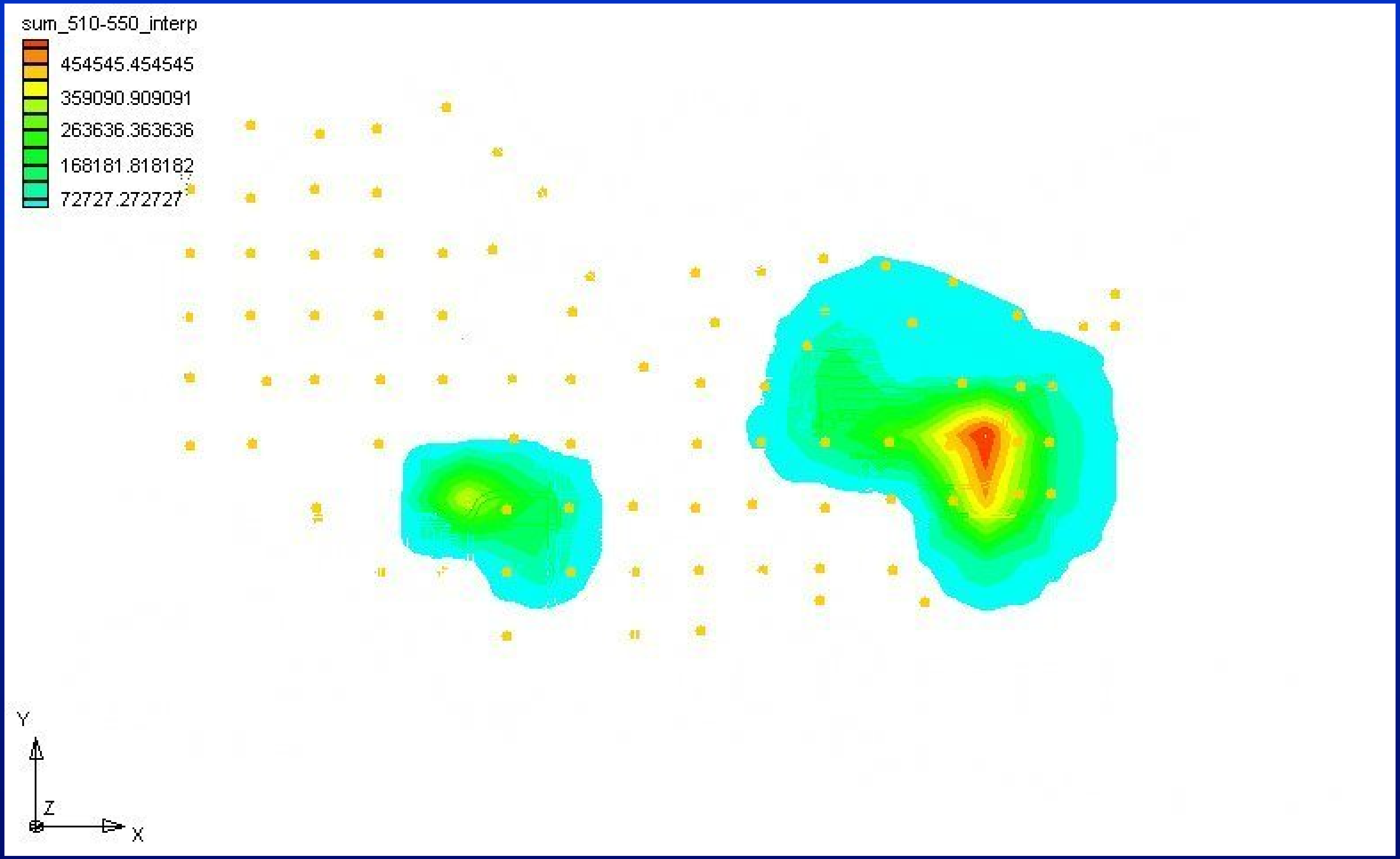
Diesel (450 - 490 nm)

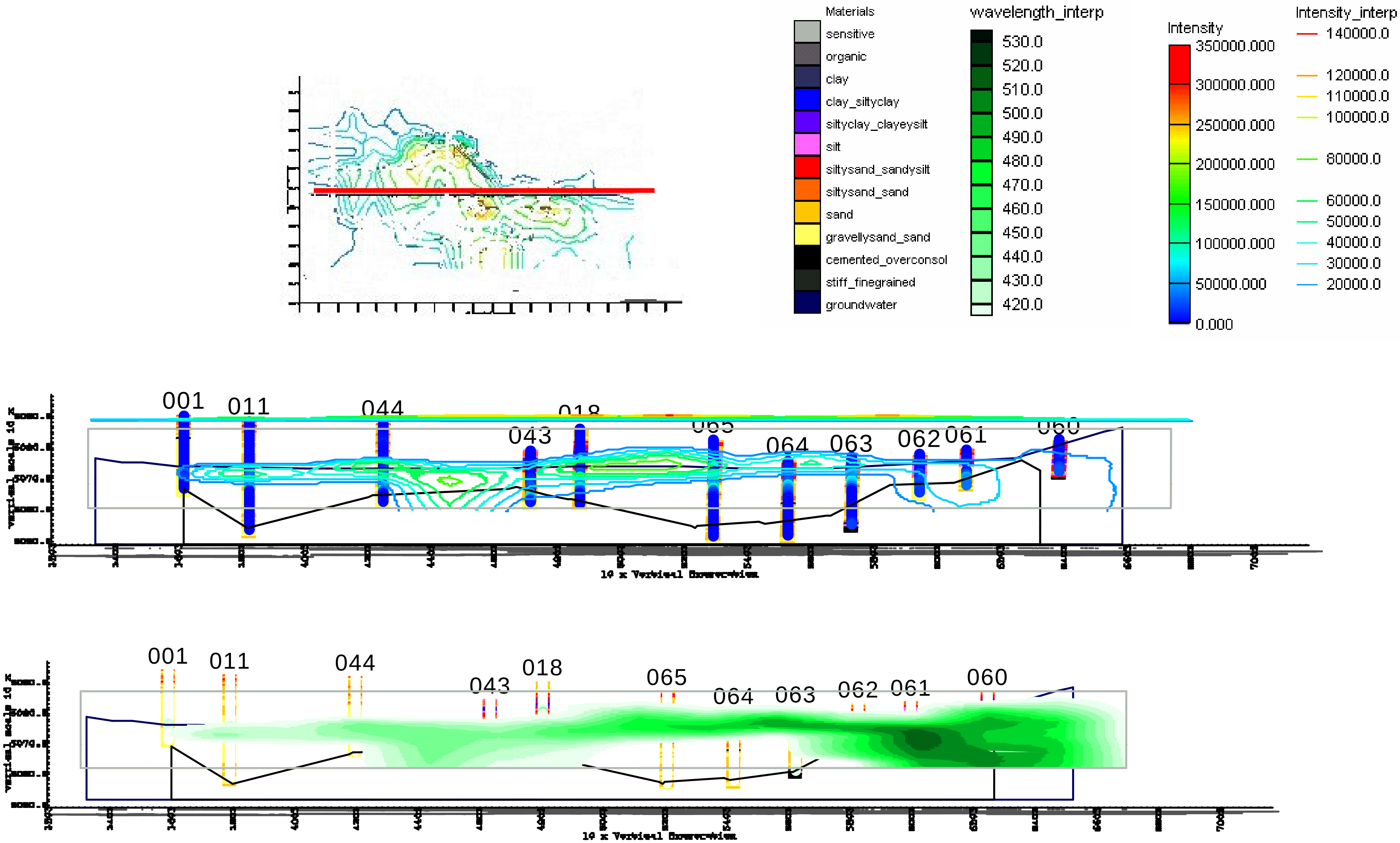


Lighter Oil (490 - 510 nm)



Heavier Oil (510 - 550 nm)




Materials
sensitive
organic
clay
clay_siltyclay
siltyclay_clayeysilt
silt
siltysand_sandysilt
siltysand_sand
sand
gravellysand_sand
cemented_overconsol
stiff_finegrained
groundwater
wavelength_interp
530.0
520.0
510.0
500.0
490.0
480.0
470.0
460.0
450.0
440.0
430.0
420.0
Intensity
350000.000
300000.000
250000.000
200000.000
150000.000
100000.000
50000.000
0.000
Intensity_interp
140000.0
120000.0
110000.0
100000.0
80000.0
60000.0
50000.0
40000.0
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001
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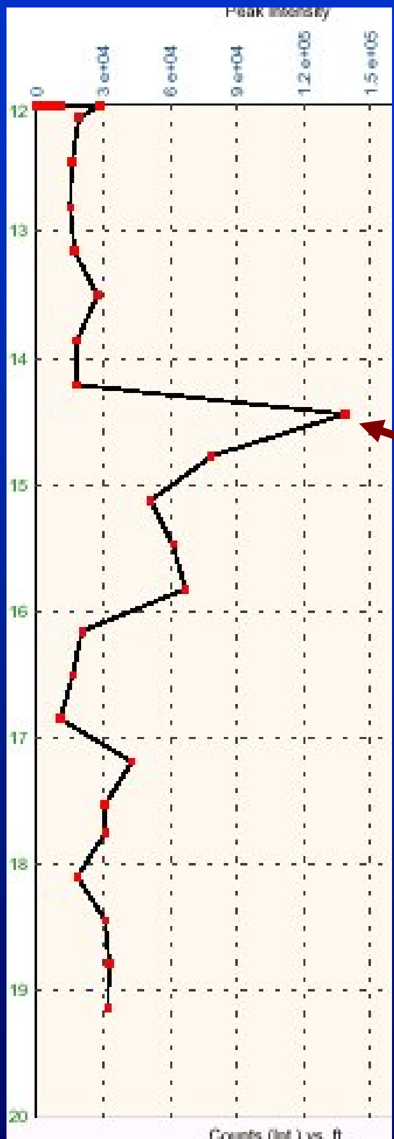
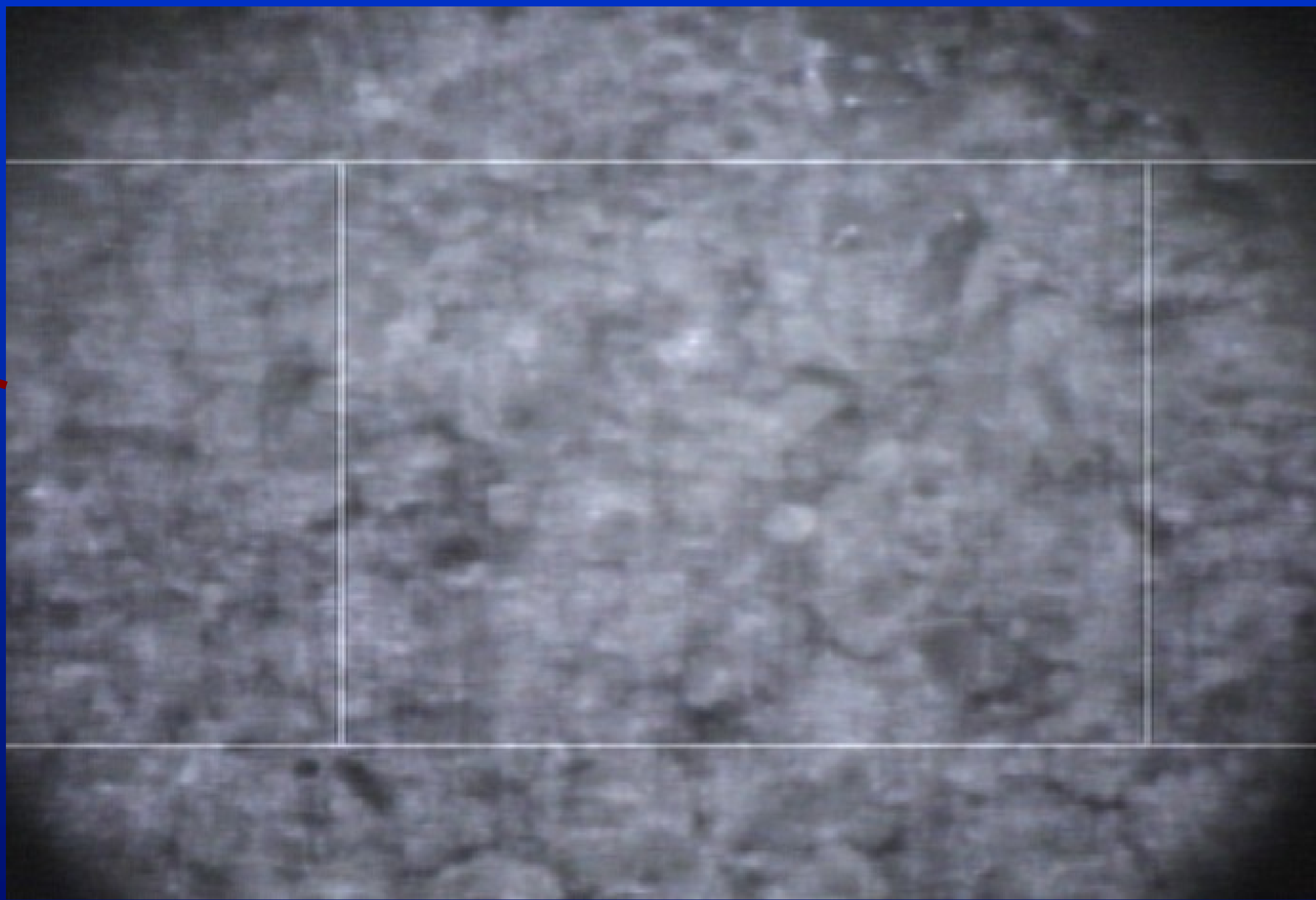
044
043
018
065
064
063
062
061
060
10 x Vertical Exaggeration
001
011
044
043
018
065
064
063
062
061
060
10 x Vertical Exaggeration

Fluorescence can be Misleading in Highly-Contaminated Unsaturated Sands

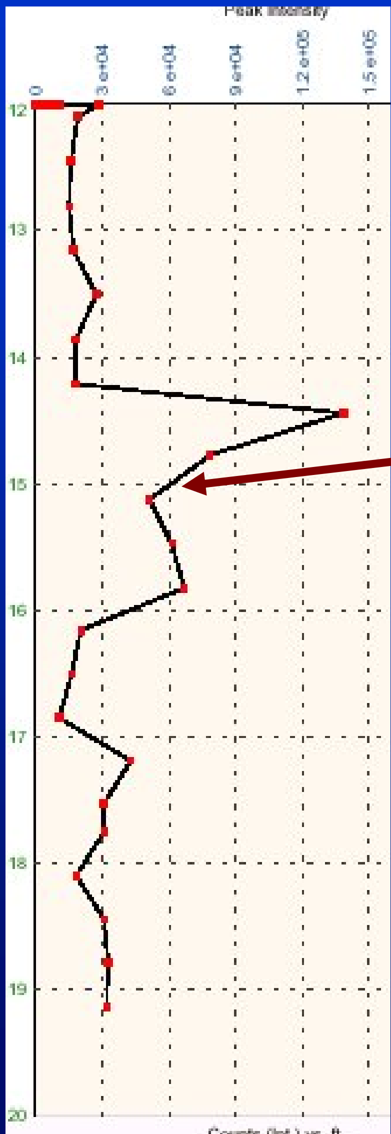


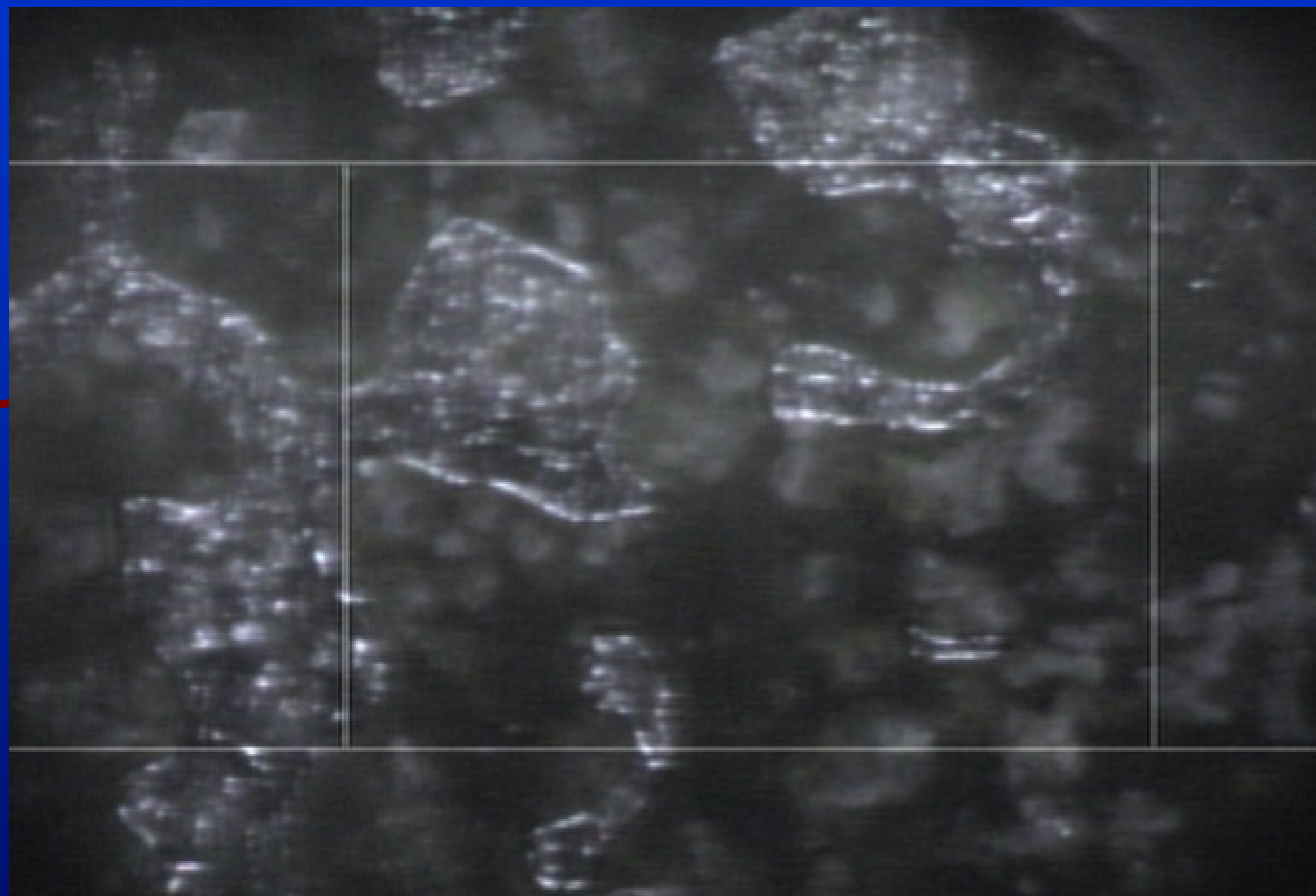


Blurriness is fuel smeared on probe window.

First Indication of Saturation

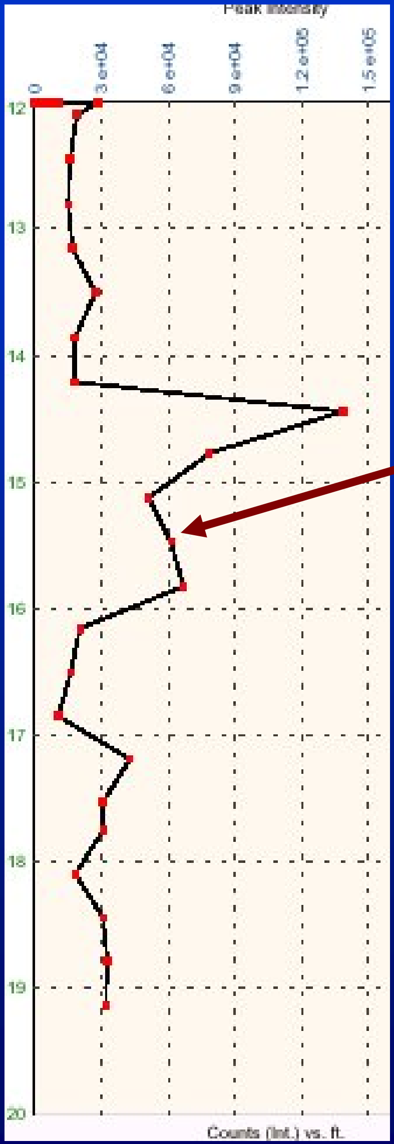
(Mix of Water, Fuel, and Gas Bubbles)

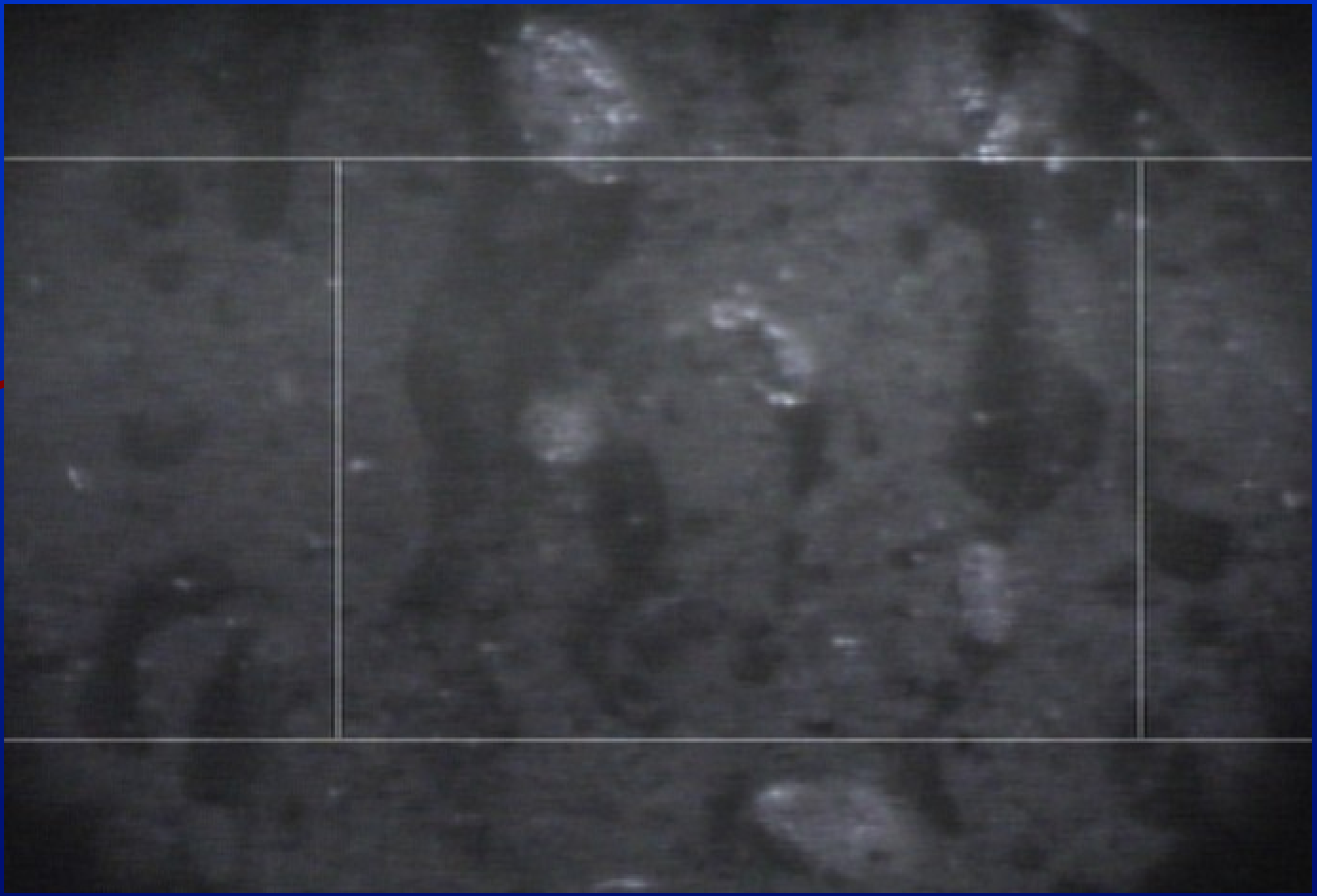




Window has been cleaned by sand and water.

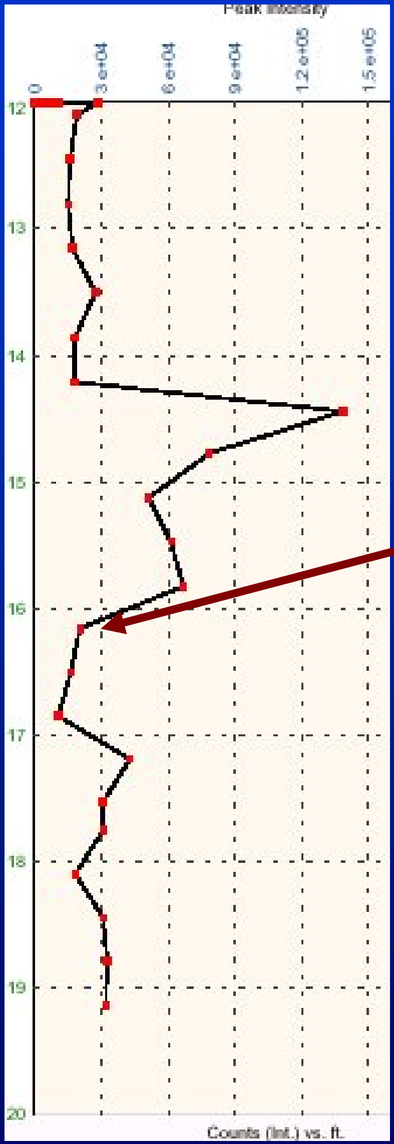
Fuel, Silty Water, and Gas Bubbles in Coarse Sand

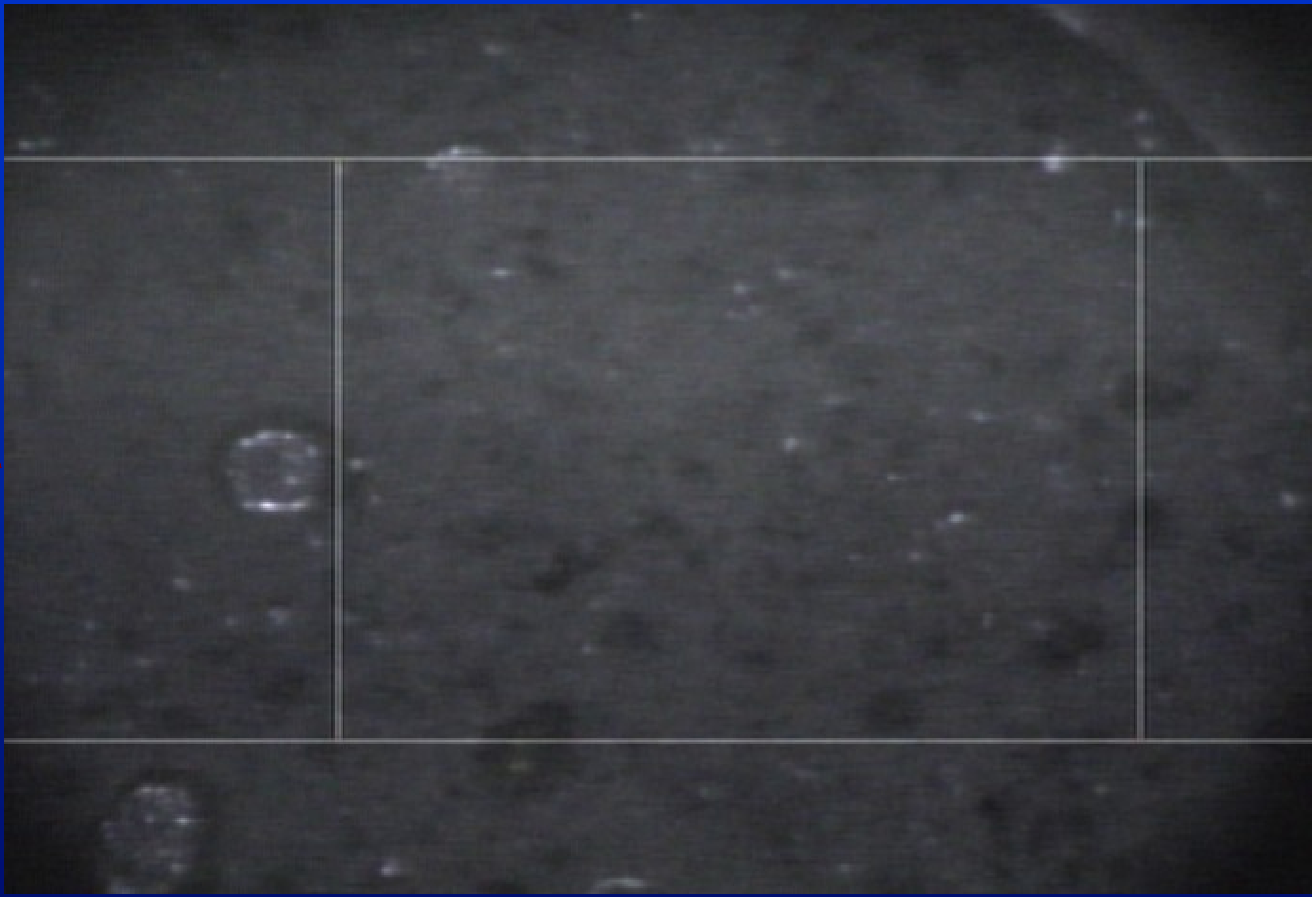




Each SCAPS LIF data point is the average of 20 laser shots.

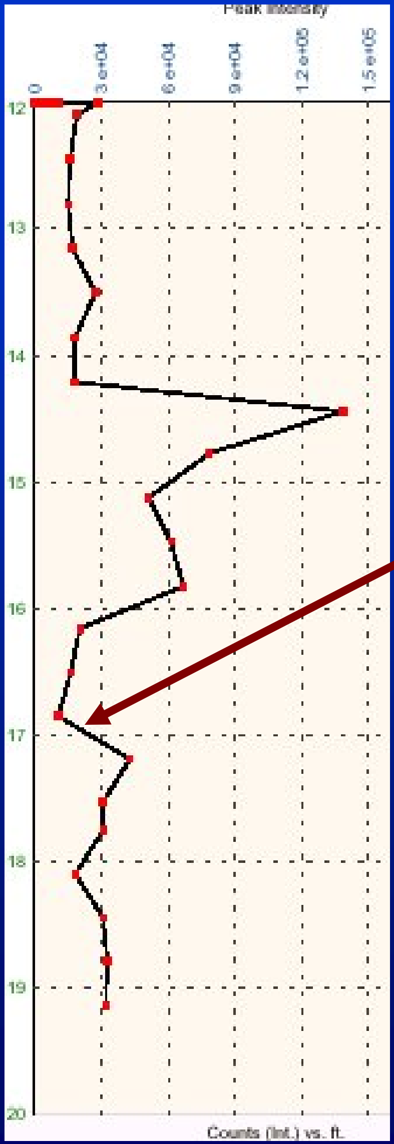
Fuel, Silty Water, and Gas Bubbles in Coarse Sand

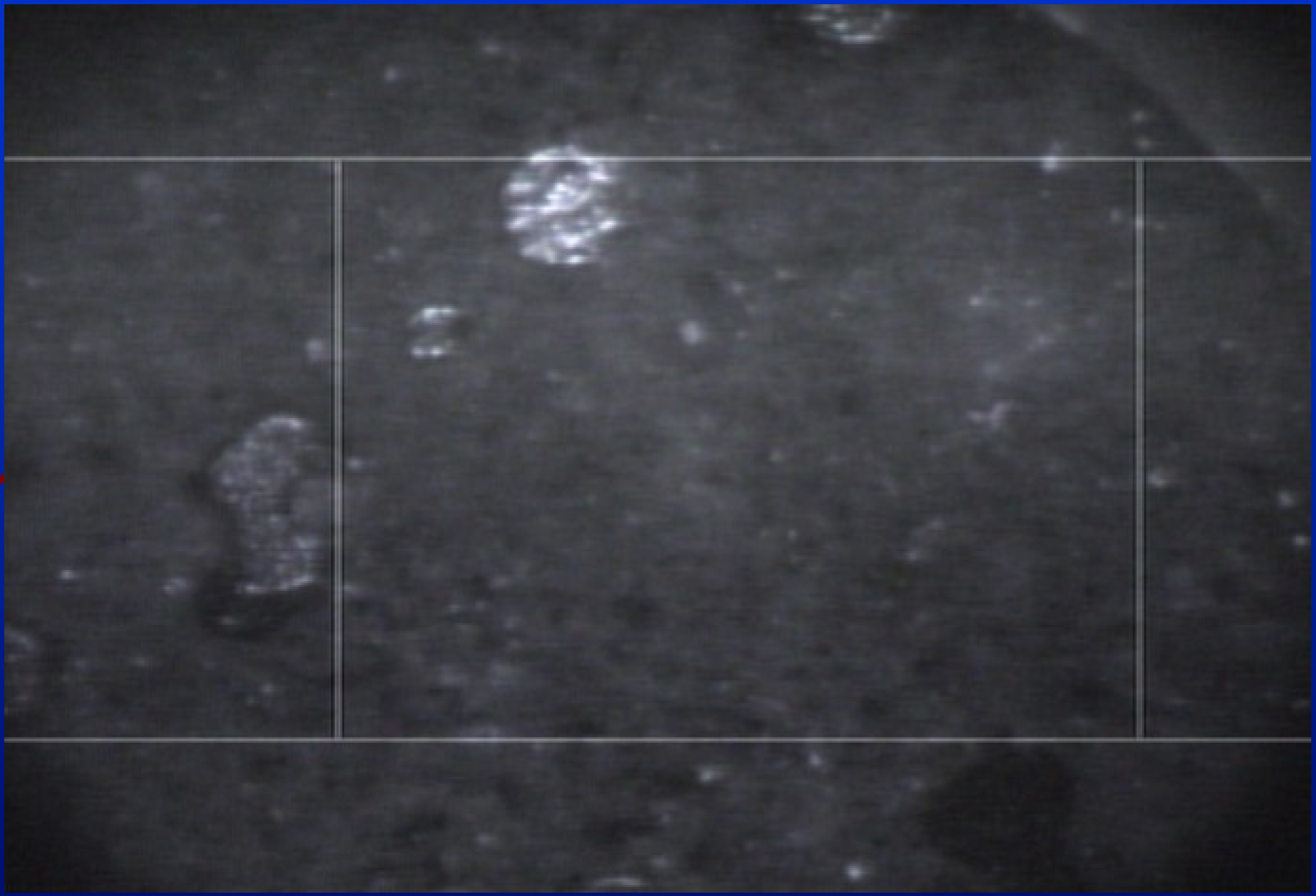




Fluorescence data is collected while probe is in motion.

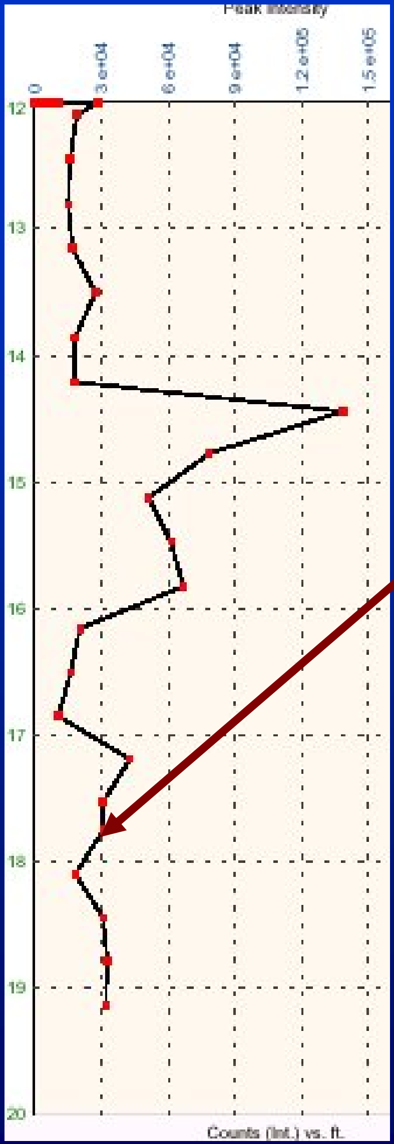
Fuel, Dirty Water, and Gas Bubbles in Coarse Sand

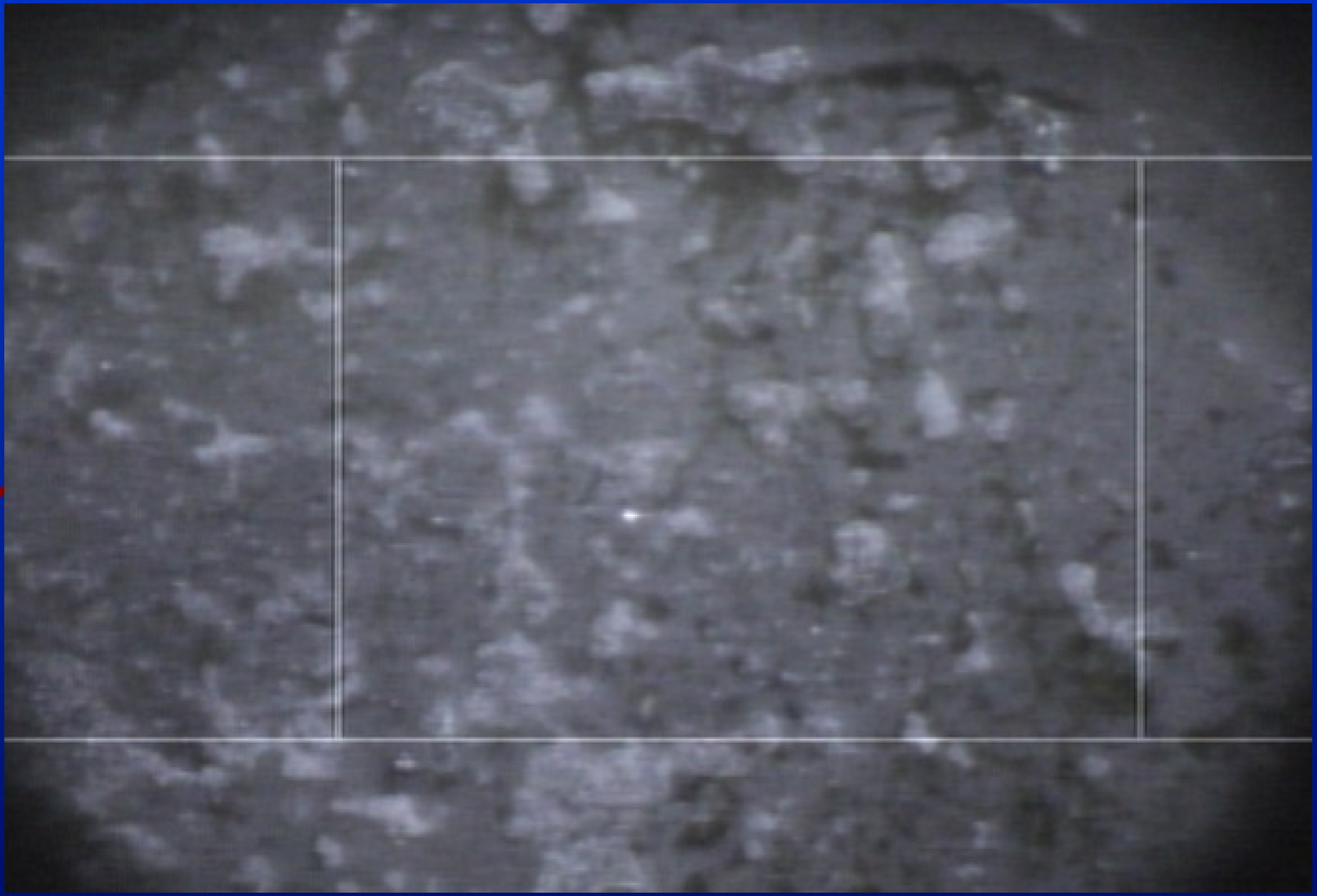




Fluorescence intensity in saturated sands may be controlled by laser beam hitting a fuel droplet.

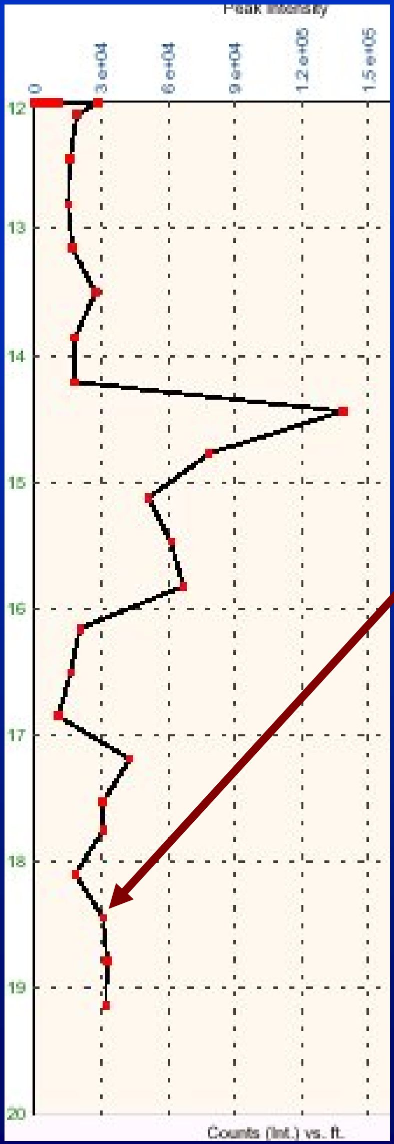
Fuel and Wet Fine Sand

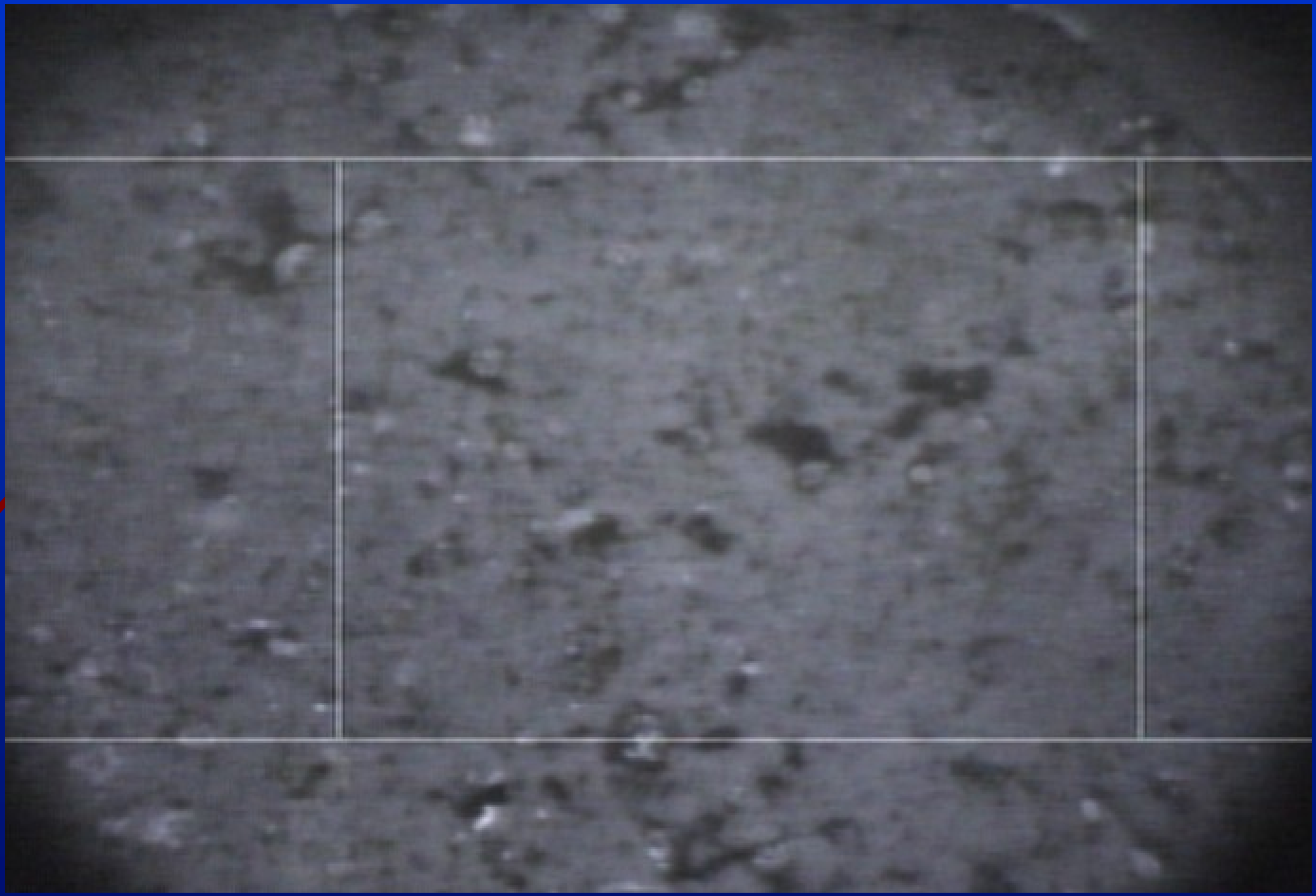




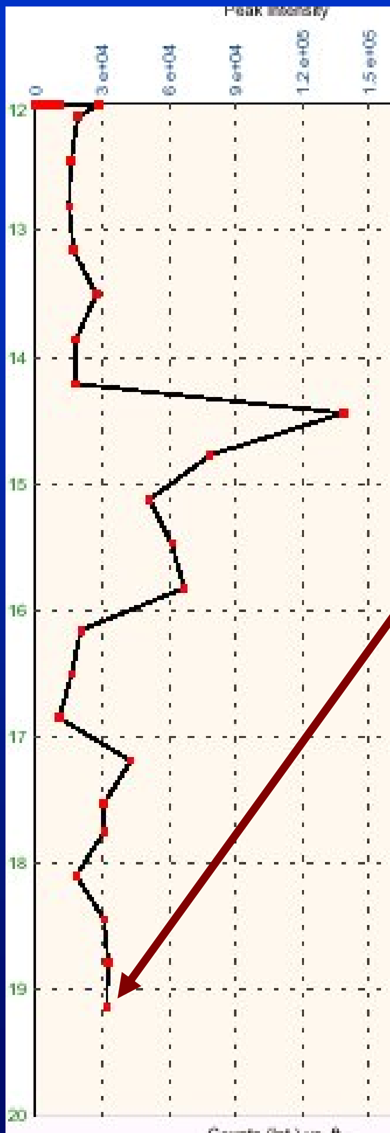
(Dry Angular Areas -- from Probe Pressure?)

Fuel and Saturated Fine Sand

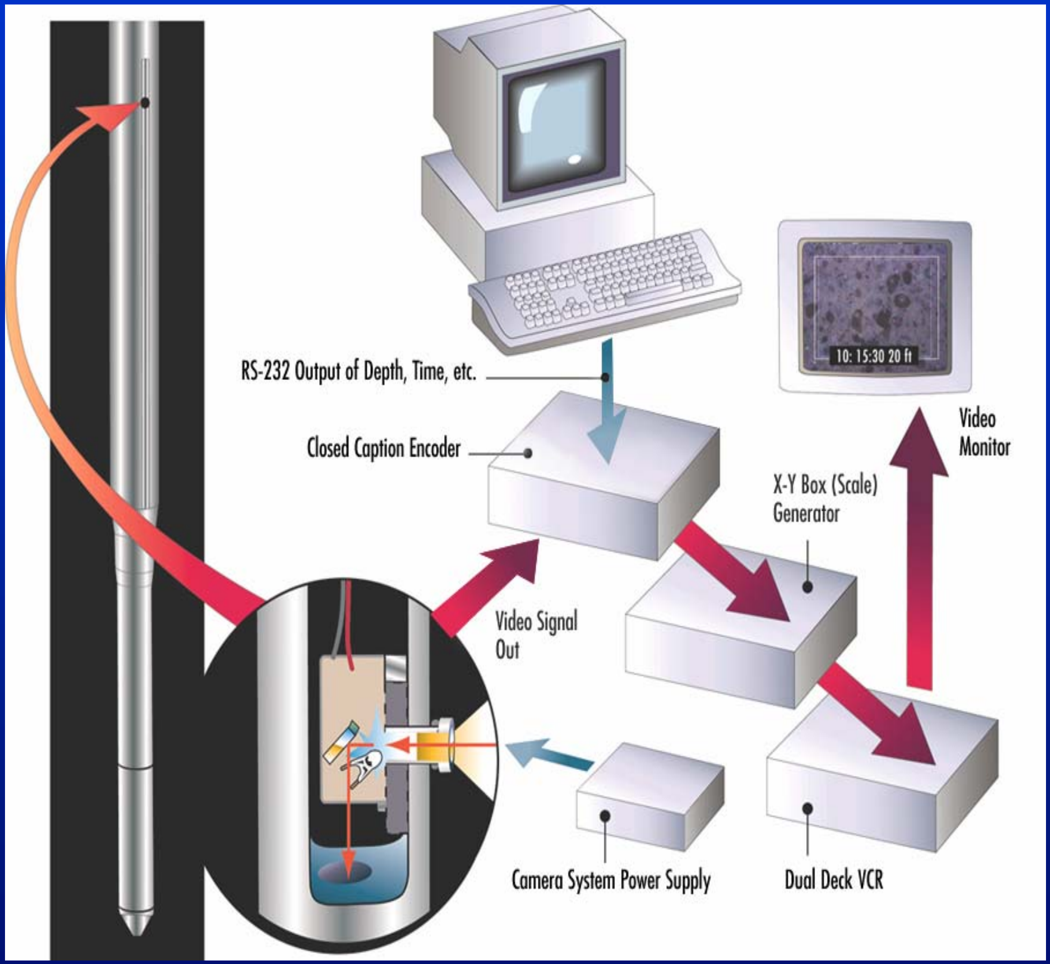


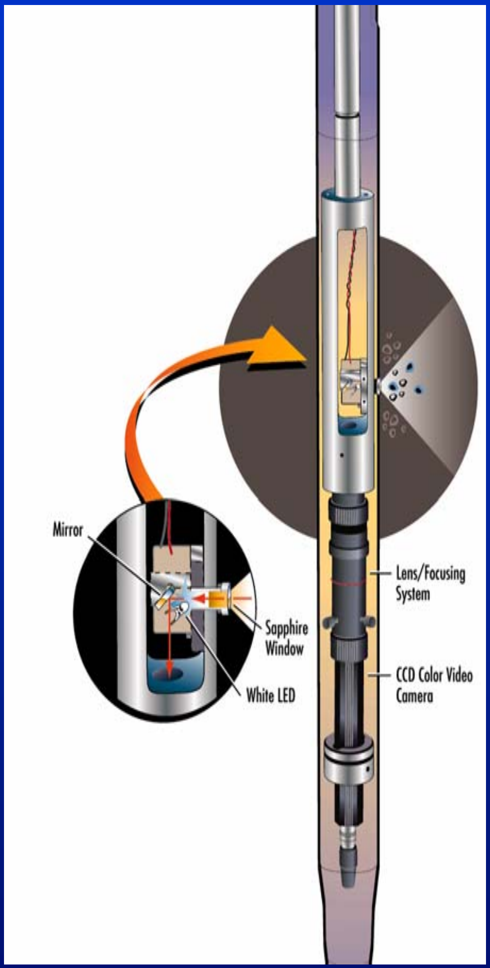


Dark Fuel Corresponding to Rise in Wavelength to ~530 nm



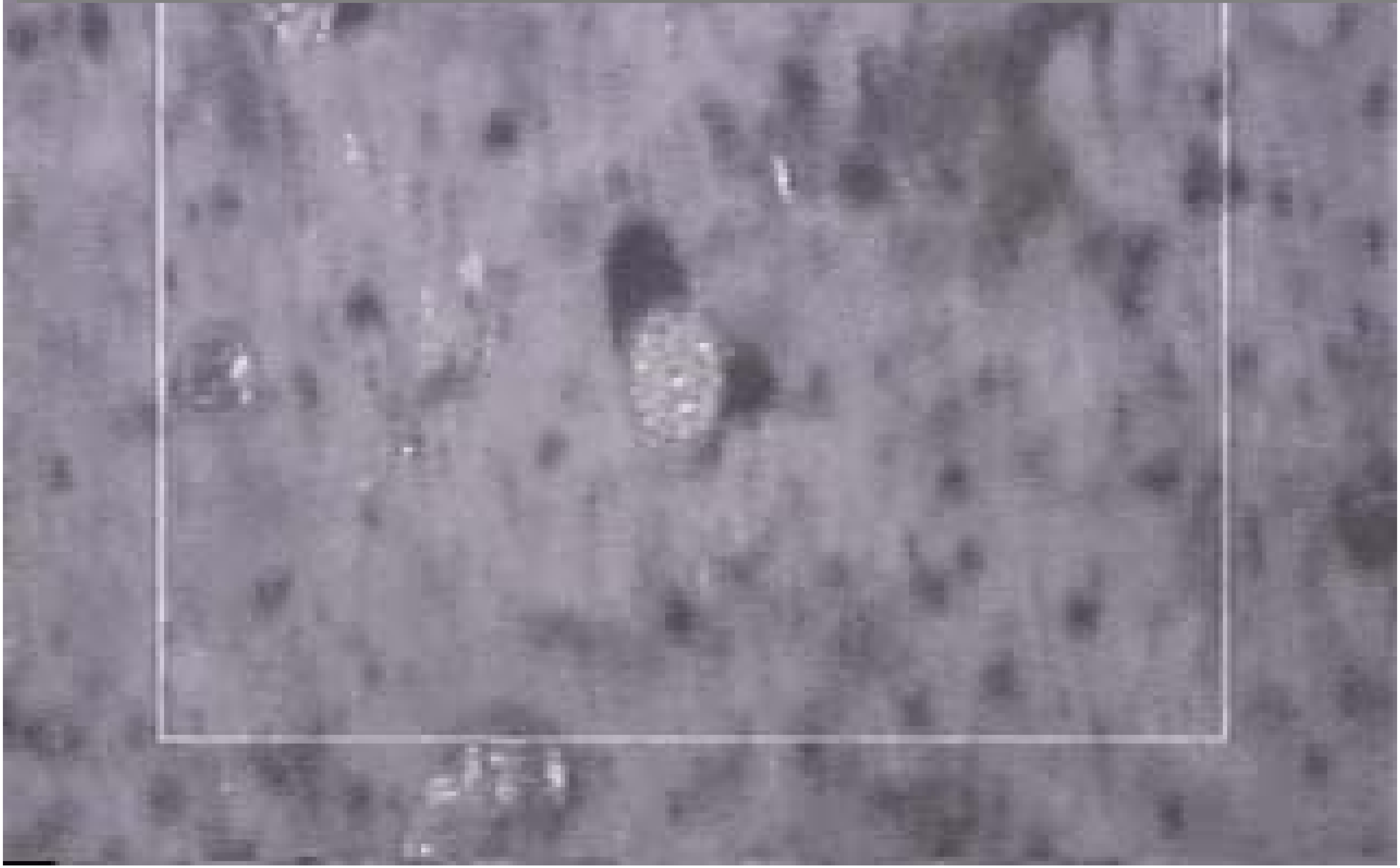
GeoVIS Video Microscope Probe



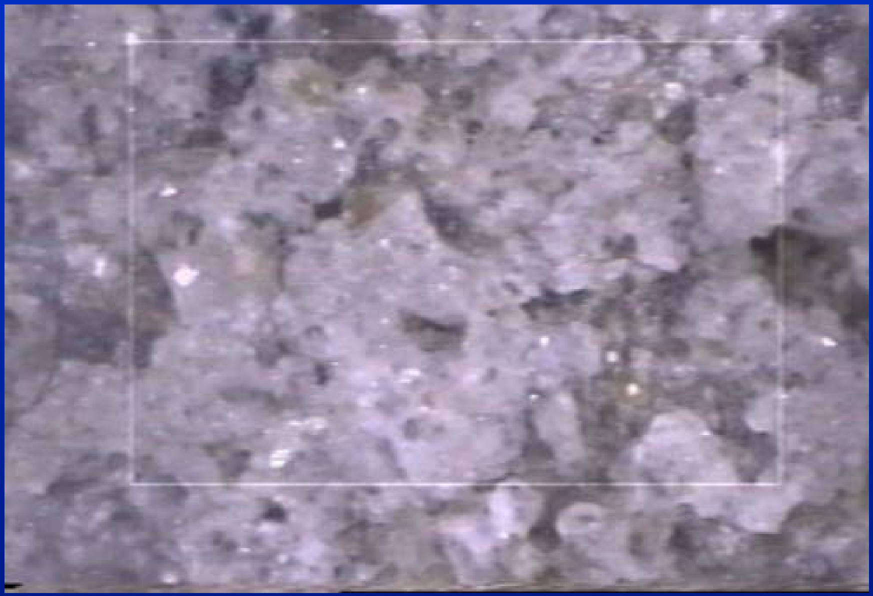


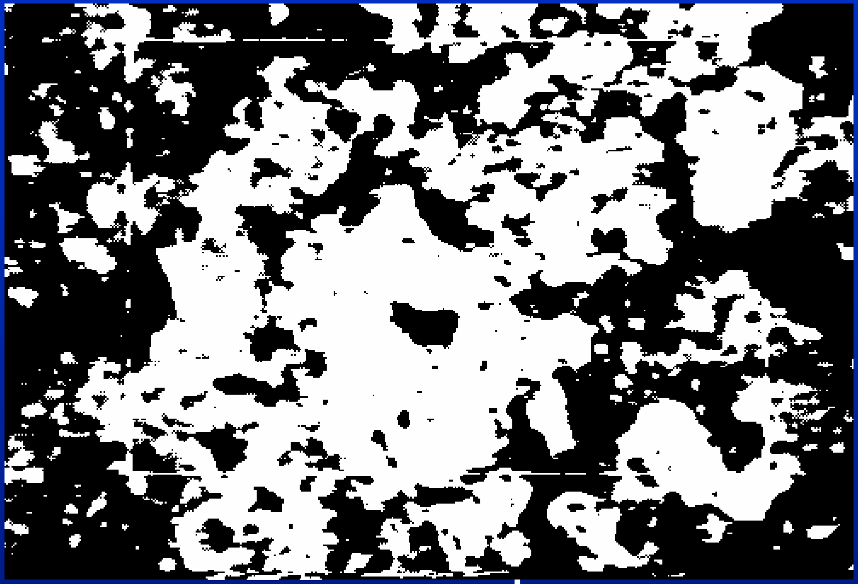
Soil video clip of lawn grass to give an impression of the scale of the video. Note the blades of grass.

Video clip of mixed DNAPL/LNAPL. The NAPL is black and globular, some with gas bubbles inside them. The water has mixed with fines and appears as the gray “background” matrix.



Estimated Soil Porosity (Vadose Zone) from GeoVIS Images





Threshold

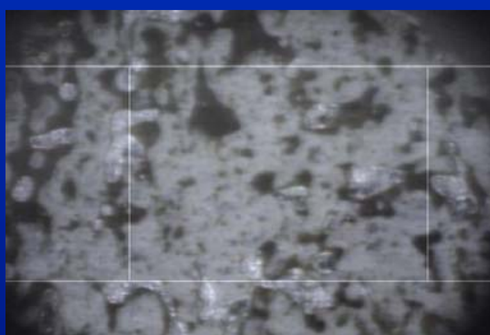
Select area within white box and calculate effective porosity (percent white vs percent black area = pores). Area to volume assuming consecutive slices.

Vadose Zone Effective Porosity Comparison

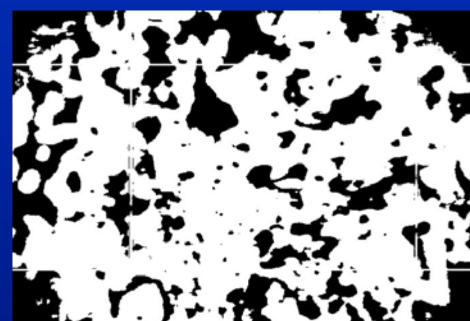
SCAPS PUSH	Photomicrograph ELEVATION (Feet, MSL)	DIGITAL EFFECTIVE POROSITY (%)	6-INCH AVERAGE	LABORATORY EFFECTIVE POROSITY (%) (API RP40)
PRW-5-9	6.06	45.7		-
	5.26	47.9	**43.8**	**45.0**
	4.96	39.2		
	4.76	44.2		
	4.46	47.0		
	3.96	42.7		-
	3.36	46.1		-
	3.06	39.7		-
	2.86	45.4		-
	2.56	50.2		-
	AVERAGE	**44.8**		
PRW-6-5	5.70	47.6	**50.5**	**49.8**
	5.60	44.5		
	5.10	59.4		
	4.90	66.1		-
	4.70	47.9		-
	4.20	40.0		-
	3.90	27.2		-
	2.90	57.9		-
	AVERAGE	**48.8**		

NAPL Saturation Processing

Effective
Porosity
36.15%



Threshold
122



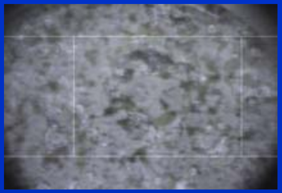
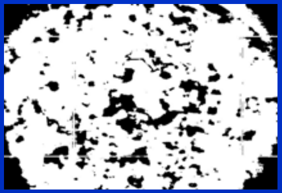
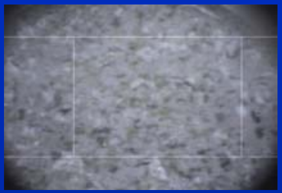
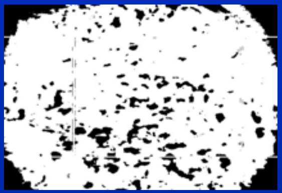
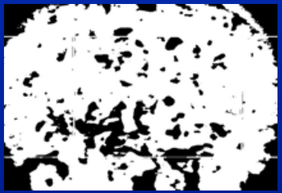
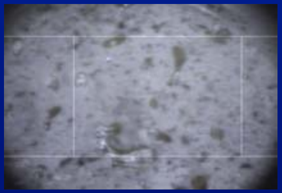
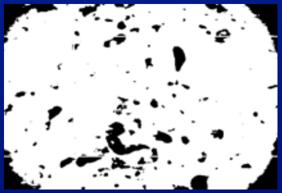
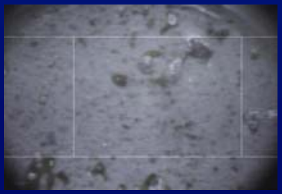
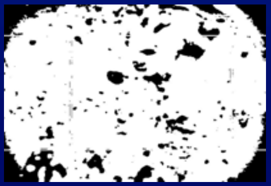
Fuel Area
26.68%

NAPL Saturation Results

Water Saturation (S_w) =
(“Wet” Area - Fuel Area) / N_e =
(36.15-26.68)/36.15 = **26.2%**

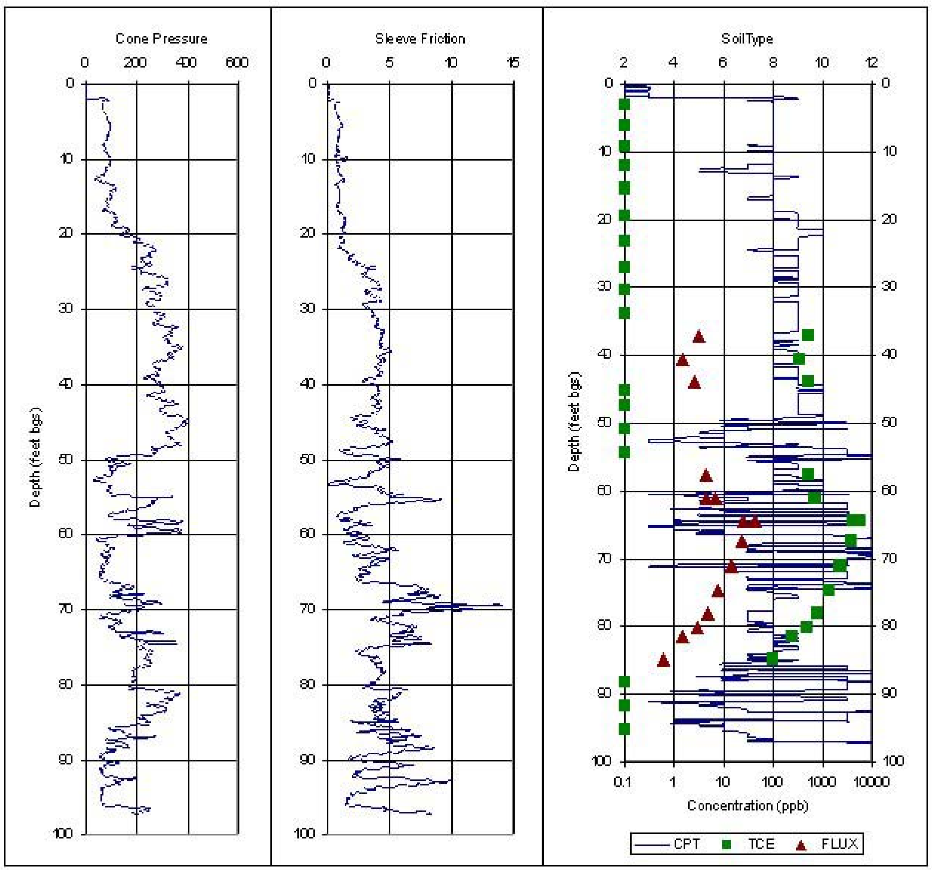
Fuel Saturation (S_o) =
Fuel Area / N_e =
26.68/36.15 = **73.8%**

Soil Video Profile

Fuel Area	Effective Porosity	Fuel Saturation		Depth (ft bgs)	Fuel Area
19.2%	32.2%	59.6%		14.0 feet	
11.3%	23.4%	48.3%		14.4 feet	
21.5%	31.1%	69.1%		16.4 feet	
8.9%	22.0%	40.5%		16.7 feet	
8.7%	27.9%	31.2%		17.0 feet	

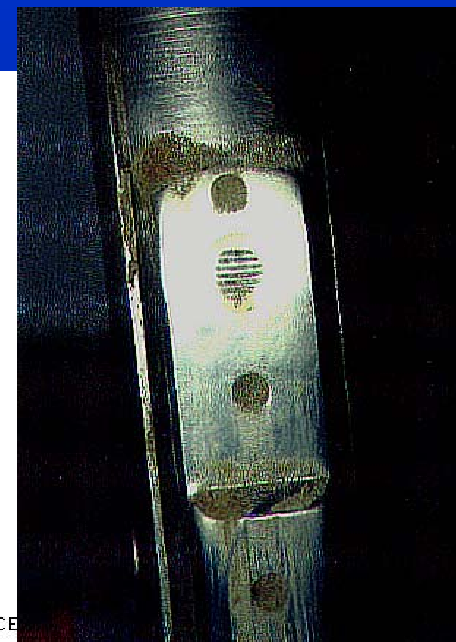
Dissolved Volatile Organic Compounds

Using Membrane Interface Probe and Direct Sample Ion Trap Mass Spectrometry

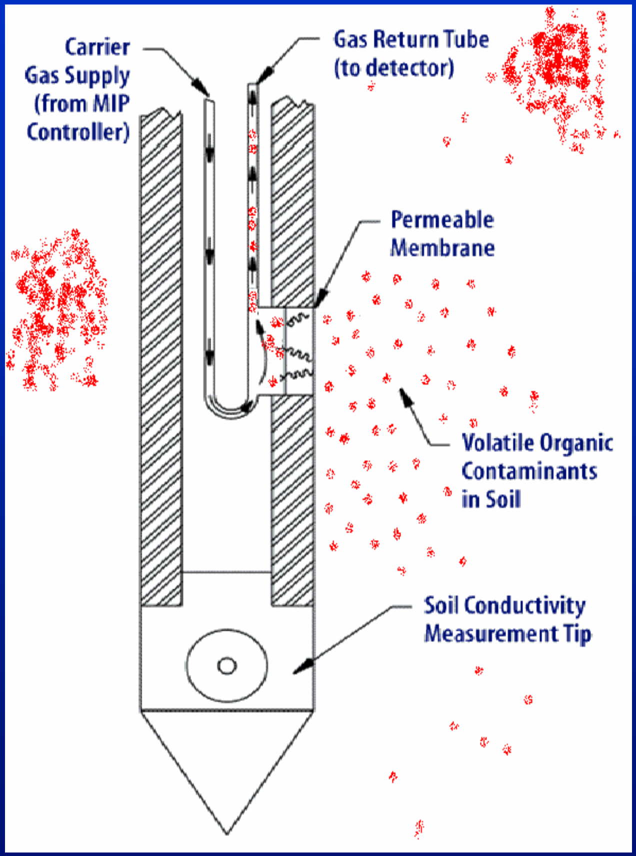


Depth	TCE (ppb)
3.2	nd
6.1	nd
9.2	nd
12.1	nd
15.4	nd
19.4	nd
23.2	nd
27.0	nd
30.4	nd
33.8	nd
37.1	500
40.6	331
44.0	524
45.2	nd
47.4	nd
50.9	nd
54.3	nd
57.7	512
61.1	700
64.5	5,693

	TCE (ppb)	DCE
61.0	738	nd
64.4	4,217	355
67.4	3,904	333
71.1	2,294	202
74.6	1,318	nd
78.0	777	nd
80.1	485	nd
81.5	239	nd
84.8	103	nd
88.2	nd	nd
91.8	nd	nd
95.2	nd	nd



Geoprobe® Systems
Membrane Interface Probe (MIP)



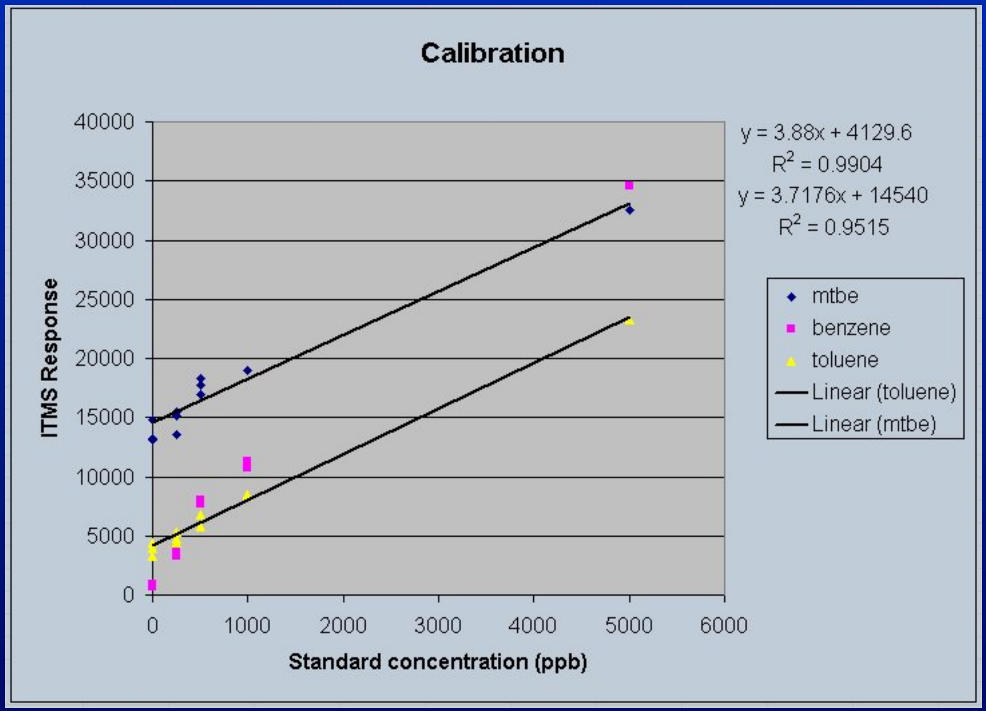
- An inert ultrapure helium carrier gas is sent down to the probe, sweeps behind the membrane, and returns to the surface to be analyzed.
- A temperature controller allows the membrane to be heated, which may optimize membrane performance.
- When the membrane is heated, VOCs advect away from the membrane. However, some of the VOCs pass through the membrane and are brought to the surface with the carrier gas to be analyzed.
- SCAPS analyzes the gas stream with a Direct Sample Ion Trap Mass Spectometer (DSITMS)

Direct Sampling Ion Trap Mass Spectrometer

- Creates gas-phase ions
- Separates the ions based on mass-to-charge ratio
- Measures the quantity of ions of each mass-to-charge ratio
  - Has a large responsive range – can take high levels of contaminants without overloading the system
  - Is fast, with minimal sample preparation. 3 minutes or so for an analysis.
  - Is a durable machine that can be deployed in the field.
- EPA Method 8265

Calibrating the system.

- Samples of water containing a known concentration of contaminant are added to sand in a calibration jig and measured with the MIP/DSITMS.
- The results are used to prepare a calibration curve.



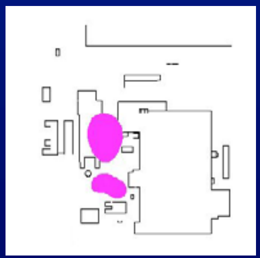
Discovering the True Source and Extent of a Plume

Traditional Phased Investigations, 1991 – 1998

Initial estimate of JP-5 and Stoddard Solvent free product plumes.

Based on wells installed during investigations in 1991 and 1993.

True nature and extent of contamination still unknown.

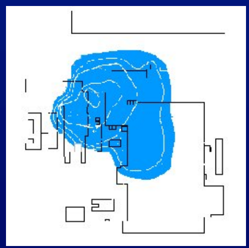


Product plume discovered to be larger than initial estimates after subsequent investigation.

Twenty product recovery wells plus additional monitoring wells were installed.

TCE (Trichloroethylene) detected during analysis of product.

True nature and extent of contamination still unknown.



Plume of TCE dissolved in groundwater based on monitoring well sampling.

Vertical and horizontal characterization is incomplete.

Dynamic Investigations, 1998 - 2000

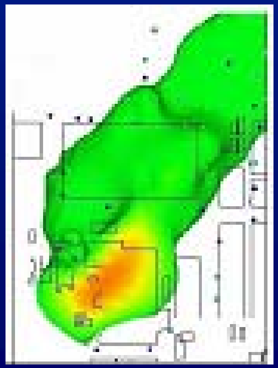
SCAPS Hydrosparge with DSITMS investigation in Summer of 1998.

Validation testing of a sensor used before the development of the MIP

Installation of temporary direct-push wells was necessary. Real time sensor was inserted into the well.

Contamination discovered deeper that previous data suggested.

True extent of contamination still unknown.

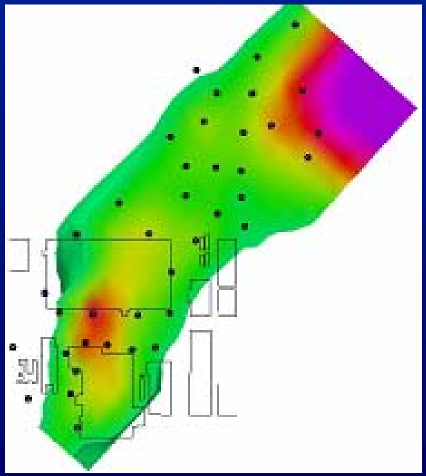


SCAPS MIP with DSITMS investigation in Summer of 1999.

Validation testing of MIP/DSITMS

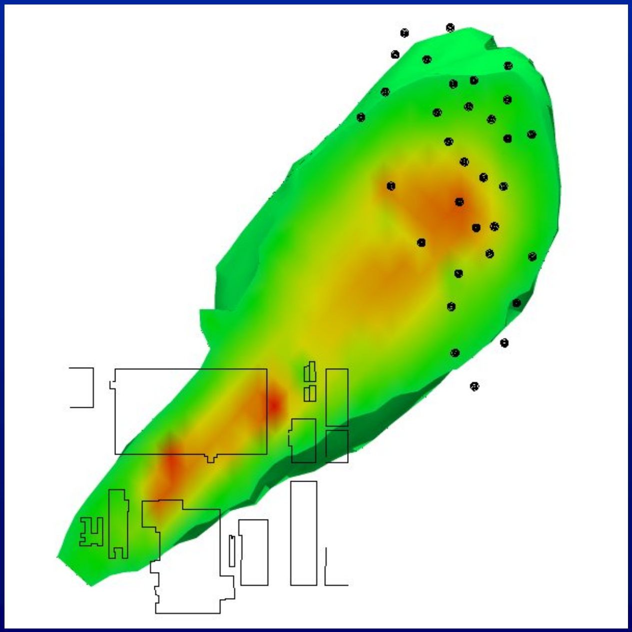
- 14 production days
- 207 measurements
- 40 Locations
- Over 2000 feet pushed.

Detected a second source downgradient.

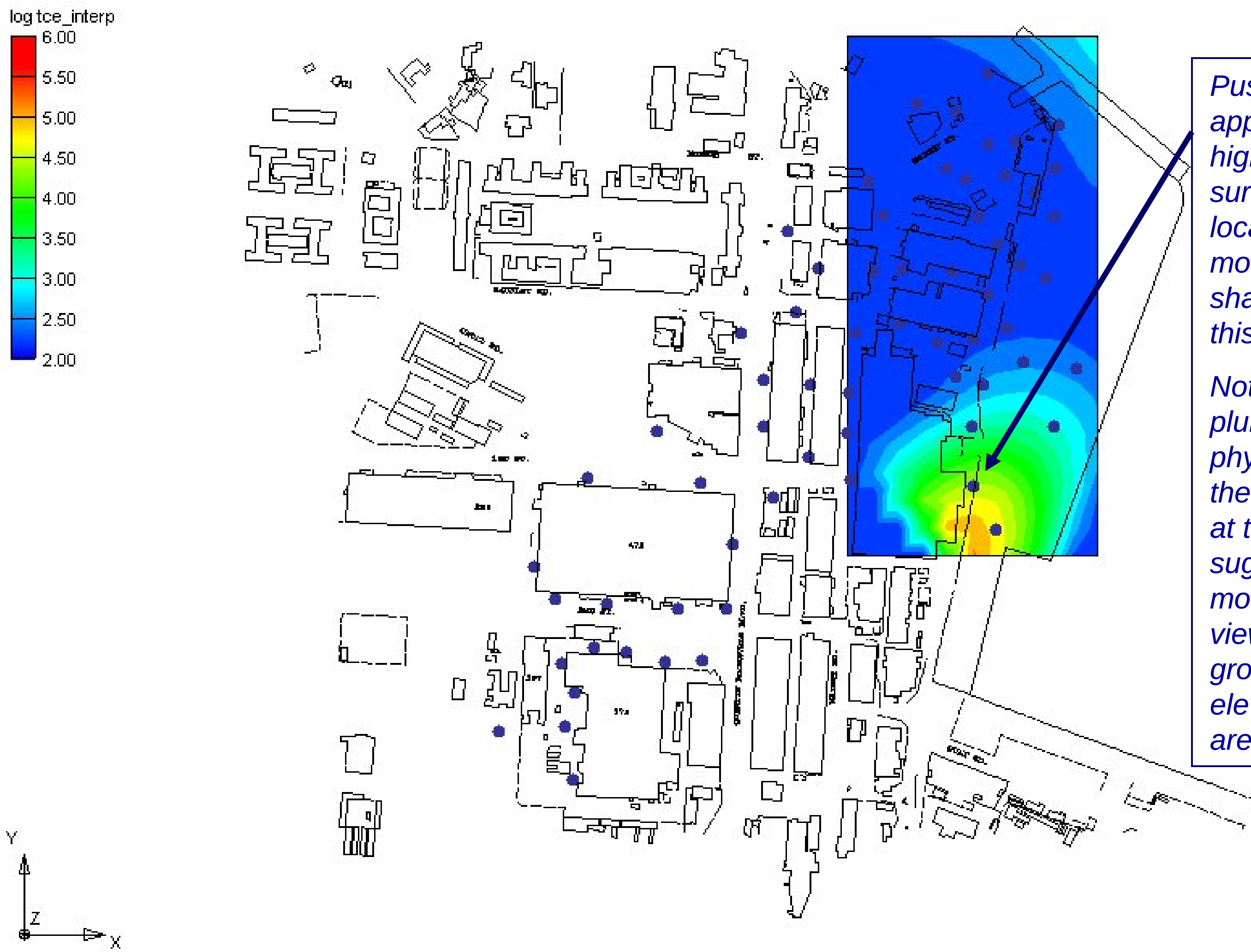


SCAPS MIP with DSITMS investigation in Spring 2000.

- Investigation completed
- 13 production days
- 485 measurements
- 29 locations
- Over 1900 feet pushed



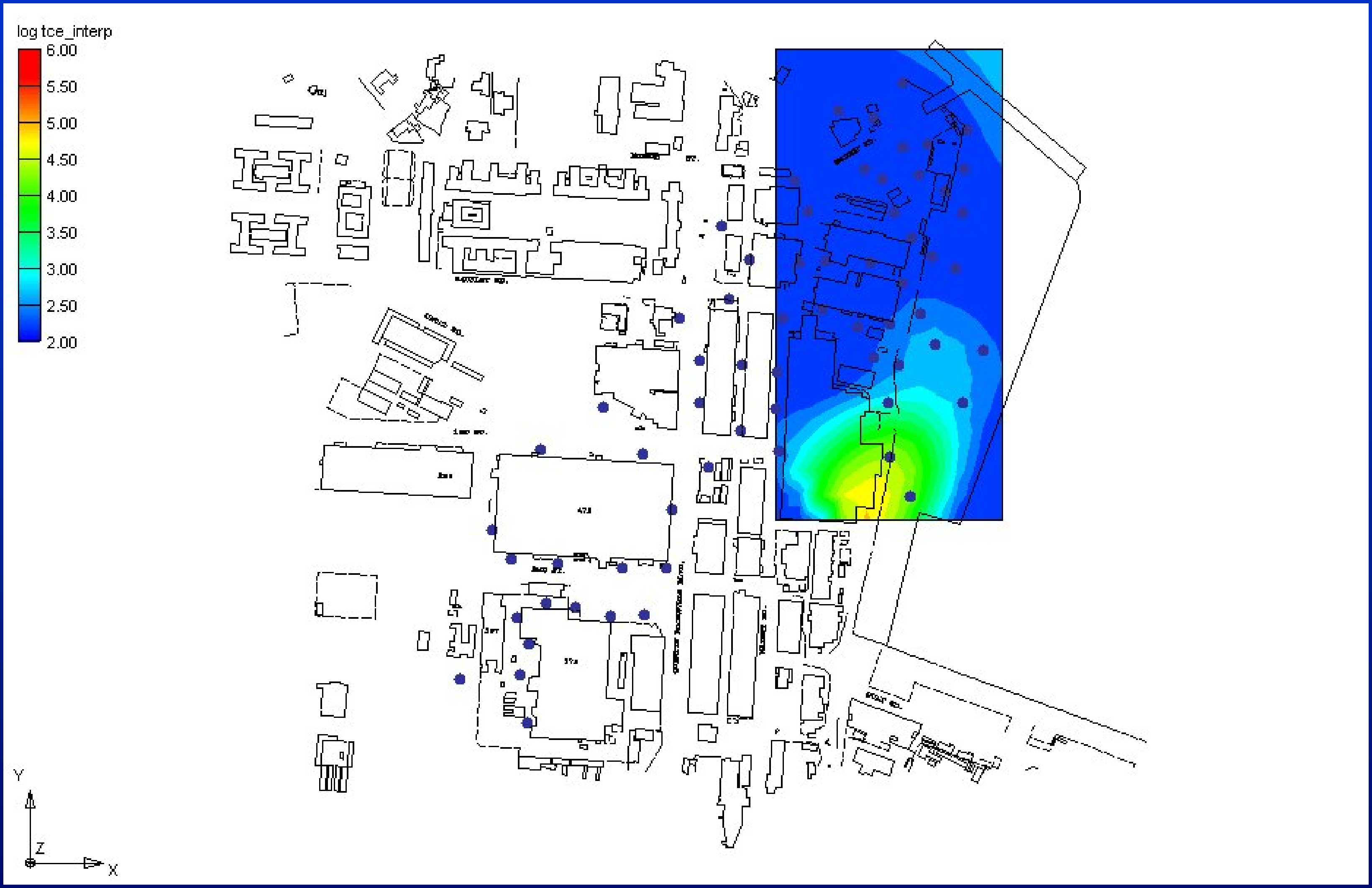
10' elevation, 0' bgs



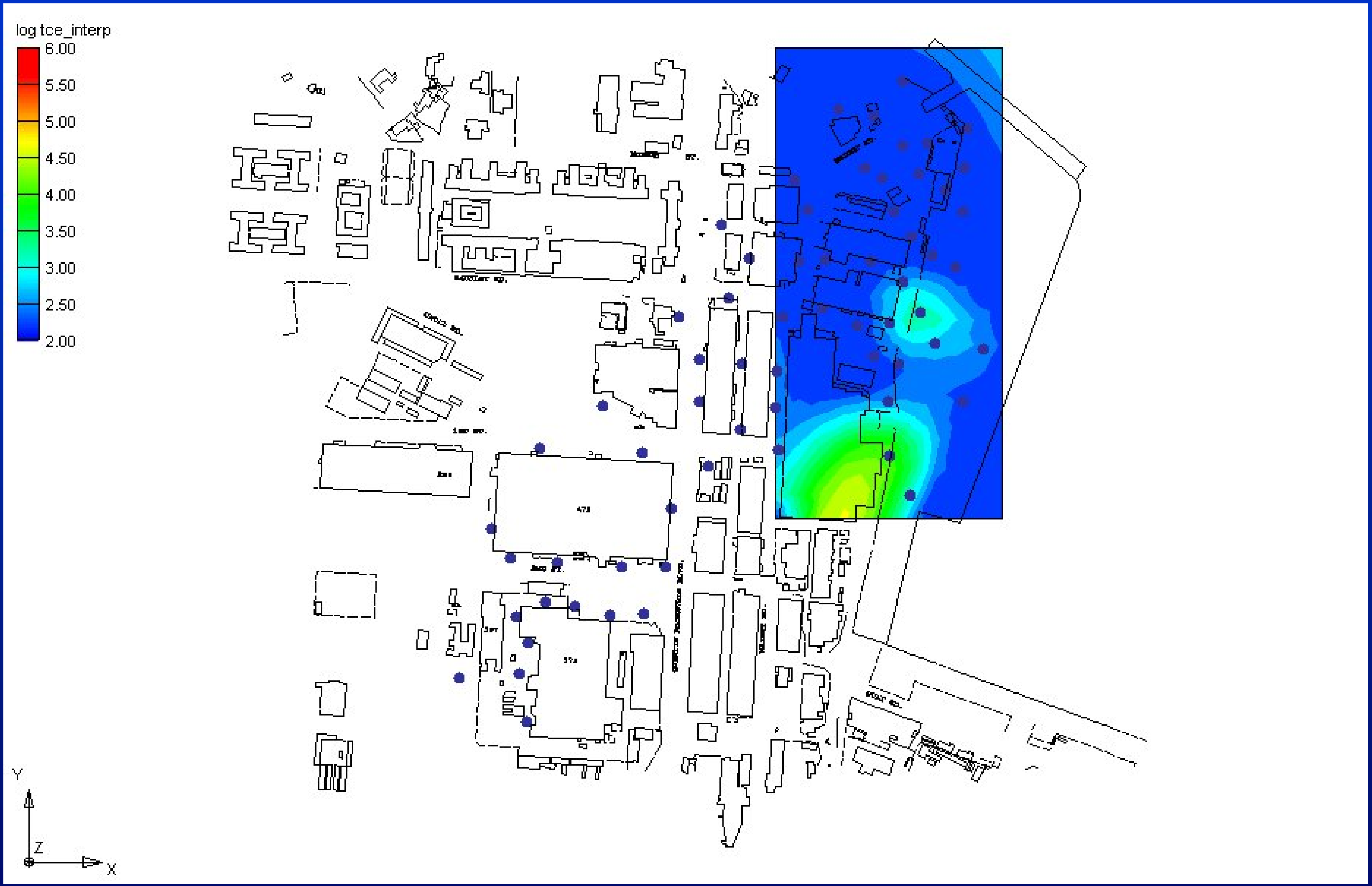
Push MIP 61 is approximately 8' higher than the surrounding push locations. The model reflects the shallow detection at this location.

Note that this plume cannot physically extend to the north and east at this elevation as suggested by the model because this view depicts ground surface elevation at these areas.

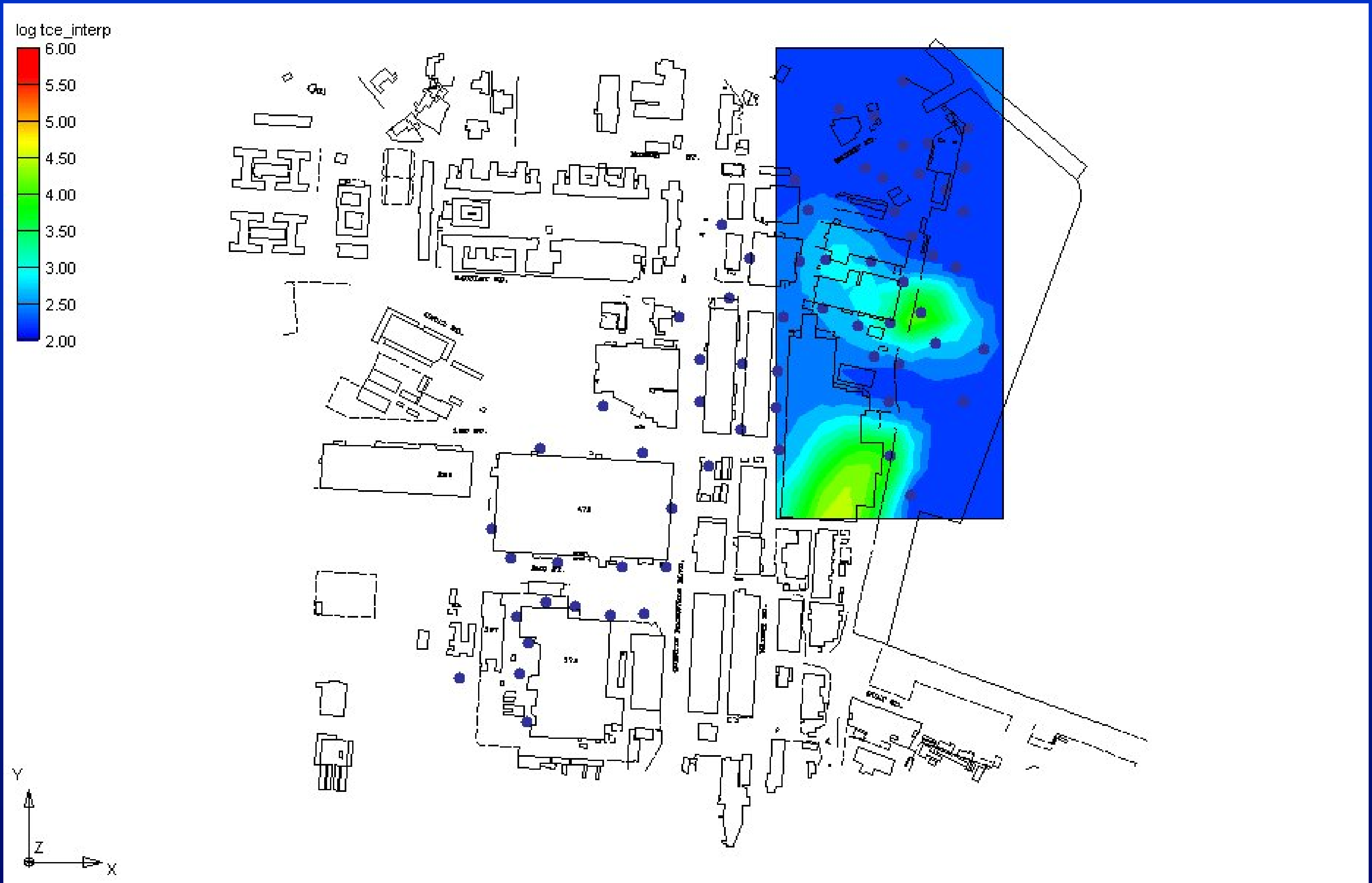
5’ elevation, 5’ bgs



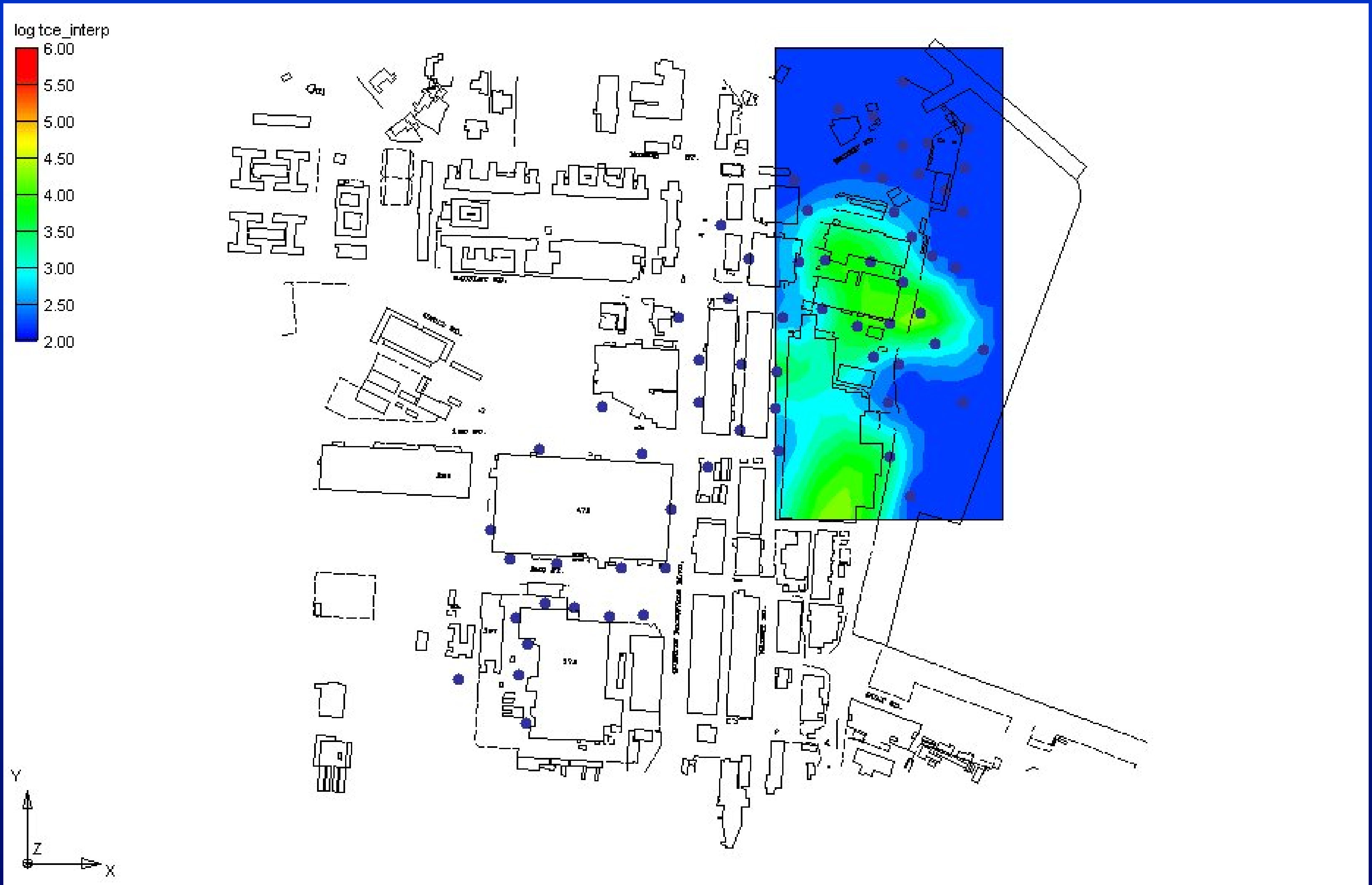
0’ elevation, 10’ bgs



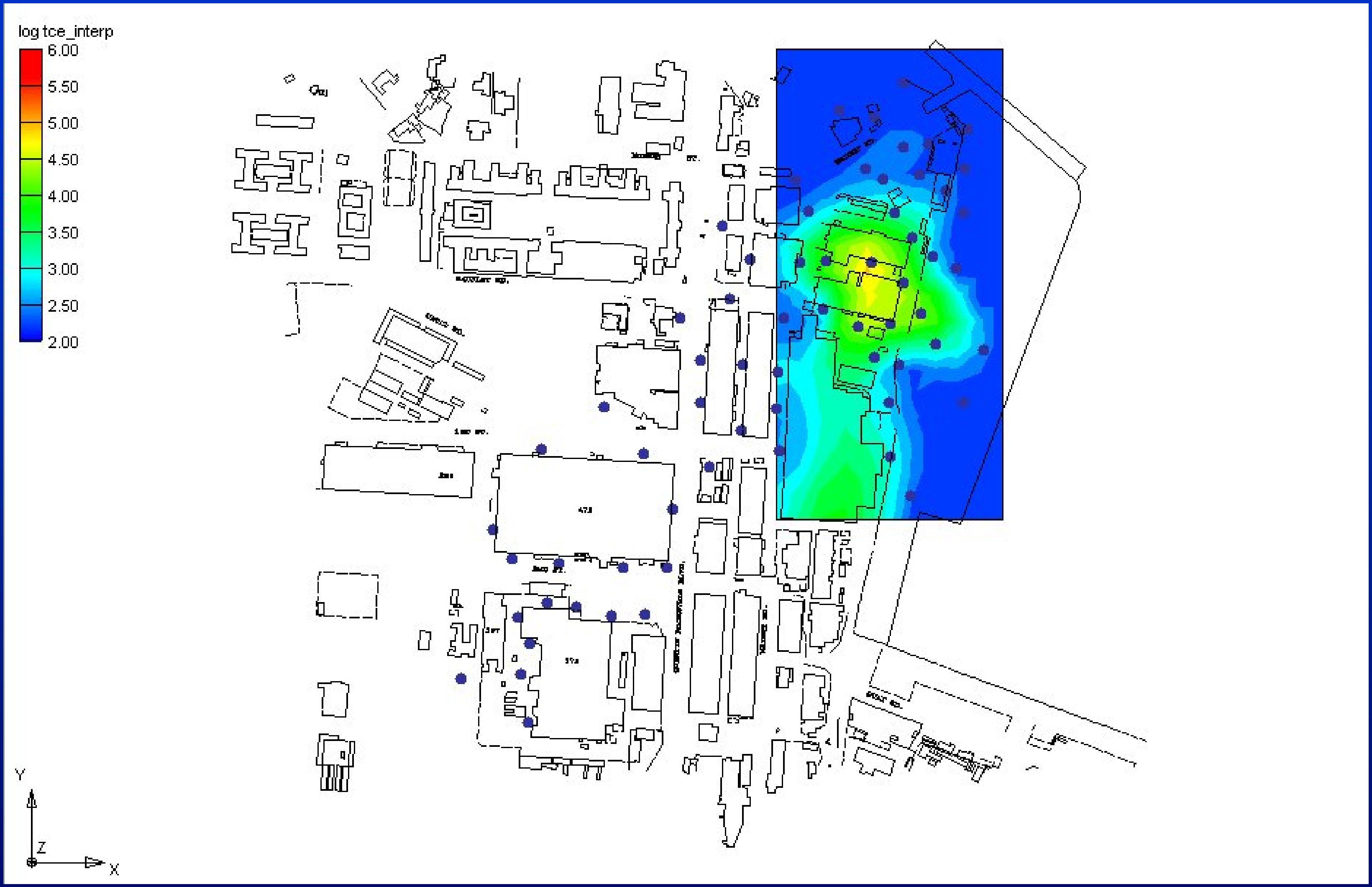
-5' elevation, 15' bgs



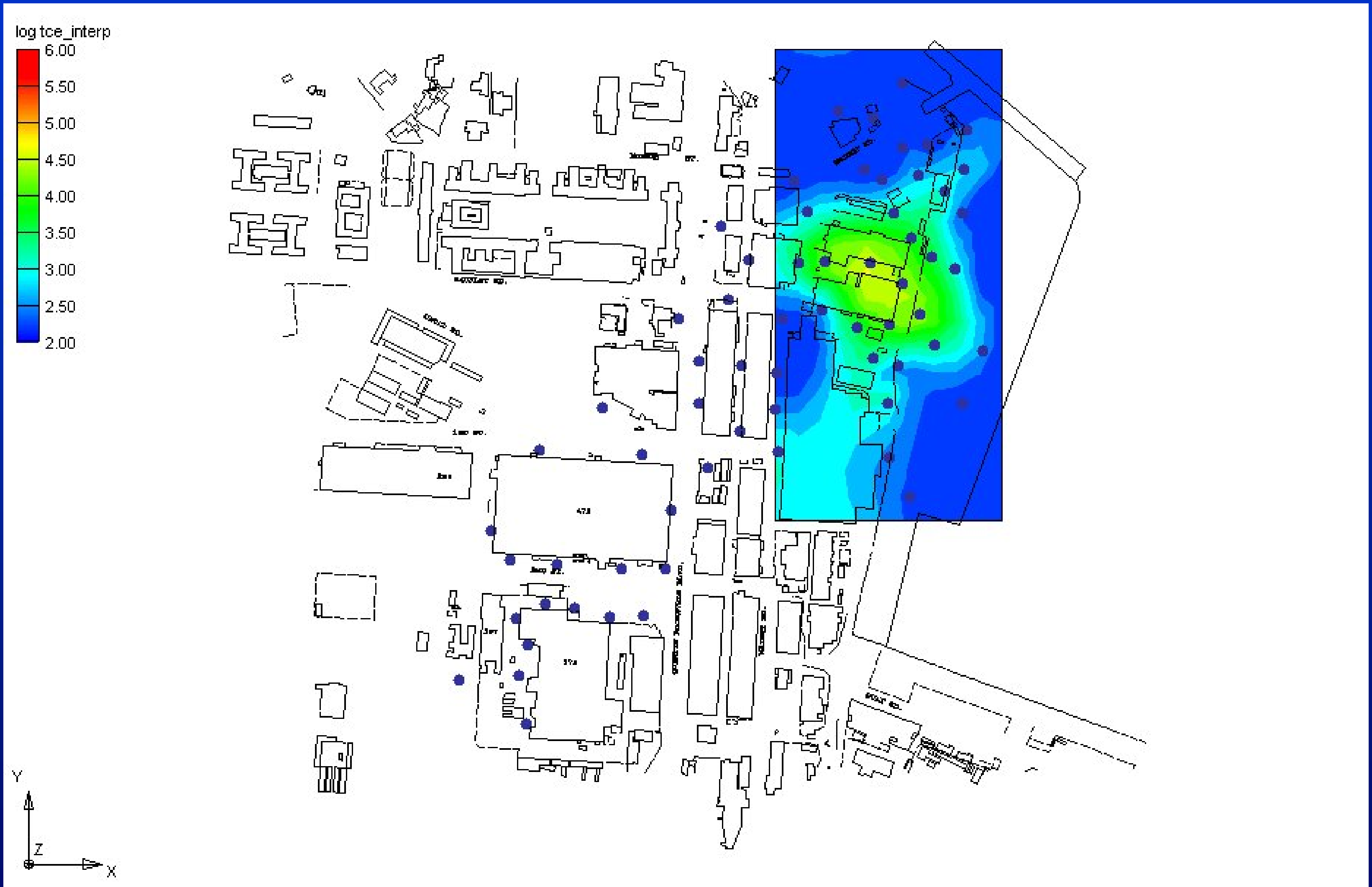
-10' elevation, 20' bgs



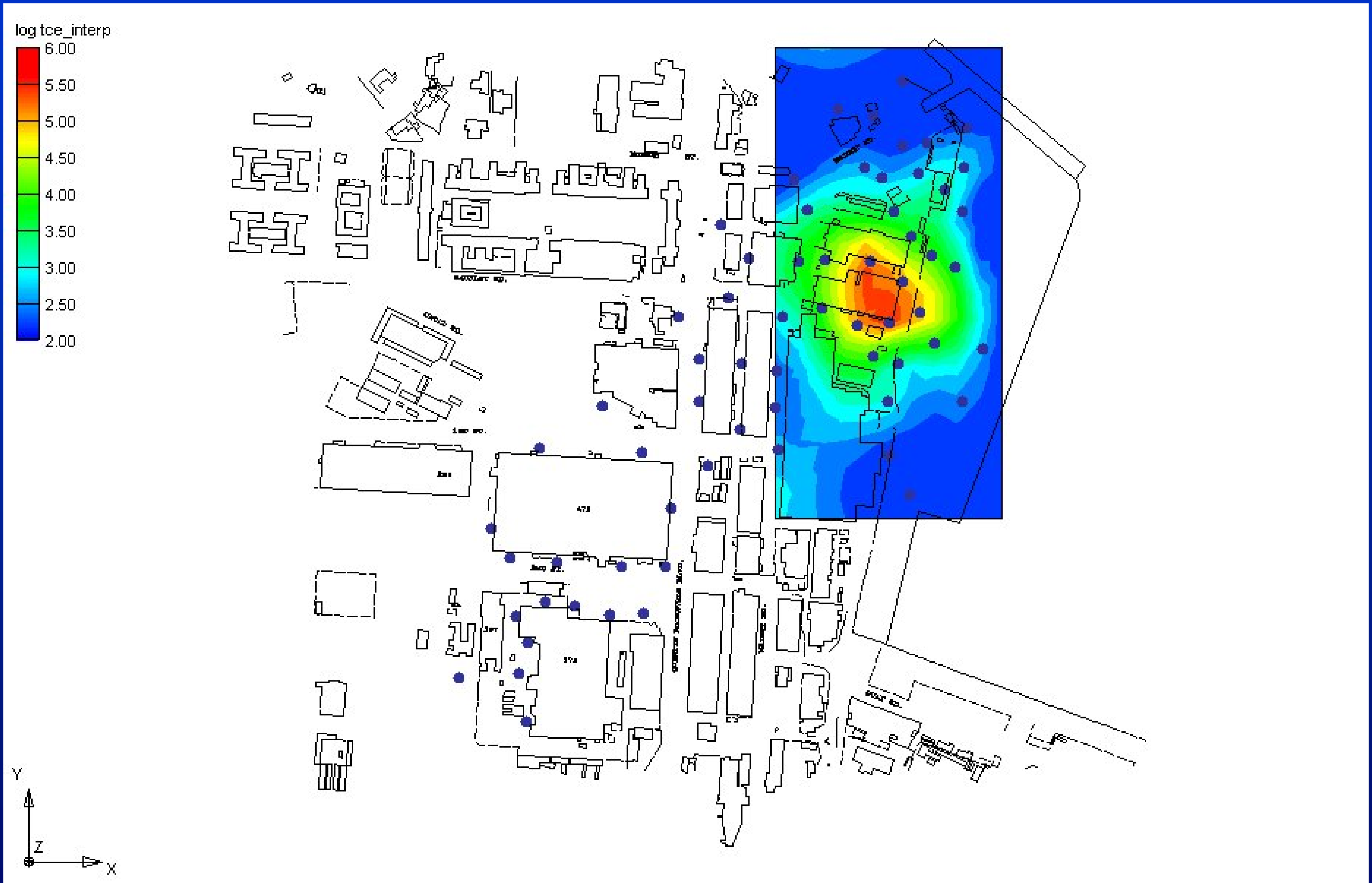
-15' elevation, 25' bgs



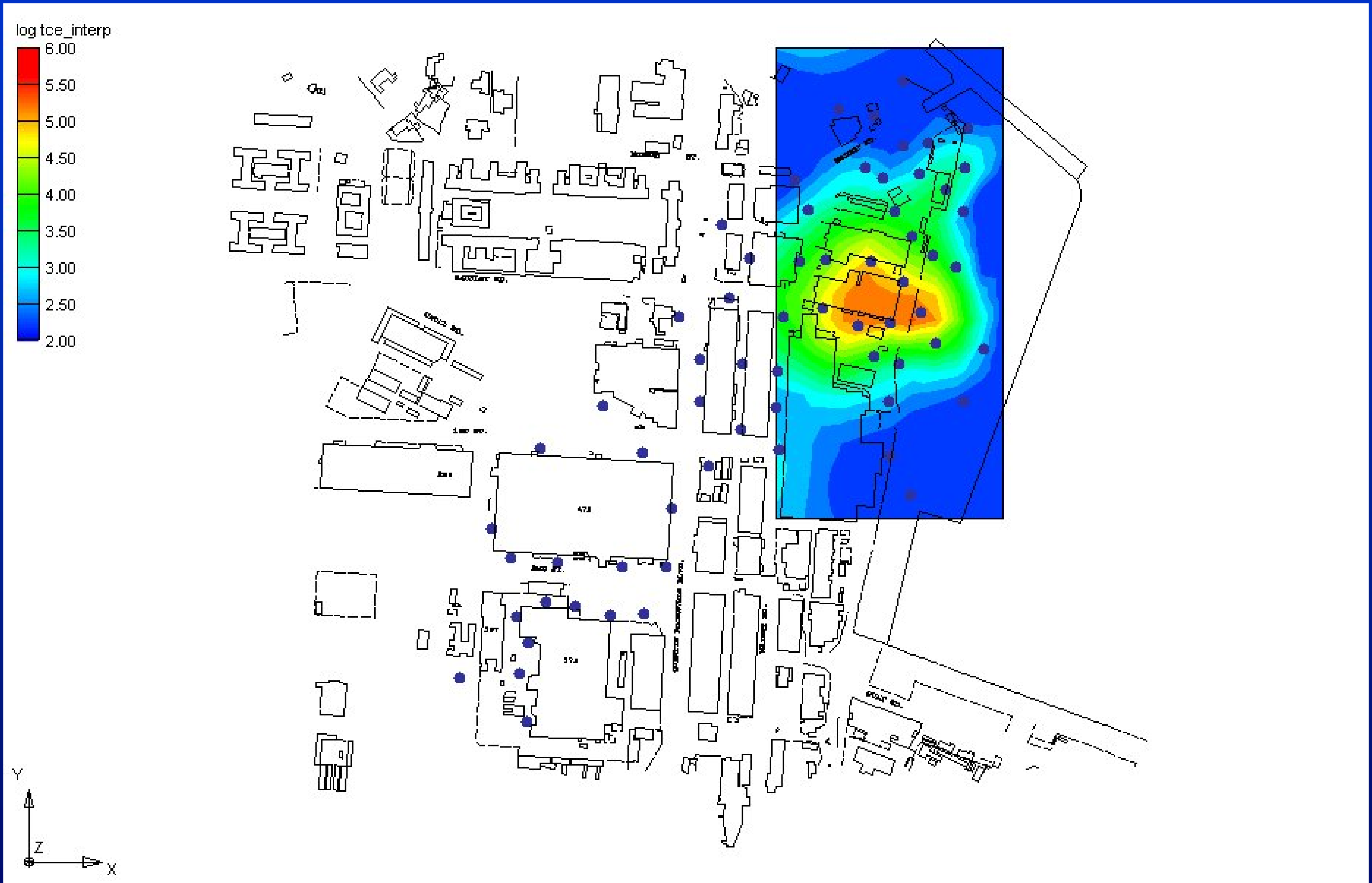
-20’ elevation, 30’ bgs



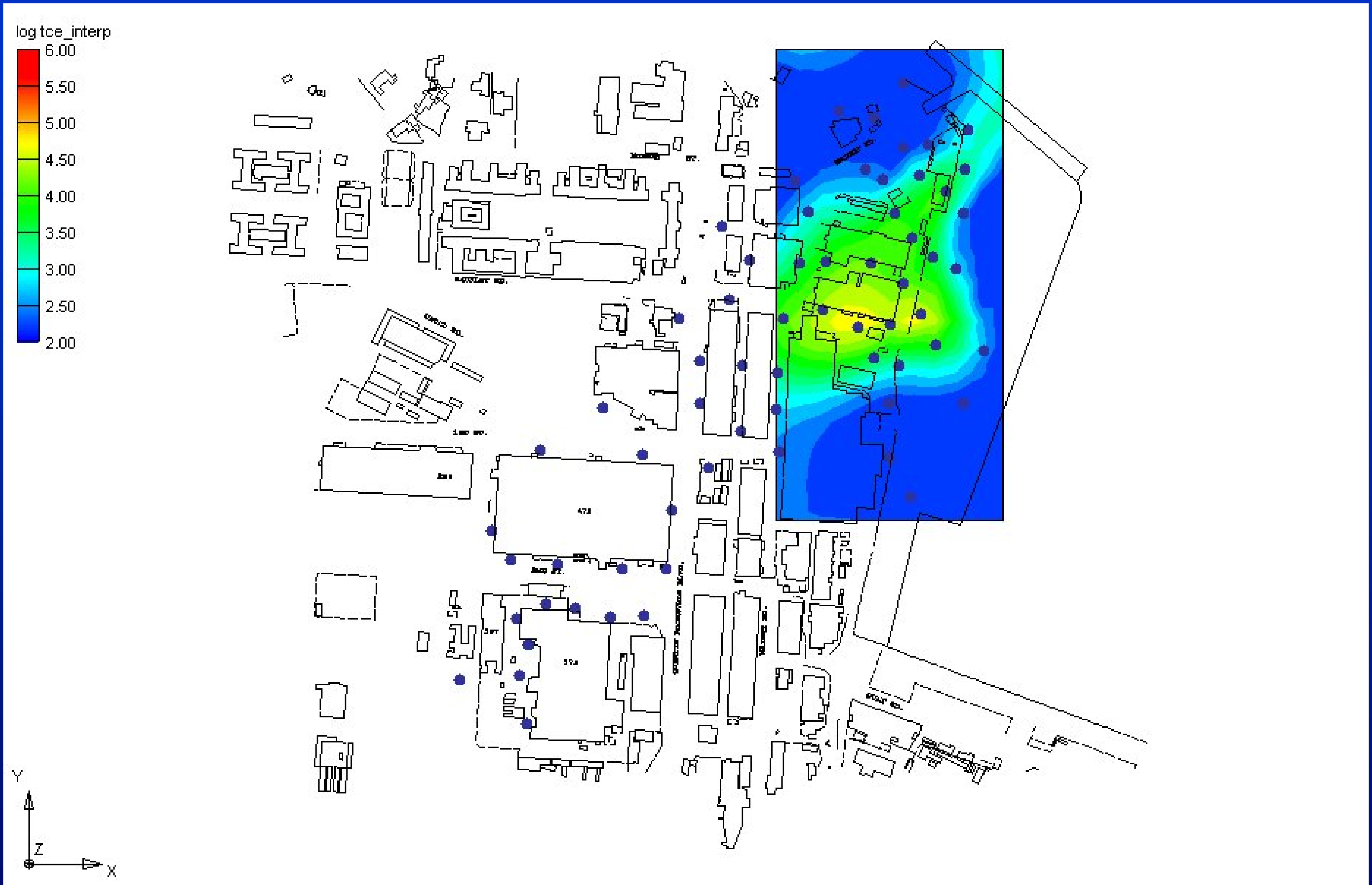
-25' elevation, 35' bgs



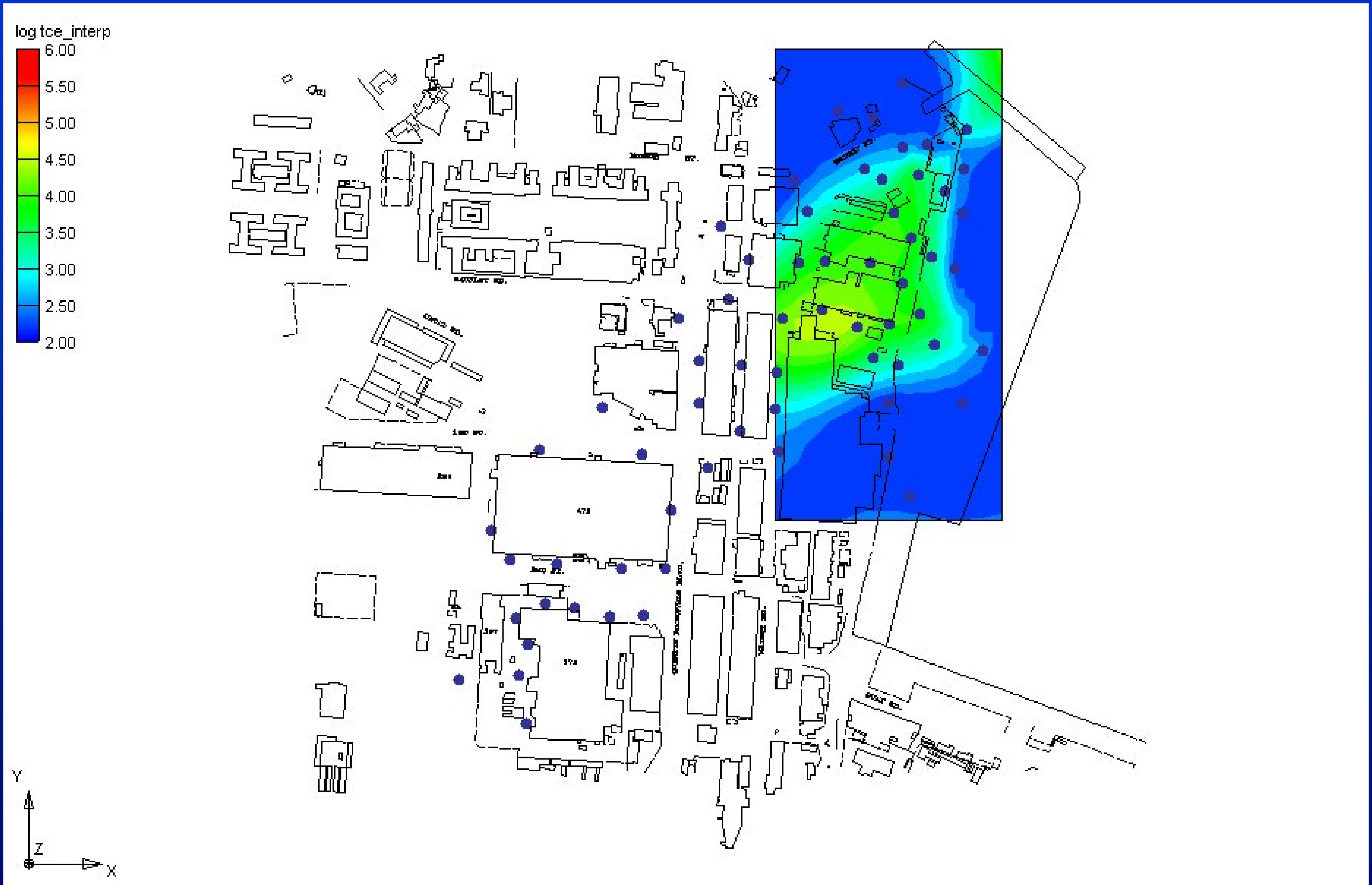
-30’ elevation, 40’ bgs



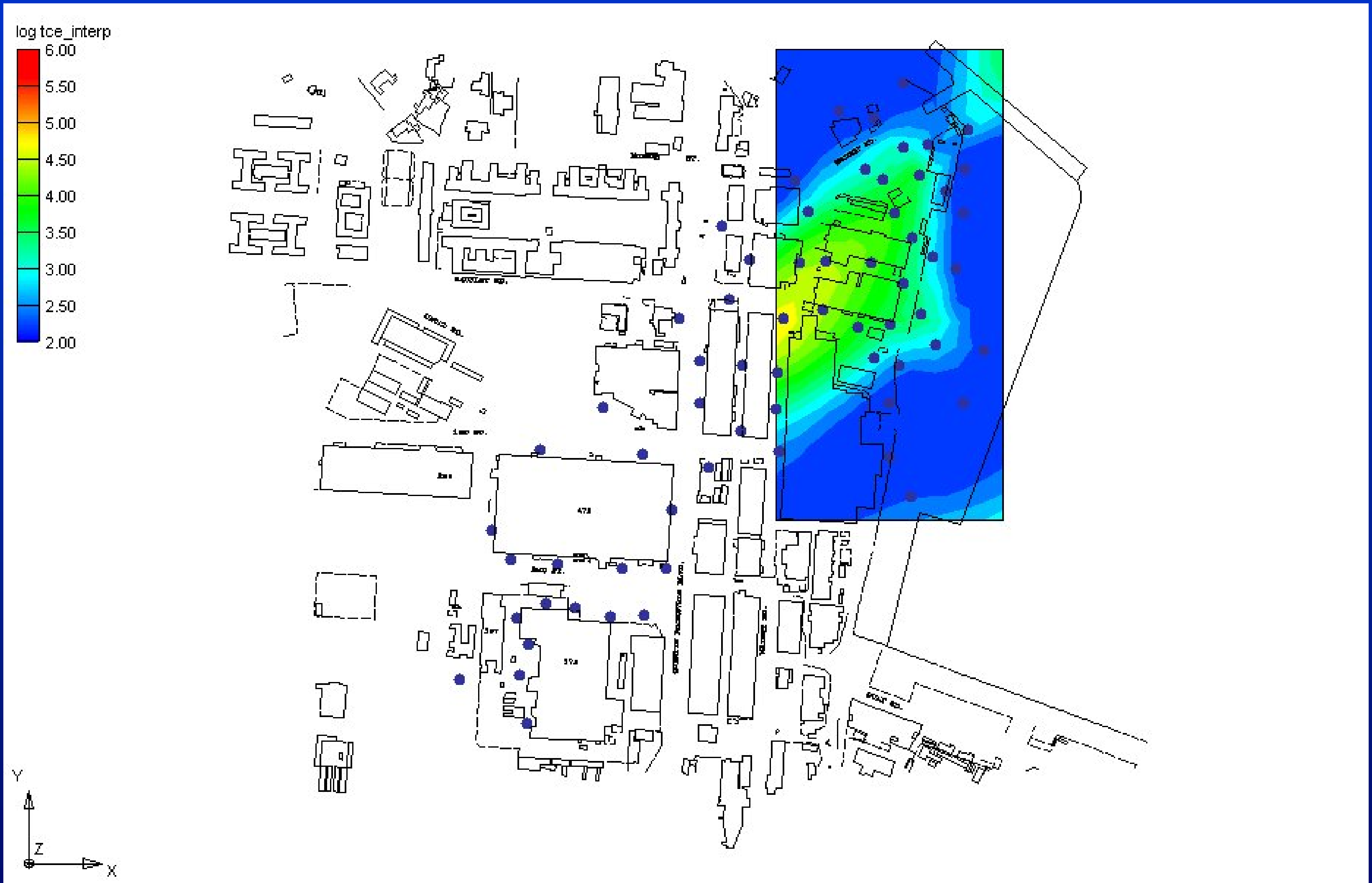
-35’ elevation, 45’ bgs



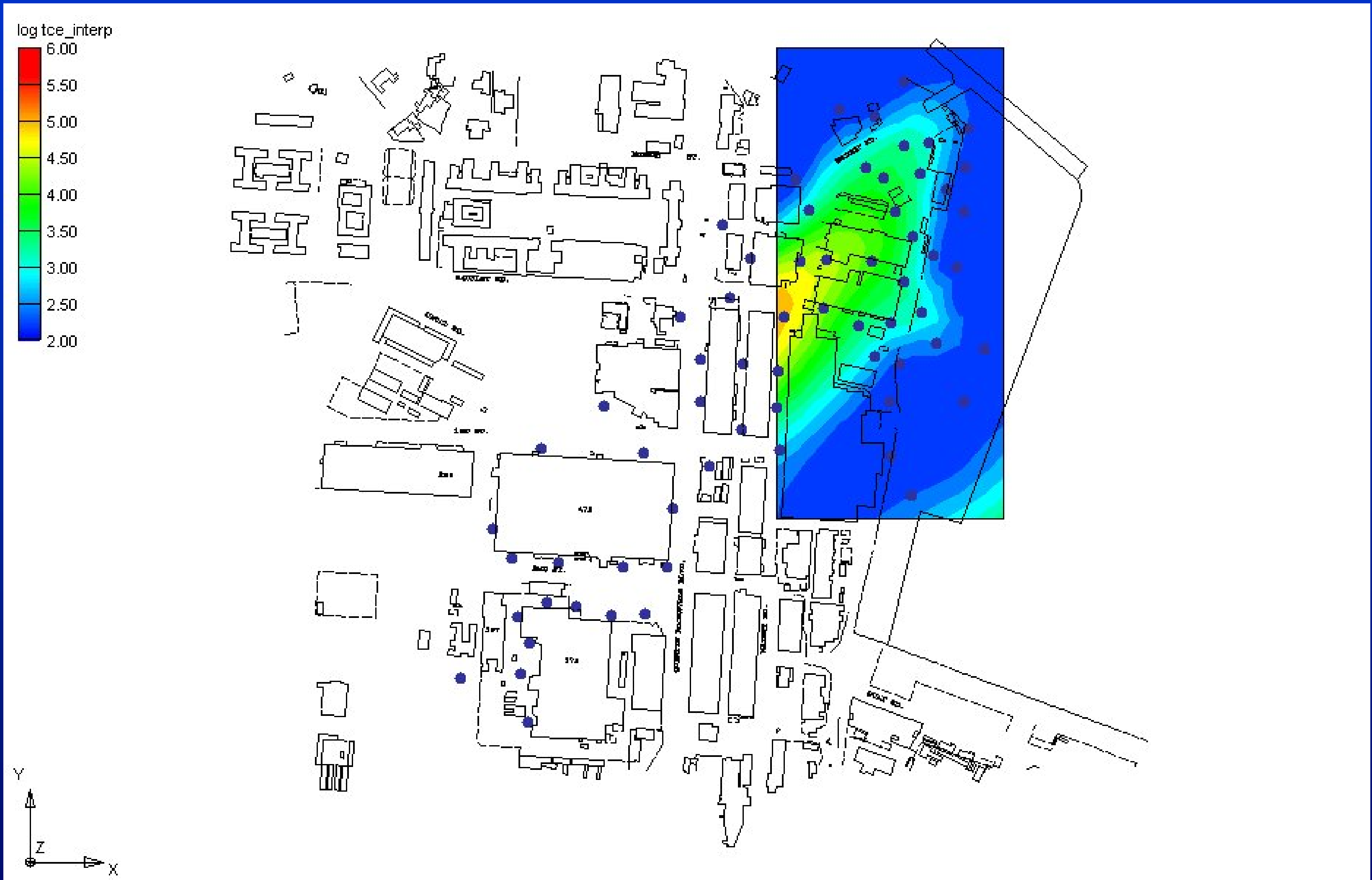
-40' elevation, 50' bgs



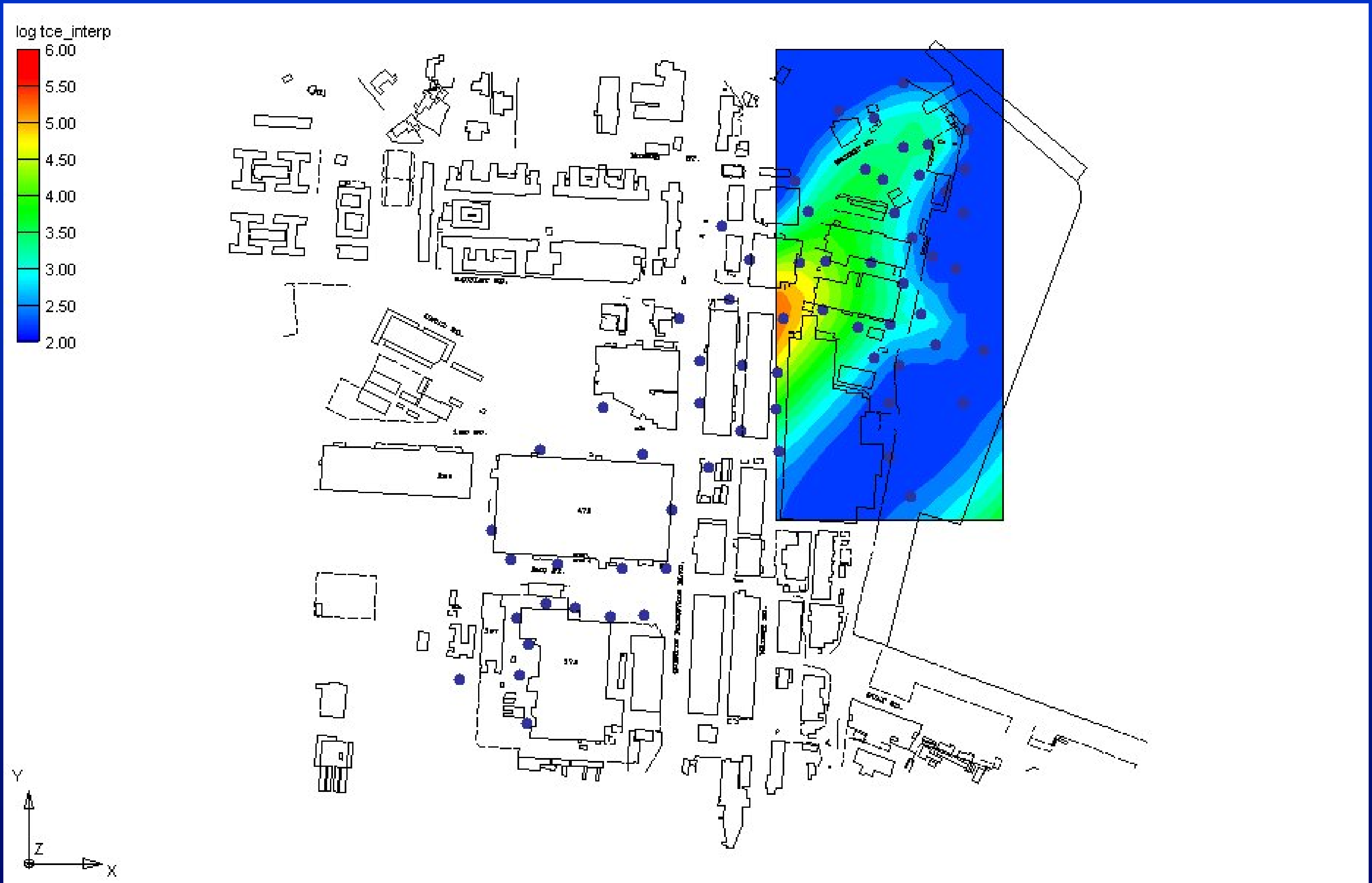
-45' elevation, 55' bgs



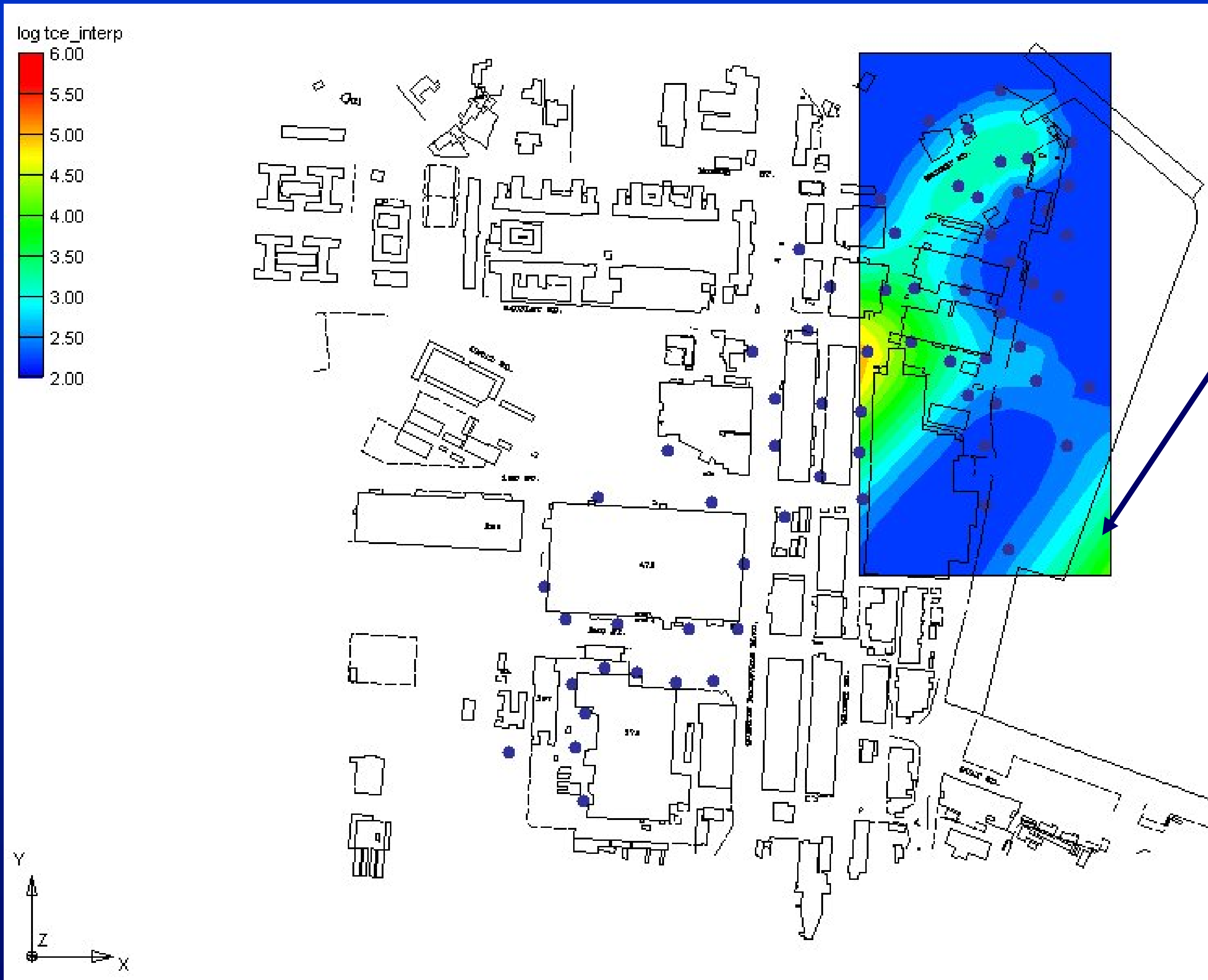
-50’ elevation, 60’ bgs



-55’ elevation, 65’ bgs



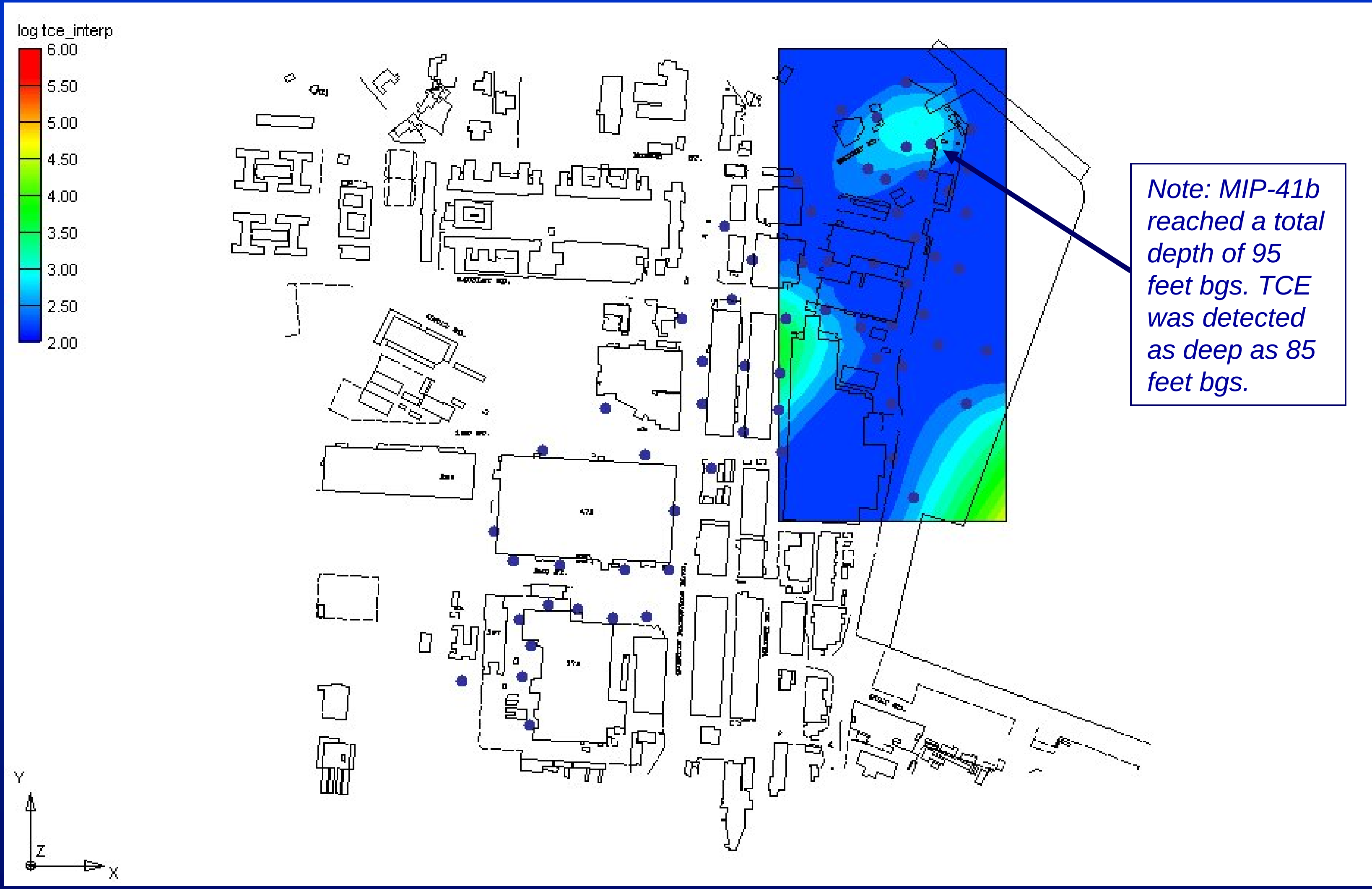
-60’ elevation, 70’ bgs



Note:

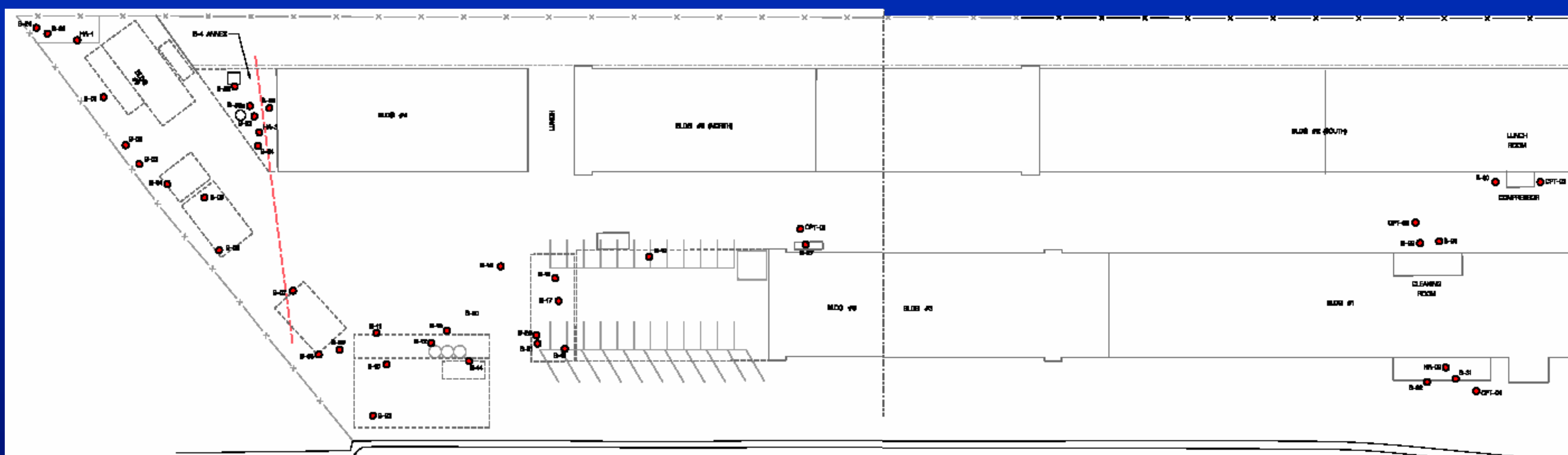
This limited area in the southeast corner of the model is an artifact of the interpolation. There is no data below 43’ bgs at this location.

-65’ elevation, 75’ bgs

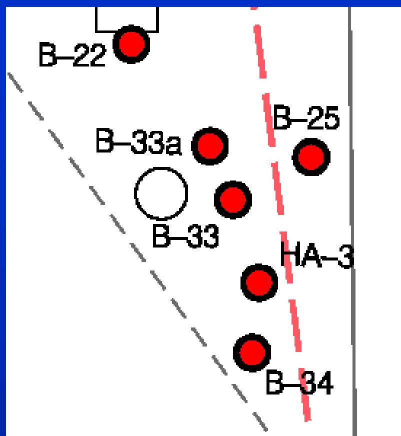


Note: MIP-41b reached a total depth of 95 feet bgs. TCE was detected as deep as 85 feet bgs.

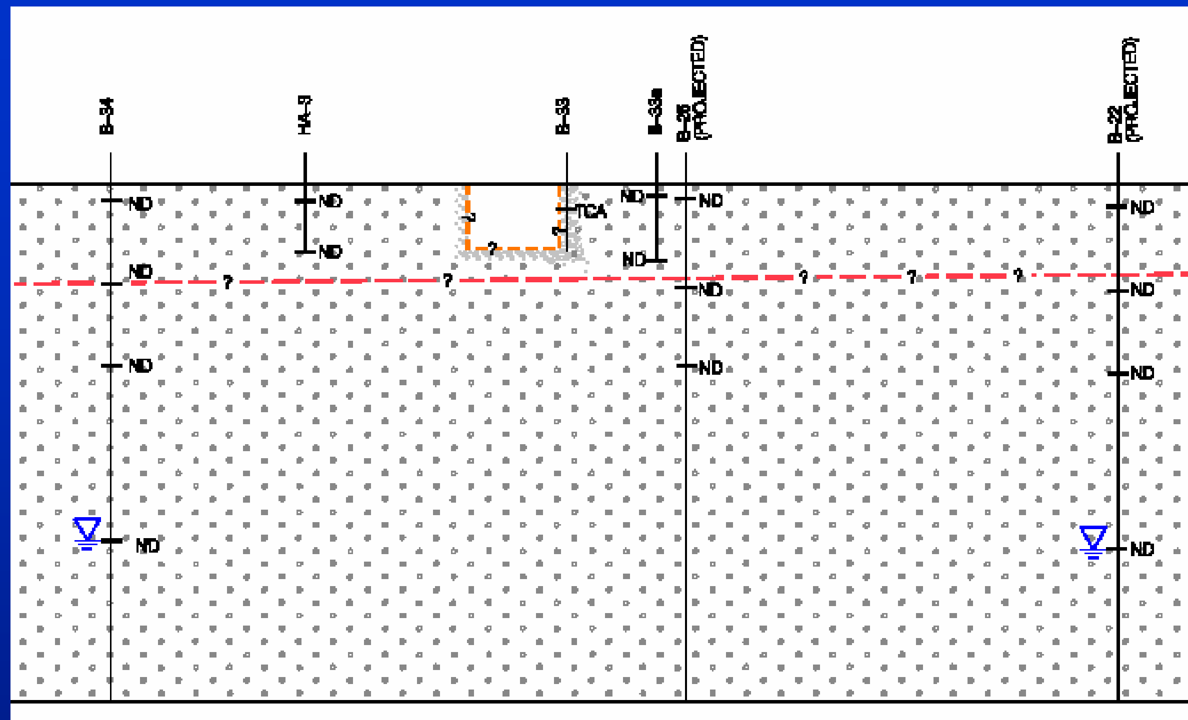
Are 3-D Mapping Tools Useful if the Site is “Clean”?



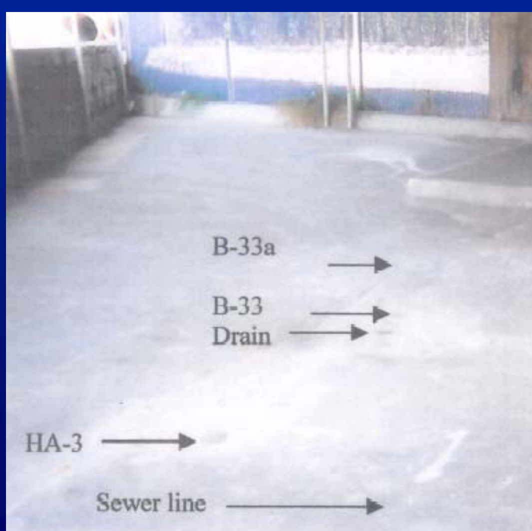
YES!



B–22
B–33a
B–25
B–33
HA–3
B–34



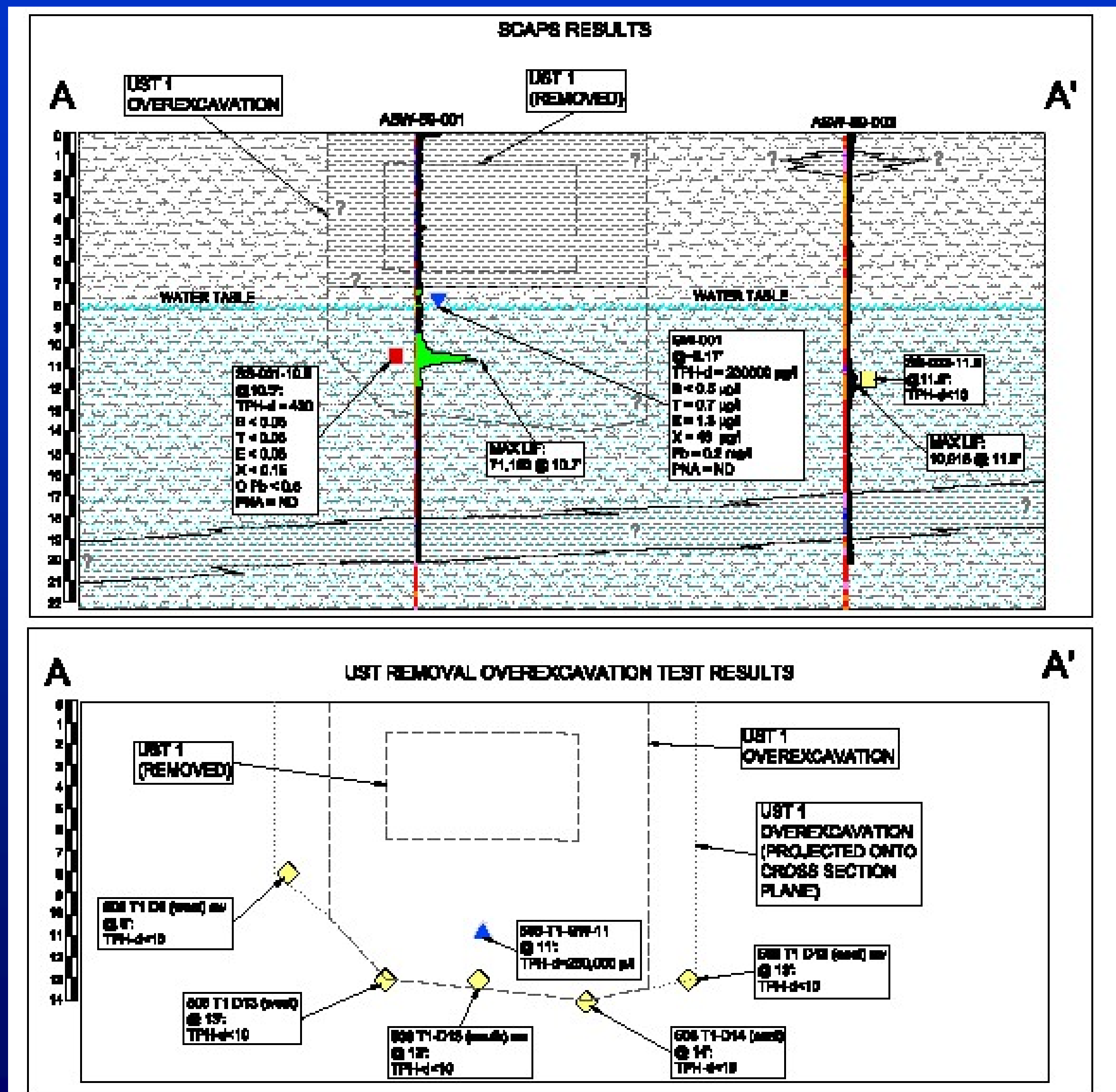
B–34
HA–3
B–33
B–33a
B–22 (PROJECTED)
ND
TCA



B-33a
B-33
Drain
HA-3
Sewer line

US NAVY Taylor St.
238 Client Samples
3.5 DAYS

3-D Mapping Tools
Put Lab Results into Context



3-D Mapping Tools Help Build Robust Conceptual Site Models, Leading to Better Decisions