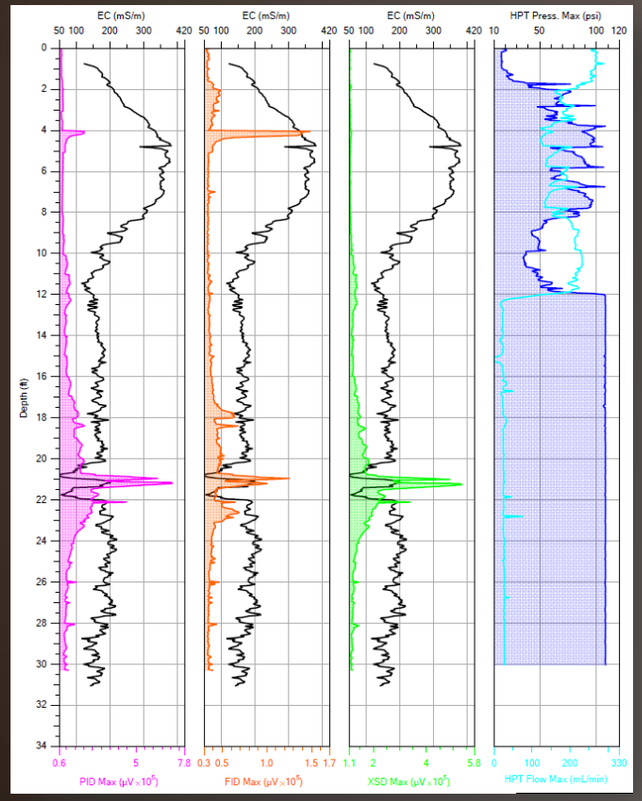
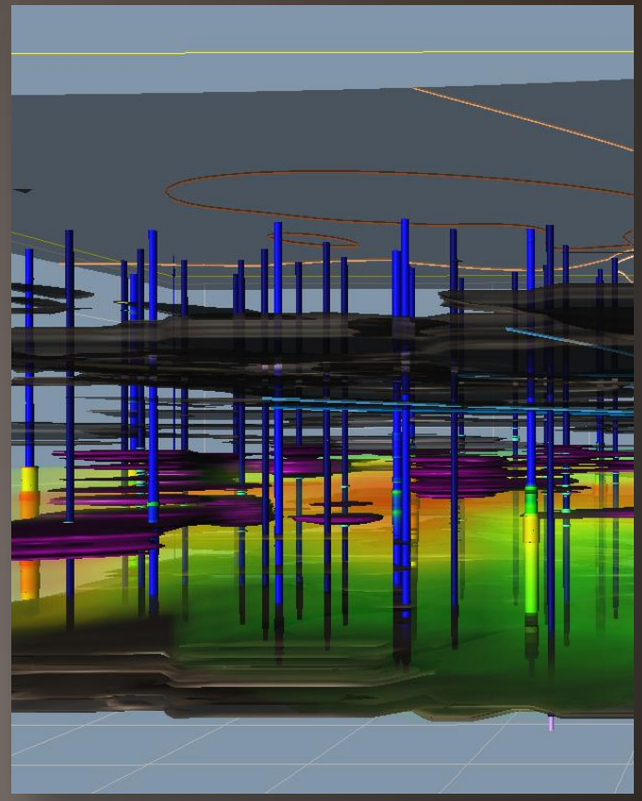
Update on High Resolution Site Characterization Technologies & Modeling for Remedial Design



John Fontana, PG

Vista GeoScience

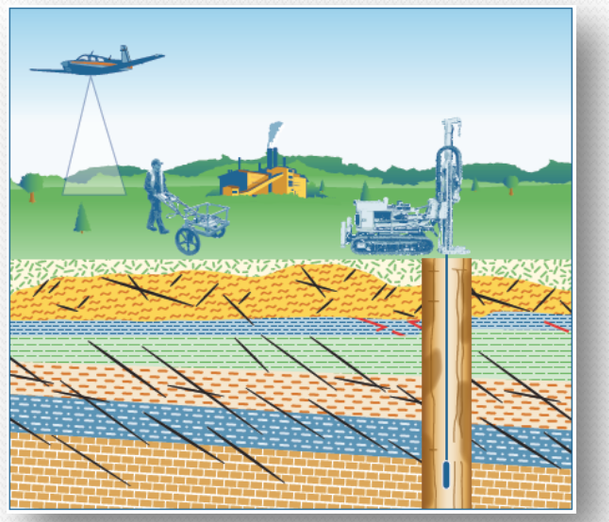
www.VistaGeoScience.com



Rocky Mountain EHS Peer Group – July 26, 2018

Watch for It! Two New ITRC Guidance Documents (Web Based?)

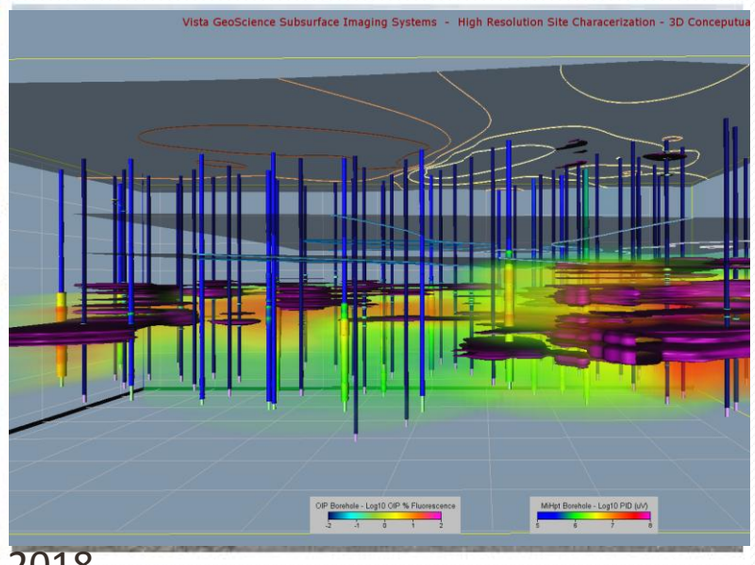
- **Implementing Advanced Site Characterization Tools**
- **Optimizing In Situ Remediation Performance & Injection Strategies**



Advanced Site Characterization

- Qualitative vs. Quantitative
- Current HRSC Direct Sensing Technologies
- Quality Control & Quality Assurance
- High Resolution Sampling Methods

- 2D & 3D Visualization for Developing Your CSM
- Case Study Examples



Qualitative vs. Quantitative Methods

- **Direct Sensing Tools** – Semi Quantitative
  - **MIP, HPT, EC, LIF/UVOST, OIP-UV, etc.**
  - **High Vertical Resolution (20 pts. per foot)**

- **High Resolution Sampling** - Quantitative
  - **Continuous Coring - Direct-Push or HSA**
  - **Discrete Point Ground Water Sampling**
    - **Geoprobe HPT-GWP** (Groundwater Profiler Tool)
  - **Mobile On-Site Labs or Fixed Lab**

Direct Sensing/Imaging Tools

ATV Mounted OIP-UV/MiHPT/EC Imaging System & Track Mounted Geoprobe

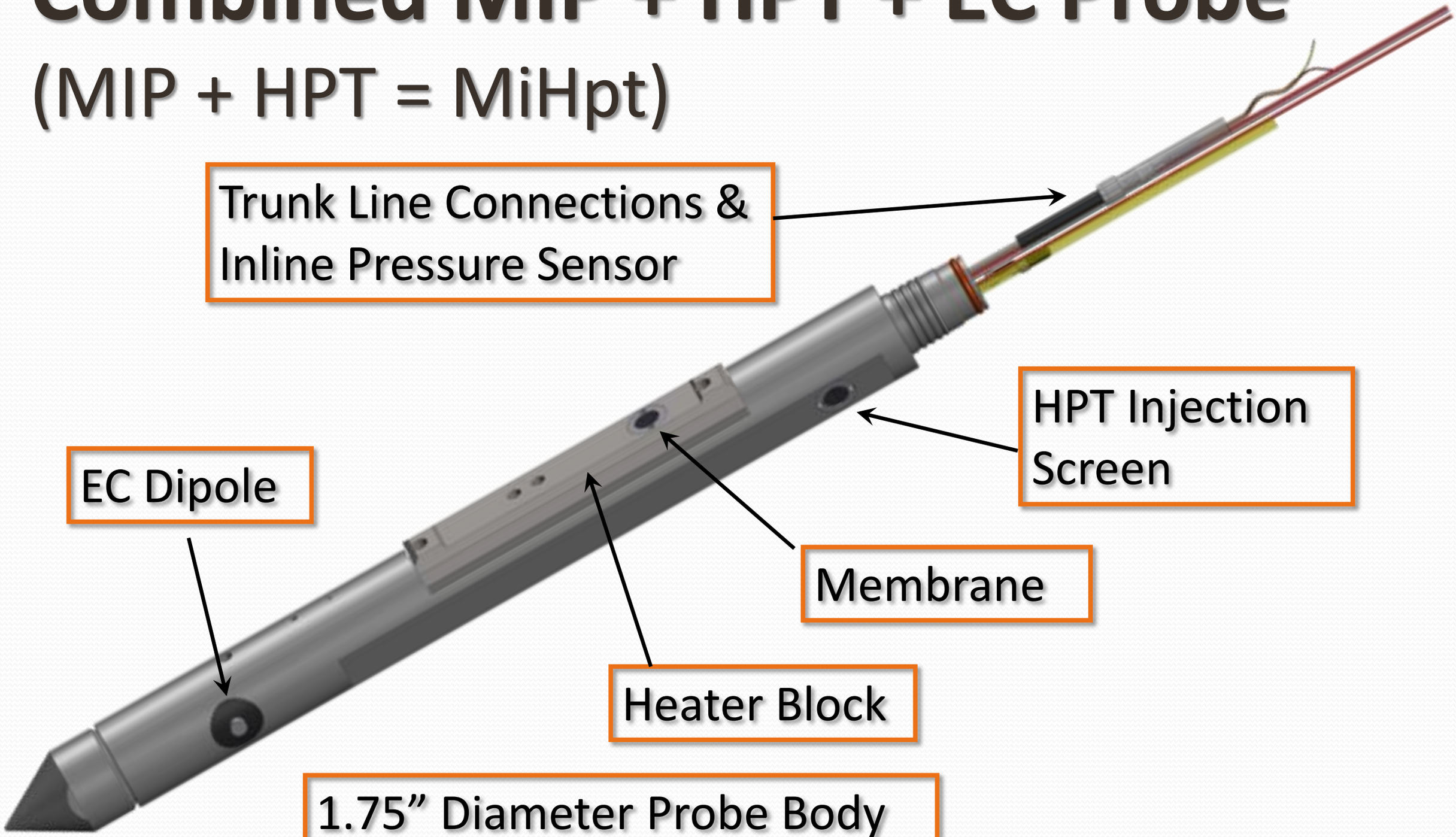
Common "Direct Sensing/Imaging" & Borehole Logging Tools for HRSC

Tools Driven by Direct-Push Technology (Geoprobe or CPT)

- **MIP - Membrane Interface Probe**
  - Dissolved Phase VOCs (PPM Levels, or PPB with **Low Level** Option
- **HPT - Hydraulic Profiling Tool**
  - Measures permeability and hydraulic conductivity
- **HPT-GWS** – HPT + Discrete Groundwater Sampling Tool
- **OIP-UV – Optical Imaging Profiler**
  - Detects Free Phase Petroleum NAPLS using Fluorescence of PAHs
  - (Similar to LIF/UVOST – Laser Induce Fluorescence/ UV Optical Screening Tool)
- **OIP-G – Green Laser Source** for Heavier Oils/PAHs (Similar to LIF/TarGost)
- **EC - Electrical Conductivity**
  - Measures Conductivity (Resistivity) of Soil
- ***NOTE: Several of these tools are now combined into single probe units***

Combined MIP + HPT + EC Probe

(MIP + HPT = MiHpt)



MIP/HPT/OIP/EC Instrumentation

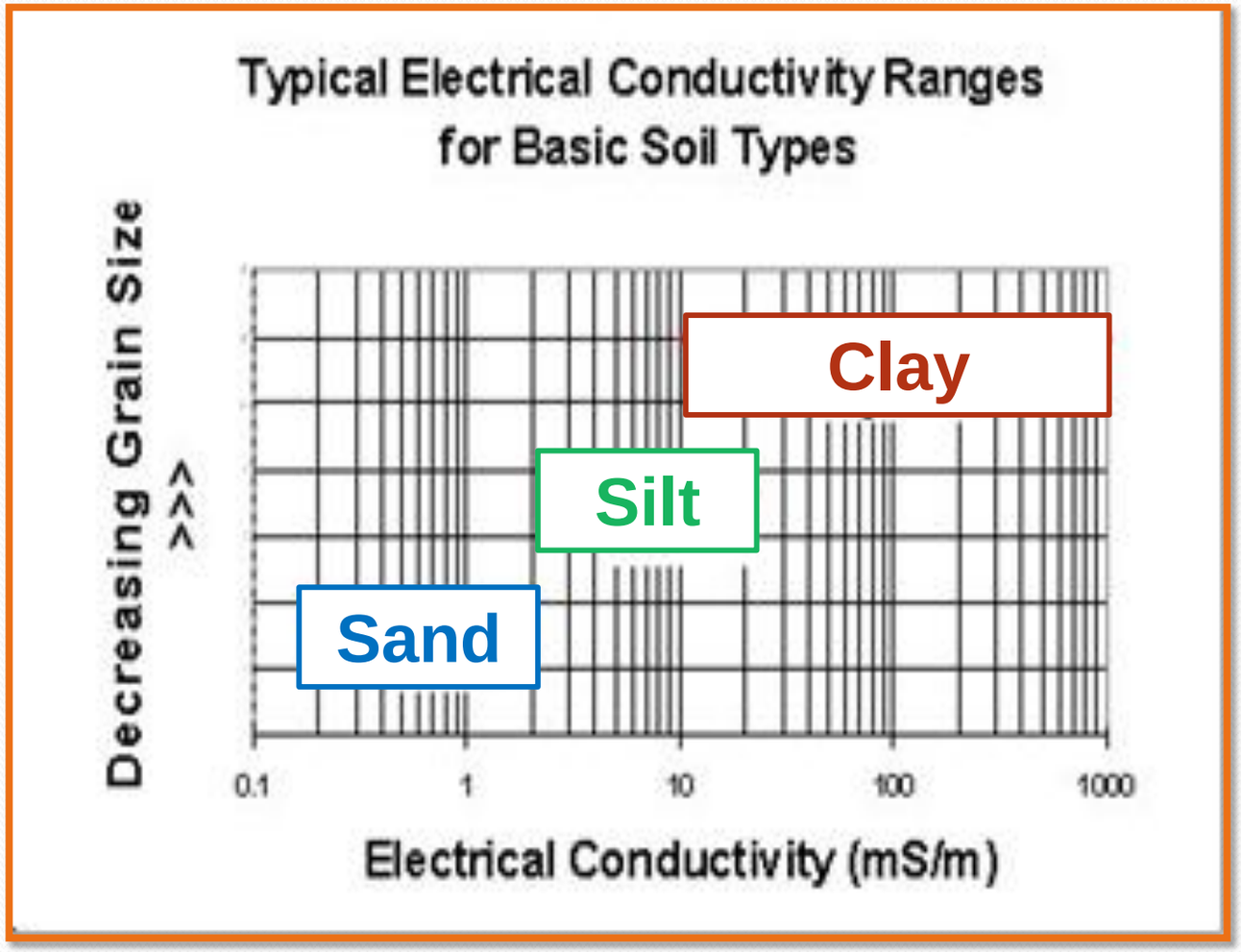
- **Digital Field Instrument**
- **MIP Flow/Heat Controller**
- **Low Level Controller**
- **Hydraulic Profile Controller**
- **Ruggedized Field Computer**
- **MIP Gas Detectors**

  Gas Chromatograph

  - **Flame Ionization (FID)**
  - **Photo Ionization (PID)**
  - **Halogen Specific (XSD)**

EC (Electrical Conductivity)

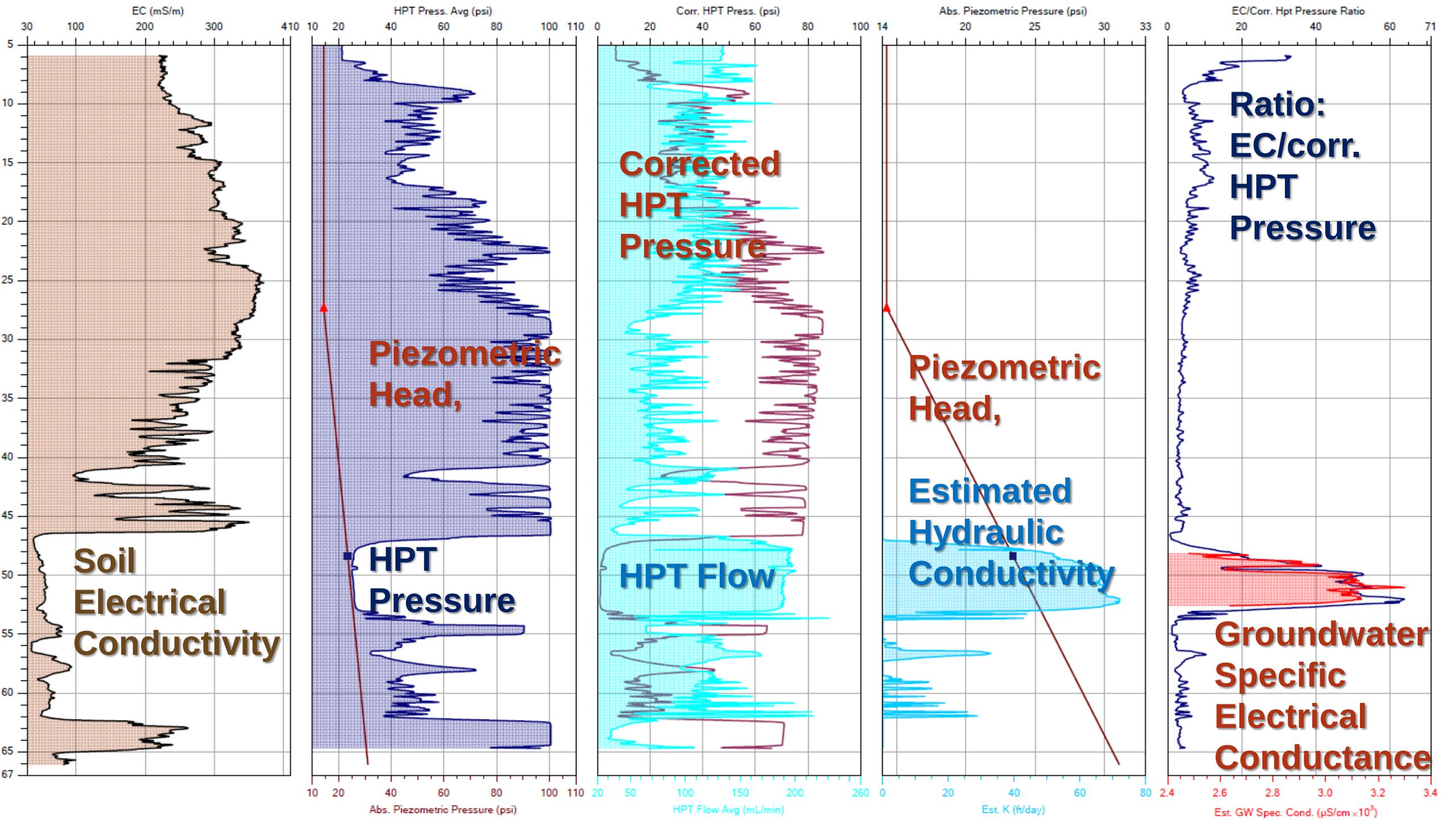
- **Measures Soil Conductivity**
- **Inverse of Resistivity**
- **Conductivity Generally Relates to Grain Size**
- **Can also see Ionic Compounds (Salts)**
- **Will Detect Metal**
- **Built into All HRSC Tools**
- *In High K Zones (low soil conductivity), can calculate groundwater* ***specific electrical conductance****!*



Hydraulic Profile Tool (HPT)

- **Injects Water into Formation through 3/8” Screen Port**
- **Measures Injection Pressure** (up to 110 psi)
- **Measures Injection Flow** (up to 300 ml/min)
- **High Pressure & Low Flow = Low Permeability**
- **Low Pressure & High Flow = High Permeability**
- **Measure Piezometric Head (by performing Dissipation Test)**
- **Combined with Electrical Conductivity (EC)**
- **Post-Log Calculations:**
  - **Estimated Hydraulic Conductivity (K_{est})**
  - **Groundwater Specific Electrical Conductance –** Calculated in High K zones, with <5psi HPT Pressure).

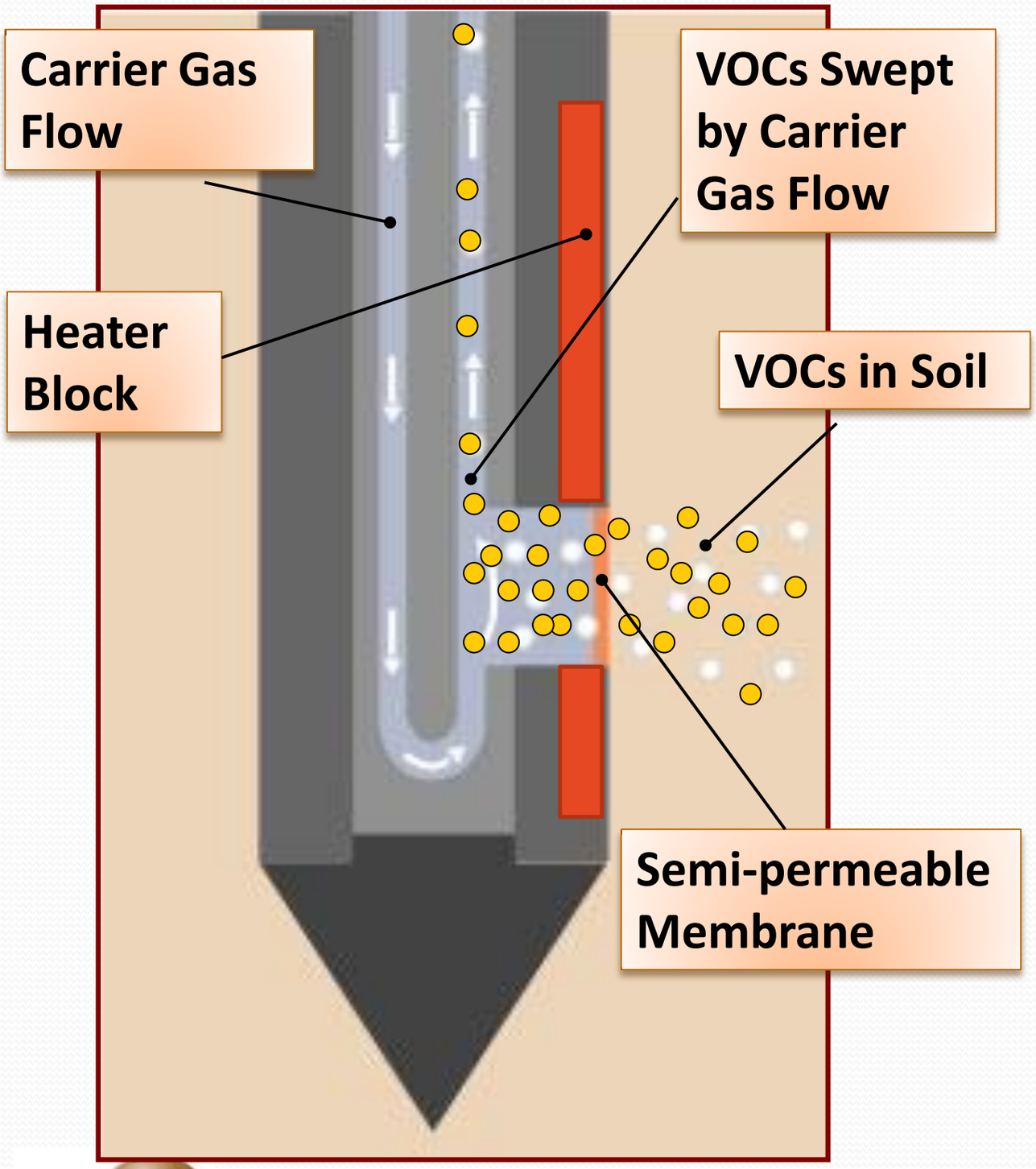
Hydraulic Profile Tool (with EC) Log



Vista GeoScience — Subsurface Imaging Systems

Company: Vista GeoScience	Operator: DF, CD	File: xxxxxx.OIHP
Project ID: xxxxx.01	Client: XXXXX	Date: 5/15/2018
		Location: xxxx, Texas

Standard MIP Operation



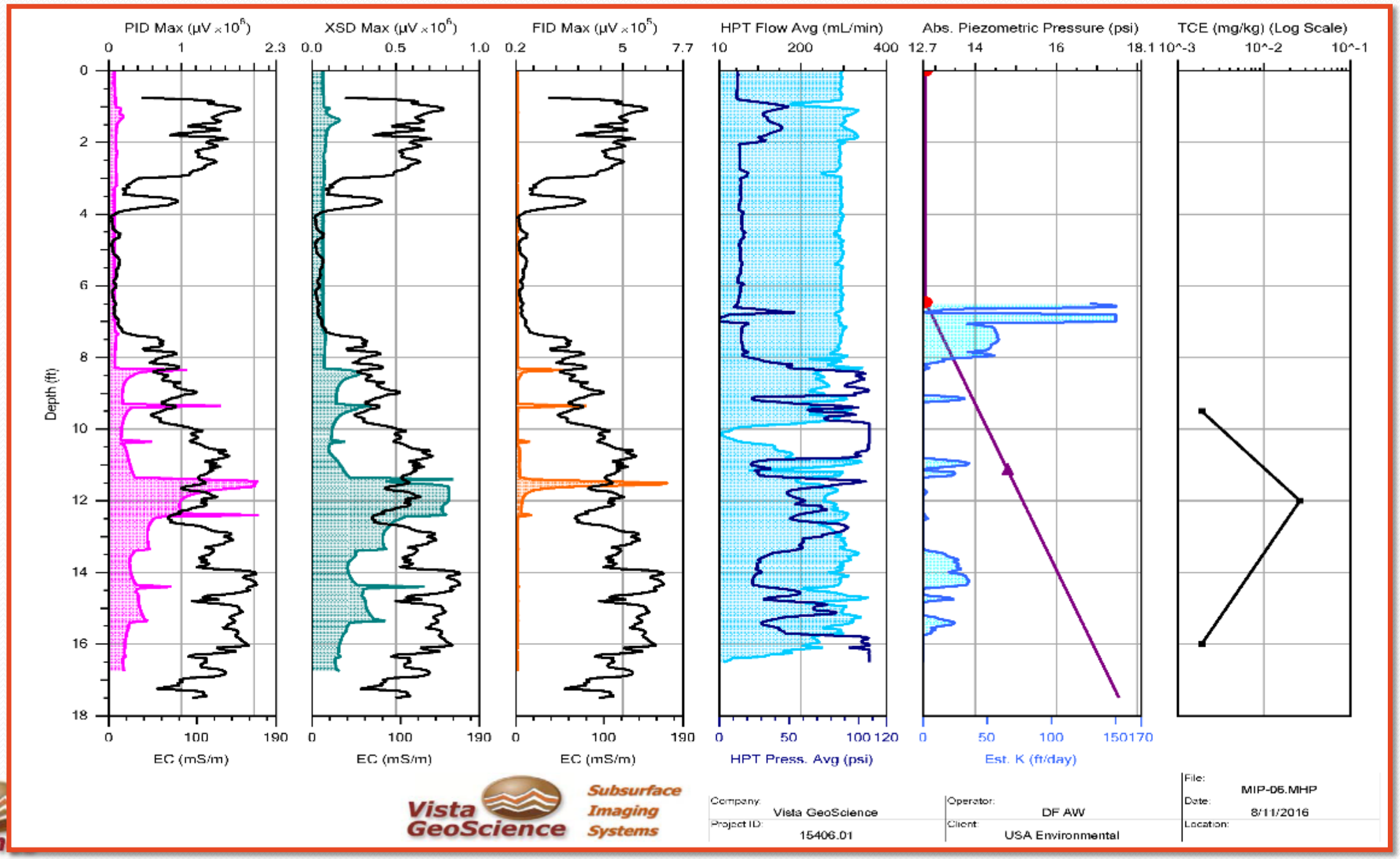
- Heater block (120°C) volatilizes VOCs in soil
- VOCs move across the membrane by diffusion
- Continuous carrier gas flow sweeps gases to detectors
- Typically pause at 1.0’ intervals to increase heating of soil.
- Average Rate of Penetration, 1 ft/min.

High Resolution = Millions of Data Points

20 data points per foot

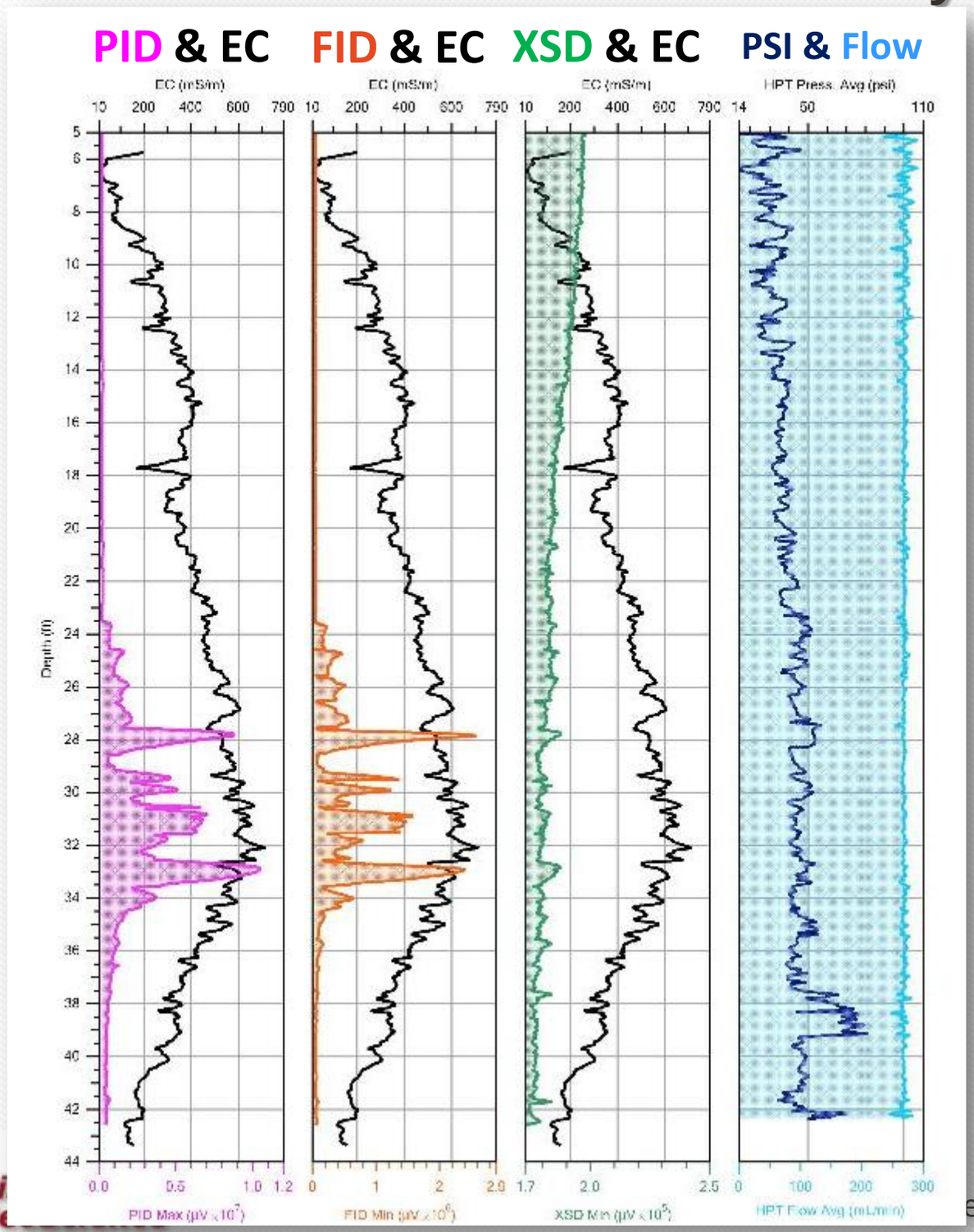
MiHpt Log - Locating VOCs & Measuring Soil Properties

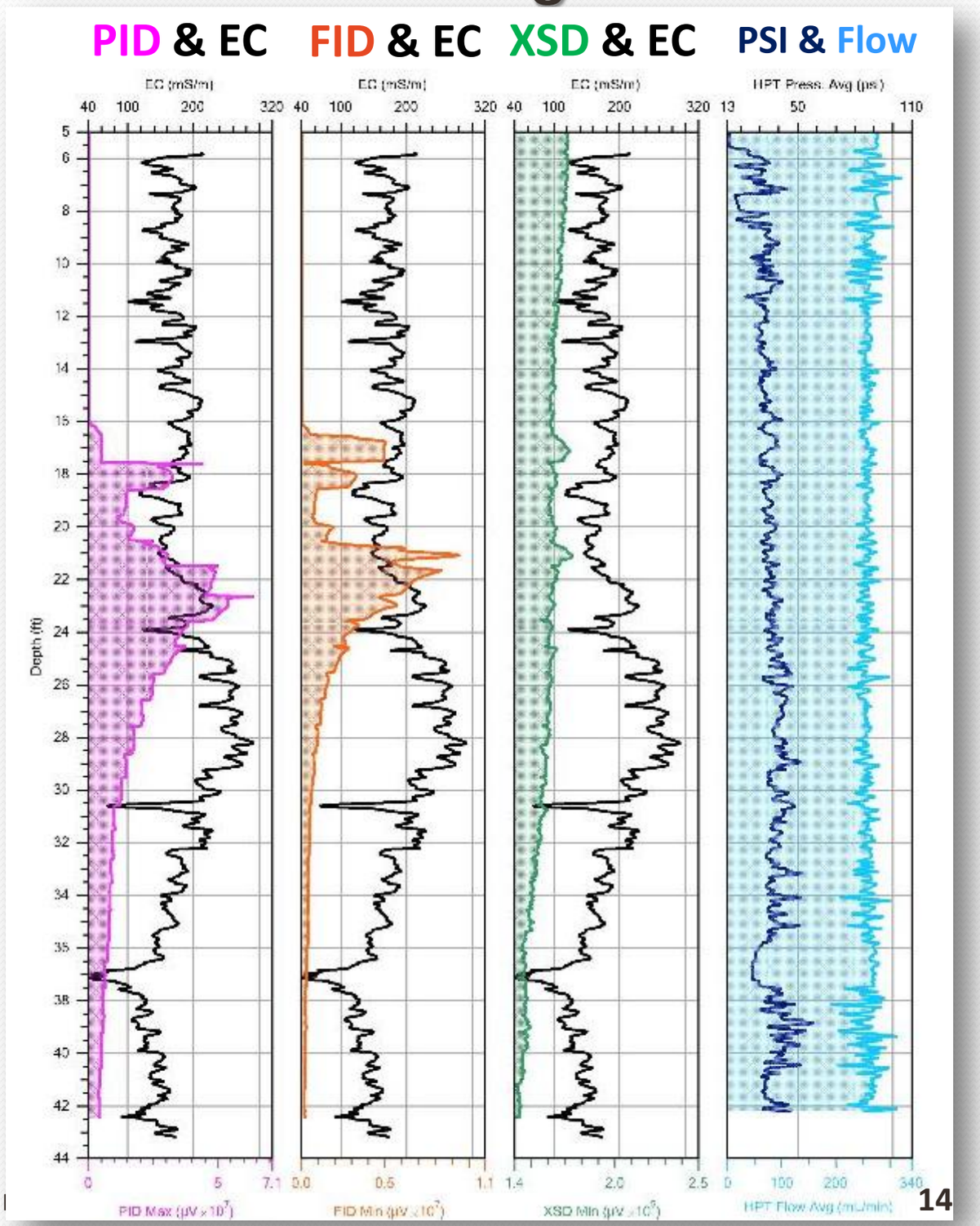
PID & EC **XSD & EC** **FID & EC** **PSI & Flow** **Est. K & Head PSI** **Soil (Lab) Data**



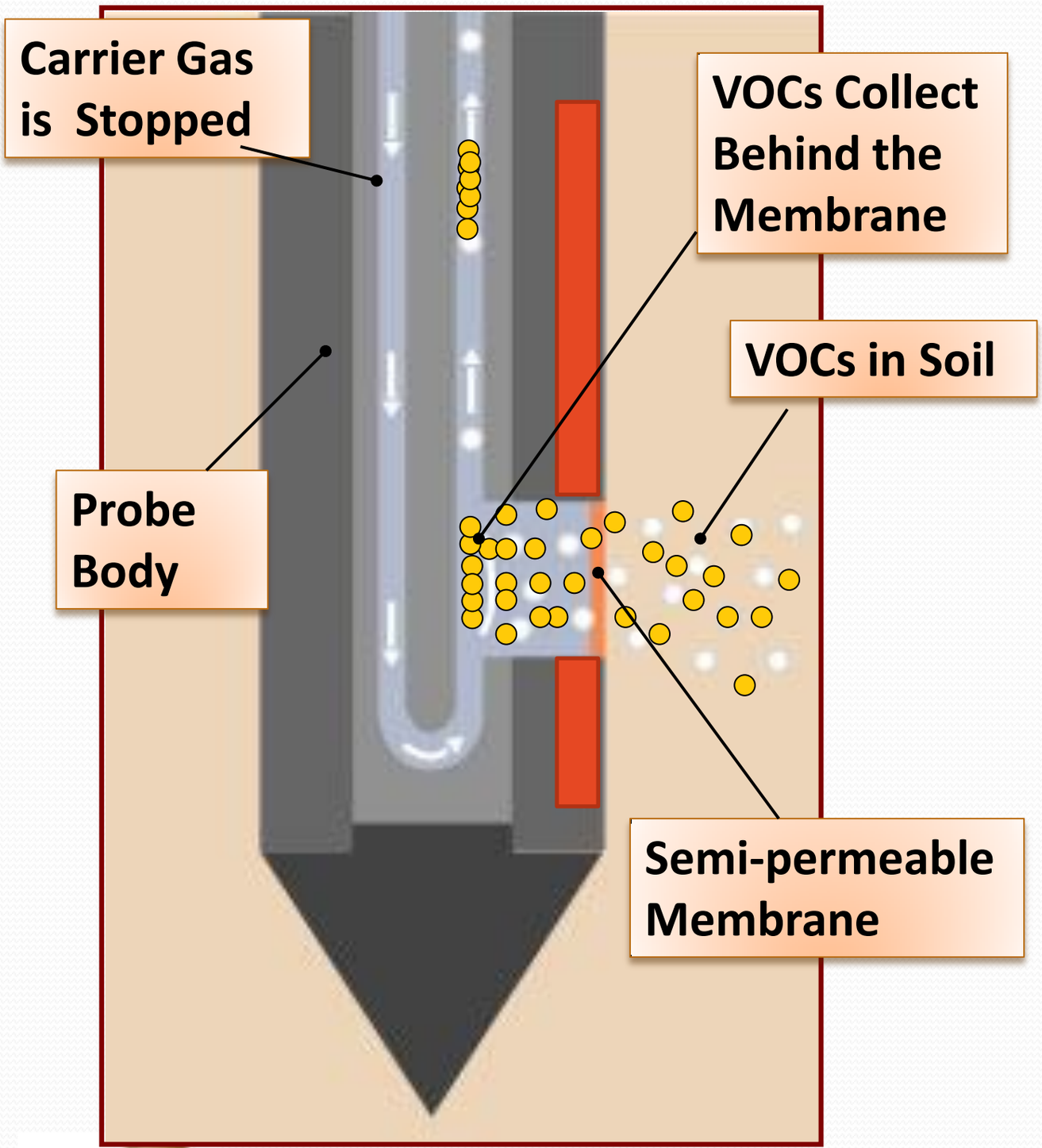
Is This a Gas Station Site?

What are in the details? Any issues with the logs?



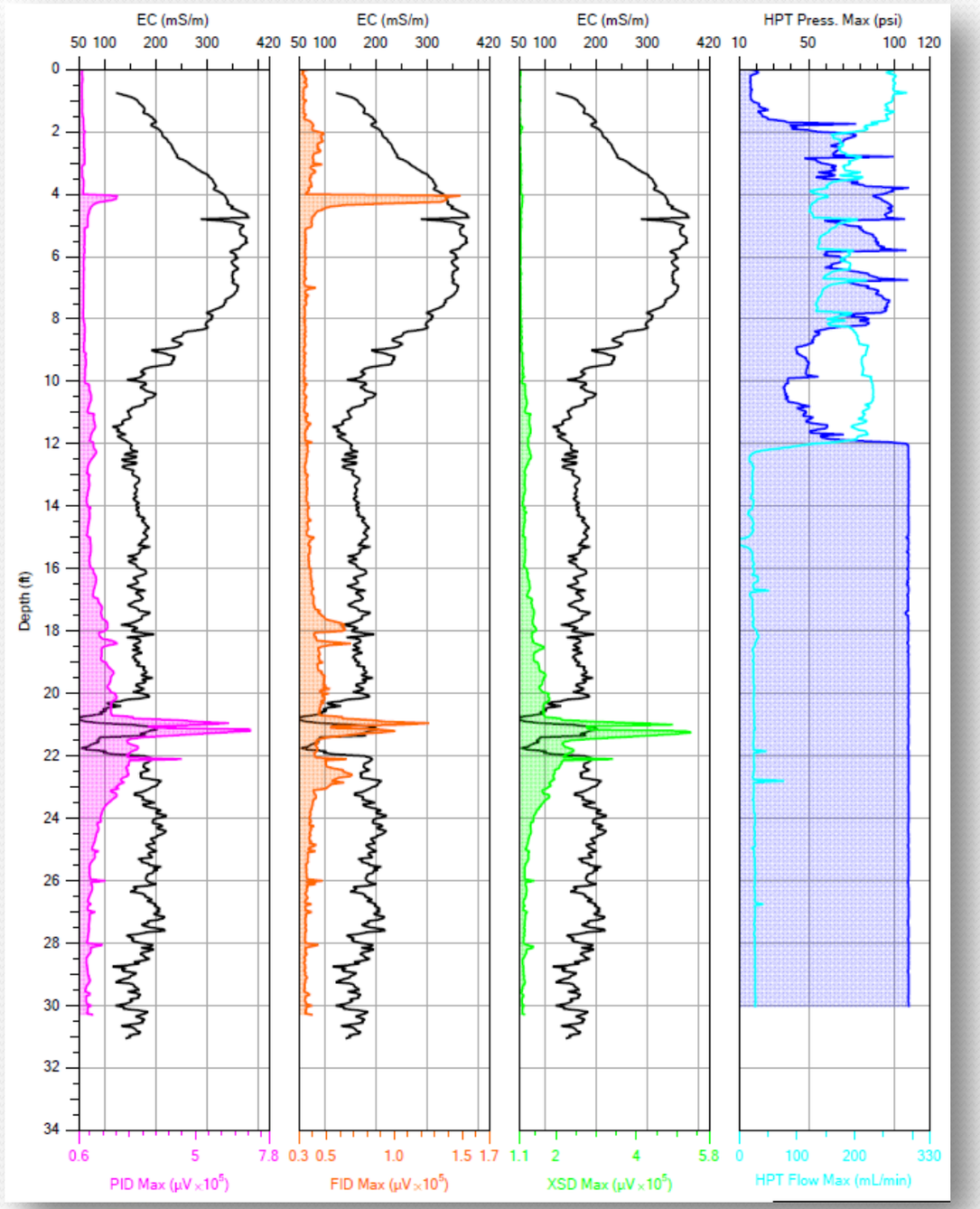


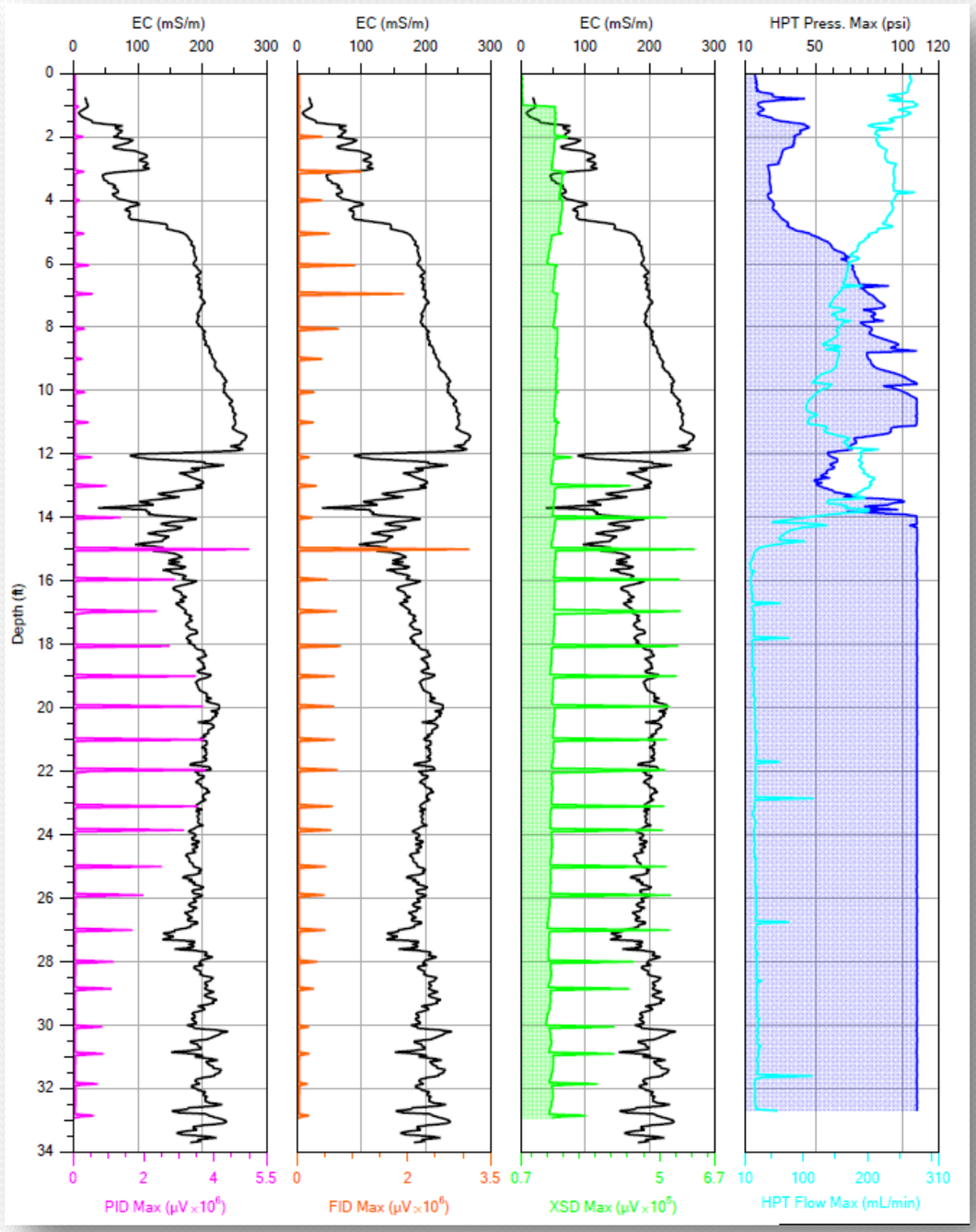
Low Level MIP Operation



- For increased sensitivity
- Carrier flow is pulsed
- VOCs move across the membrane via diffusion
- VOCs accumulate behind the membrane
- Carrier gas flow is resumed
- Then the contaminant mass (peak) is transported to the detectors

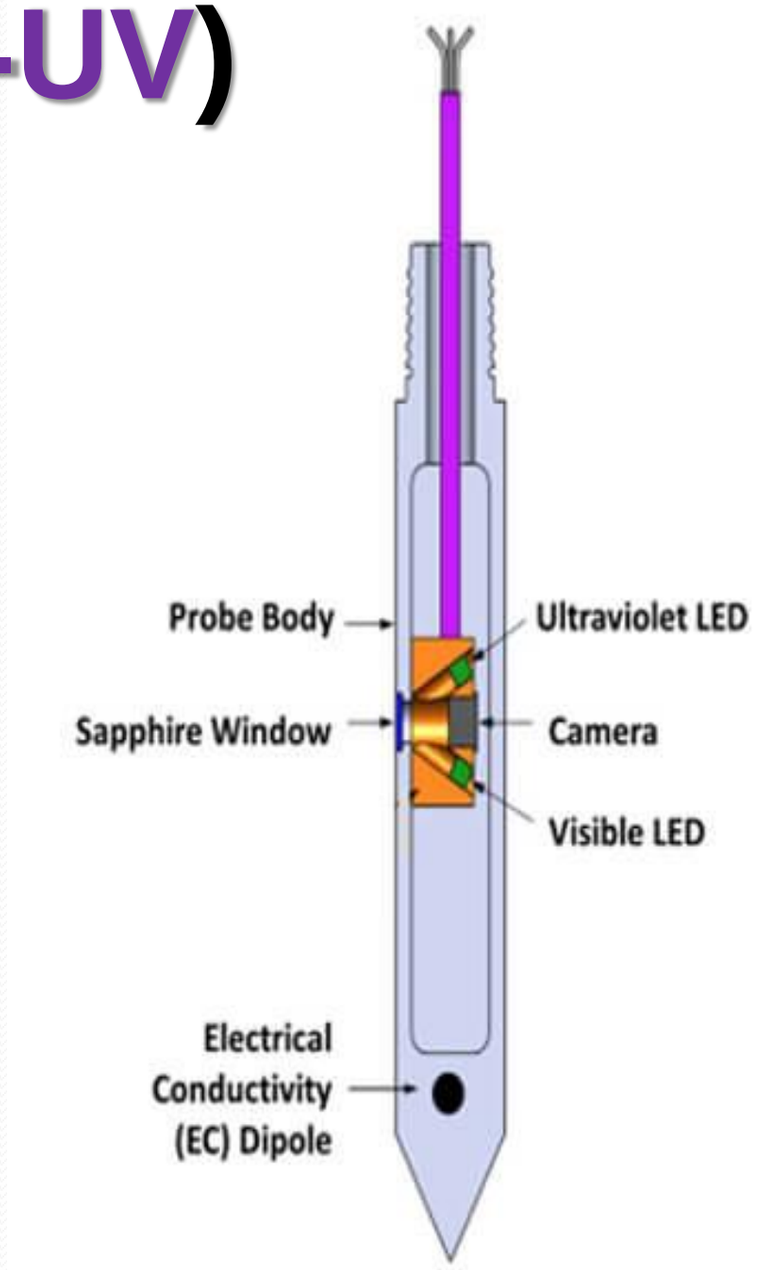
Standard MIP vs. Low-Level MIP Logs





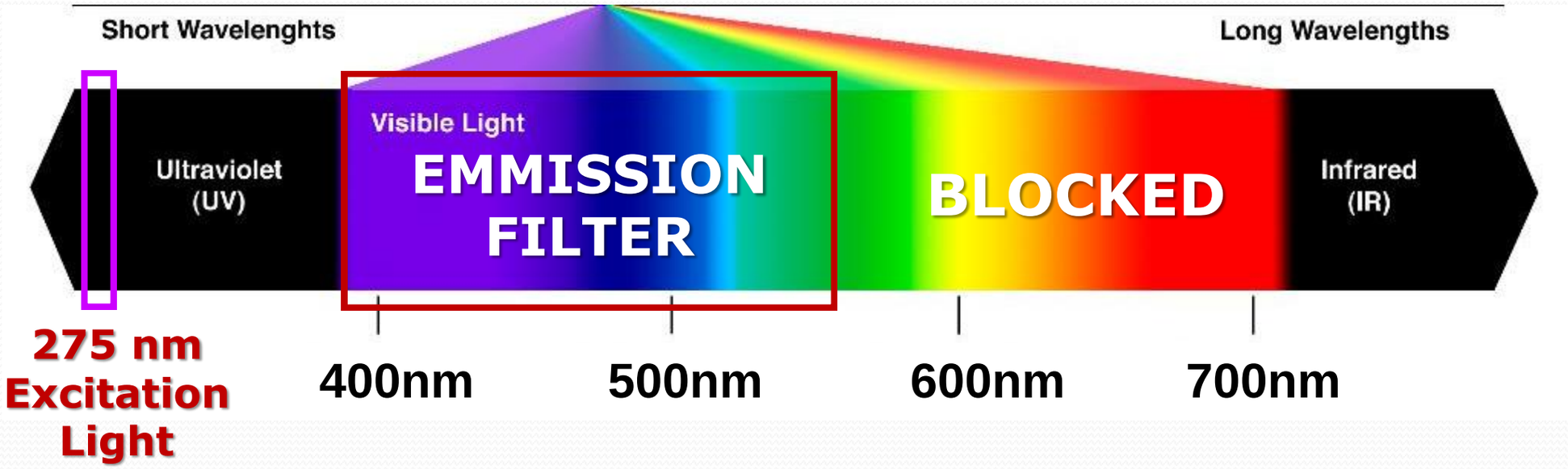
Optical Image Profiler (OIP-UV)

- MFG: Geoprobe (Direct Image®)
- Tool Function:
  - Detect Fluorescence of Petroleum NAPLs (PAHs)
- Excitation Light Source:
  - Ultra-Violet (UV) LED Light Source (275nm)
  - Also - Visible (White) LED Light Source
- Sensor:
  - CMOS Camera (Captures UV or Visible Images)
- Measured Response
  - % Area Fluorescence (%AF)
- Visible Light LED Allows for Capturing Images of Soil Texture and Color
- **Software – Geoprobe DI Viewer** (Free Download at Geoprobe.com)



Analysis of Fluorescence

- **Excitation (LED) Light – 275nm (UV)**
- **Emission Light Filter – 400-550nm (purple, blue, green)**
- **Records Data Like your digital camera!**
  - **HSV -** Hue, Saturation, & Value (Brightness)

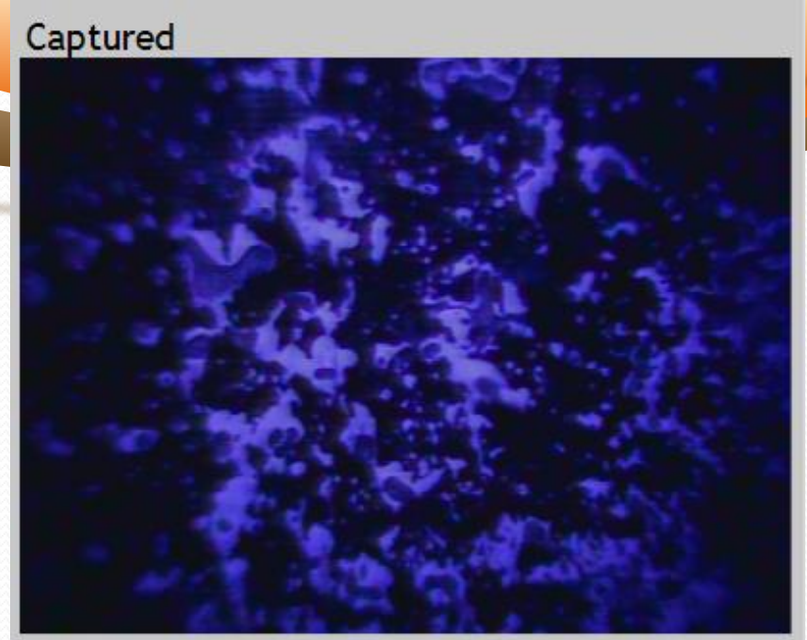


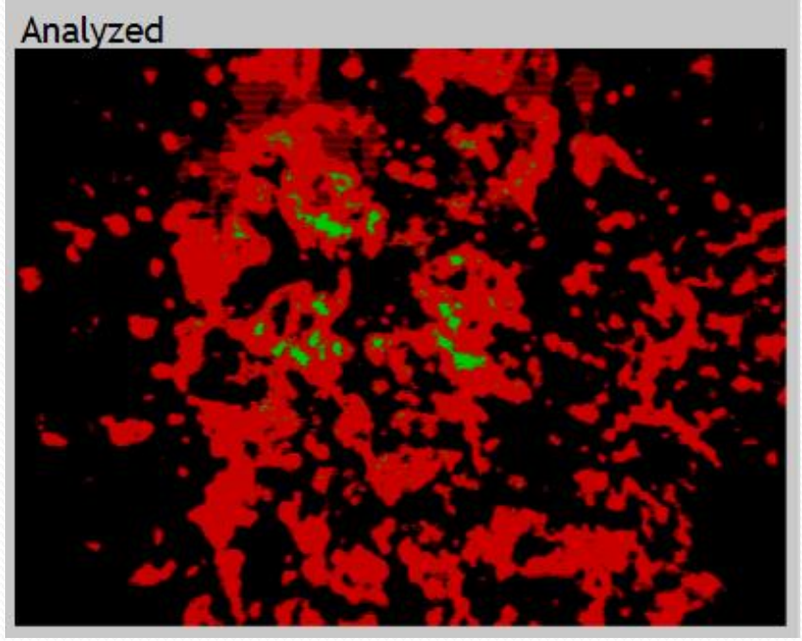
OIP Images

- **Captured Fluorescence Image under 275nm UV LED Light**

- **Software Analysis of % Area Fluorescence (%AF)**

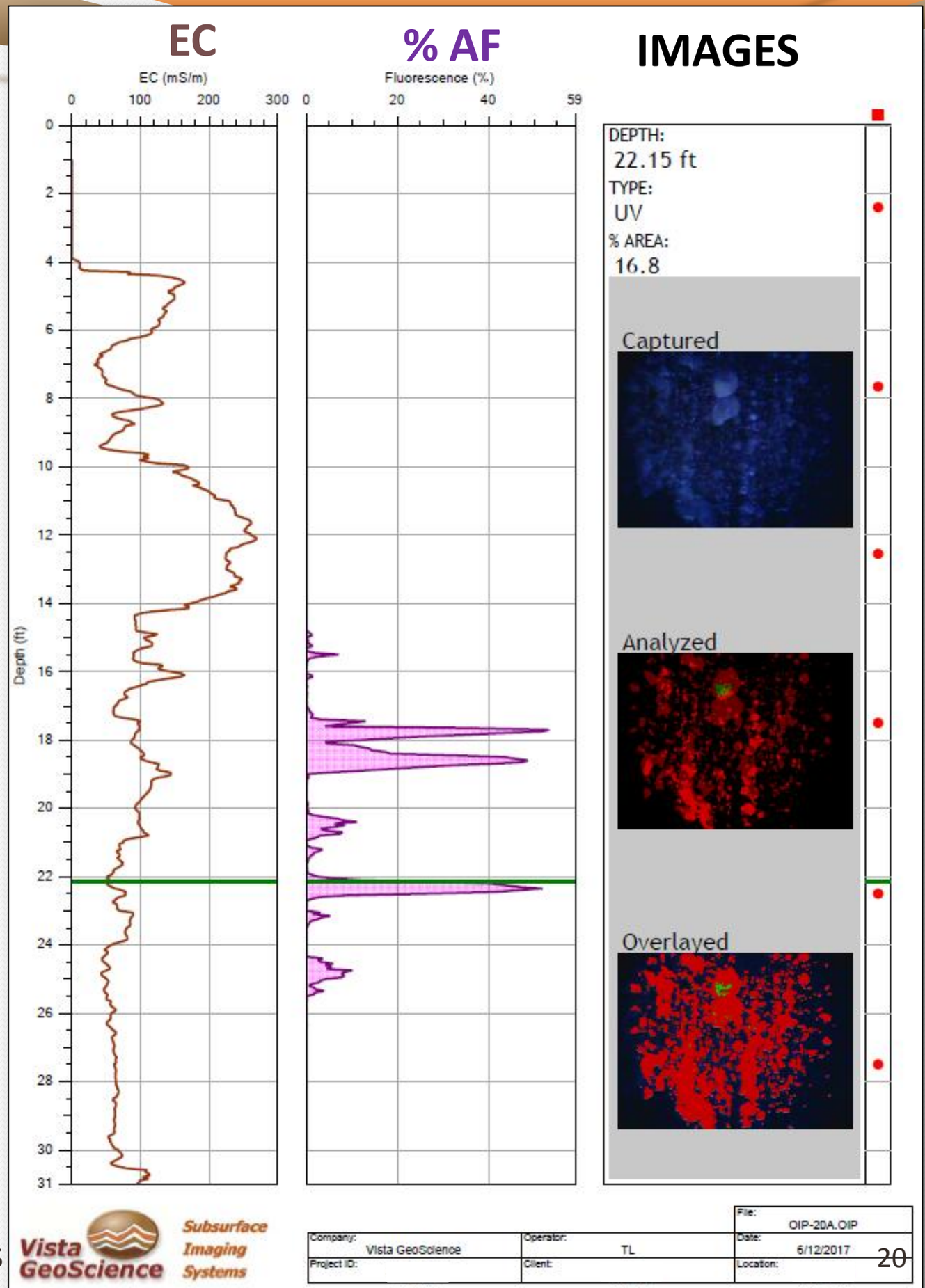
- **Captured Soil Image under Visible (White) LED Light**





Typical OIP-UV Log Display

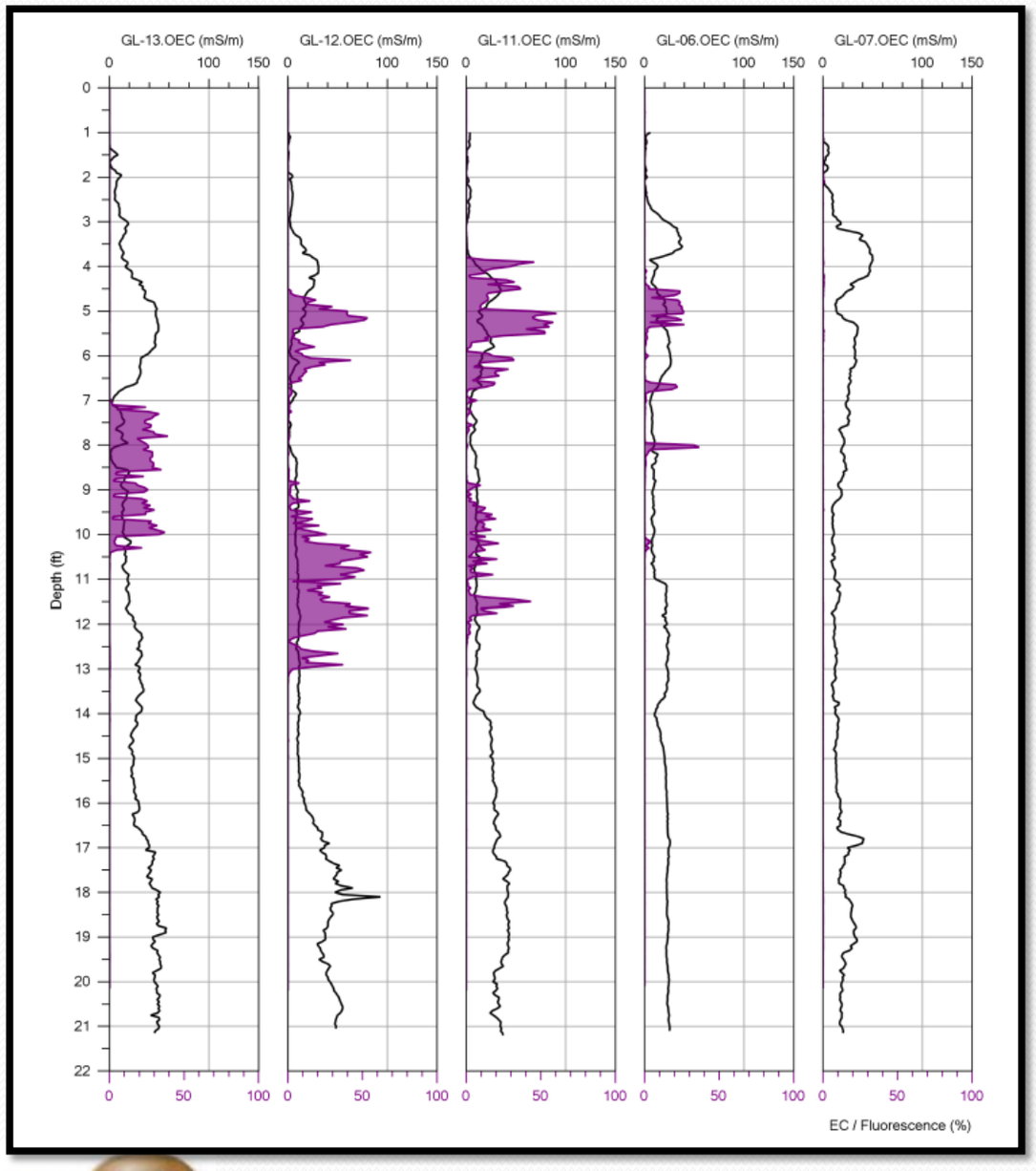
- Electrical Conductivity
- % Area Fluorescence
- Viewing Software Allows Scrolling Through All Images
- Green Line Marks Depth of Current Image Displayed



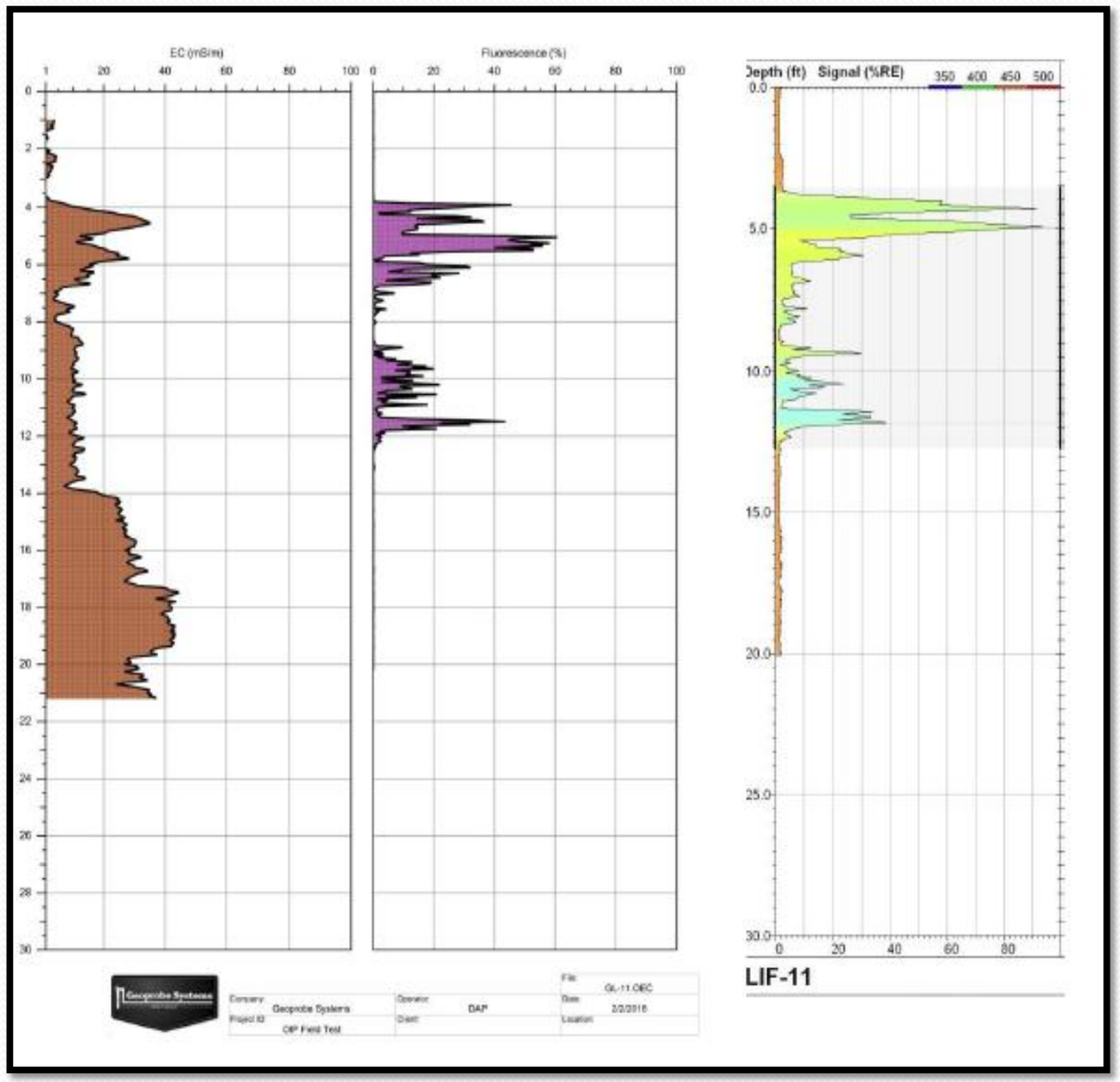
Comparison of OIP-UV and LIF/UVOST

OIP Essentially Equivalent to LIF/UVOST Response

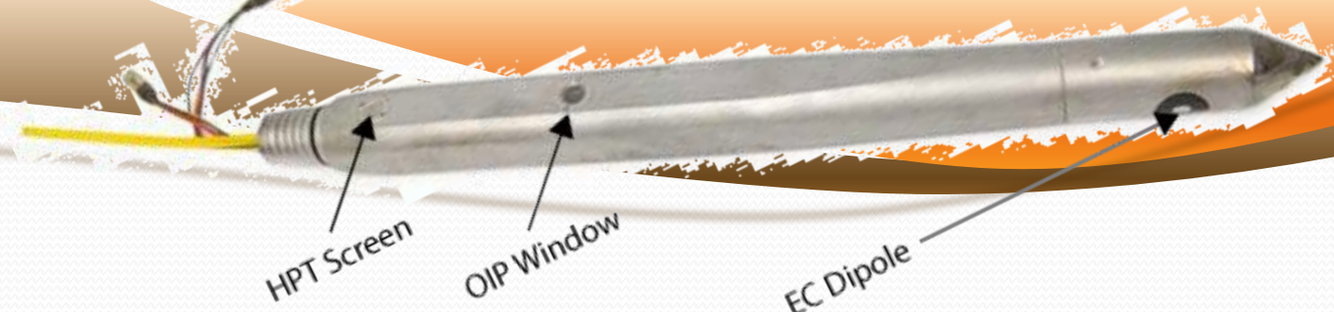
Cross Section of EC & OIP Logs



EC OIP LIF/UVOST



OIP + HPT = OiHpt Probe



EC

% AF

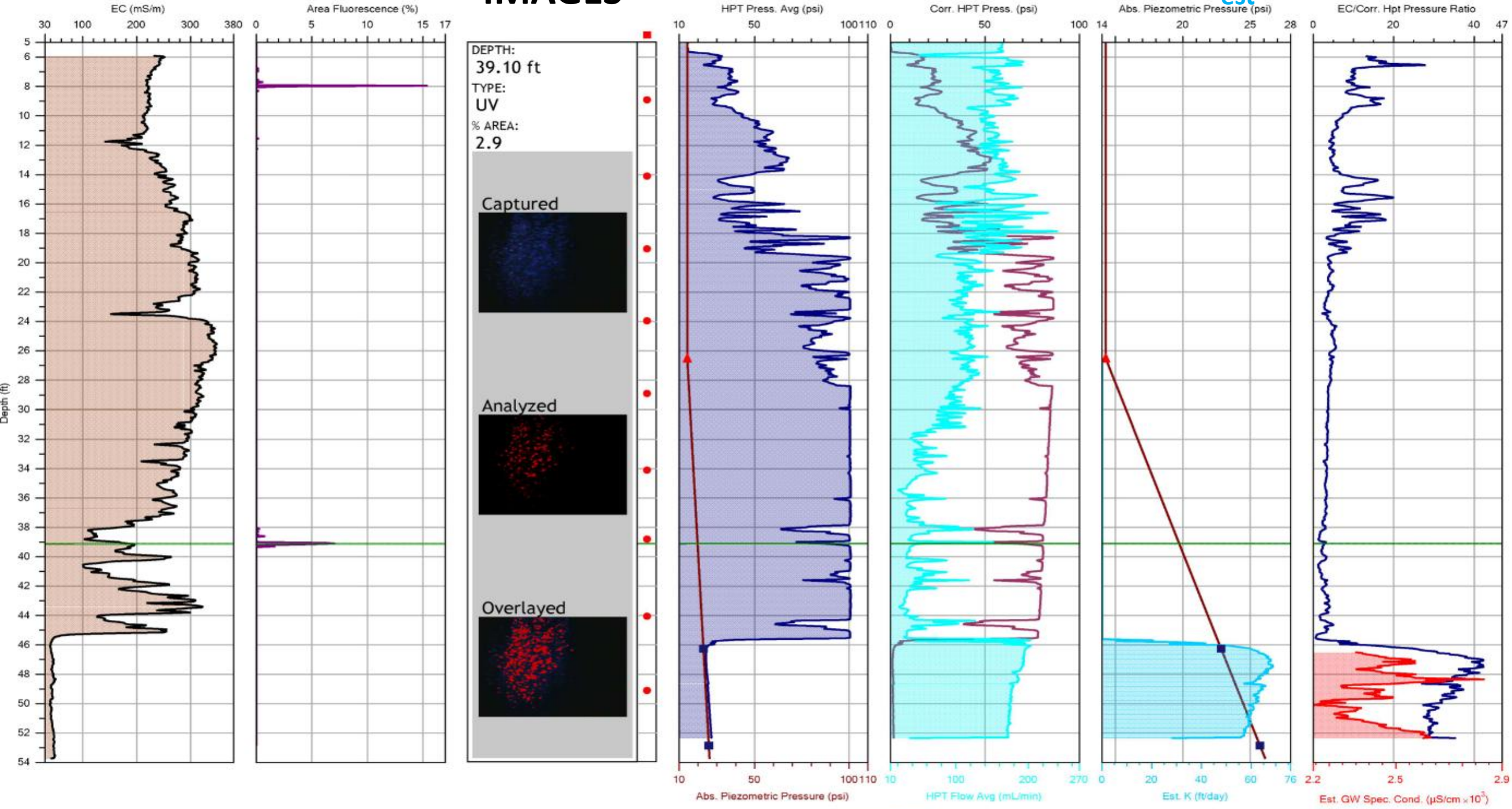
IMAGES

HPT PSI

Corr. PSI & FLow

Piez Head & K_{est}

EC/Corr-PSI & SEC



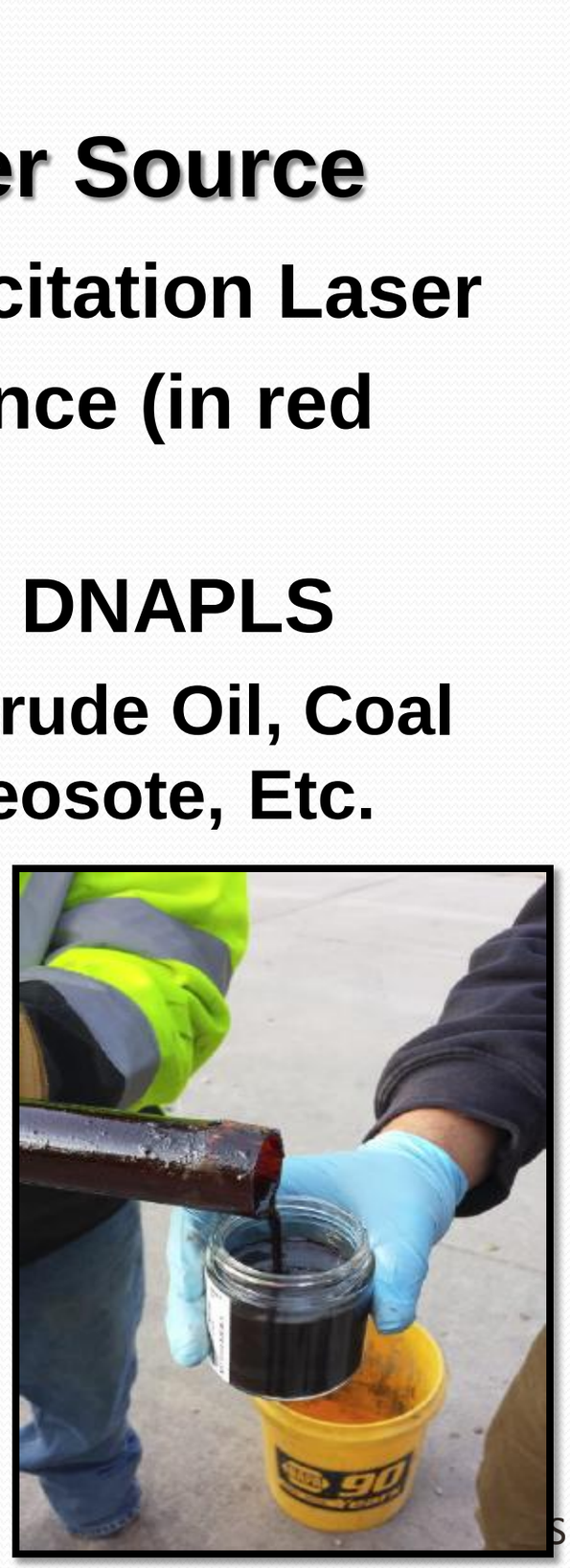
Single Log from Combined Electrical Conductivity, Optical Image Profiler -UV, Hydraulic Profile Tool.
Horizontal green line indicates depth of fluorescence image shown.
Logs on Right: Calculated Estimate of Hydraulic Conductivity & Specific Electrical Conductance.

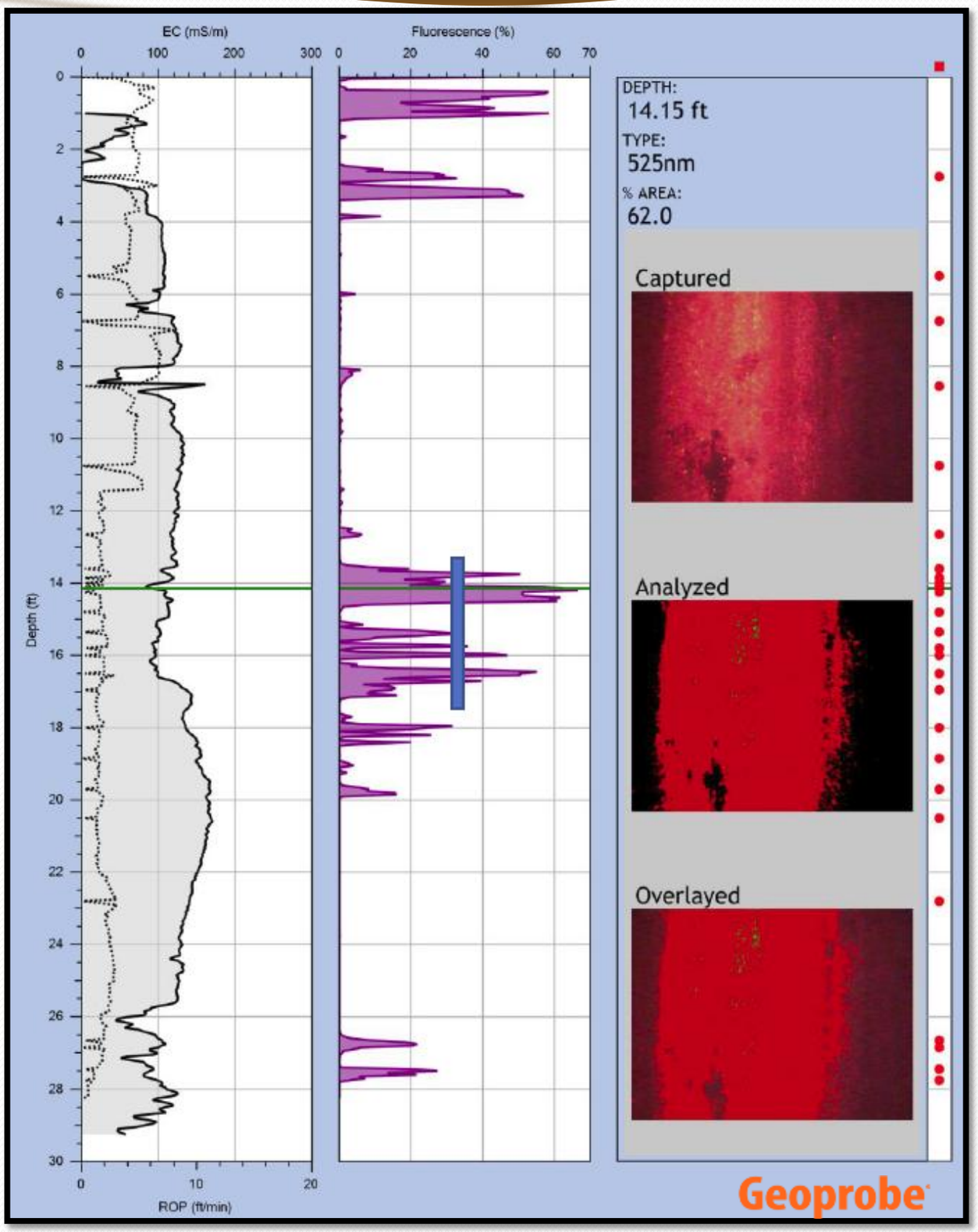
Company: Vista GeoScience	Operator: DF, CD	File: OH-01B.OIHP
Project ID: xxxxx.01	Client: xxxxxxxxx	Date: 5/14/2018
		Location: xxxxxx TX

OIP-G

Green Laser Source

- 520nm Excitation Laser
- Fluorescence (in red region)
- Petroleum DNAPLS
  - Heavy Crude Oil, Coal Tars, Creosote, Etc.



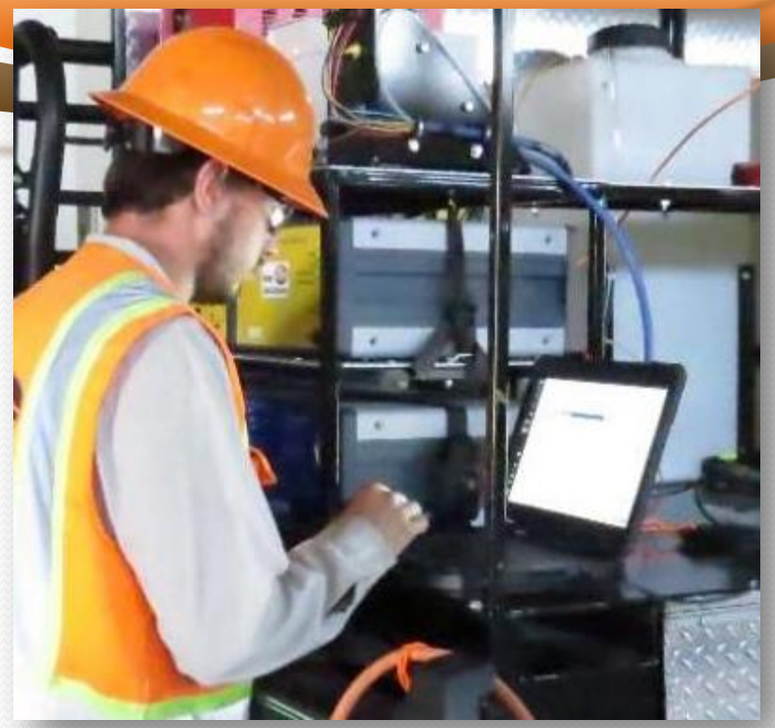


Configuration Options

- **2 or 3 Person Crew**
  - **3rd Person Required for Utility Clearing for Efficiency**

Vista GeoScience

Data Acquisition



- **Typical X-Y Spacing:** 10’ – 100’
- **Maximum Rate of Penetration:**
  - **MiHpt** – 1.0 ft/min, 150-250 ft/day
  - **EC/HPT/OIP** 4.0 ft/min ROP max., 200’-300’ ft/day
- **GPS or Site Survey for Location Coordinates (X, Y, Z)**
  - GPS or Google Map for **X-Y** = **+/-2 feet**
  - **Z** for Contaminants = **+/- 0.1 feet**.
  - **Z** for Groundwater modeling = **+/- 0.01 feet**
  - *Can use **Relative** Elevation with **Auto Level > > >***

Vista GeoScience

HRSC Tools Quality Control

.nfo File Log Records *ALL THIS DATA for Data Review:*

- **Software Alarm Settings:**
  - Flows, Pressures, Temps
- **Sensor Response Tests**
  - MIP Chemical Std. Tests
  - HPT Pressure Sensor
  - Electrical Conductivity
  - OIP Fluorescence Tests
- **ASK FOR THE RAW DATA FILES FOR YOUR RECORDS!!**

```
M-01a.zip
SITE INFORMATION -- DIRECT IMAGE MIP+HPT PROBE
Geoprobe DI Acquisition Software for Windows
Version: 3.0   Build: 17007

EC PRE-LOG TESTS BYPASSED

COMPANY: Vista GeoScience
OPERATOR: DF
PROJECT ID: 17151.01
CLIENT: AECOM
UNITS: ENGLISH
PROBE AND ARRAY: MH6530/6532 MiHPT Probe with Top Dipole
LOCATION: Paris TX
100 INCH STRING POT USED
ROD LENGTH: 5 feet

MIP PRE-LOG RESPONSE TEST
FILENAME: M-01a.pre.tim
COMPOUND: Benz, TCE
CONCENTRATION: 10, 10 ppm
FLOW: 36.1 mL/min
RESPONSE TEST START TIME: Thu Sep 28 2017 09:52:40
RESPONSE TEST ATTENUATION CHANGES
   TIME         DET1    DET2    DET3    DET4
      0            1       1       1       1

TRIP TIME: 45 sec
Gas Used: nitrogen

PRE-LOG HPT REFERENCE TEST VALUES
PRE TEST TIME: Thu Sep 28 2017 10:04:40
        TEST            HPT PRESSURE (psi)      FLOW (mL/min)   HPT PRESSURE (kPa)
TOP with FLOW=0          15.502                    0.0           106.880
TOP with FLOW>0          15.889                  304.3           109.550
BOTTOM with FLOW=0       15.299                    0.0           105.480
BOTTOM with FLOW>0       15.677                  302.6           108.090

EXPECTED FLOW=0 HPT DIFF.: 0.22 psi (1.5 kPa) +/- 10%
  ACTUAL FLOW=0 HPT DIFF.: 0.20 psi (1.4 kPa)

TRANSDUCER TEST PASSED

DETECTOR NAME: PID FID XSD None
HPT IDEAL COEFFS:       2.2696e1,-2.2356
HPT SENSOR CAL NUMBERS: XD30850A,0.0000,0.0000,0.0000,0.0000,9.9460e-1,-1.1500

Temperature out of range (42.0 deg C) at 0.00 ft (0.000 m)
Temperature out of range (38.8 deg C) at 0.00 ft (0.000 m)

LOG START TIME: Thu Sep 28 2017 10:06:30
```

Vista GeoScience

A Few Things to Watch For:

- **Most Important for Planning:**
  - If LNAPL is present, start with OIP-UV and find the LNAPL edge, then surround with MIP to map dissolved.
- **Swamping of MIP Trunkline in Hot Zones**
  - High concentrations will cause carry over, false pos., and field delays
- **Off Scale Readings (5 volts)**
- **Mineral Fluorescence on OIP-UV or LIF/UVOST**
- **First 5' – Was it potholed? Hand augered? or backfilled?**
- **Fill Material will give false or altered readings**
- **Don't Use Low-Level MIP on Fuel Plumes**
- **Use similar compounds for response tests**
  - (ex. Benzene for fuels, TCE for chlorinated plumes)
- ***EXPERIENCED & TRAINED OPERATORS!***

Quantitative Tools

Soil & Groundwater Sampling

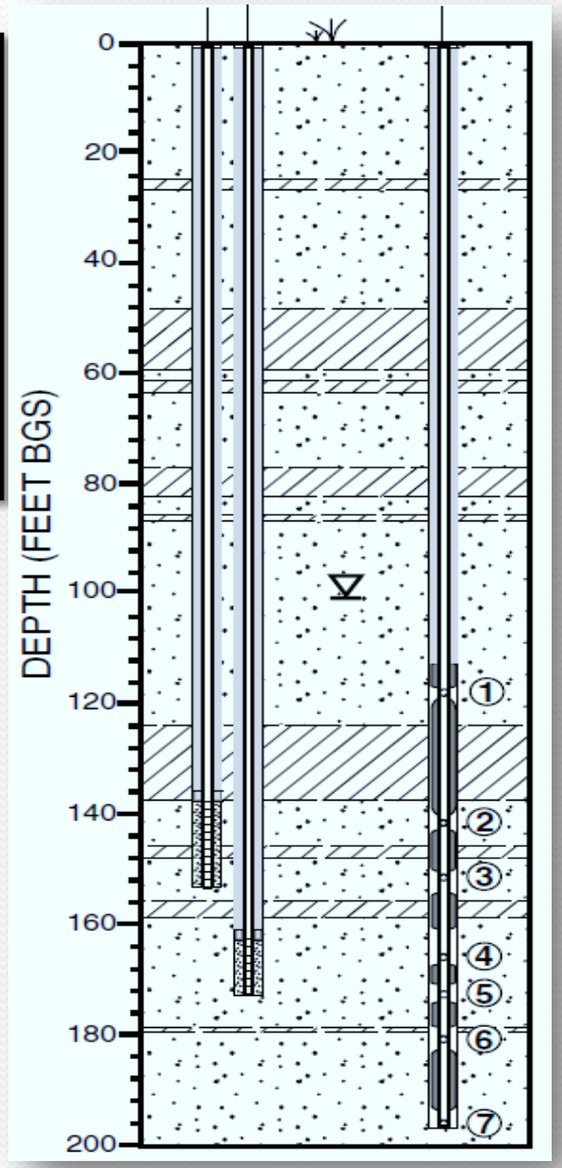
High Resolution Soil Sampling

Collect Continuous Soil Cores!

- **Think TRIAD**
- **PLEASE, NO MORE…**
  - **18” or 24” Split Spoons every 5’ = HUGE DATA GAPS!**
  - **Macro-Cores (smeared holes, slough)**
- **Use Geoprobe Dual-Tube Cased Hole Coring Systems** (2.25” or 3.25”)
- **or HSA Continuous Coring Systems** (5 ft.)

DPT Discrete Groundwater Sampling

- **Screen Point Samplers**
- **Nested Wells/Peizometers**
- **Pneumatic Slug Tests**

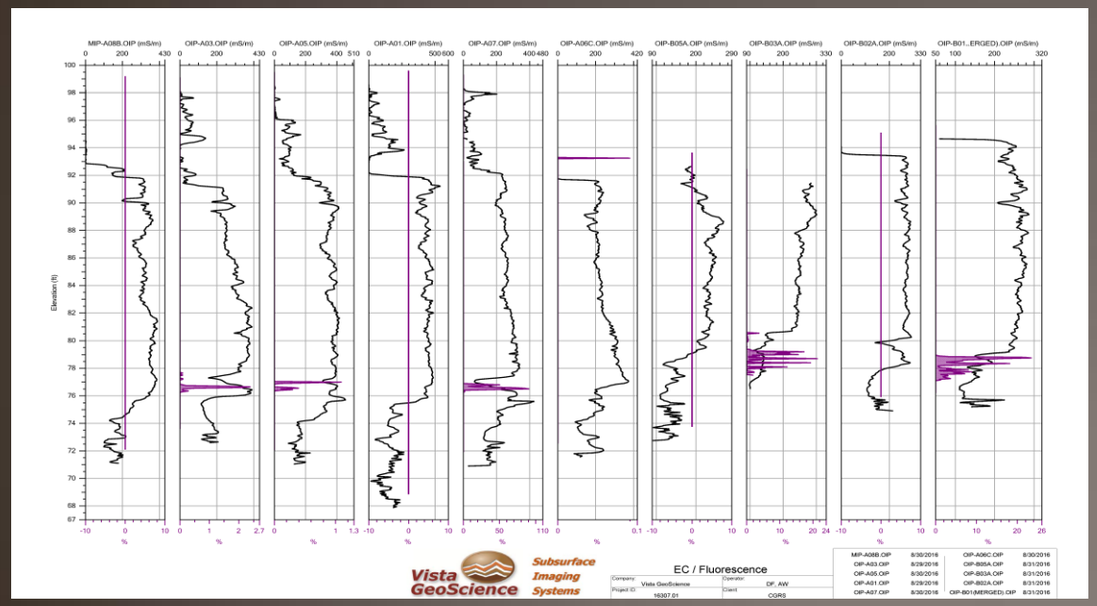


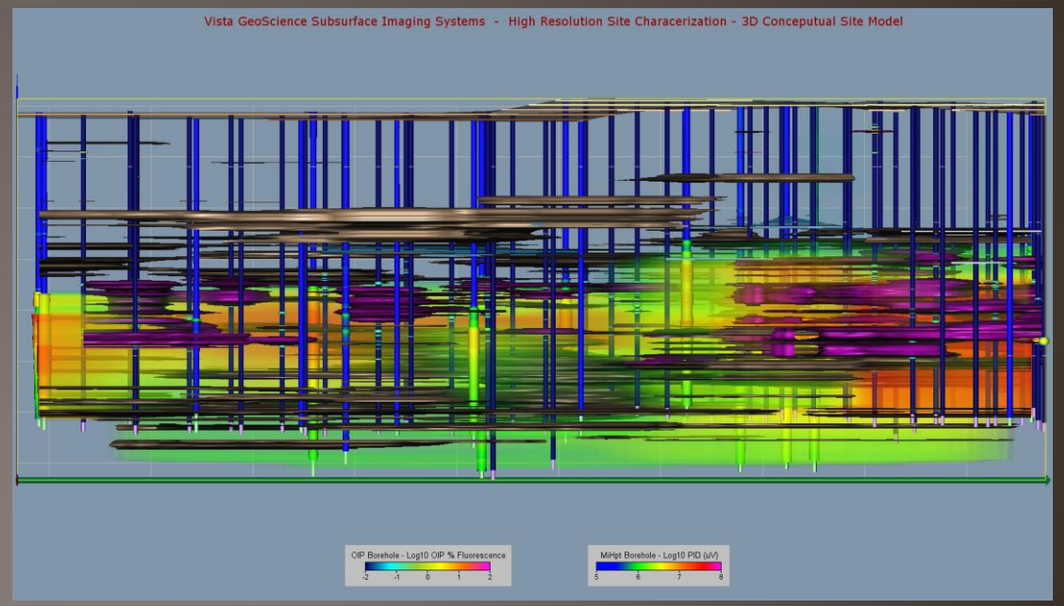
The Use of Direct-push Well Technology for Long-term Environmental Monitoring in Groundwater Investigations (SCM-2) Mar-2006

HPT-GWP – Groundwater Profiler

- ***New!*** ***Simplified/Robust Discrete Groundwater Sampler***
- **20 - 3/8”screen ports over 6” interval.**
- **Only two water lines**
- **Measures injection pump pressure and flow. (No K)**
- **Can be driven without drive cushion.**
- **Peristaltic Pump or Mechanical Bladder Pump**
- **Measure GW parameters while sampling!**
- **30-40 minutes per sample**

Reporting & Data Visualization





HRSC Report Options

Basic Reporting

- **Boring Location Map**
- **Final Edits of Logs (PDFs)**
  - Detectors Individually Scaled
  - Detectors Common Scaled
- **Field Notes Summary**
  - Basic Log Run Comments
  - Log Run Issues
  - Maximum Detector Values
- **Raw Digital Data, Log Files**

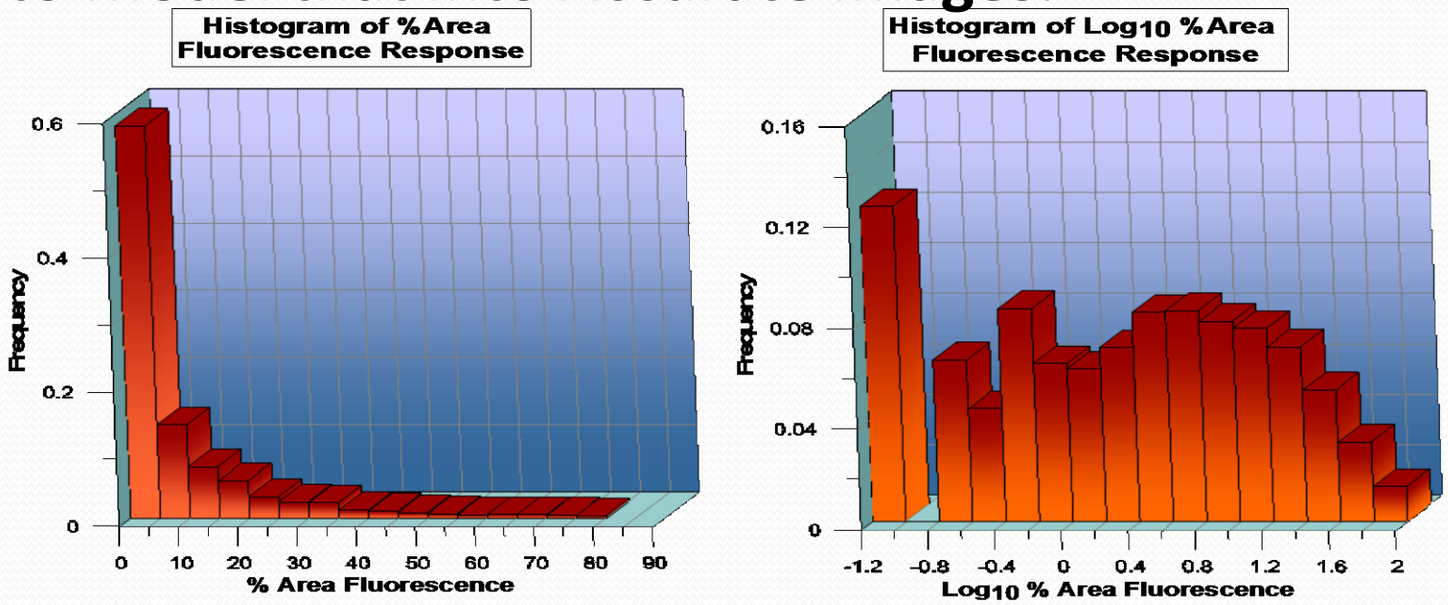
Advanced Reporting Options

- **Real Time Field Upload to Server**
  - PDF Logs, Map
- **Interpretive Report**
  - QA/QC Review, inf file prints
- **2D Symbol or Contour Maps**
- **Cross Section Displays**
  - From DI Viewer
  - Other Software
- **3D Visualization Models**
  - Groundwater Model
  - Hydrogeology
  - LNAPL Distribution
  - Dissolved Phase Distribution
  - Monitor Wells
  - Confirmation Boring/Samples

2D & 3D Visualization Techniques

Accurate Models Require Understanding of:

- **Baseline Noise vs Actual Contaminant Signal**
- **Potential Interferences, False Anomalies**
  - **Carry Over, Pressure Fluctuations**
  - **Mineral Fluorescence**
  - **Salty Water**
- **Which Data are Logarithmically Distributed and How to use that Knowledge in Choosing the Right Surface Contouring Algorithms.**
- **Anisotropic Nature of High Vertical Resolution Data (20 data points per vertical foot) and How to Model that into Accurate Images.**



Vista GeoScience

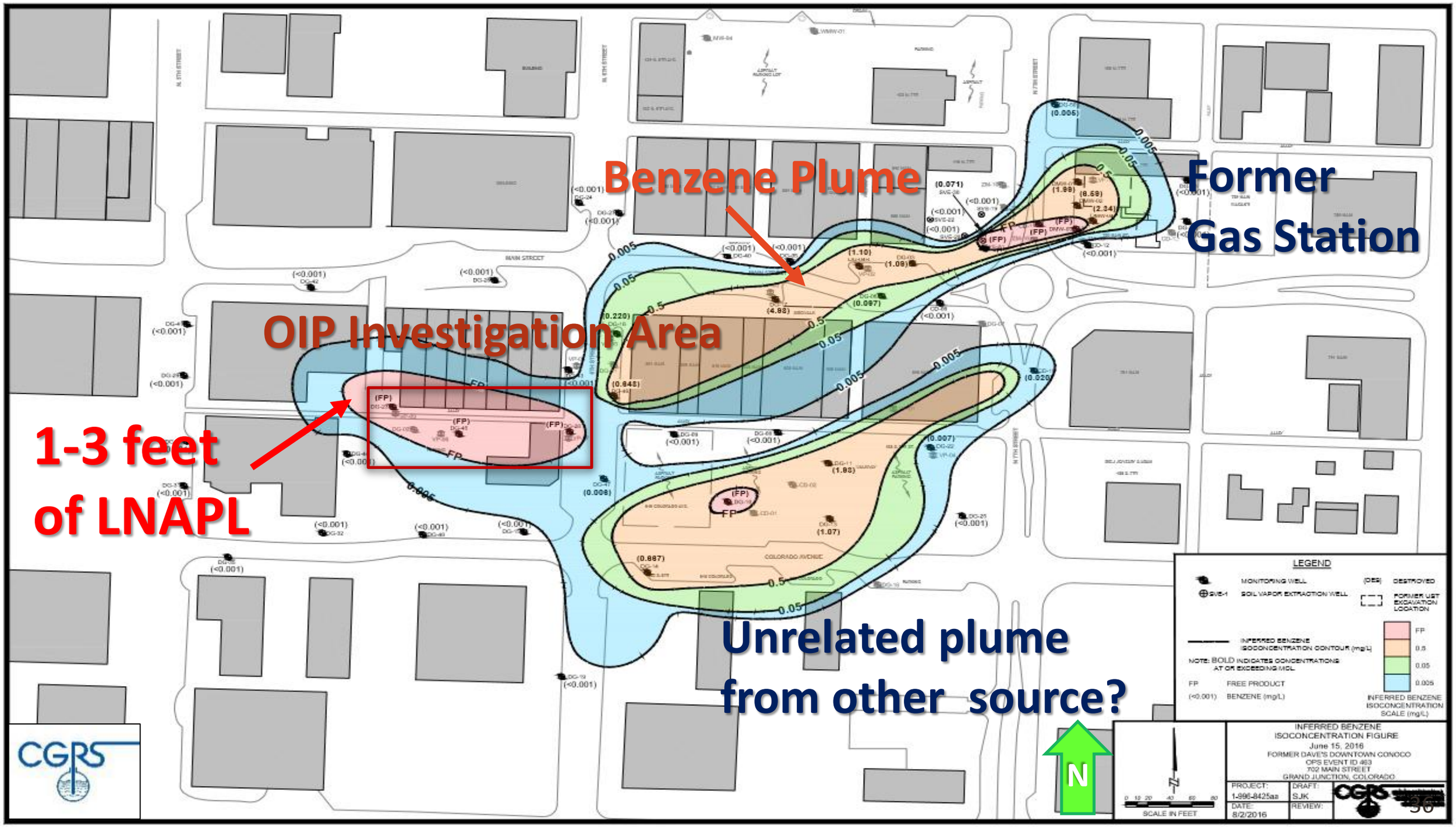
HRSC Conceptual Site Model Case History 1: Grand Junction, CO

Unidentified Historic Gasoline Source

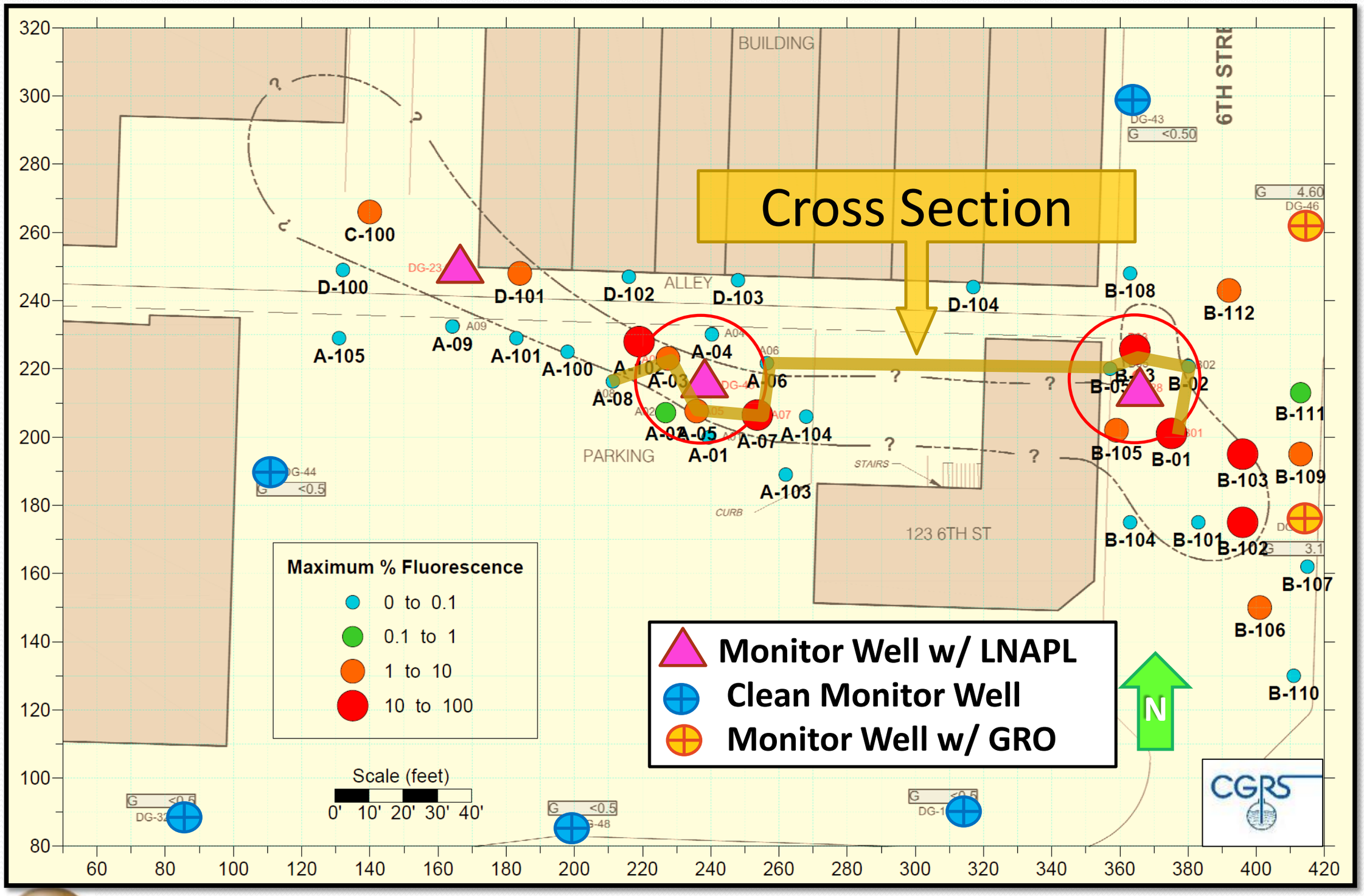
OIP-UV / EC Logs Identified Confining Conditions that Presented False Thickness of LNAPL in Some Monitor Wells

Downtown Grand Junction, CO

LNAPL discovered down gradient with leaded gasoline dating to 1930's.

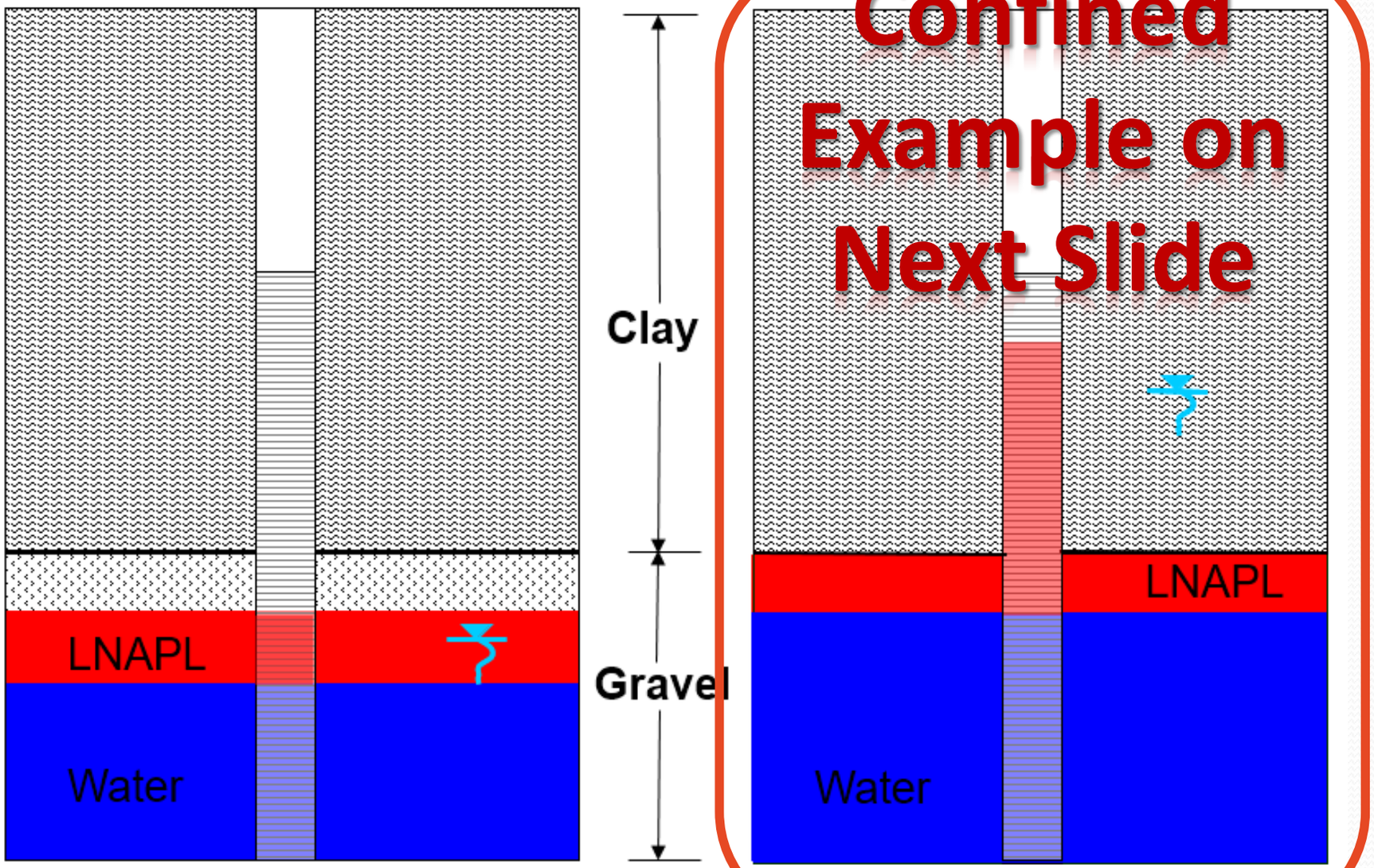


LNAPL Investigation Area - OIP-UV



ITRC LNAPL Short Course Example

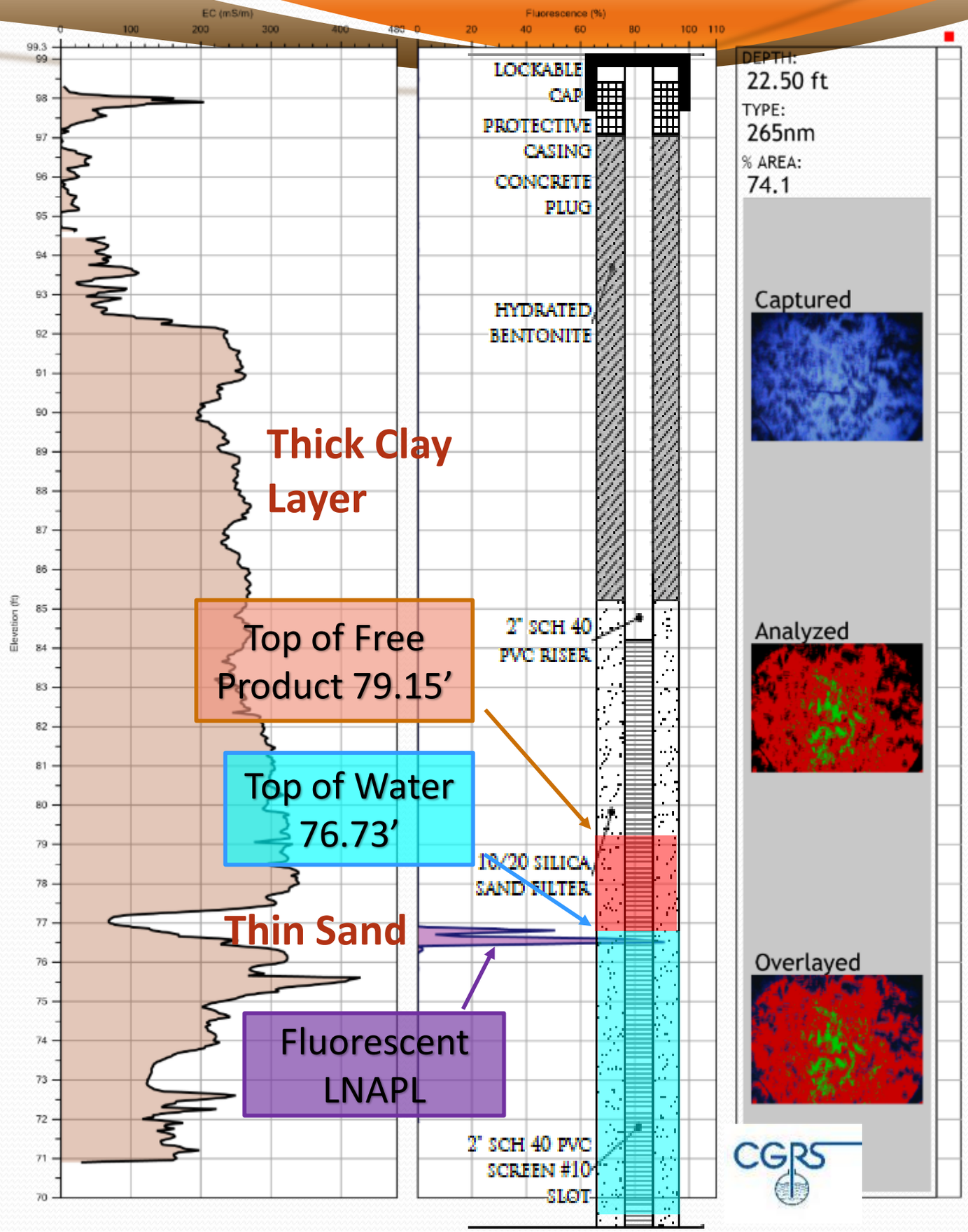
LNAPL Thickness Variation in Monitor Wells



Monitoring well is a giant pore!

OIP-A07 Shows LNAPL Not as Bad as it Looks in Well!

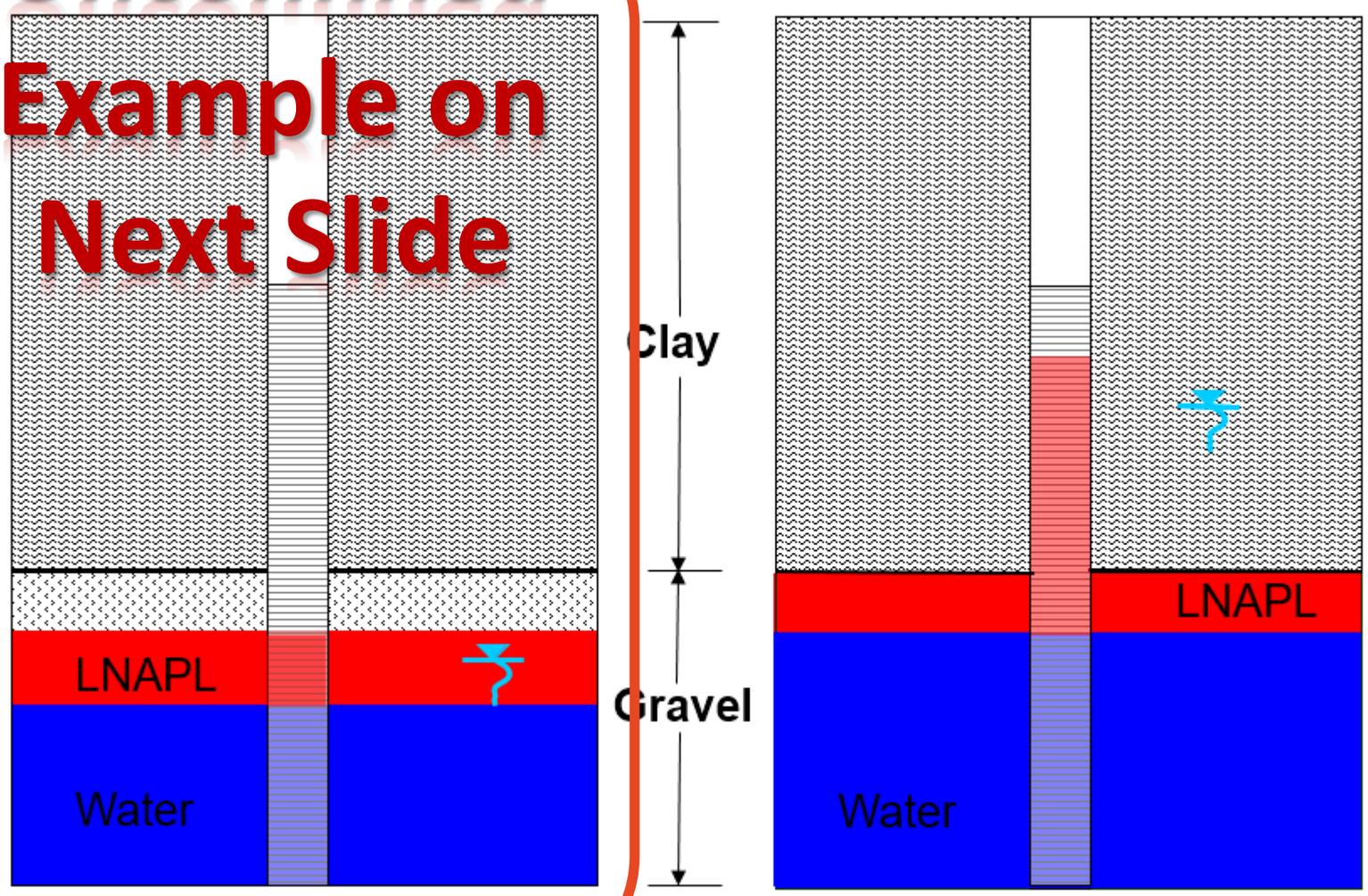
- **Well 20’ from OIP Boring**
- **Thick Low Perm Clay**
- **LNAPL in Thin Sand Stringer, below water table.**
- **LNAPL displays *false* thickness in well.**
- **Du**



ITRC LNAPL Short Course Example

Unconfined

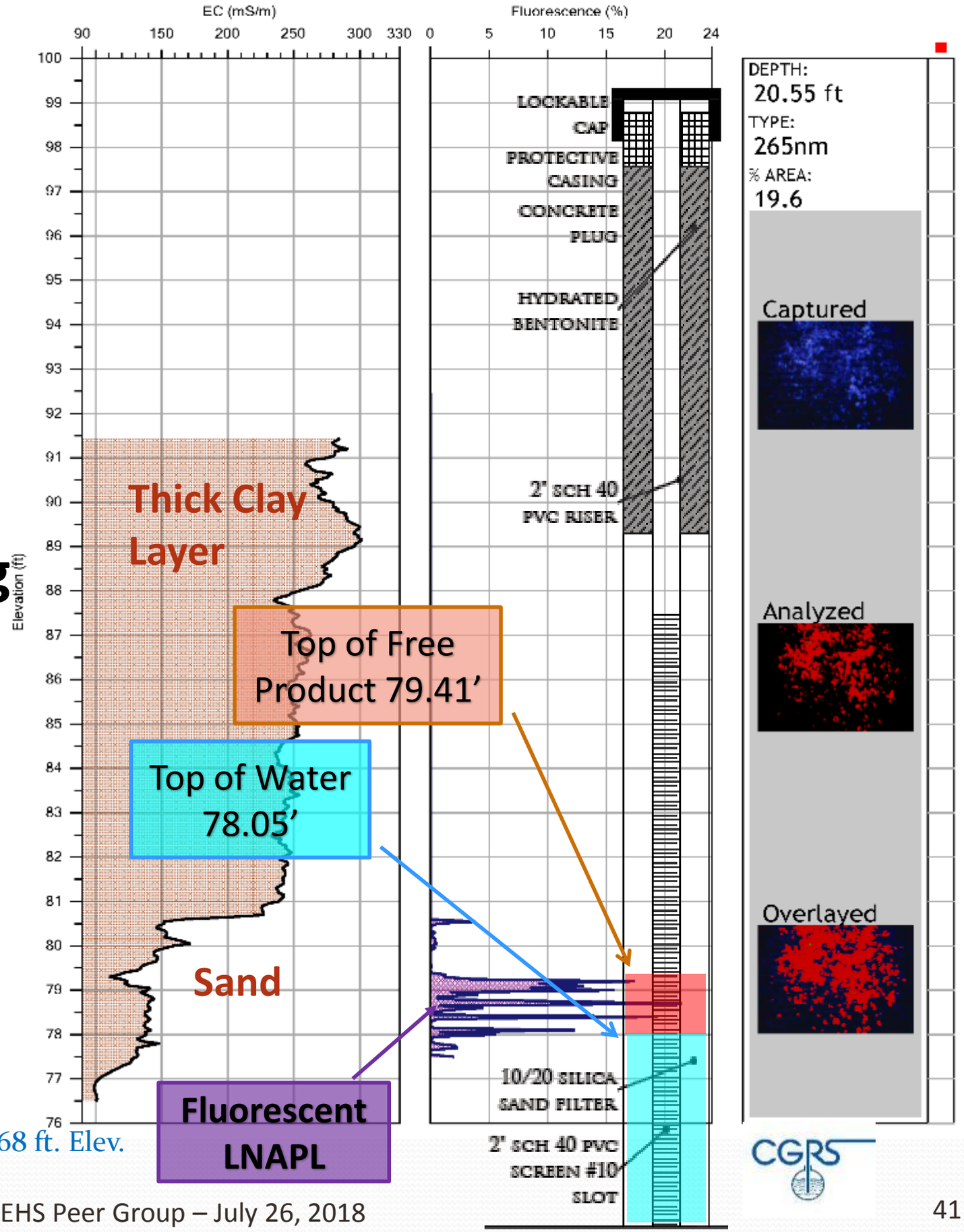
Example on Next Slide



Monitoring well is a giant pore!

OIP-B03 Shows LNAPL *is* as Bad as it Looks in Well!

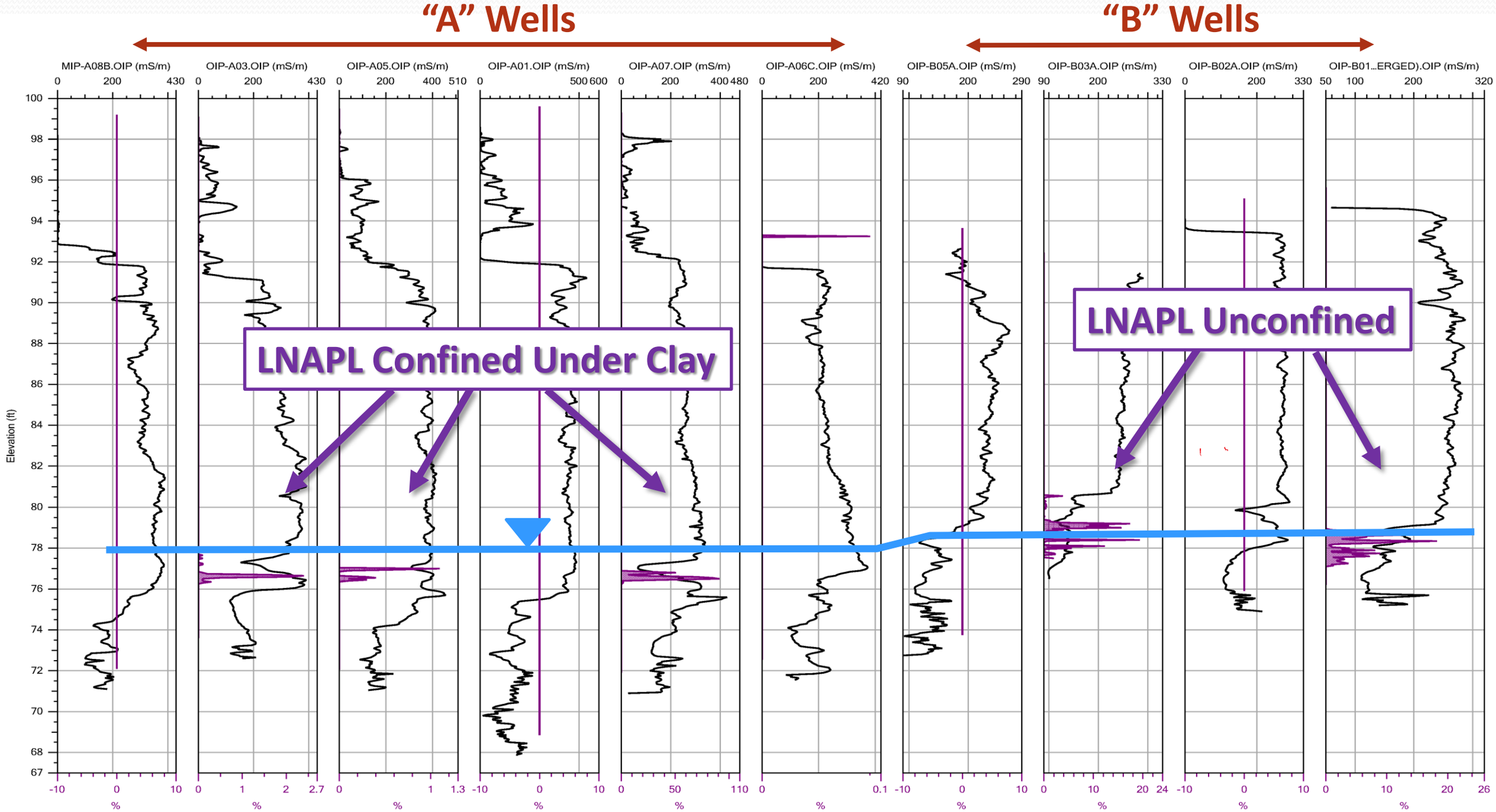
- **Well 10’ from OIP Boring**
- **Thick Low Perm Clay**
- **LNAPL in main sand body, not confined below water table.**
- **LNAPL displays *actual* thickness in well.**



Note: Actual bottom of well at 68 ft. Elev.

West to East Cross-Section (%AF & EC)

A wells demonstrate confined LNAPL conditions. B wells base of clay is higher, LNAPL is unconfined. *Could the LNAPL migrate up dip under the confined clay?*

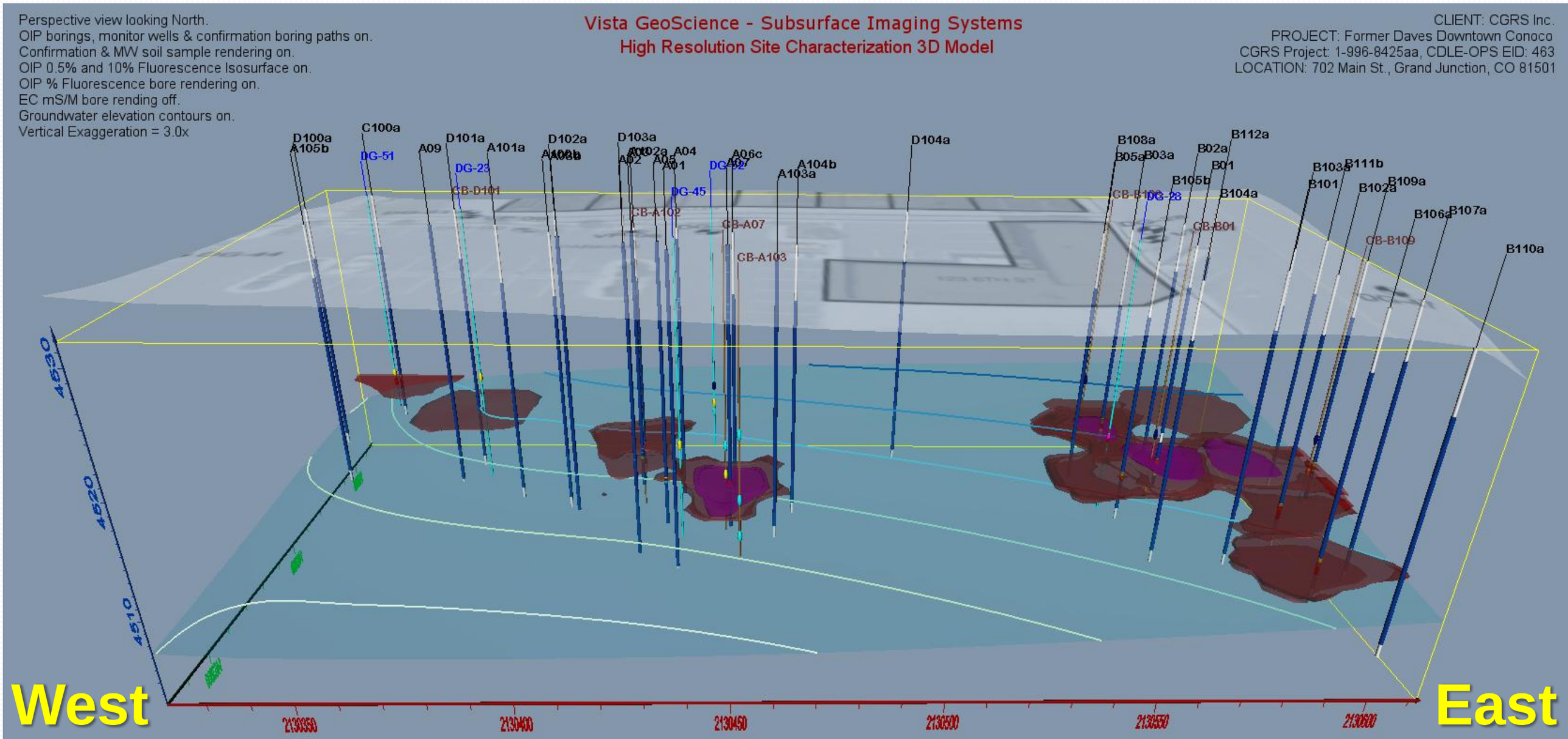


EC / Fluorescence

Company:	Vista GeoScience	Operator:	DF, AW
Project ID:	16305.01	Client:	CGRS

MIP-A08B.OIP	8/30/2016	OIP-A06C.OIP	8/30/2016
OIP-A03.OIP	8/29/2016	OIP-B05A.OIP	8/31/2016
OIP-A05.OIP	8/30/2016	OIP-B03A.OIP	8/31/2016
OIP-A01.OIP	8/29/2016	OIP-B02A.OIP	8/31/2016
OIP-A07.OIP	8/30/2016	OIP-B01(MERGED).OIP	8/31/2016

Expanded Survey
3D Model of LNAPL and Groundwater

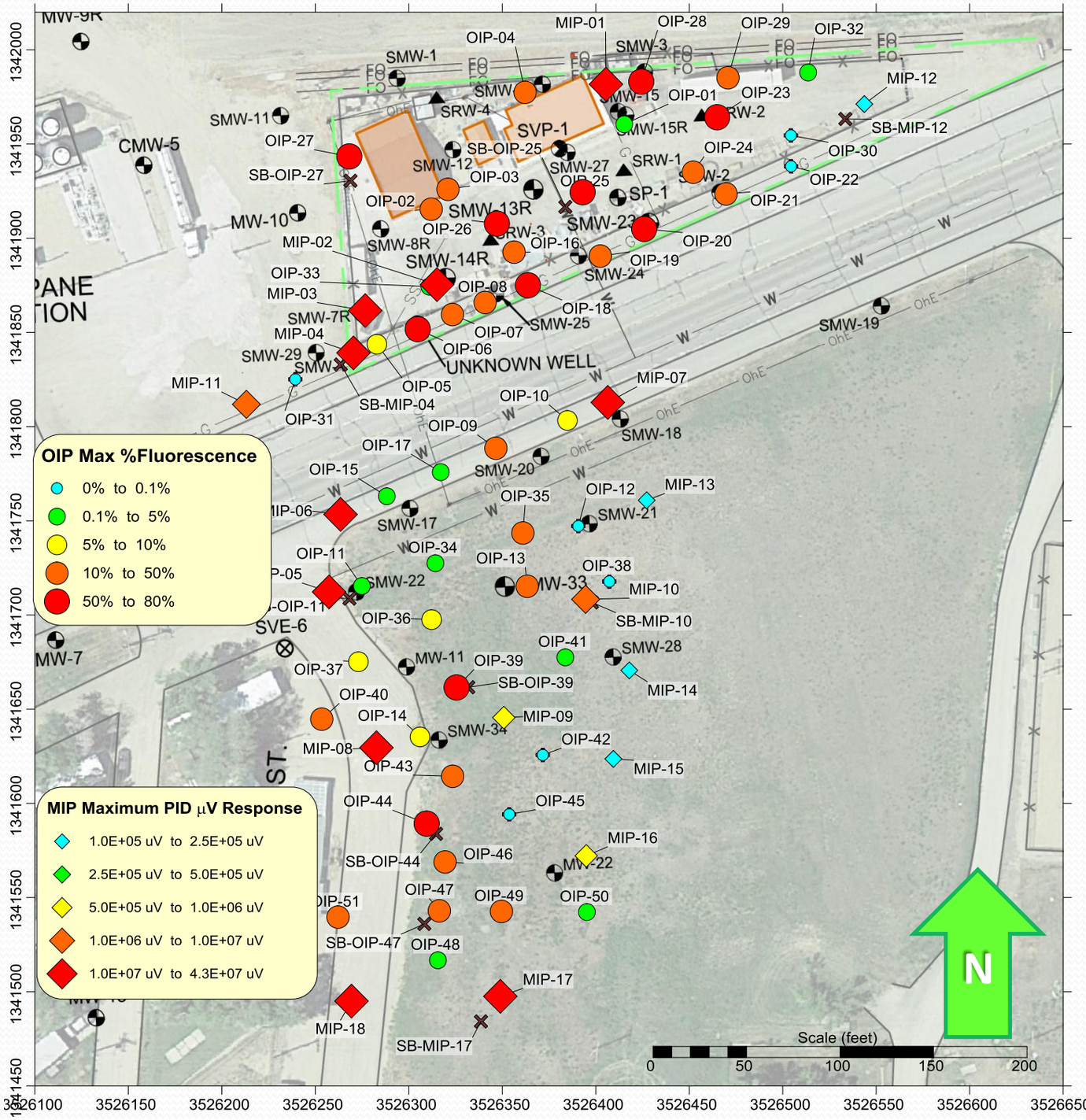


HRSC Conceptual Site Model Case History 2: Eastern Colorado

OIP-UV and MiHpt Identified Migration of LNAPL Plume moving opposite of ground water gradient

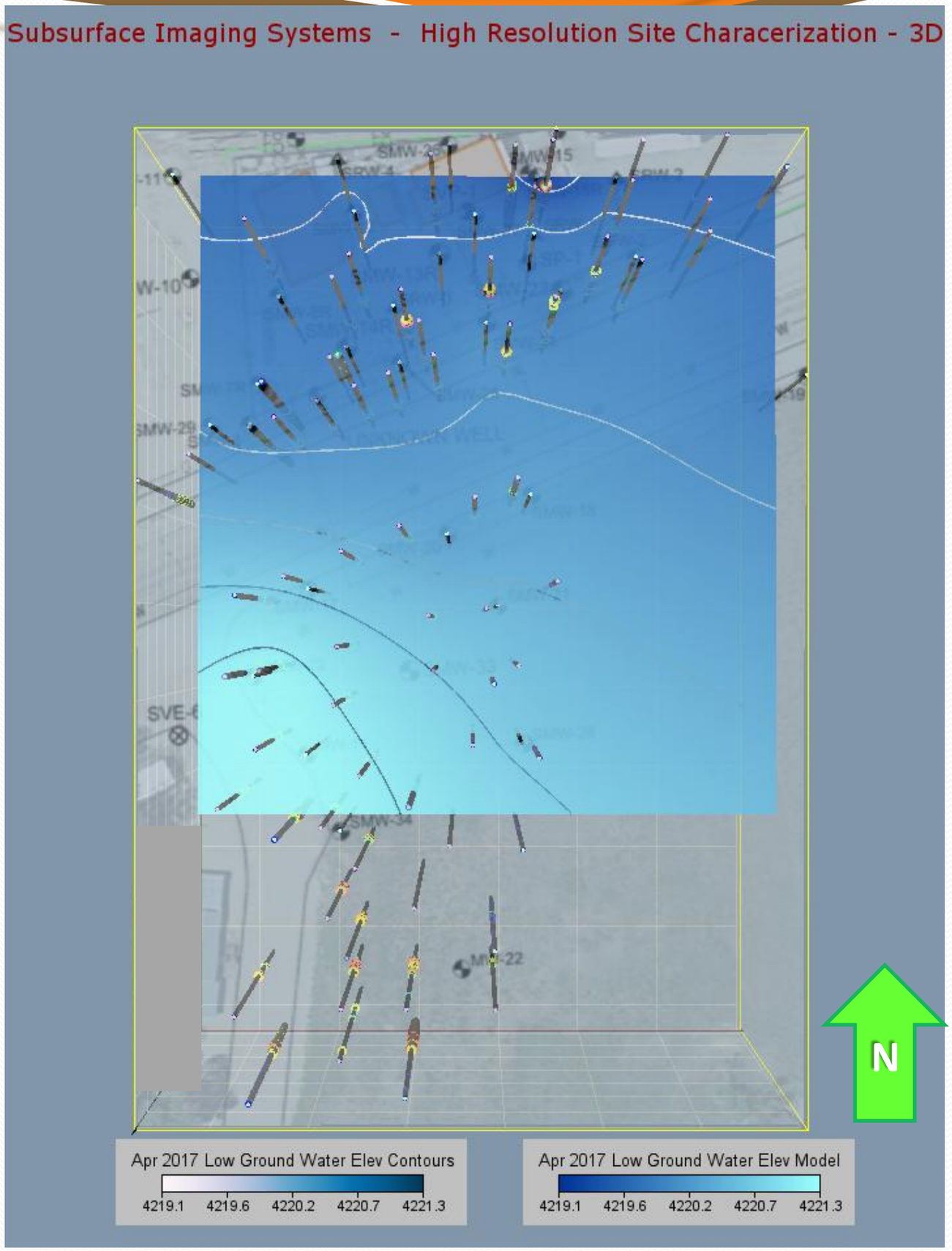
2D MiHPT & OIP Survey Map

- **Classic 2D Bubble Map used to display maximum values at each log boring.**
- **Max. MIP-PID (uV)**
- **Max. OIP %Area Fluorescence**
- **Source Area:** AST & dispenser releases in the site on the north side of the highway.
- **Data Collected**
  - 51 OIP Borings
  - 18 MiHPT Borings
  - 10 Confirmation Soil Core Borings



Ground Water Elevation Models

- Elevation modeled at two time periods, August, and April (April shown)
- Gradient on both shows north trend, towards a major river system about 2-3 miles north.
- Irrigation activity in the area may have intermittent affects on direction.



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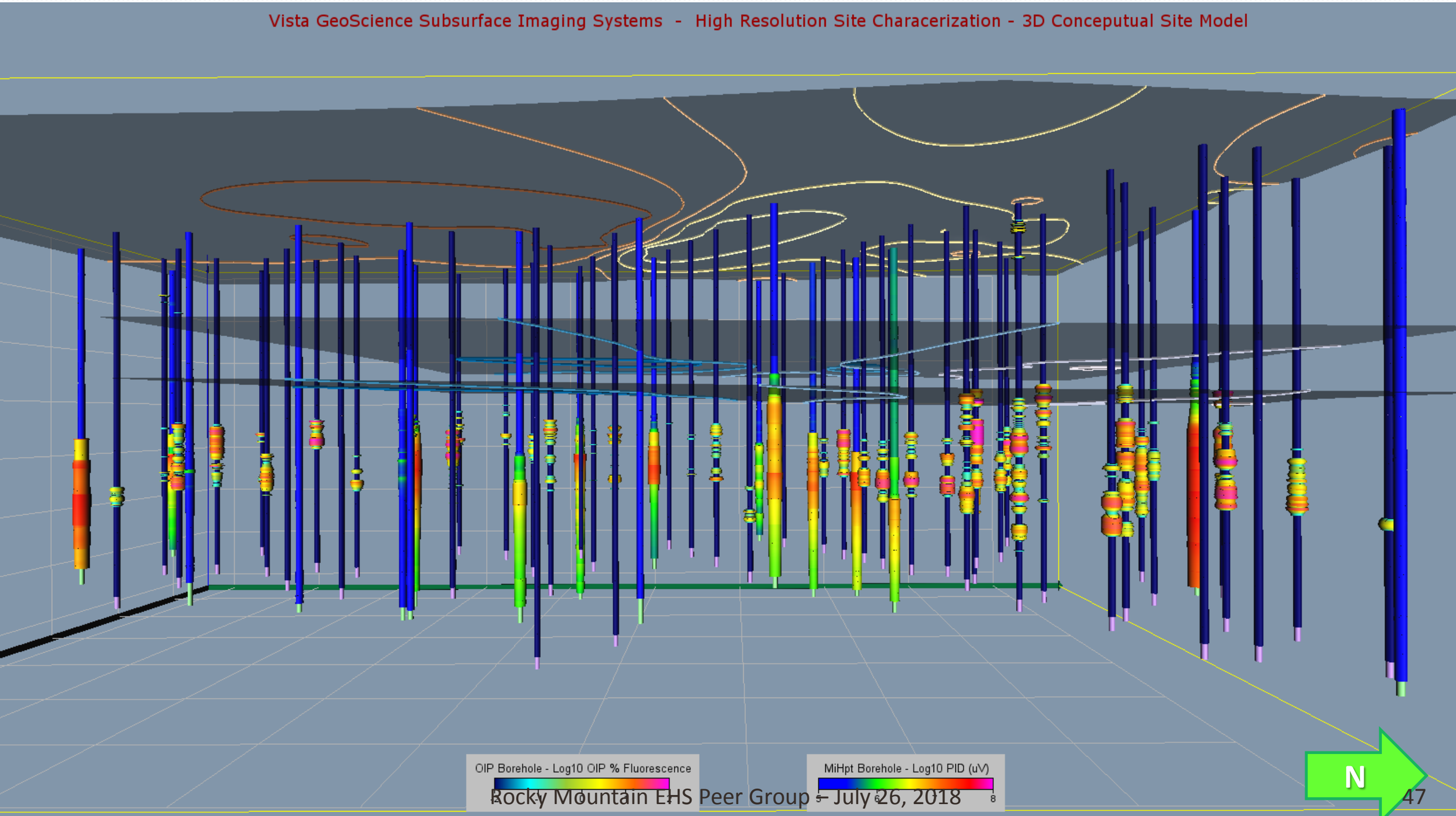
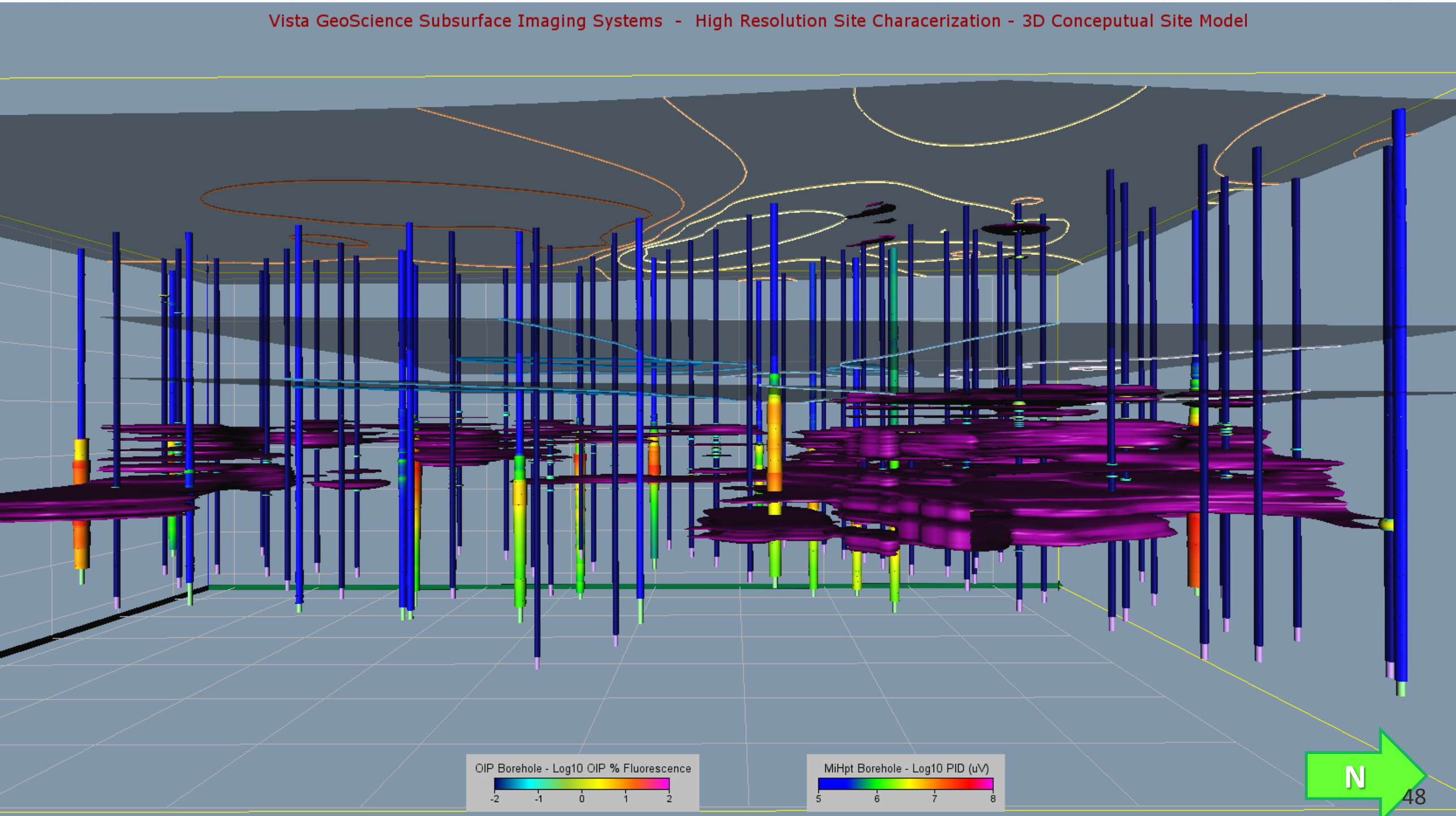
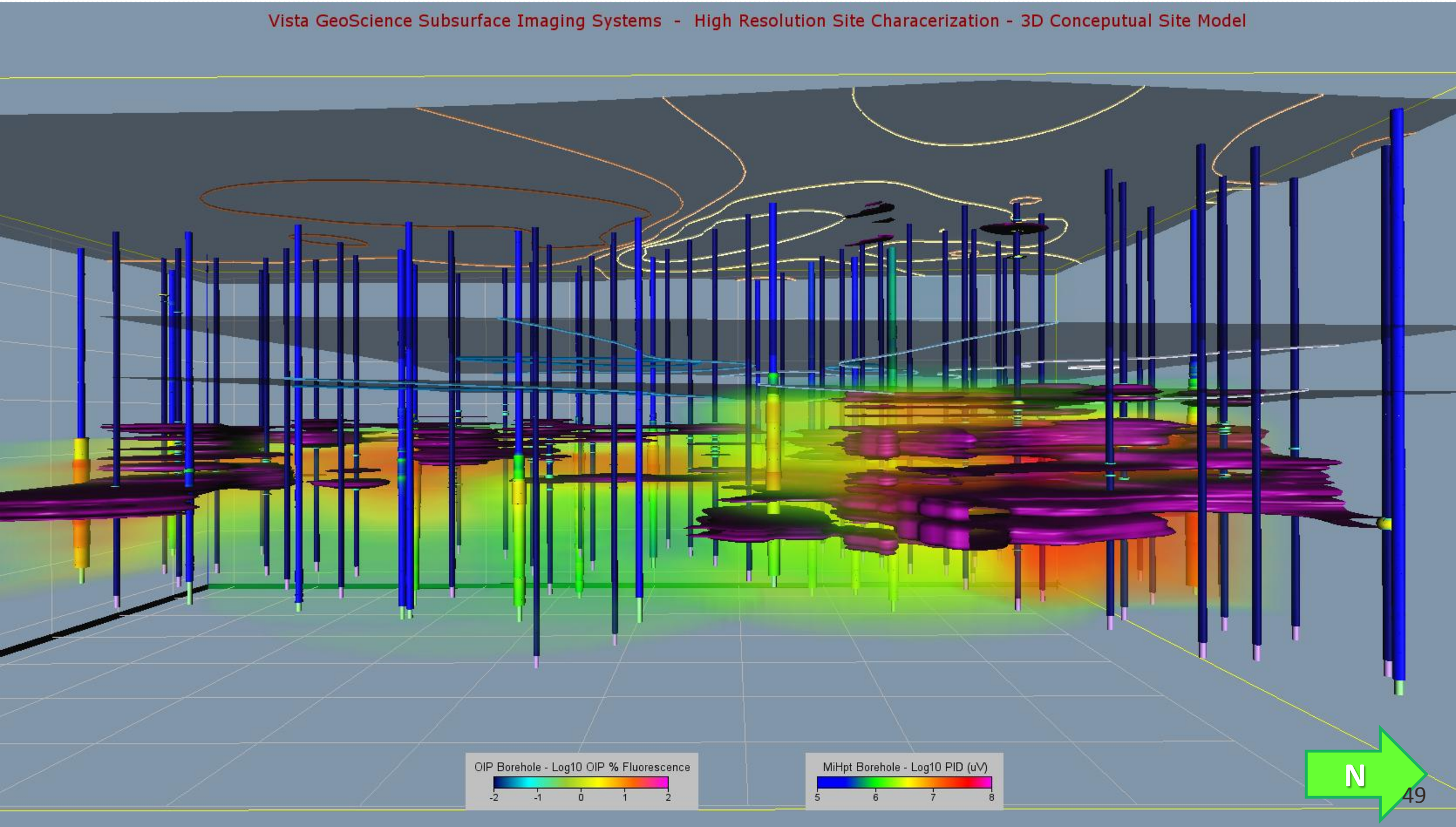
OIP-UV & MIP (PID) Boring Renderings



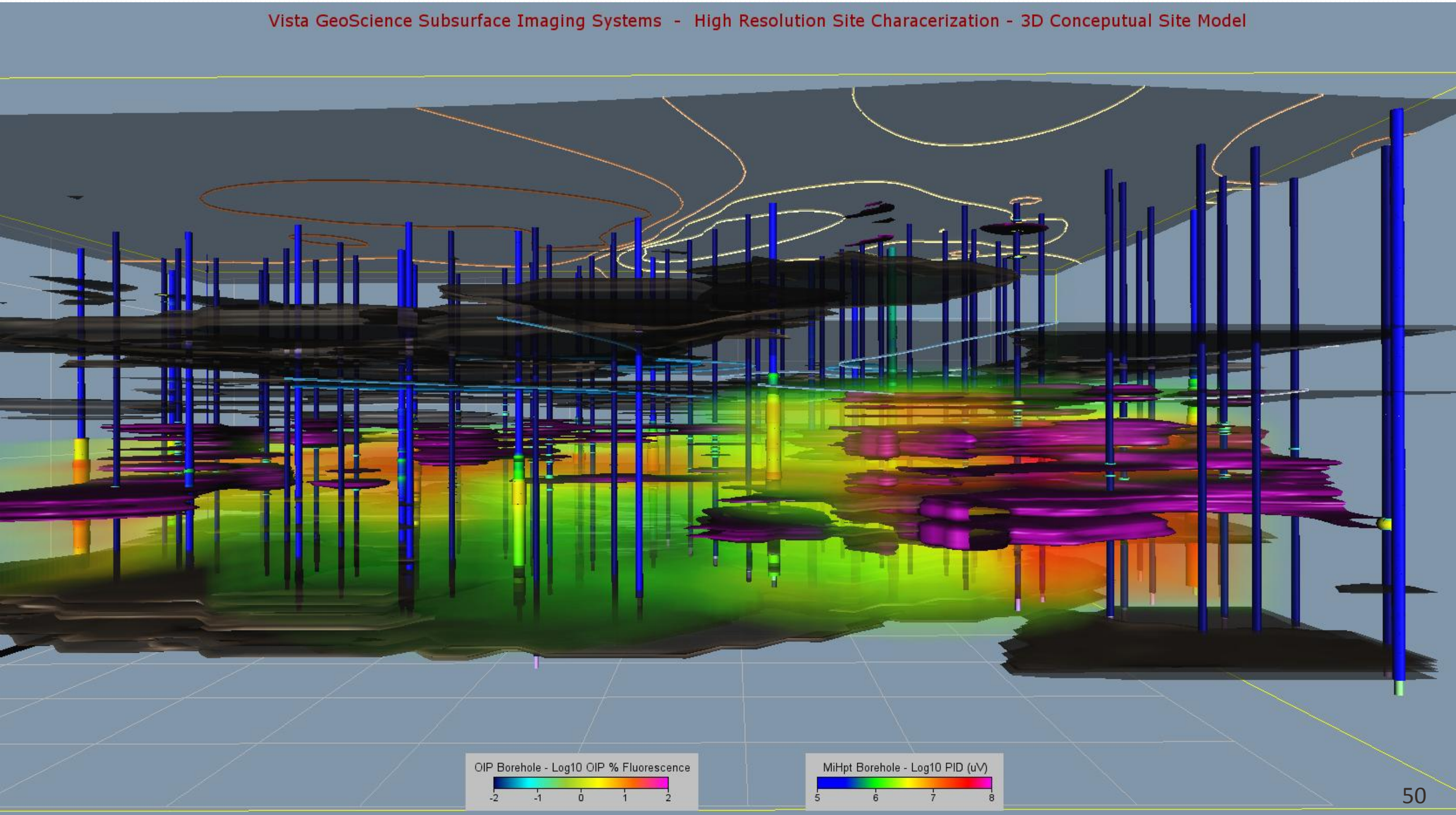
OIP-UV Fluorescence >0.1% Isosurface



MIP-PID Volume Rendering



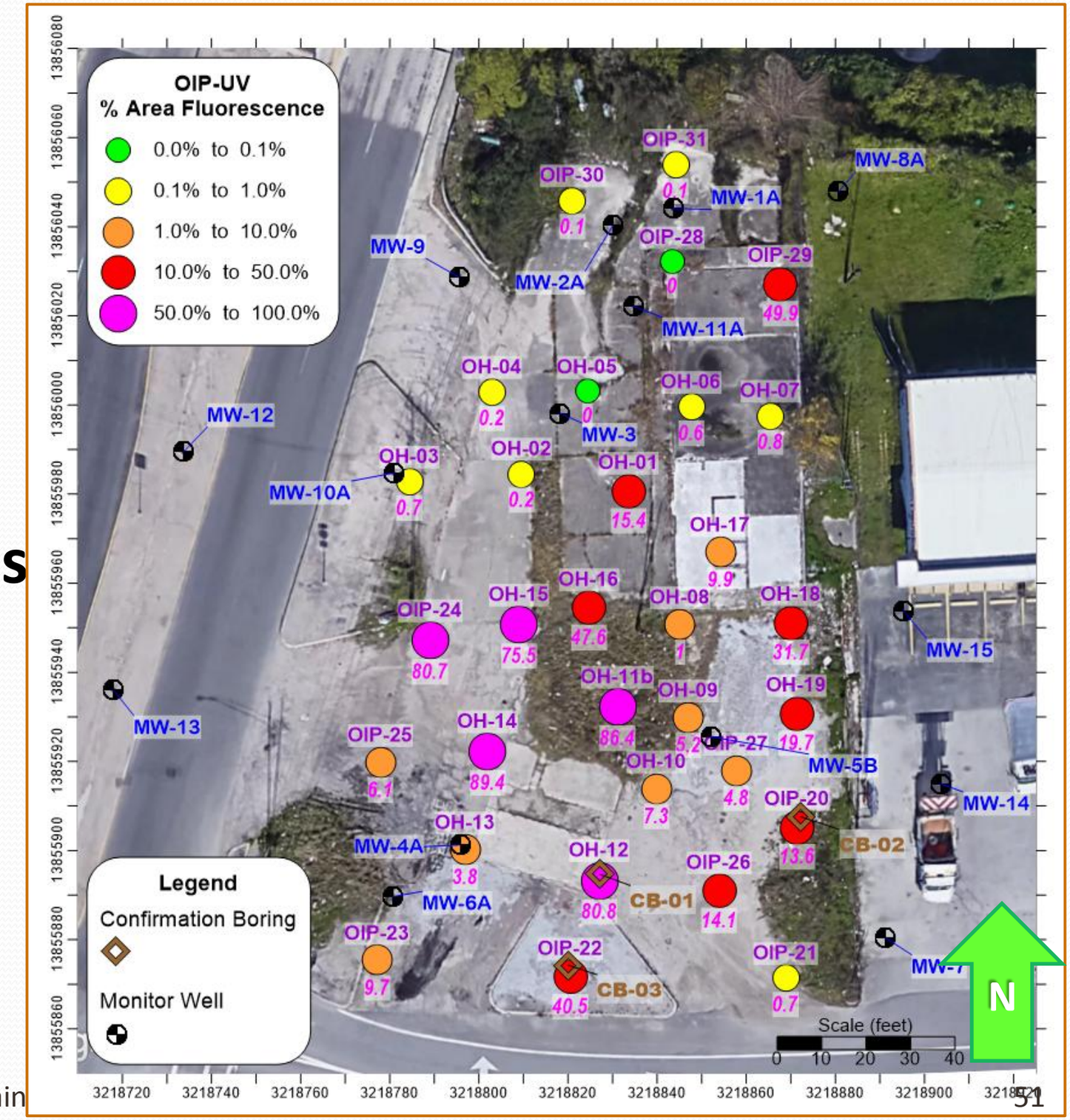
All Previous Components Visualized



Old Abandoned Gas Station, Baytown, TX

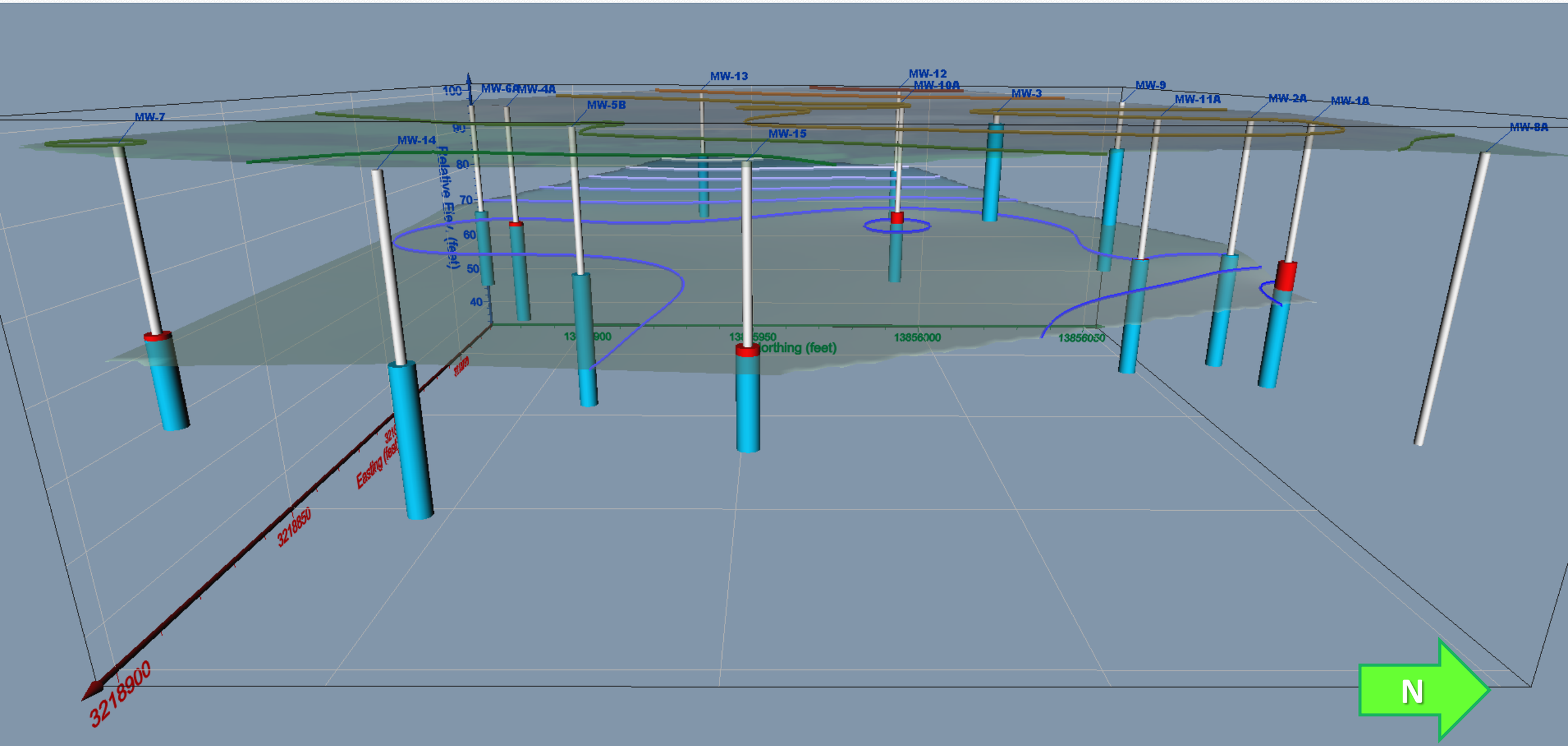
Tanks long removed, LNAPL in scattered wells

- **Map of OIP-UV Maximum %AF**
- **Original Investigation, 1997**
- **31 OIP-UV Borings**
- **3 Confirmation Soil Cores**
- **Groundwater Table Modeled from MWs**
- **All elevations relative ft.**

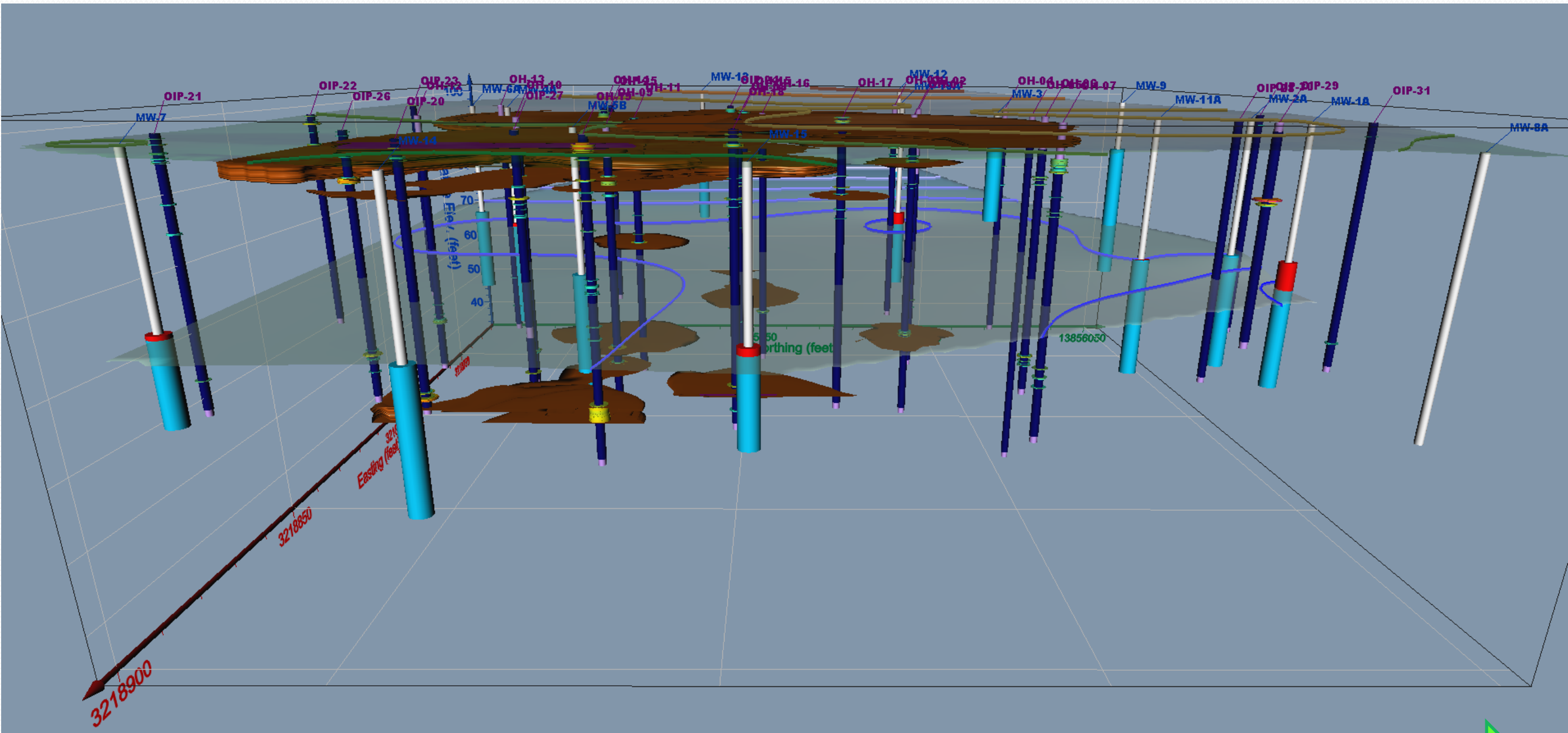


Ground water Elevation Model

Monitor wells with **water** and **LNAPL** column - View looking West



LNAPL Plume –
> 1% Area Fluorescence (%AF)



OIP-UV Borings - Log10 % AF
-2.0 -1.0 0.0 1.0 2.0

Surface Elevation (feet)
97.2 98.3 99.5 100.6 101.8

Surface Elevation Contours
97.2 98.3 99.5 100.6 101.7

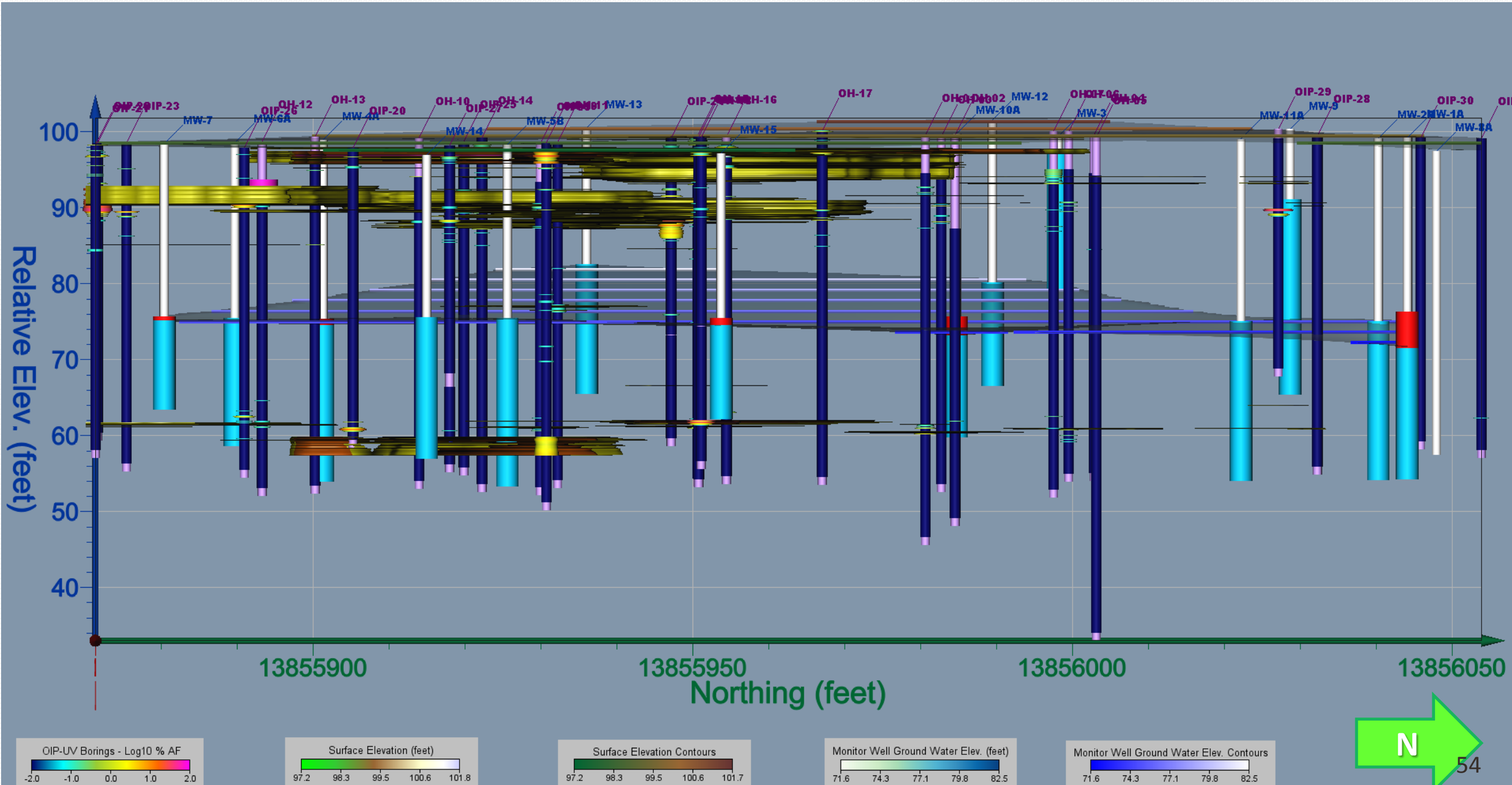
Monitor Well Ground Water Elev. (feet)
71.6 74.3 77.1 79.8 82.5

Monitor Well Ground Water Elev. Contours
71.6 74.3 77.1 79.8 82.5

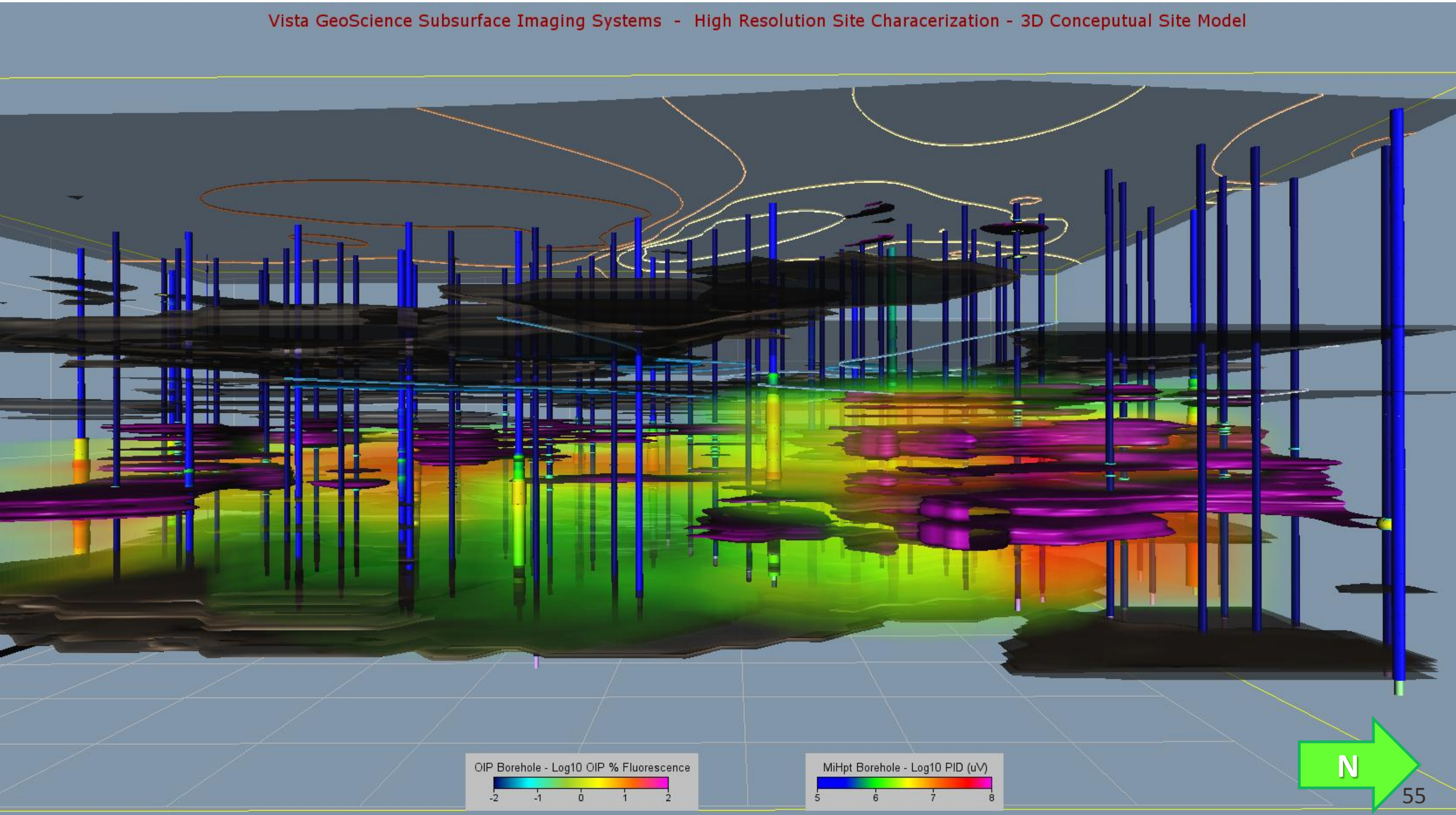
N

Orthographic View of Site Looking West –

Shows LNAPL in perched zone above water table, and confined 15’ below water piezometric head.



HPT – Pressure >45 psi Isosurface



Summary

- **HRSC tools have advanced and include new combined tools, such as MiHpt and OiHpt, and can be deployed in any soil friendly to direct-push methods.**
- **OIP-UV and LIF/UVOST produce the same relative fluorescence response in fuel spills.**
- **DI Viewer software allows end users print, compare, manipulate, QC logs, and display simple cross sections.**
- **The HRSC equipment is complex, requires significant field troubleshooting skills, and only experienced operators should be hired that have thorough training, operating experience, and understanding of the instrumentation.**

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Summary

- 2D and 3D modeling of HRSC data is the most efficient can quickly display where contaminant mass is present, moving, and why it is trapped in confining layers.
- Integrating HPT data into a HRSC model is key to understanding contaminant migration.
- LNAPL in confining conditions can result in erratic and false thickness in monitor wells, which does not represent the location of LNAPL in the soil.
- By pinpointing where the bulk of contaminant resides, HRSC can aid in more efficient remediation, or site closure solutions.

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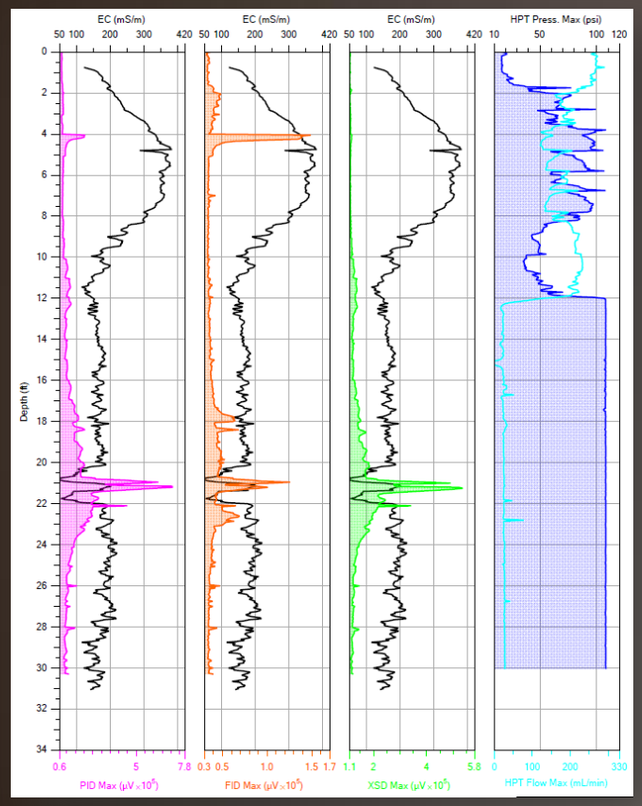
Questions?

Update on High Resolution Site Characterization Technologies & Modeling for Remedial Design



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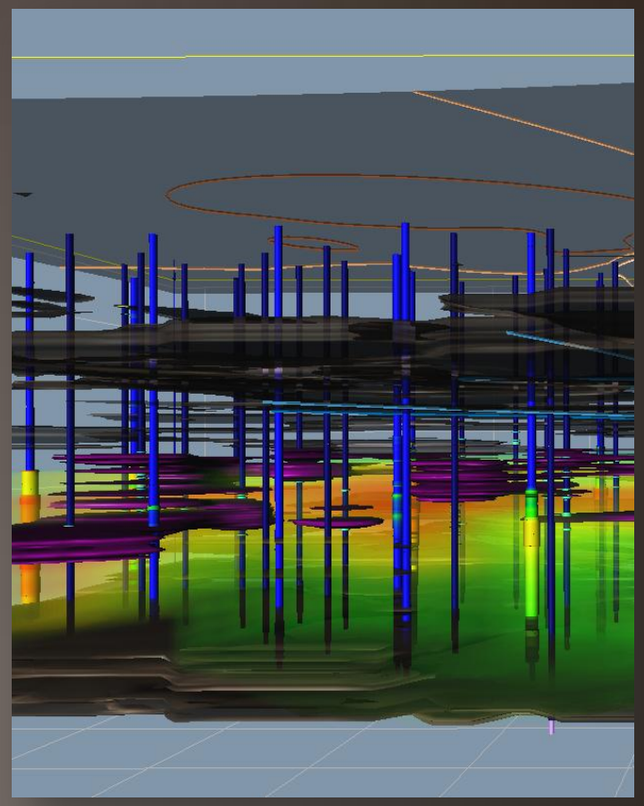

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