

# Optical Imaging Profiler (OIP)

## OIP Introduction



July, 2017

Geoprobe Systems, Salina, Kansas.

Note: A Patent is Pending for this System.



# Topic Overview

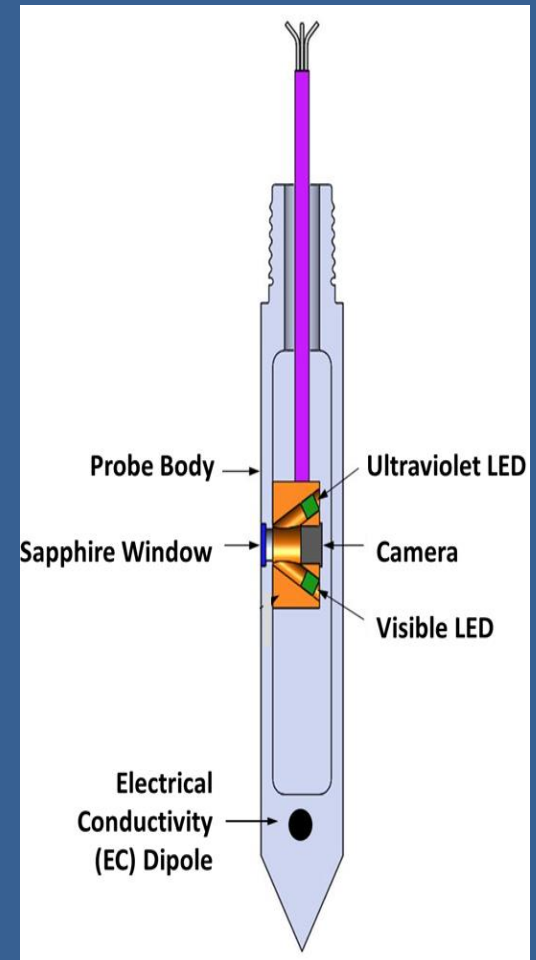
- What is OIP
- The Principles Behind OIP
- Image Analysis
- Logging with the OIP
- Viewing OIP Logs
- OIP Site Examples



# OIP Probe Description

The probe contains a:  
275nm UV LED light source  
Visible light LED light source  
CMOS Camera our detector  
Sapphire Window – interface to the soil

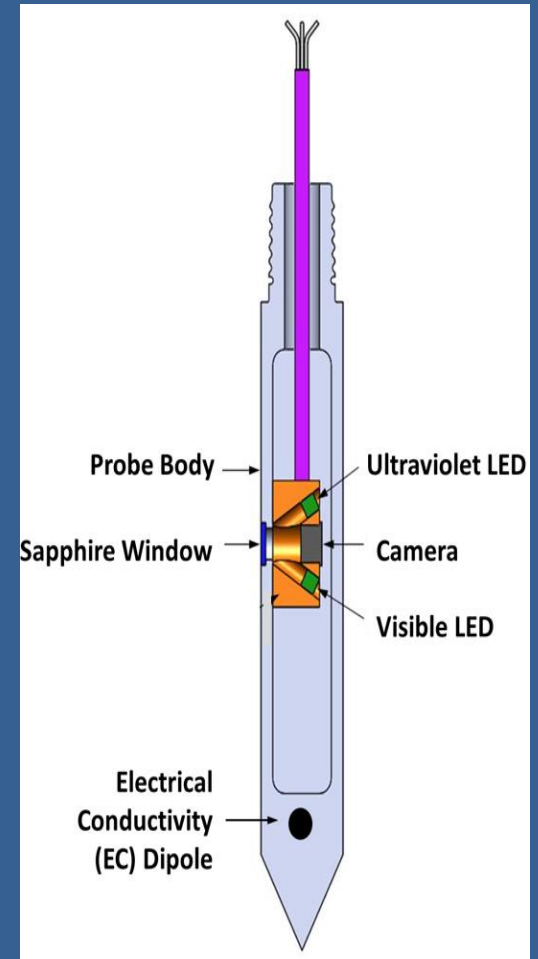
UV images are analyzed for fluorescence at a rate of 30 frames per second (FPS) as the probe is advanced.



# OIP Probe Description

- Purpose: Detecting UV induced fluorescence of light non aqueous phase liquids (LNAPL) in soil. Primarily petroleum hydrocarbons.
- Method: UV light directed at the soil causes components of the LNAPL to fluoresce. An Image of the soil and any contained fluids is captured and analyzed for fluorescence.

Visible light images of the soil may also be obtained at the operators discretion.

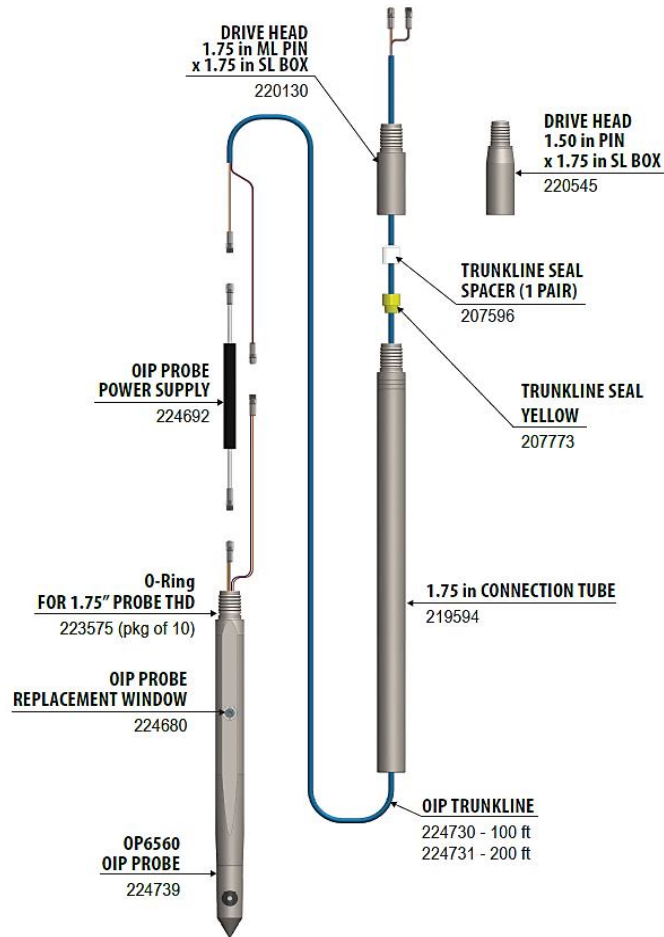


# OIP Probe Description

- Square Probe Design: with simple connections to the trunkline.
- Percussion Drivable: Using GH60 series hammers.
- Compatible: With Geoprobe® 1.5 inch and 1.75 inch rod systems.



# OIP Tool String Diagram



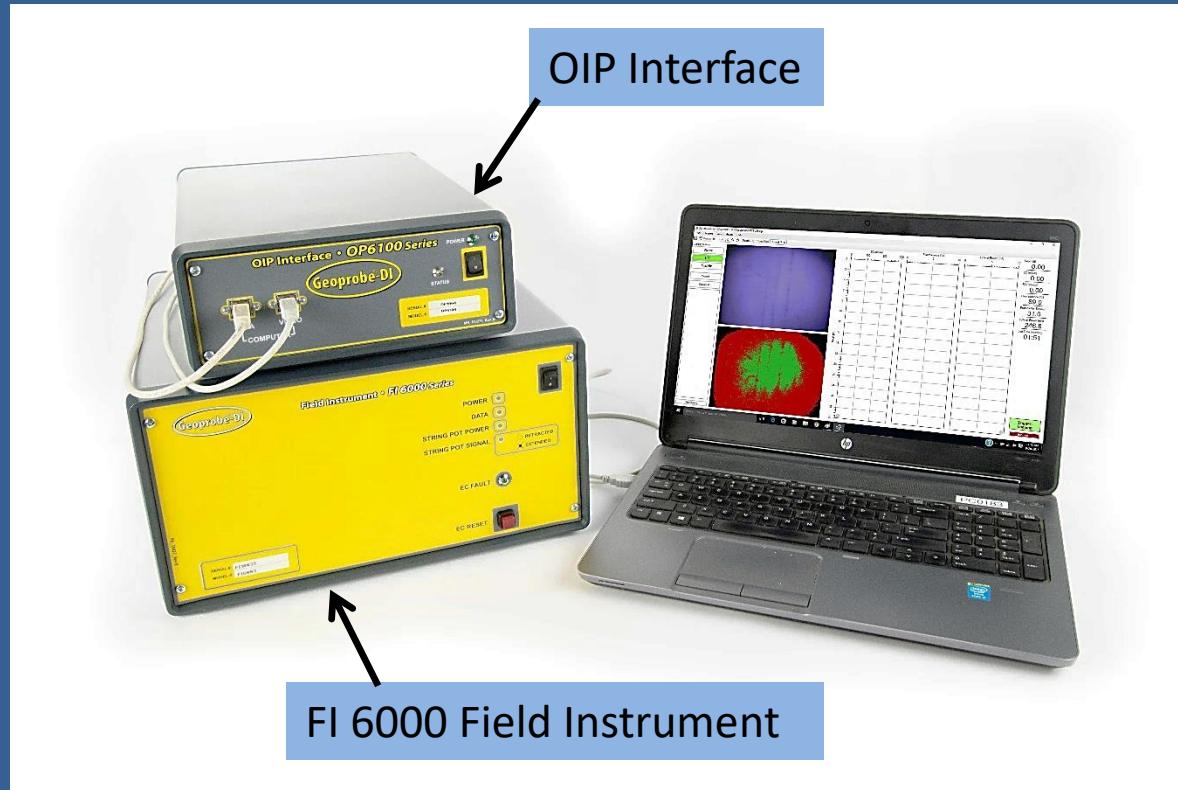
This diagram shows the major components of the downhole probe and trunkline system.

Additional rods are pre-strung with the trunkline.

Rods are added incrementally as the probe is advanced to depth.



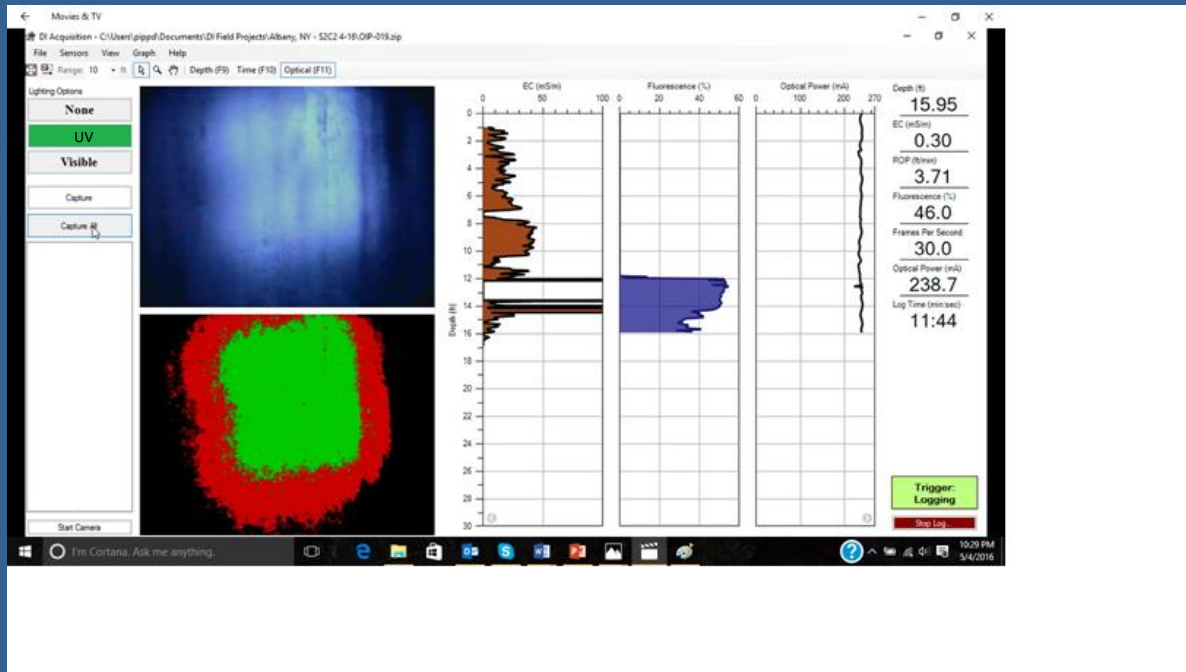
# OIP Instrumentation



Instrumentation to run optical logs includes the FI6000, OIP Interface, and a laptop computer.

The instrumentation connects to the probe via the OIP trunkline.

# OIP DI Acquisition Software



This is a screen print of the DI Acquisition software taken as a log was being run. (DI = Direct Image)

The image on the upper left is the live OIP camera feed of the UV fluorescence detected by the CMOS camera as the probe is being advanced. The image on the lower left is the analysis of this UV image (discussed later).

The 3 graphs on the log show EC, %Area of Fluorescence and Optical Power (current). The rate of penetration (speed of advancement) can also be displayed.

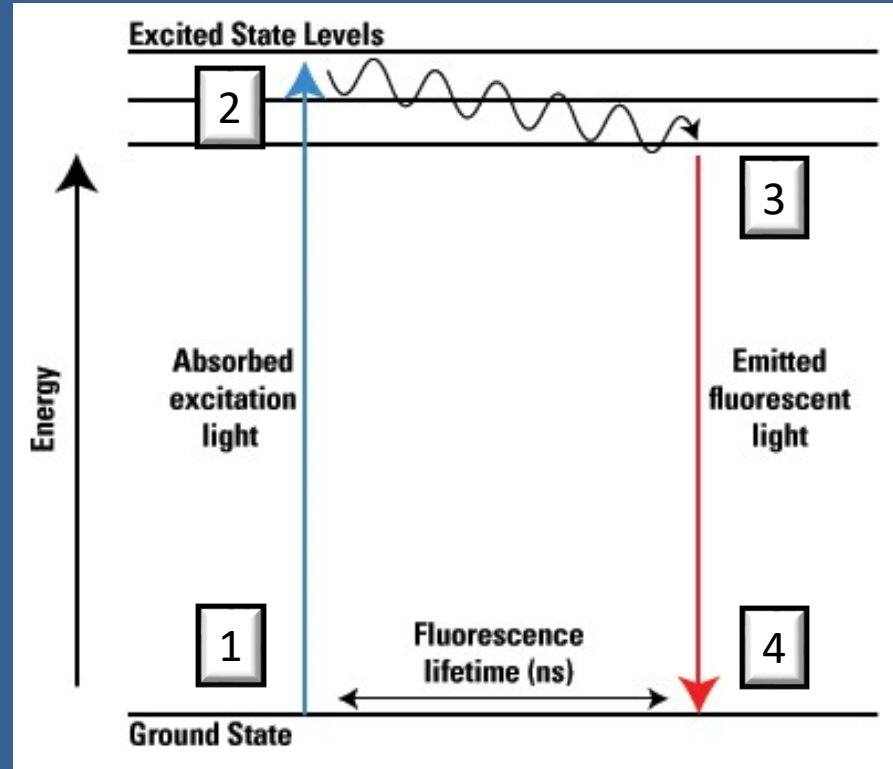
The Optical Power is a quality assurance indicator for the optical system.





# Fluorescence

Electrons in a fluorescent molecule (called a fluorophore) are normally in the ground state energy level (1). Incident UV radiation excites the electrons and they jump to an excited state (2). By a process called internal conversion the excited electrons lose some energy (squiggly line)(3). From this slightly reduced energy state the excited electron then releases a light photon (fluorescence) and returns to the ground state (4). This entire process occurs in about 1 nanosecond.



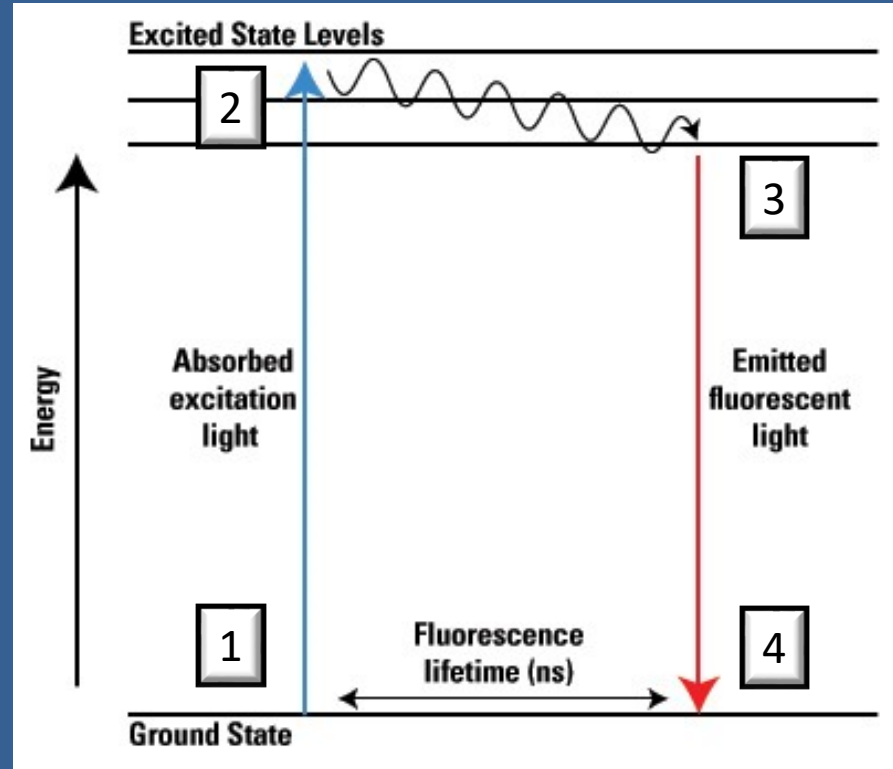
Jablonski Energy Diagram of Fluorescence

<https://www.thermofisher.com/>

# Fluorescence

It is important to note that the emitted light energy is always less than the absorbed energy. Lower energy means longer wavelength. Since the OIP UV excitation light source is 275 nm wavelength all fluorescent light will be at a lower energy and longer wavelength.

(After: Lakowicz, Joseph R. 1999. Principles of Fluorescence Spectroscopy, 2<sup>nd</sup> Ed. Kluwer Academic/Plenum Publishers, New York, NY.)



## Jablonski Energy Diagram of Fluorescence

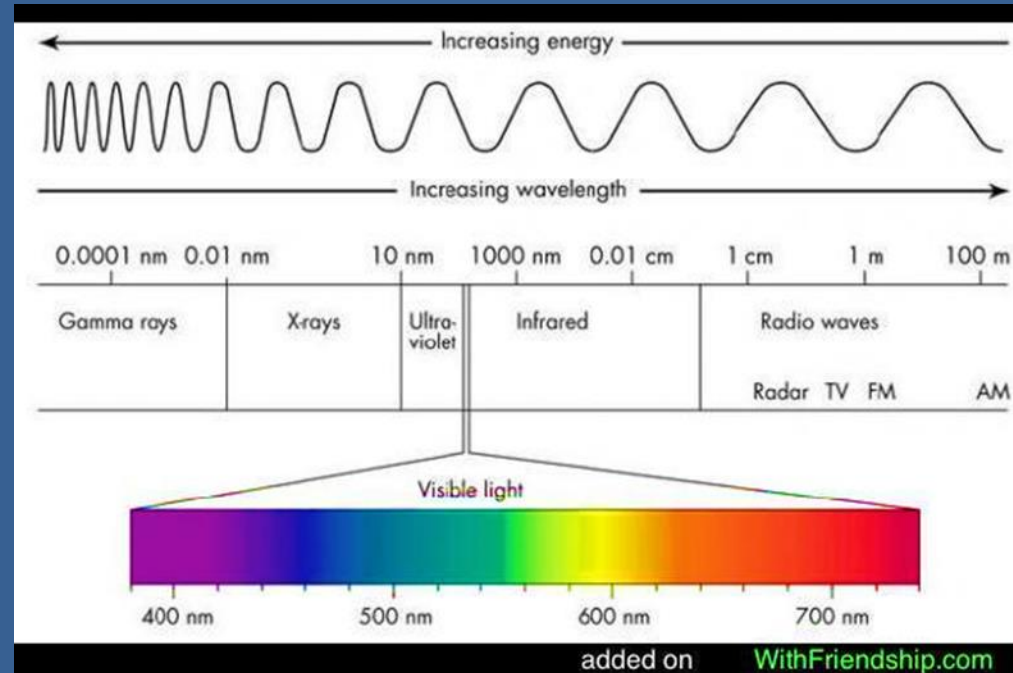
<https://www.thermofisher.com/>



# Light Wavelengths

The human eye sees only a very tiny portion of the entire electromagnetic (light) spectrum. Typically we see from about 380nm to 750nm wavelengths.

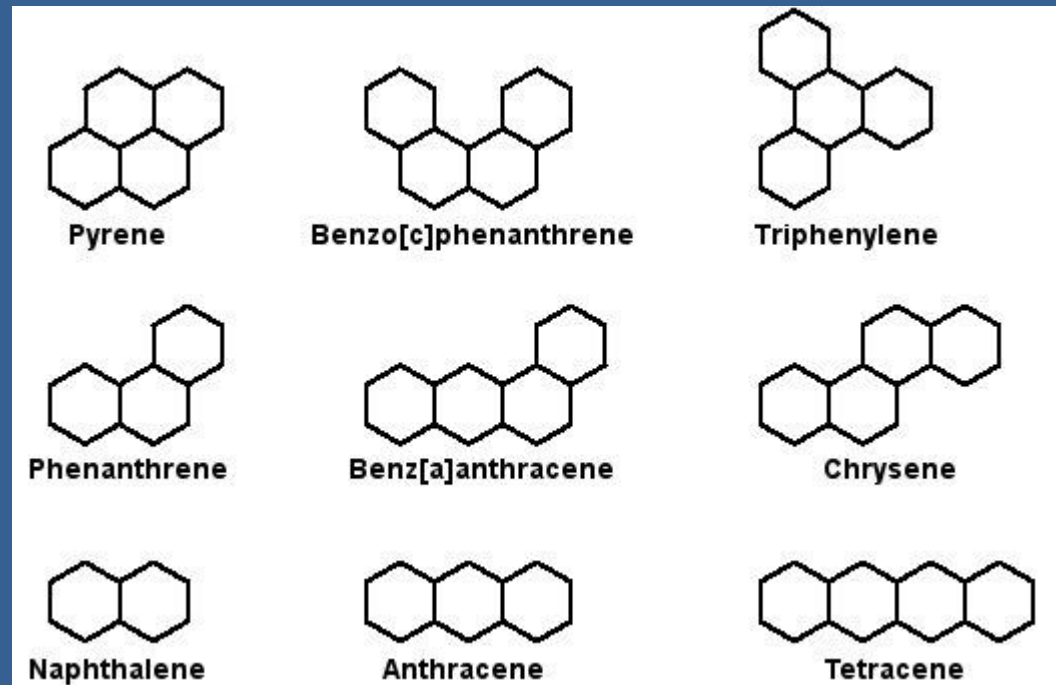
The OIP UV LED emits light at 275nm, so falls in the UV-C range. This is **damaging radiation** so don't look in the sapphire window when the UV LED is active.



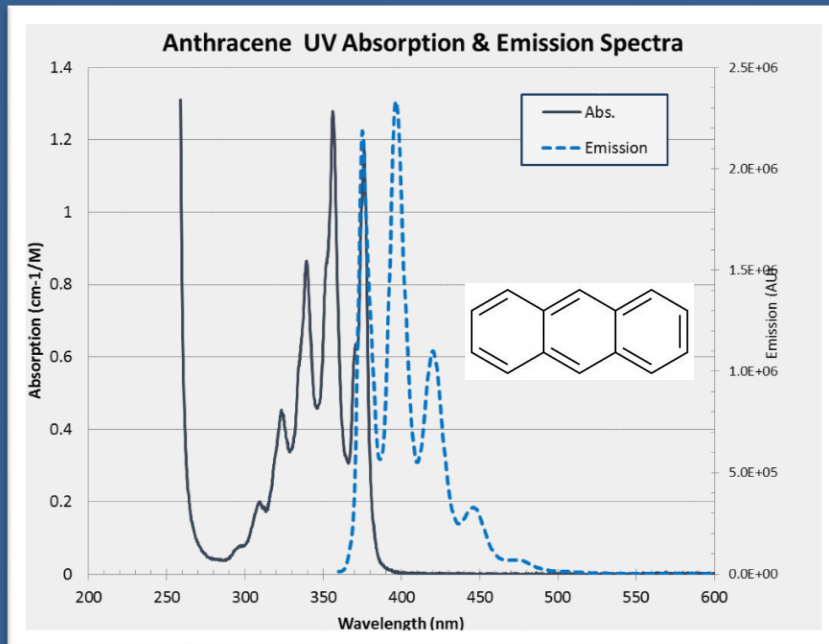
Most of the resultant fluorescent light from petroleum hydrocarbons falls in the upper end (shorter wavelength) of the visible spectrum. This fluorescent light is captured by the CMOS camera. Of course, if there is no fluorescence downhole the image is dark.

# Polycyclic Aromatic Hydrocarbon (PAH) Fluorescence

- Smaller PAH Compounds
  - Gas and Diesel
  - UV Detectable
- Larger PAH Compounds
  - Coal tar, Heavy Fuels
  - Not UV Detectable
- Chlorinated VOCs
  - Typically Not UV Detectable
- Dissolved Contaminants
  - Typically Not UV Detectable

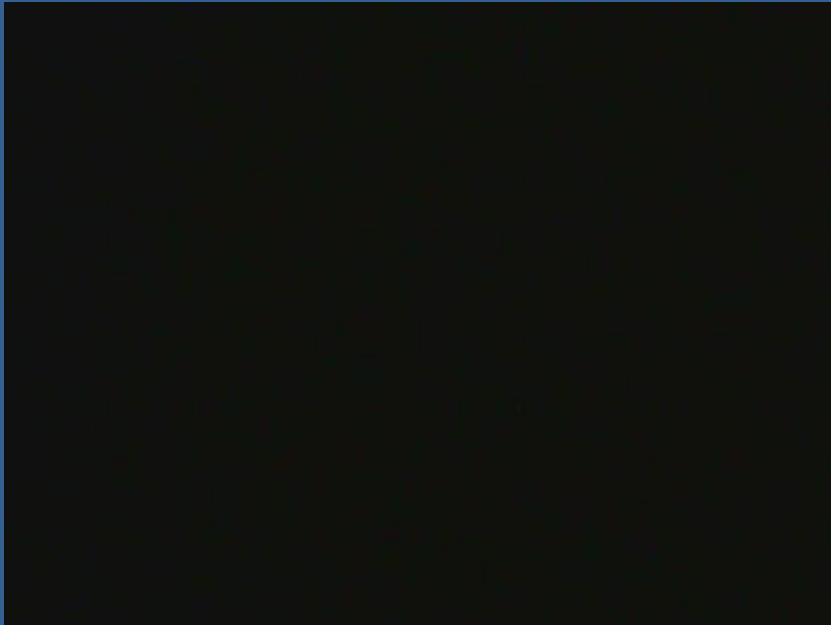


# Polycyclic Aromatic Hydrocarbon (PAH) Fluorescence

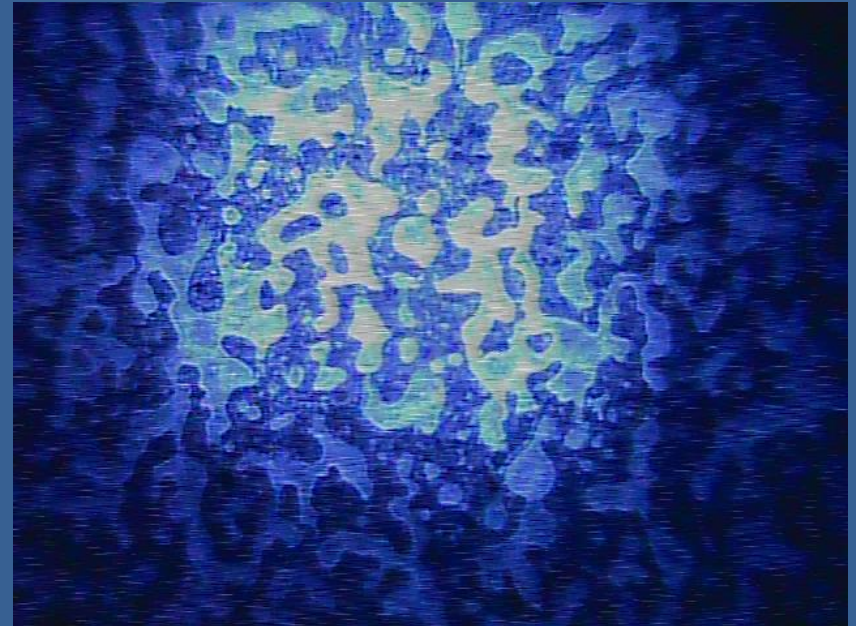


This is a plot of the absorption and emission spectra for Anthracene. The spectra display a mirror-like symmetry for some molecules, as seen here. Note that most of the absorption range is in the UV while most of the emitted light (fluorescence) is in the visible range for anthracene. Again, it is important to note that the wavelengths of light absorbed are at shorter wavelength (higher energy) than the wavelengths emitted.

# OIP UV Images



Typical OIP background image where no LNAPL is present resulting in a dark image

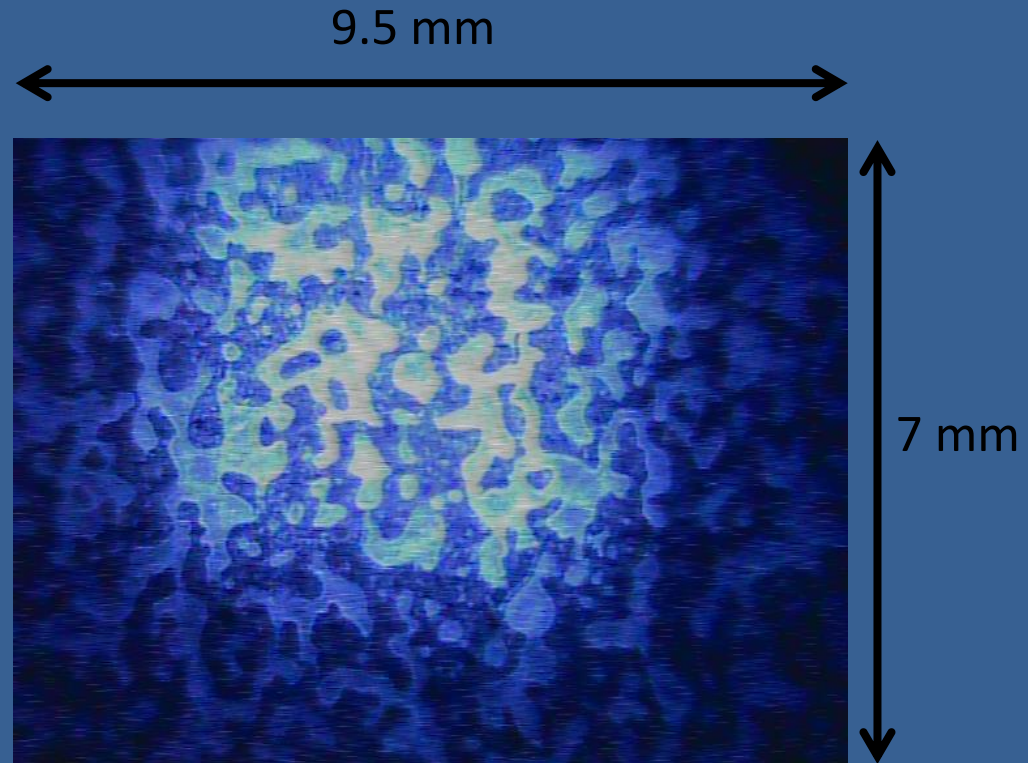


Typical OIP image of LNAPL fluorescence



# OIP UV Image

- Image size: 9.5 x 7 mm
- Resolution: 640x480 pixels
- Capture rate: 30 fps
- Save rate: 1 image for each 0.05 ft. (15mm)



Typical OIP image of  
LNAPL fluorescence

# OIP Stills and Visible Images



Fluorescence images of fuel globules in soil

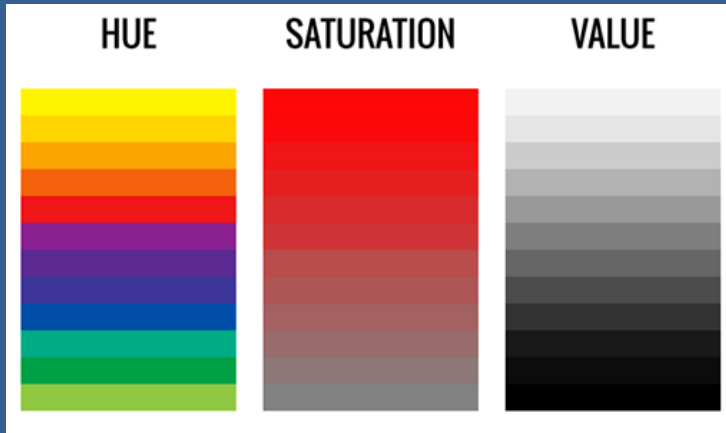


Visible image of the same soil  
Sand matrix.

- UV and Visible still images can be captured at any point during the log but are automatically captured at every rod addition to the tool string
- Still images have greater clarity and sharpness than images captured while the probe is moving (e.g. while logging).
- Visible still images can be helpful in assessing soil textures

# Image Analysis

## HSV Color Space

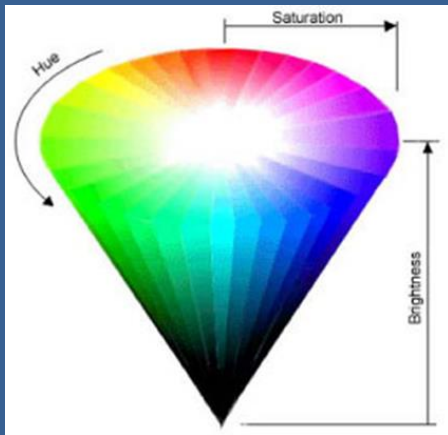


The images are analyzed to determine the presence and % area of fluorescence. The HSV, or HSB, model describes colors in terms of hue, saturation, and value (brightness). HSV is used to define the color in each of the pixels in the captured images.

Hue corresponds to the color of the pixel in the image.

Saturation corresponds to the amount of color in the pixel. Saturation ranges from full hue to gray.

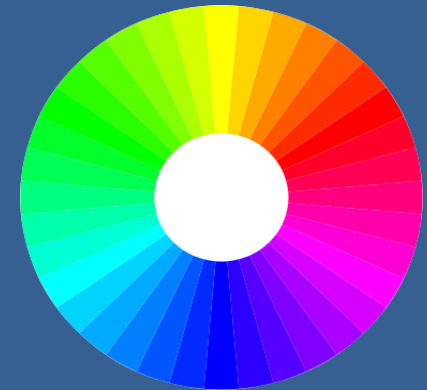
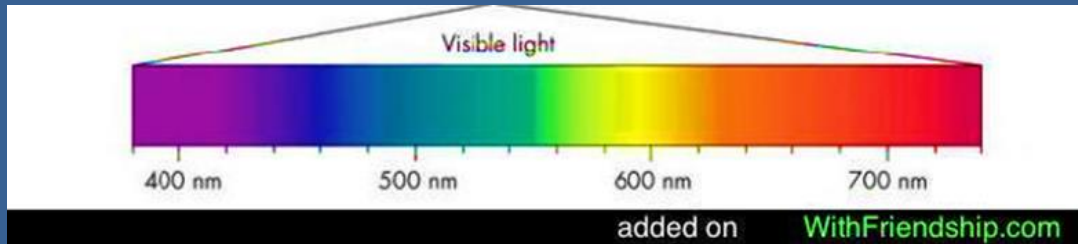
Value corresponds to the brightness or intensity of the pixel in the image.



Color defined by Hue,  
Saturation and Value (HSV)

# Hue and the Visible Spectrum

Hue can be directly related to Visible Light and wavelength



Hue Color Wheel

Advantages of using HSV is that hue defines the color of the pixels in the image independent of how much color is present and how bright the pixel is. Hue can also be directly related to wavelength in the visible spectrum.



# Image Analysis

## (Patent Pending)

- Percent Area
  - Pixel by pixel analysis
- Filter Parameters
  - Hue, Saturation, Value/Brightness
- Multi Stage Filter
  - First filter: High levels of saturation/color
  - Second filter: High level brightness
  - The second filter is conditionally restricted by the first filter

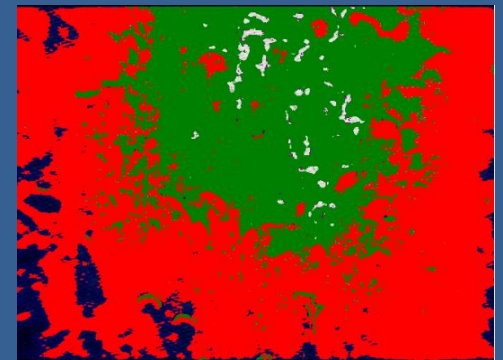
Original Image



Filter 1: 57.5%

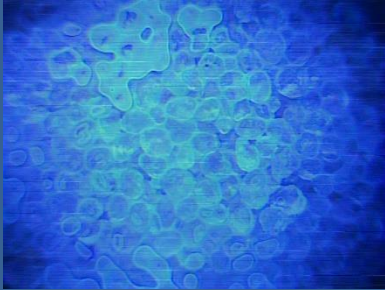


Filter 2: 33.2%

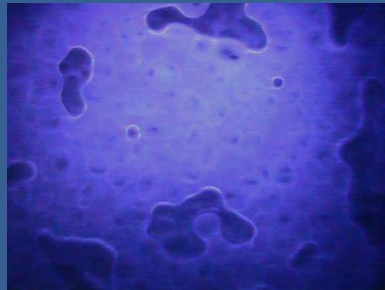


Filter 1 + Filter 2 = Total : 90.7%

# Color Analysis

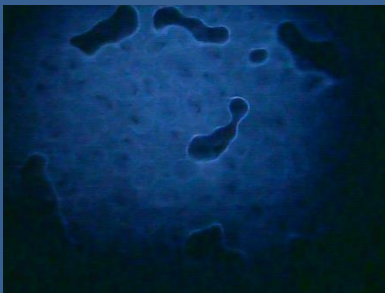


Motor Oil SAE 30

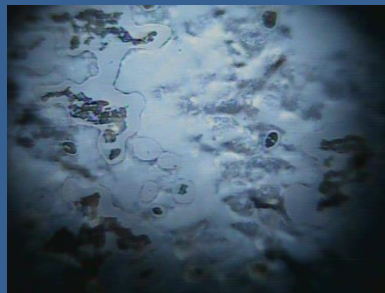


Diesel

Here are some of the pure petroleum products and their fluorescent colors under the OIP UV LED. As you can see these are all in the “blue” range with slightly different hues.



Unleaded Gasoline



Crude Oil

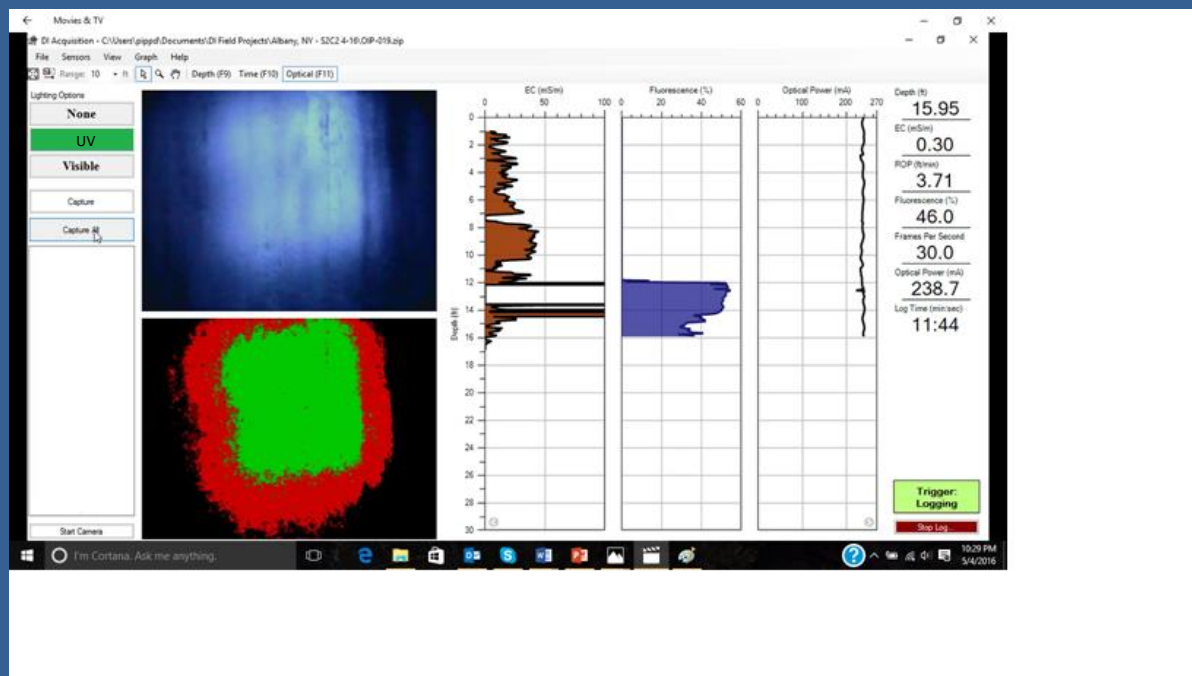
Crude oil is a blue green fluorescence with low saturation.

If you visually distinguish differences in Hue (similar to above) you may wish to target sampling those different depth intervals/locations to determine if different products are present.

At this point in the OIP system/software development an indication of fuel type based on the observed fluorescence is not provided.



# OIP DI Acquisition Software



OIP Logging Requires:  
DI Acquisition 3.0  
or greater

Image on the upper left is the live OIP camera feed, image on the lower left is the analysis of the same image.

The red in the analyzed image represents the first stage filter and the green represents the second stage.

Because images are saved every 15mm the OIP log files are typically 200+mB



# Recommended Field Operation

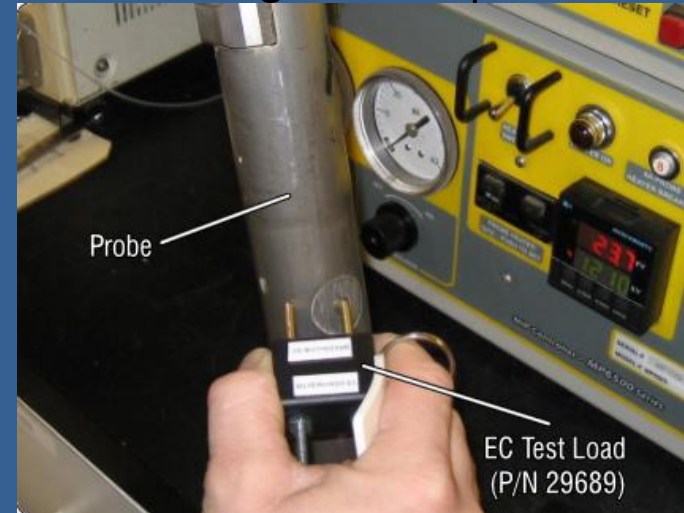
- GH60 Series Hammers (or smaller)
- Rate of Push: 2-4 ft. per min (1-2 cm per sec)
- Use of a Drive Cushion
- Pre-Probe First 2 ft. (.6m)



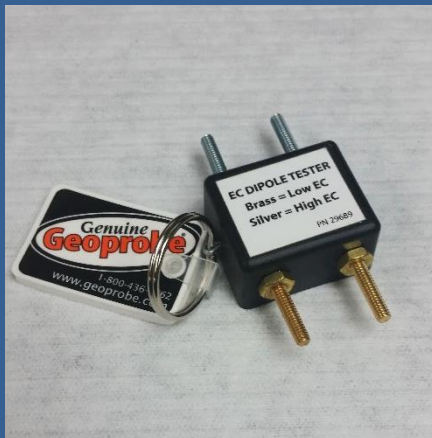
# Quality Assurance (QA) Testing

- QA Tests are performed before and after each log
- EC Dipole Test
- Optical Test

Testing the EC Dipole



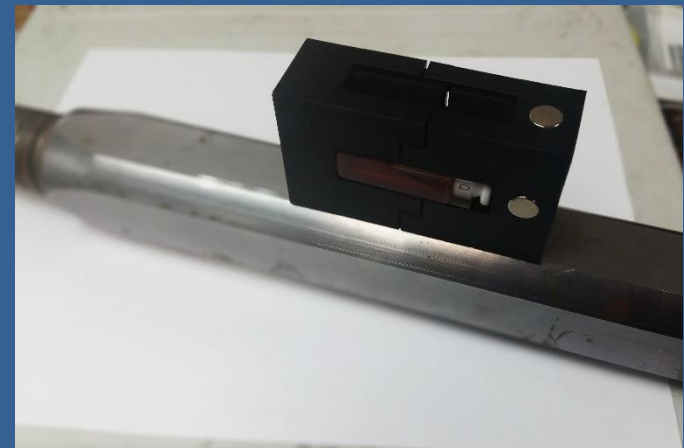
EC Test Load



OIP Cuvette Holder



Testing the Optical Components and System Response

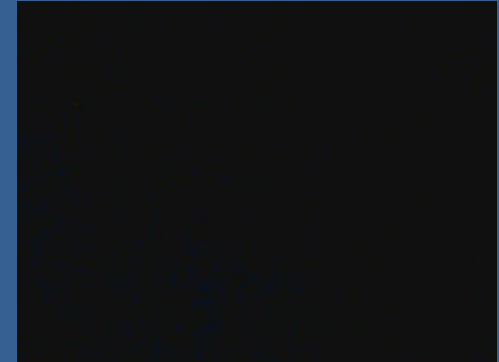


# Optical QA Test

- Image Assessment
  - Visible Target
- Background Assessment
  - Black Box
- Fluorescence Assessment
  - Diesel
  - Motor Oil



Visible Target



Black Box



Diesel Fuel Cuvette



Motor Oil Cuvette

# OIP Field Operation



The OIP probe is connected to the trunkline.

The trunkline is pre-strung through the probe rods and is connected to the OIP Interface box before logging is started.

The OIP interface connects to the FI6000 which is in turn connected to the laptop computer with the Acquisition software.



# OIP Field Operation



As the probe is advanced to depth rods are added to the string.

Still images of both UV and visible light are captured each time the probe advancement is stopped to add the next probe rod.





# OIP Field Operation



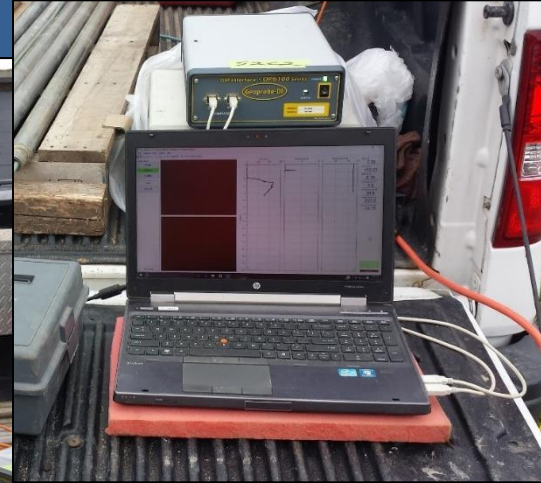
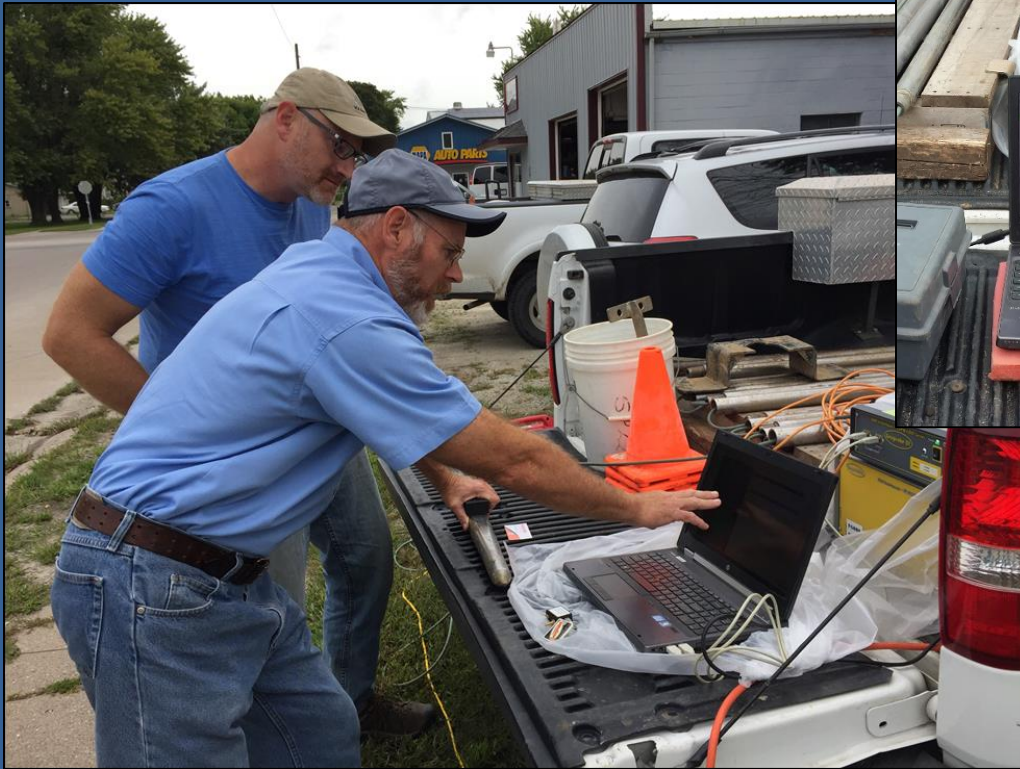
Advancing the OIP probe under the hammer of a 6712 unit using a drive cushion.

A string potentiometer is attached to the probe mast and is used to track probe depth as the tool string is advanced.

String Pot

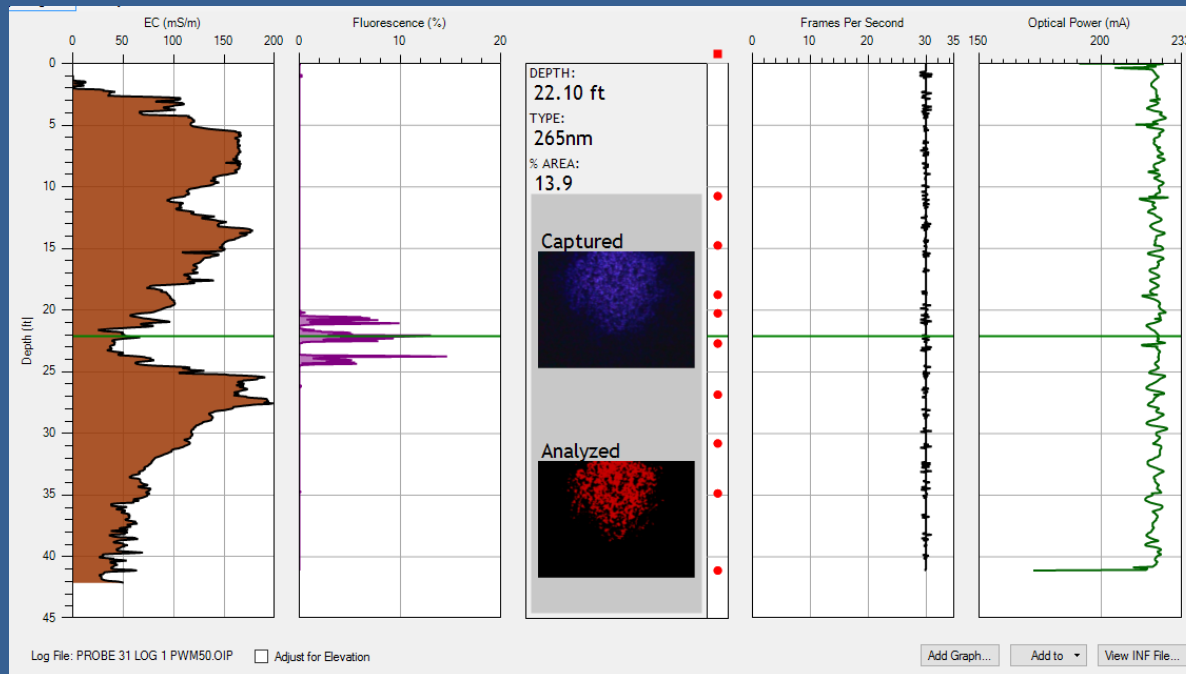


# OIP Field Operation



Viewing the OIP logs as they are captured in the field allows the project manager to see what is going on in the subsurface and make decisions about placement of additional OIP logs or the locations and depths for confirmation sampling.

# OIP DI Viewer Software



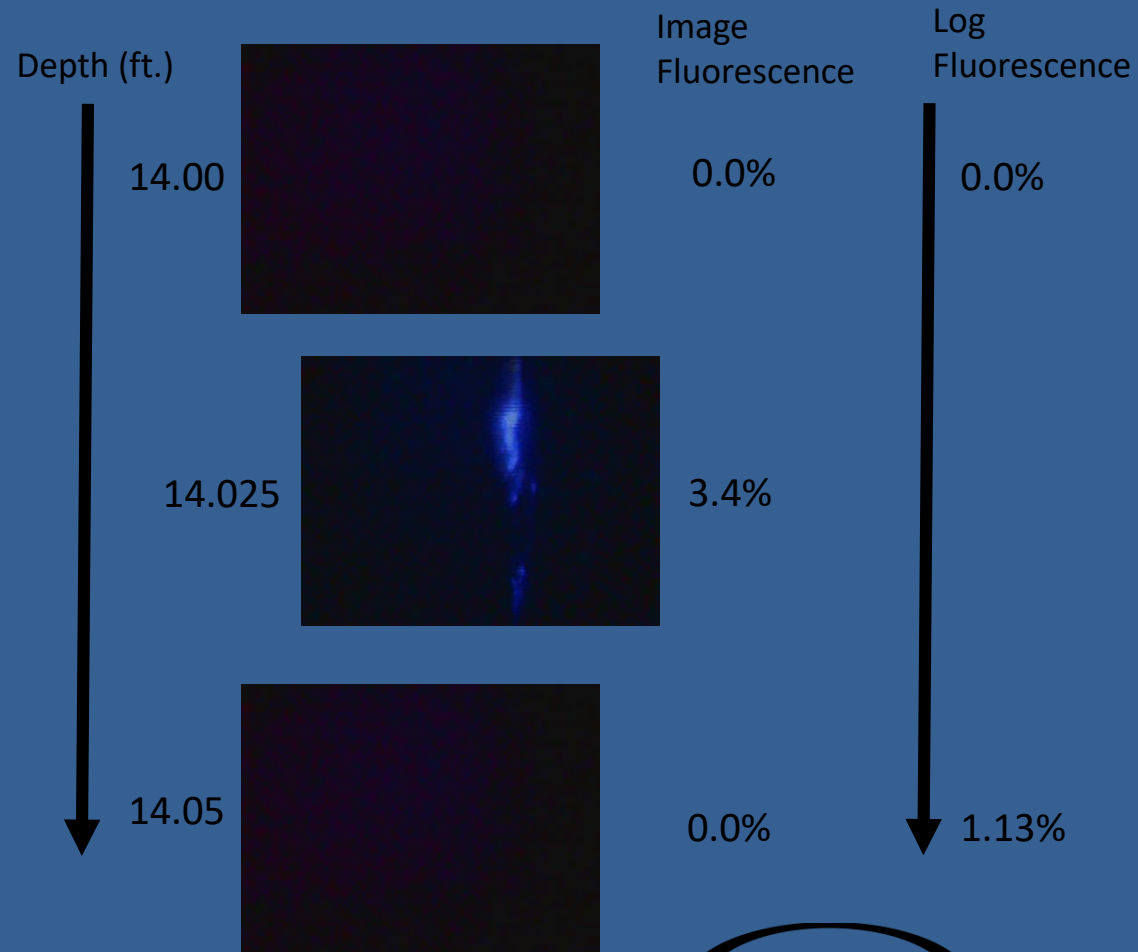
- Review logs
- Requires DI Viewer 3.0 or greater
- Image display of captured stills every 0.05 ft. (15mm)
- Creating cross sections and overlays
- Watch video at:

<http://geoprobe.com/videos/viewing-oip-log-div>



# Fluorescence Averaging

- Image Fluorescence: % area of fluorescence identified in a single image
- Log Fluorescence: Average % area fluorescence of all the images analyzed in a 0.05ft (15mm) increment



# OIP Data Examples: Gasoline Fluorescence

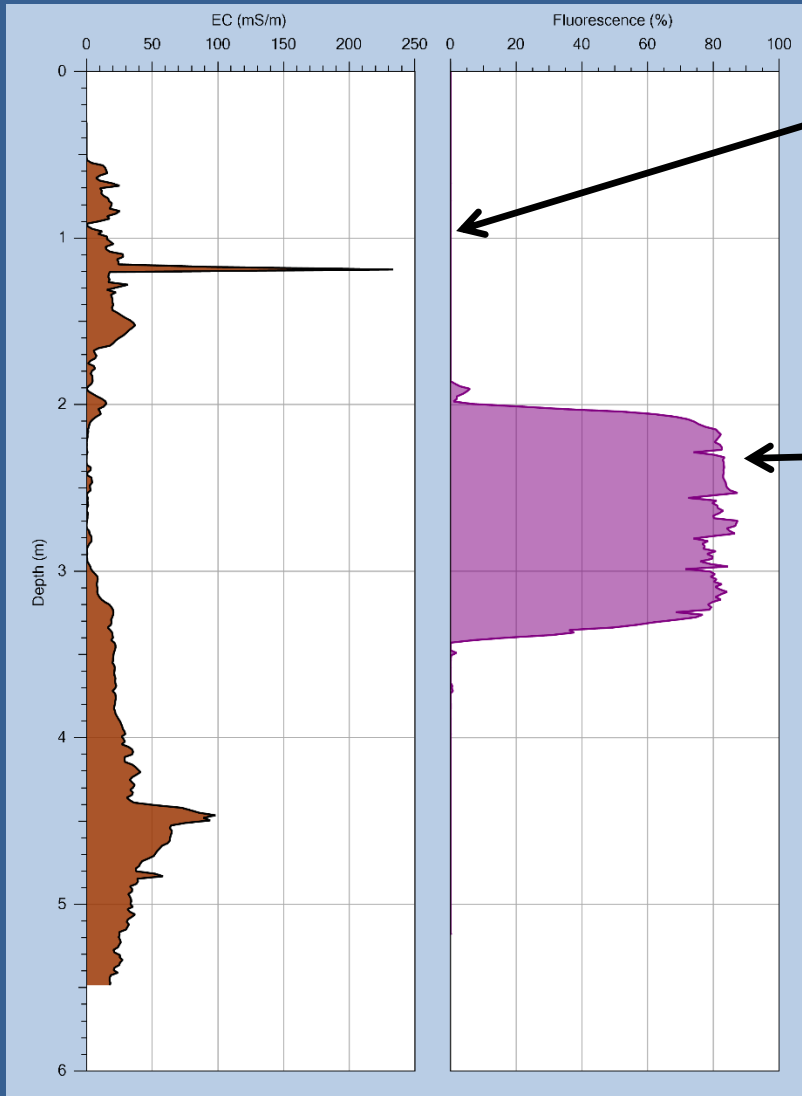


Image at 1.0m  
is essentially  
non-detect

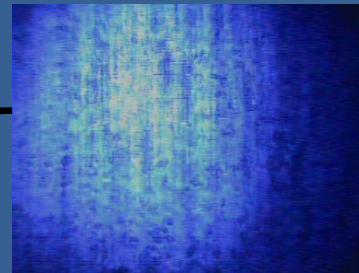


Image at 2.2m  
displays significant  
fluorescence



# OIP Data Examples: Gasoline Fluorescence

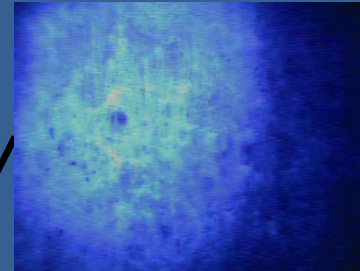
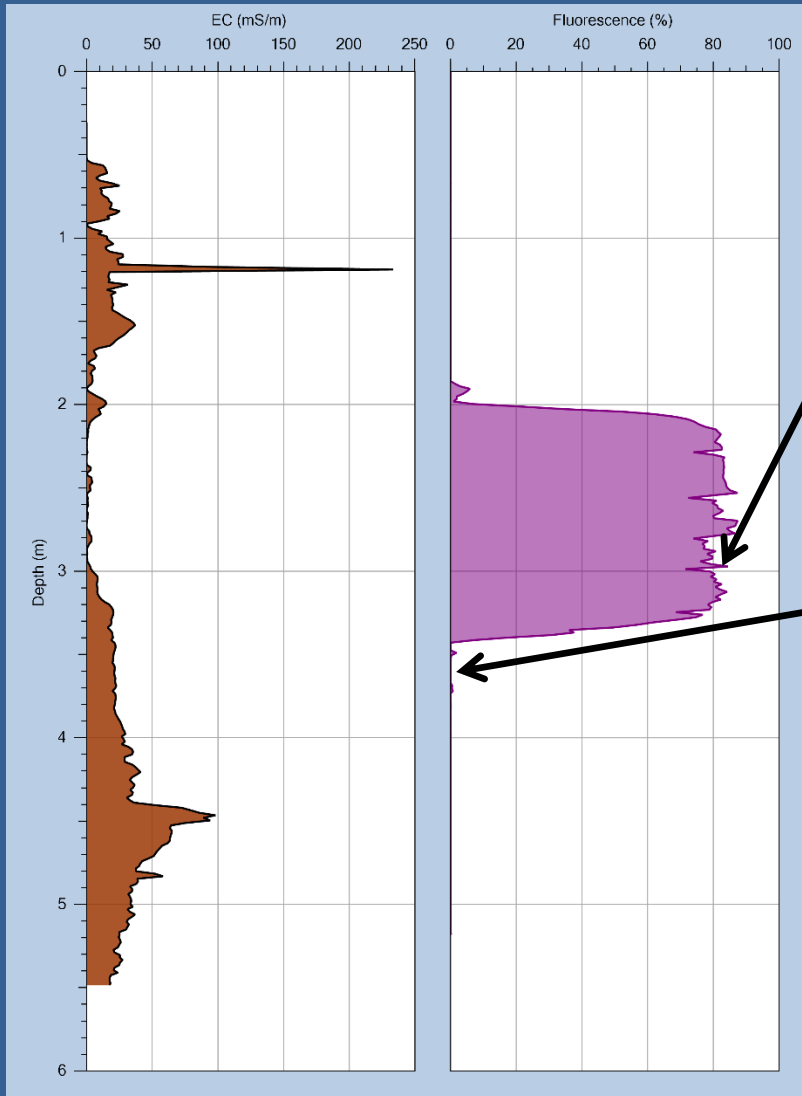


Image at  
3.0m



Image at  
3.5m

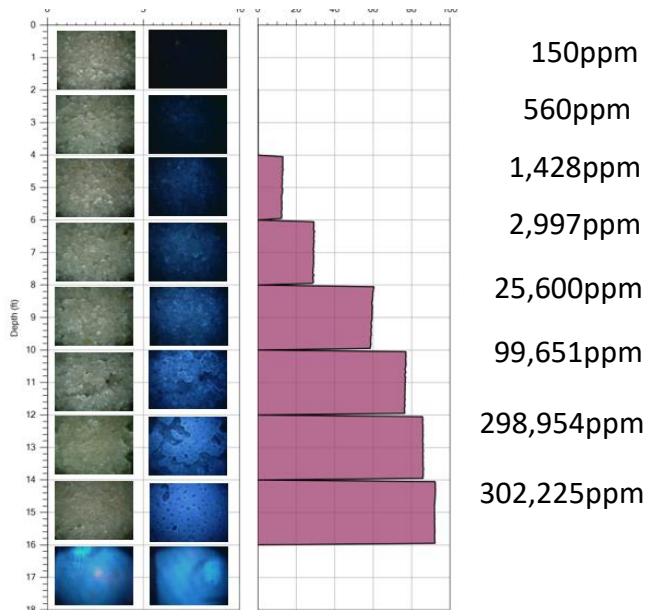
Good fluorescence is observed at 3.0m.

The image at 3.5m is essentially non-detect showing clear definition of the bottom of the LNAPL body.



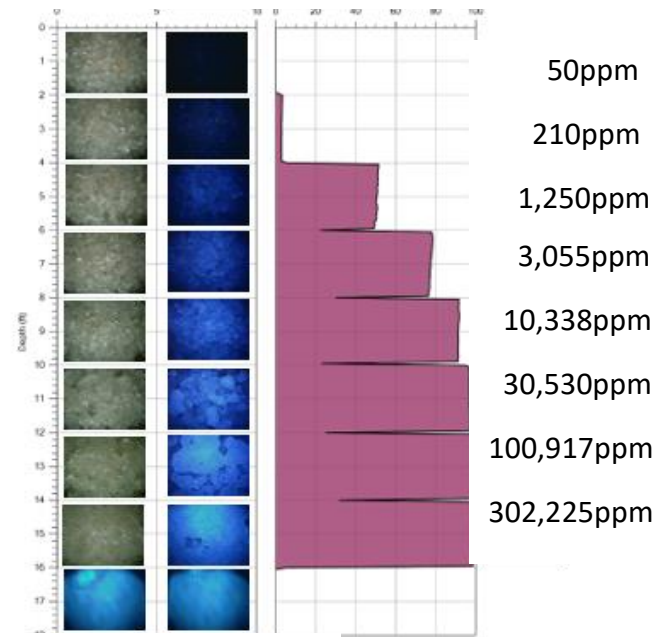
# OIP Fuel Fluorescence

OIP Fluorescence Test : Unleaded Gasoline  
10-20 mesh silica sand, 10% water content



Diesel Fuel  
Pre-log: 90% Post Log: 85%

OIP Fluorescence Test: Diesel Fuel  
10-20 mesh silica sand, 10% water content

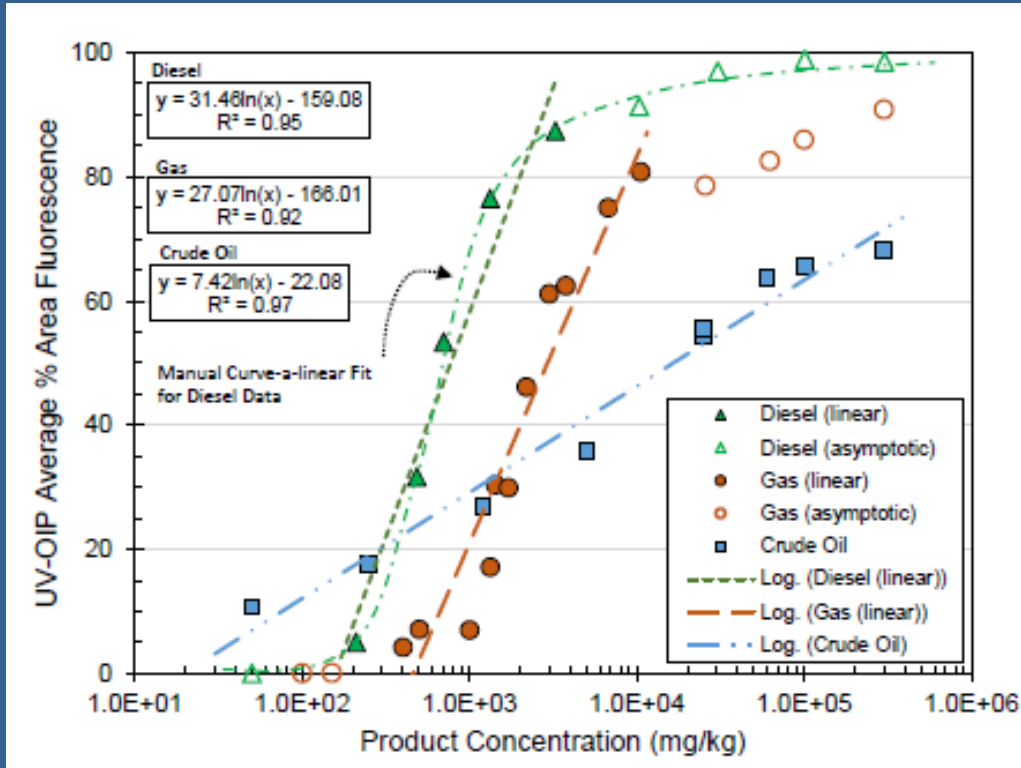


Diesel Fuel  
Pre-log: 92% Post Log: 91%

In these bench tests, fresh fuel was manually mixed with the clean sand and water then placed over the OIP sapphire window for testing. As expected, as the amount of fuel increases in the sample the amount of fluorescence increases.

This is not a calibration of the OIP probe or system.

# OIP Fuel Fluorescence



Bench tests of gasoline, diesel and crude oil in silica sand with +10% moisture content.

Fluorescence response is the % of the image area or the % of pixels in the image that exhibit fluorescence.

Refined fuels show a log-linear response over approximately an order of magnitude concentration range. Two to five sample replicates averaged for each plotted data point. Fluorescence response in complex and heterogeneous natural soils will vary.

# Field Site: Former Truck Stop Brooklyn, Michigan



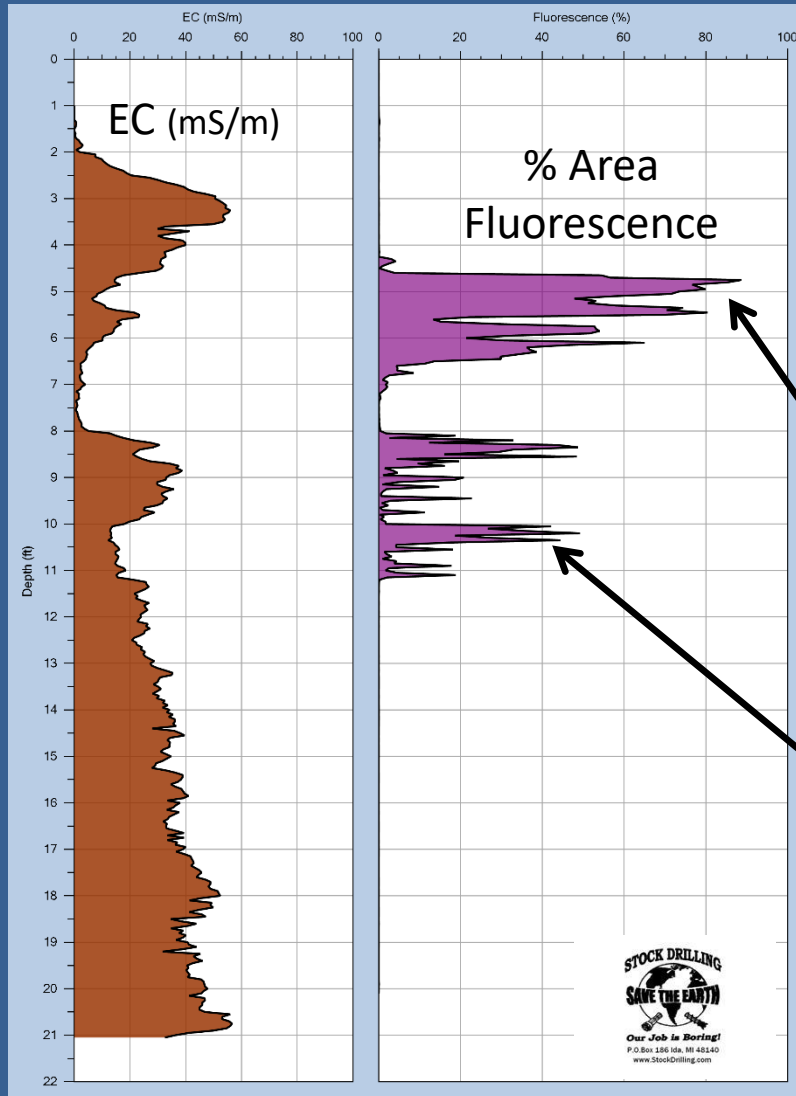
Geoprobe worked with Stock Drilling, Sheryl Doxtader at Michigan DEQ and Mark Peterson at Compliance, Inc to conduct a side-by-side comparison of the OIP system with the UVOST system. Performed February, 2016.

The primary contaminant at this site was Gasoline.



# Field Site: Brooklyn, Michigan

## OIP Log



This is OIP log GL-19 from the Michigan site.

The images from 5.0ft and 10.20ft display significant fluorescence.

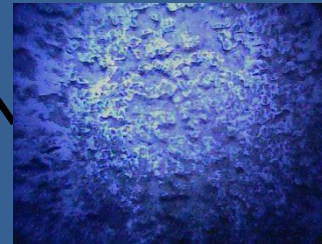


Image at  
5.0ft

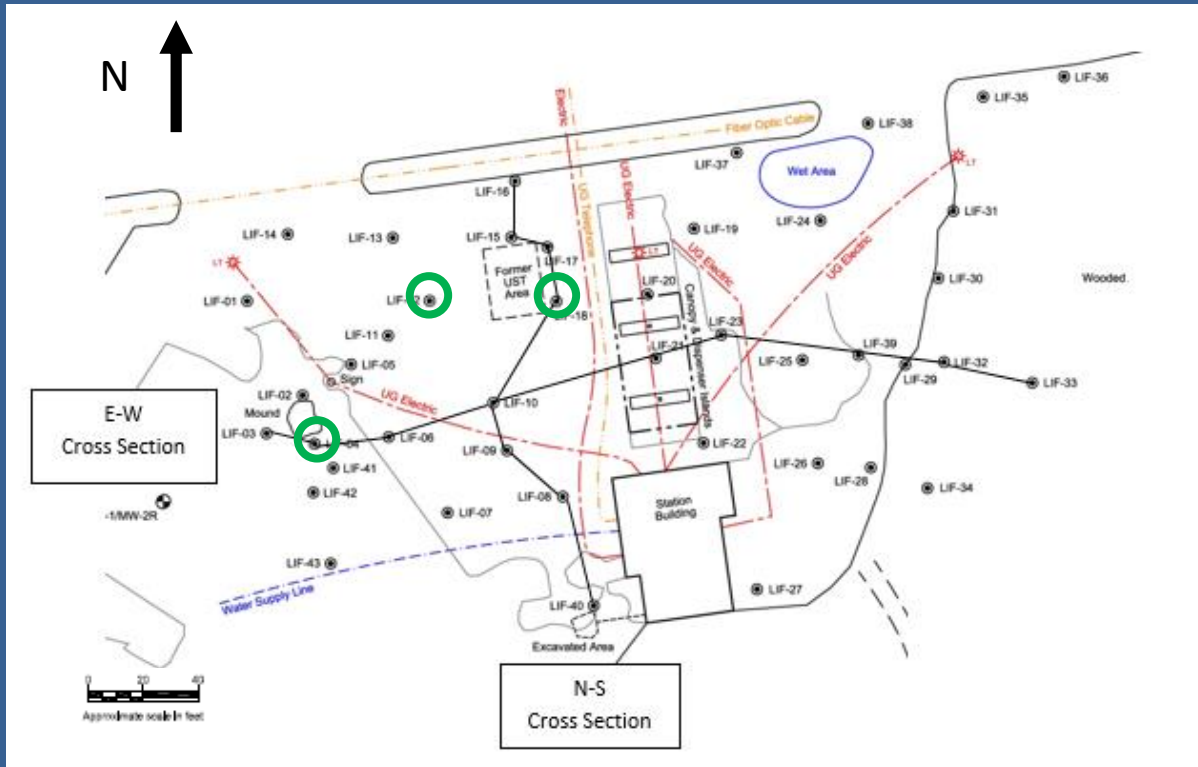


Image at  
10.20ft



# Field Site: Brooklyn, Michigan

## Site Map



Site map showing log locations and cross section lines.

Three of the paired OIP and UVOST logs will be compared in detail below. These log locations are circled in green.

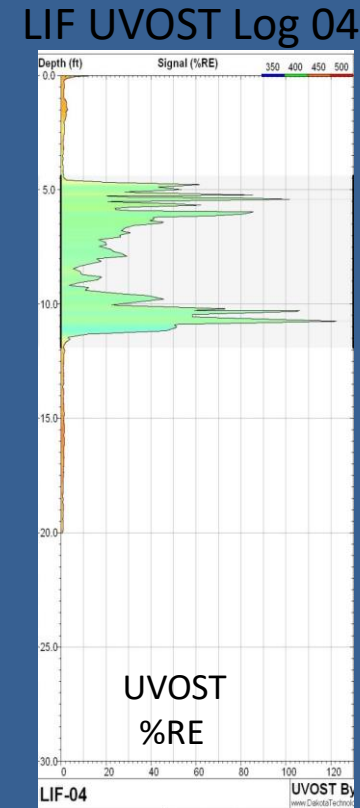
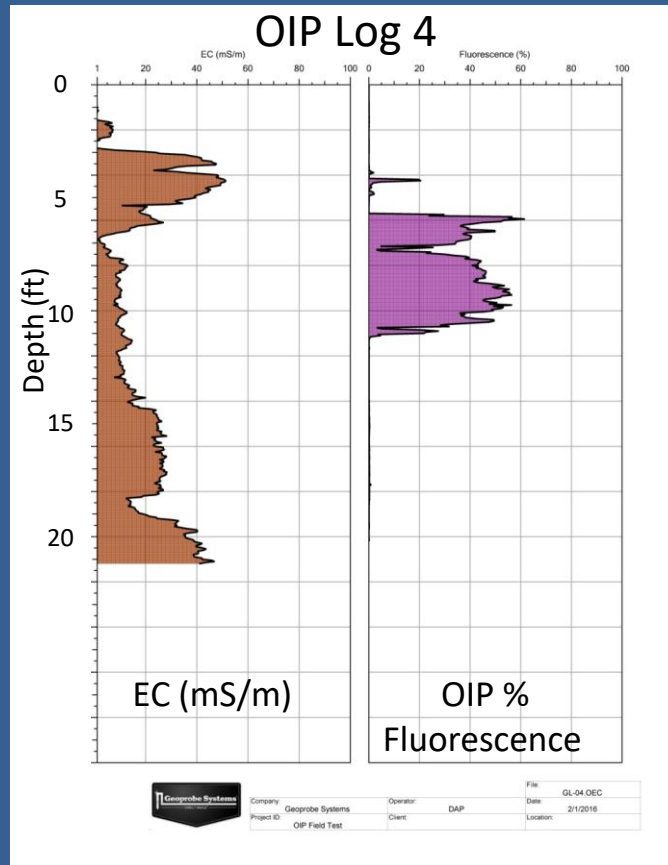
This will be followed by review of the paired logs from the cross sections shown on the above map.

Geoprobe worked with Stock Drilling to run 37 OIP logs adjacent to LIF UVOST logs that were just completed. The co-located OIP logs were all run about 3ft (1m) from the LIF UVOST logs.



# Field Site Data

## OIP-EC to UVOST Comparison

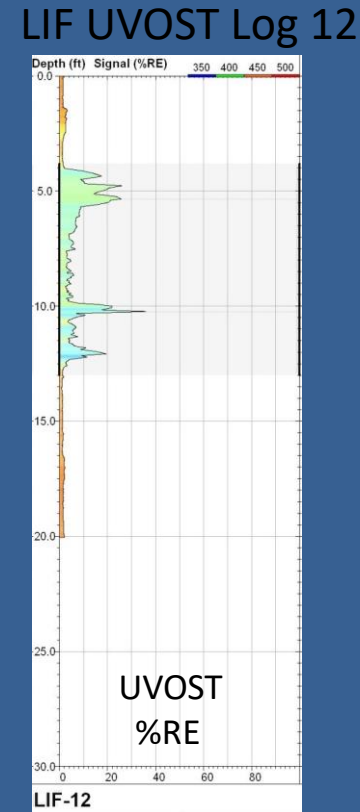
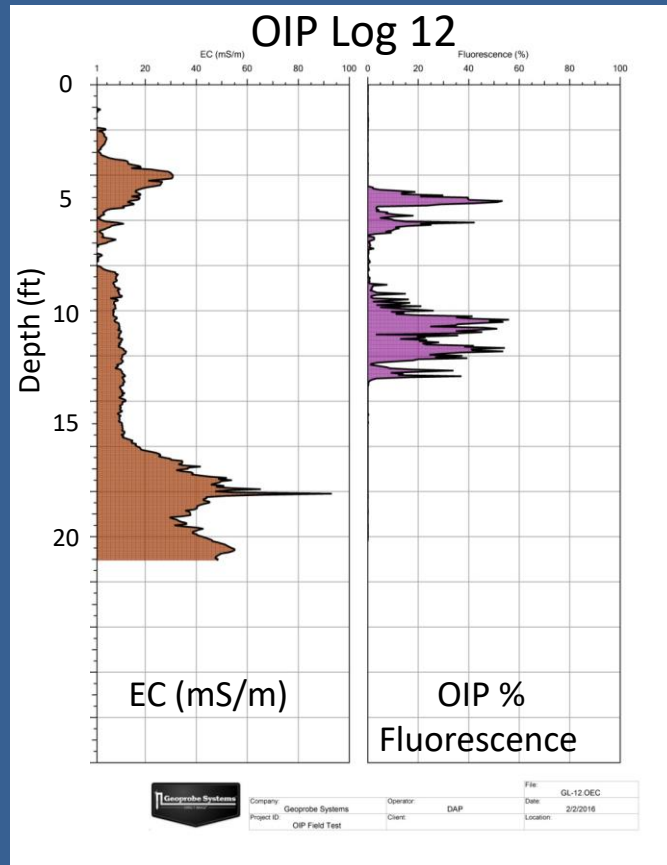


The vertical distribution of fluorescence in both the OIP and UVOST logs are similar. The EC log indicates the LNAPL is present primarily in sandy materials at this location (lower EC).



# Field Site Data

## OIP-EC to UVOST Comparison



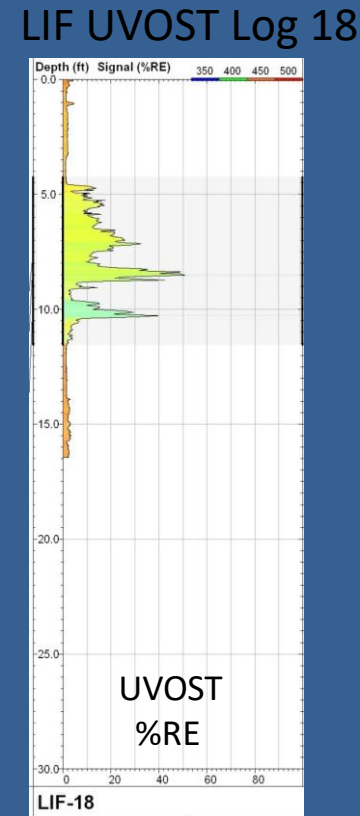
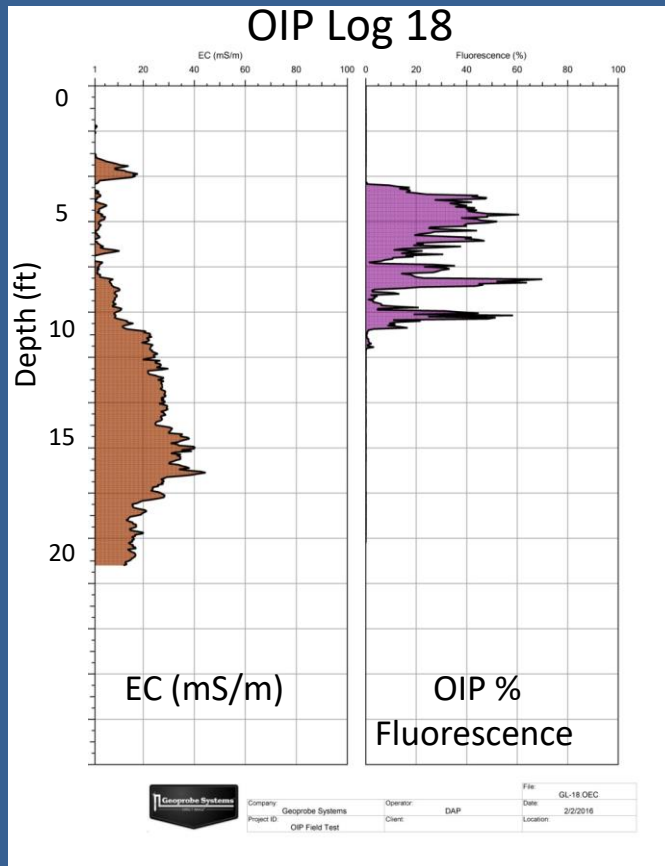
The log 12 comparison also shows very similar vertical distribution of fluorescence in both the OIP and UVOST technologies.





# Field Site Data

## OIP-EC to UVOST Comparison



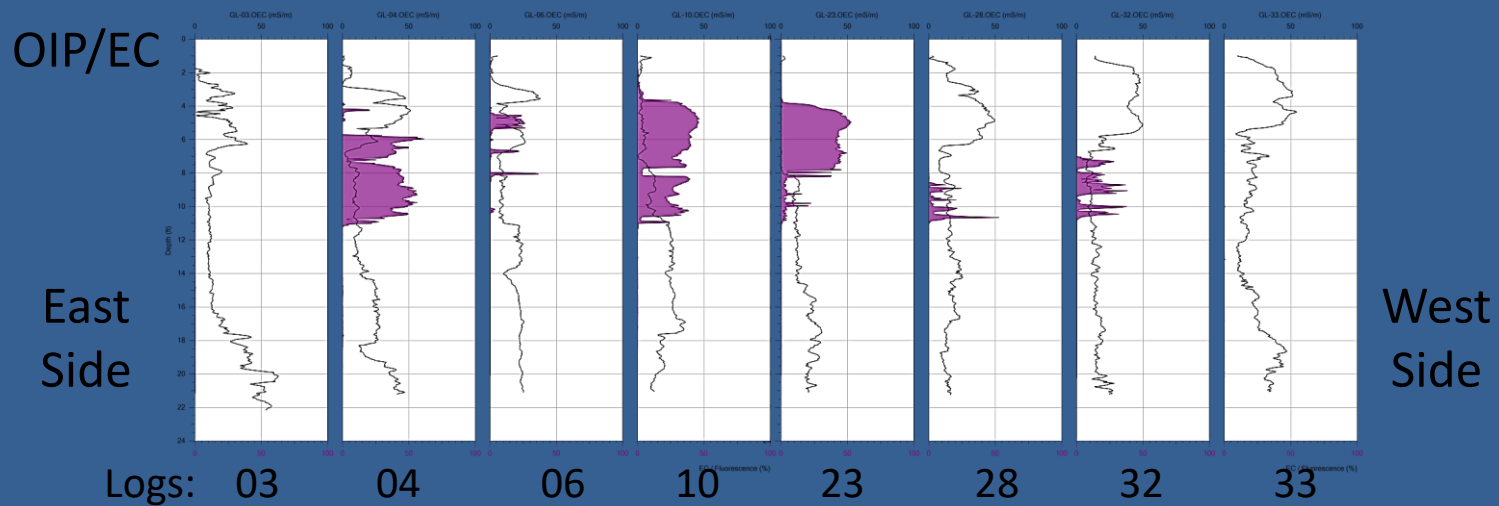
Both logs again display similar vertical distribution of the LNAPL.

All EC log shows that the LNAPL generally occurs in lower EC zones of the formation, so coarser grained materials.

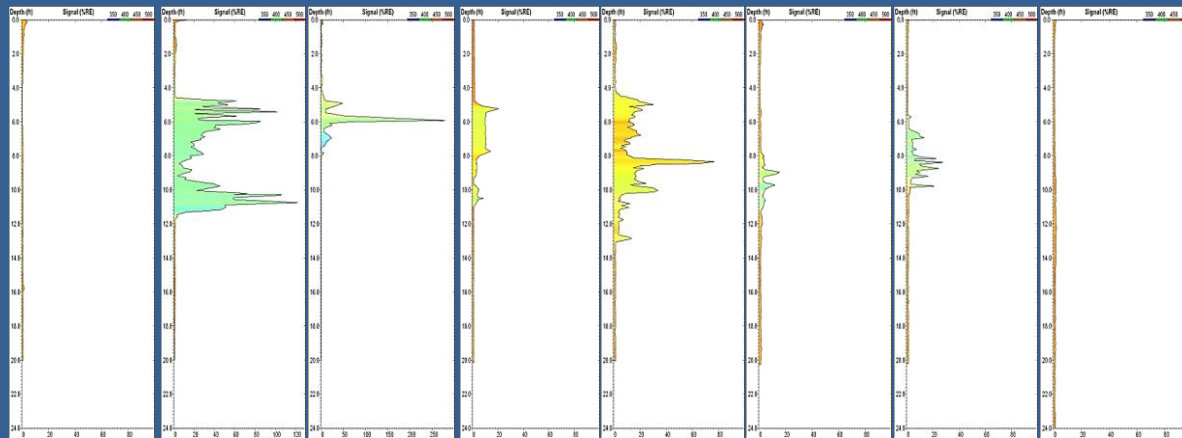


# Field Site Data

## OIP/EC to UVOST Comparison



LIF  
UVOST



Both technologies display similar vertical and horizontal contaminant distribution.

**Note:** Logs are displayed with equal spacing in the simplified cross sections, not equally spaced on the ground: not to scale.

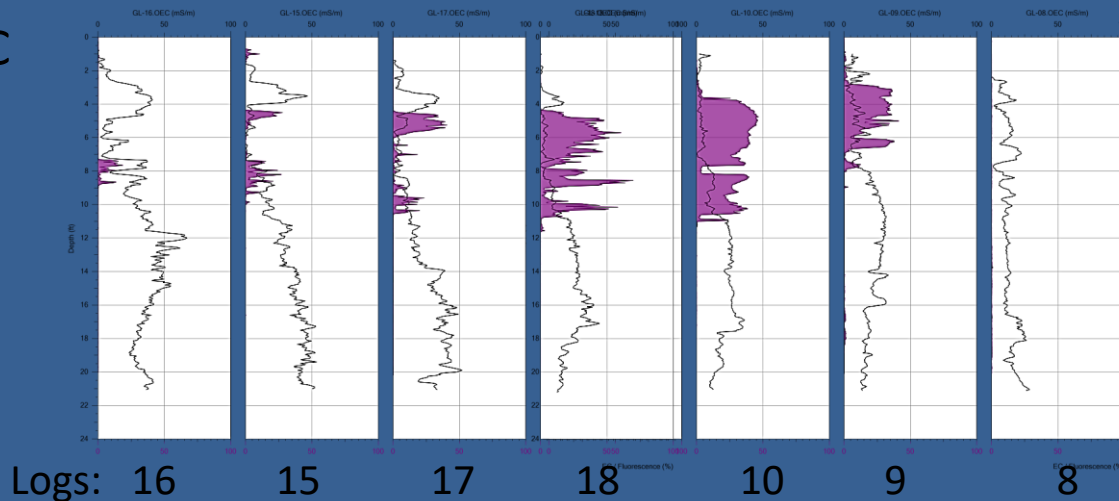
# Field Site Data

## OIP/EC to UVOST Comparison

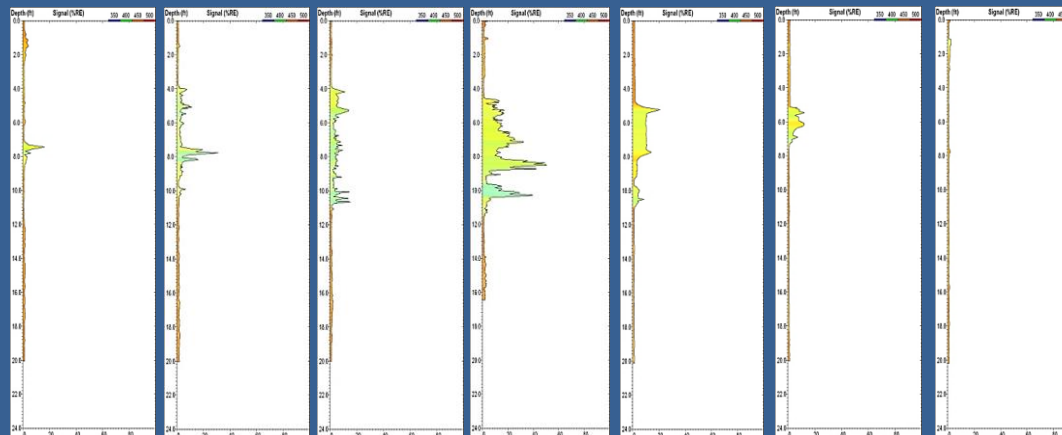
OIP/EC

North  
Side

South  
Side



LIF  
UVOST



Where UVOST in non-detect the OIP is non-detect. Where there is fuel to fluoresce both technologies detect it and with similar profiles.

# Field Site: Former Service Station Grand Junction, CO



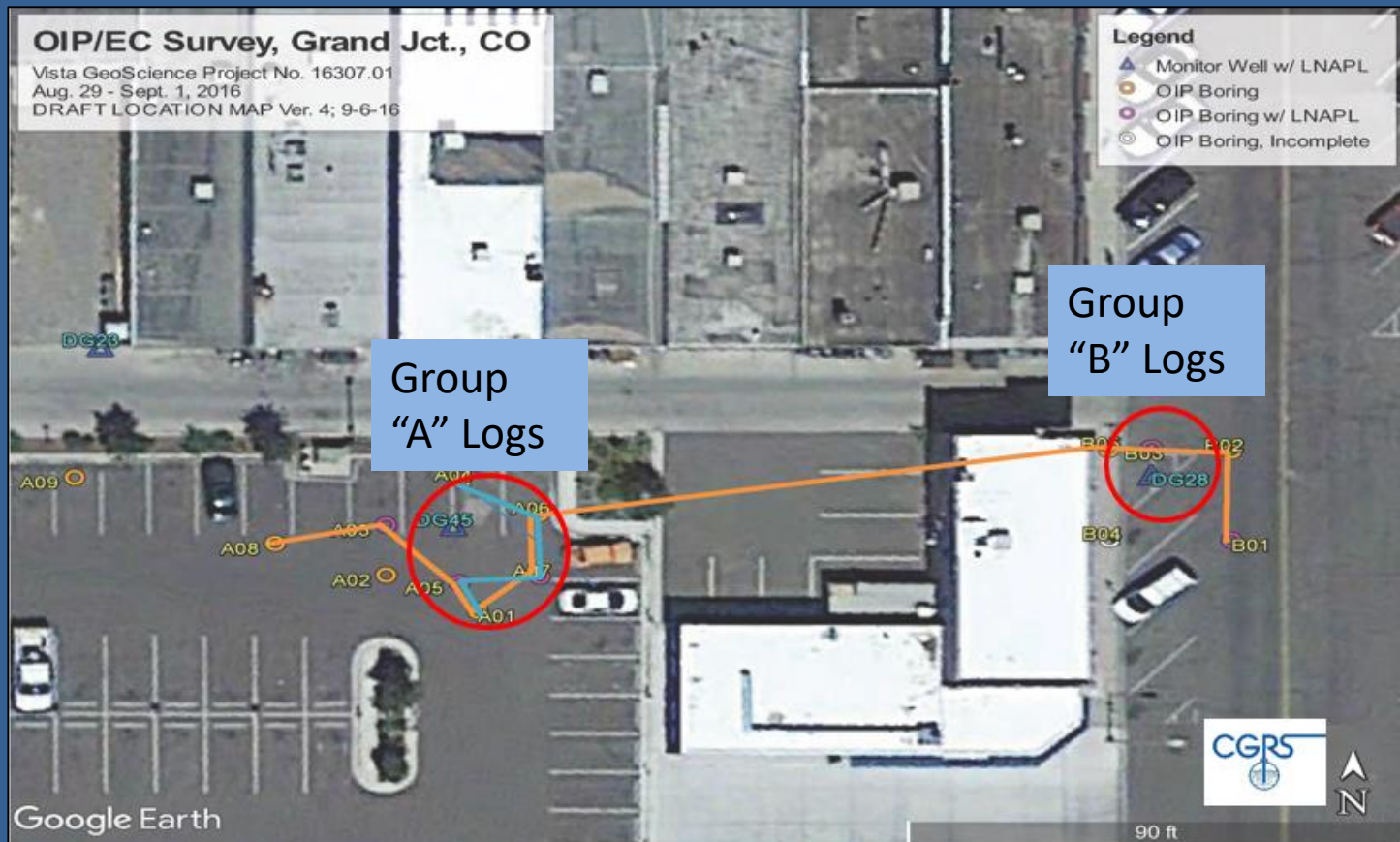
Worked with Vista GeoScience on this project







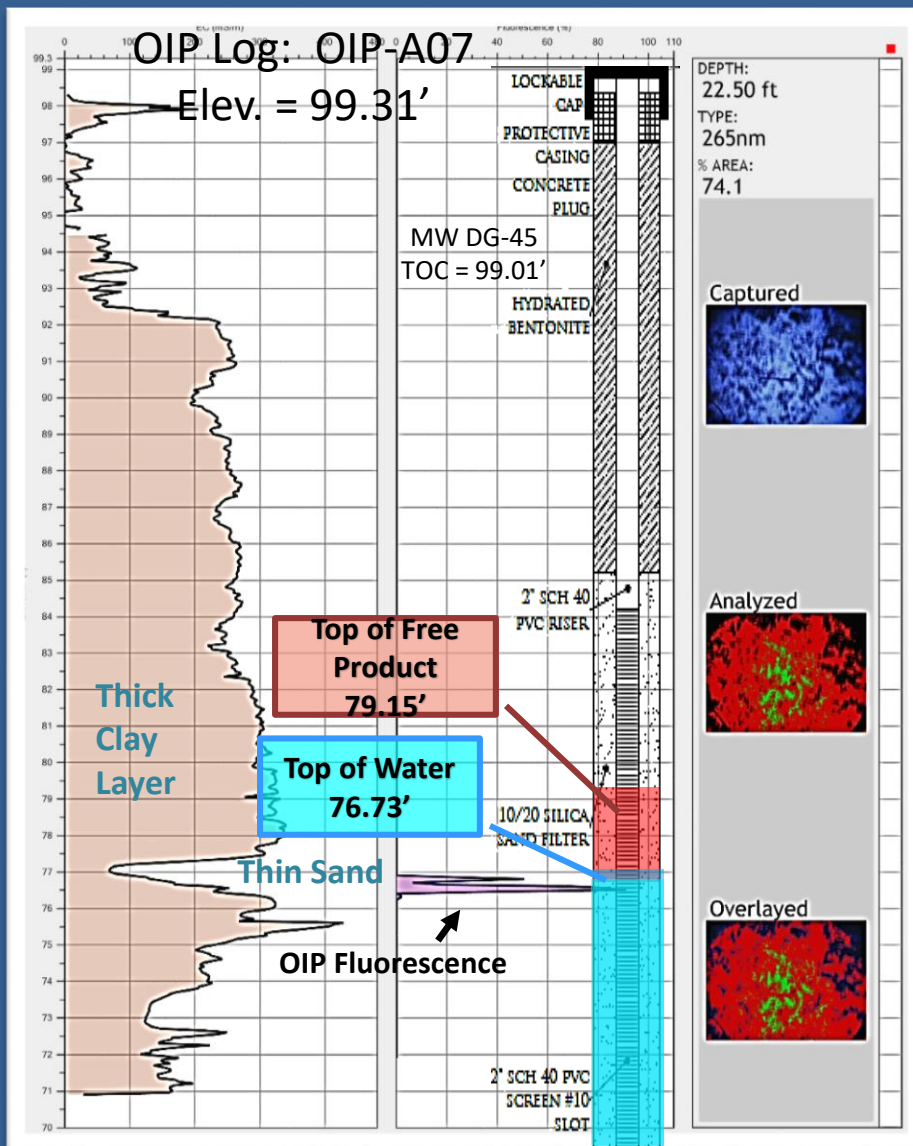
# Field Site: Former Service Station Grand Junction, CO



The solid orange line = Cross Section.



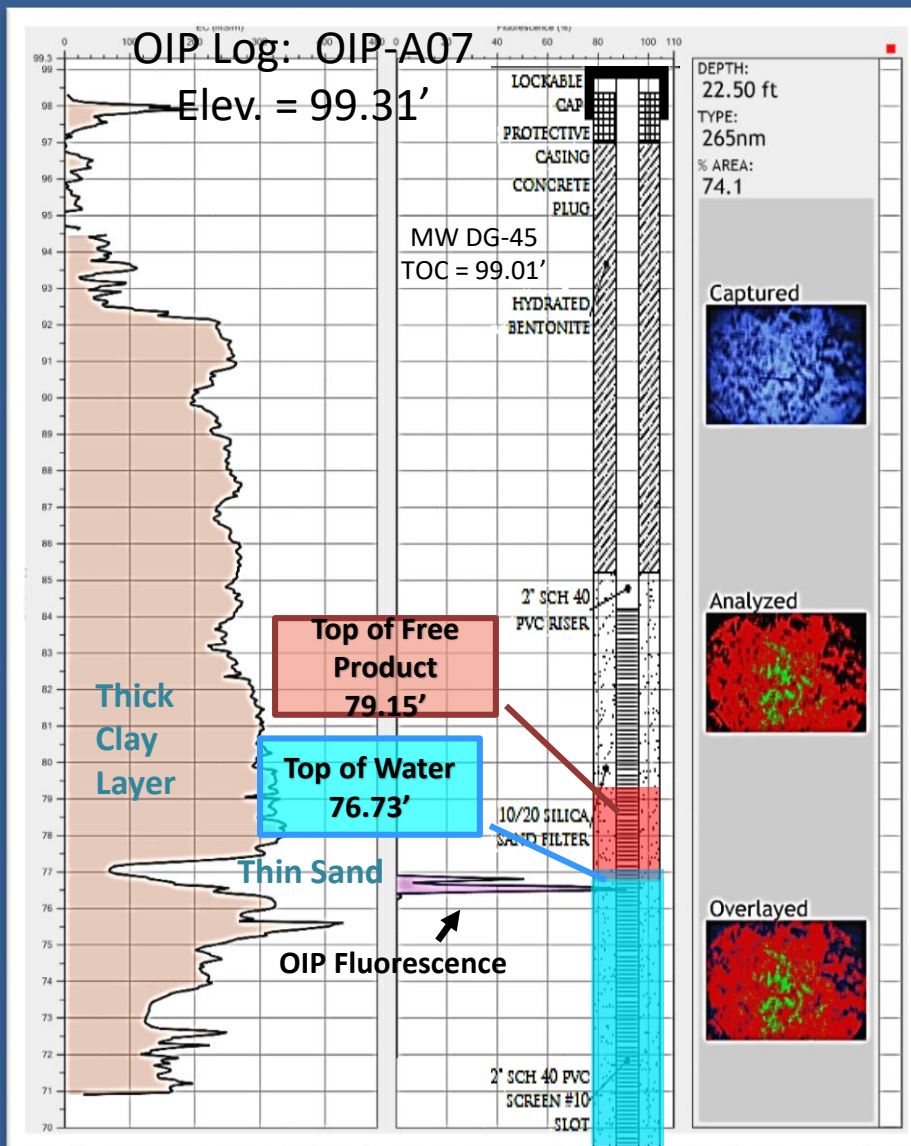
# Field Site: Grand Junction, CO



This OIP log was ~20' from the DG-45 well. The EC log indicates the presence of a narrow sand seam (~1ft thick) at an elevation of approximately 77ft. This sand layer is enclosed by clay above and below this elevation (elevations based on local benchmark defined as 100ft).

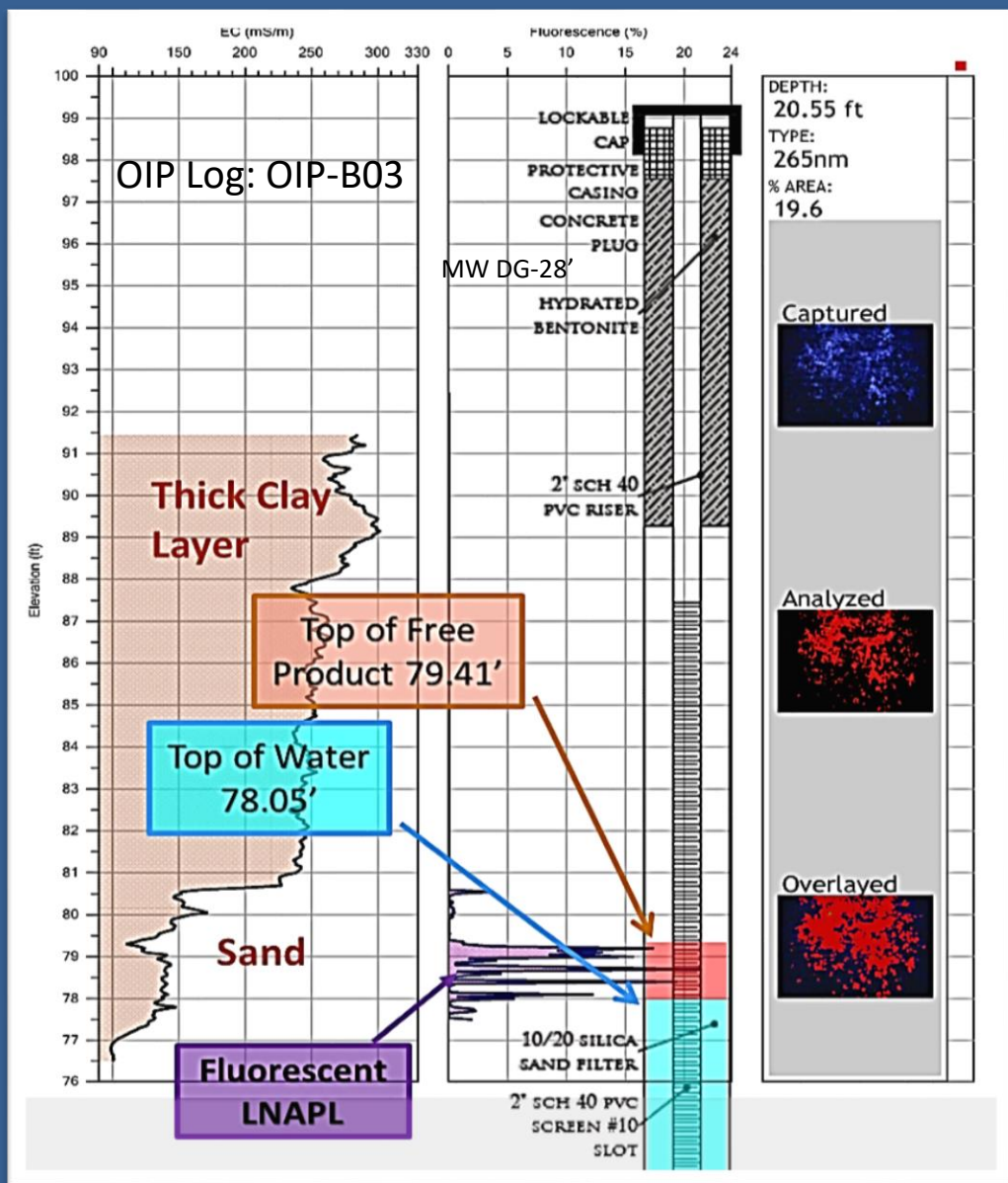
The fuel fluorescence detected by the OIP in the formation is occurring only within the narrow sand seam. However, measurement with an interface probe in the well shows approximately 2.4ft of product on top of the water. The elevation of the contact between the product and the water in the well appears to fall within the sand seam.

# Field Site: Grand Junction, CO



These results indicate that the narrow sand seam is supplying product to the well under positive head (confined), so that the product in the well forms a layer that is now more than twice the thickness of the product layer present in the formation. This well is allowing for spread of product through the screen higher in the formation. This may increase environmental & exposure risks.

# Field Site: Grand Junction, CO

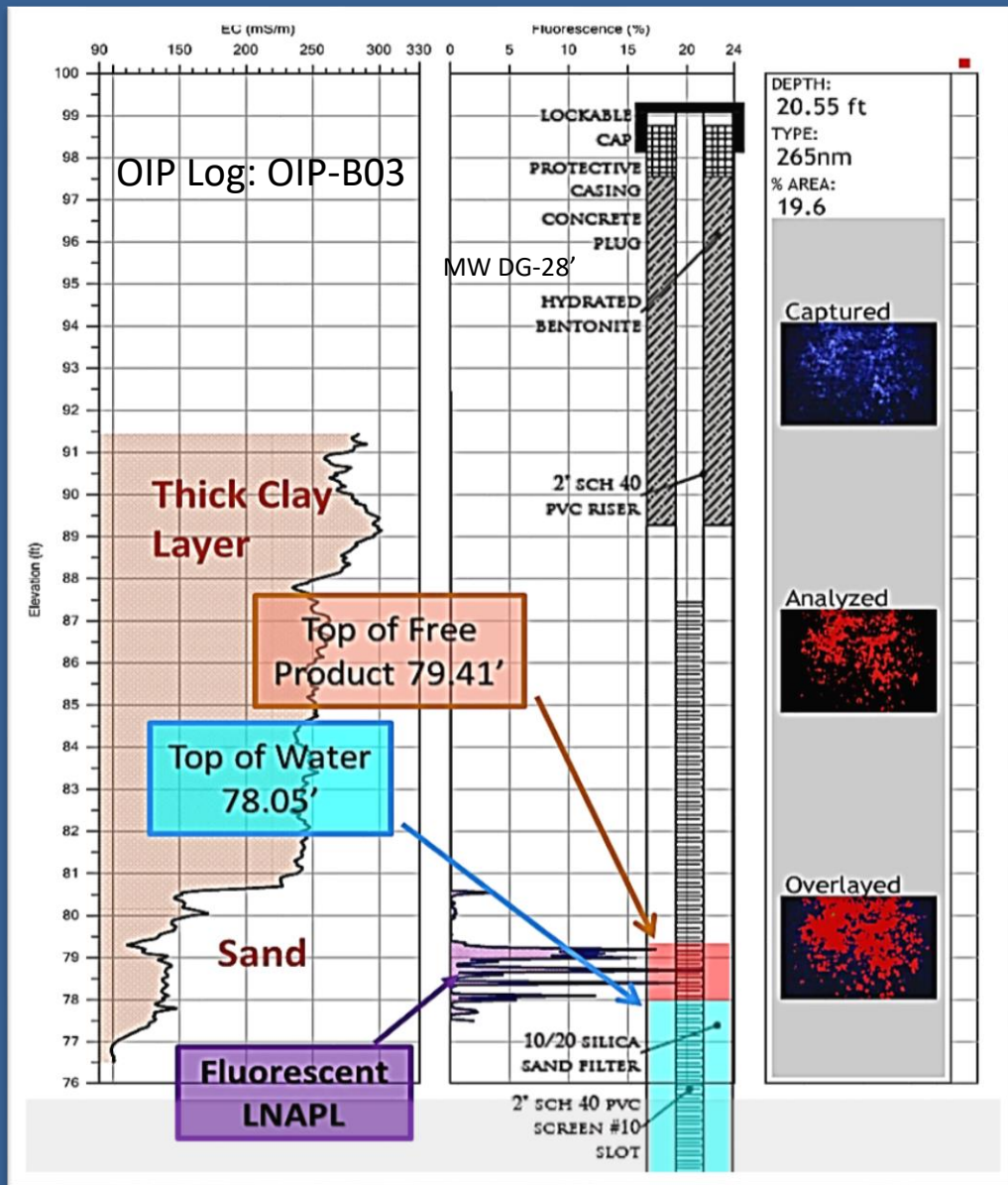


This OIP log was run ~10' from the DG-28 monitoring well. The EC log indicates the formation is sandy (lower EC) below an elevation of about 81.5ft. Above this elevation the formation is clay rich (higher EC).

The fuel fluorescence observed by the OIP probe all occurs below ~81ft, in the sandy material, and is spread primarily over about a 2ft interval.



# Field Site: Grand Junction, CO

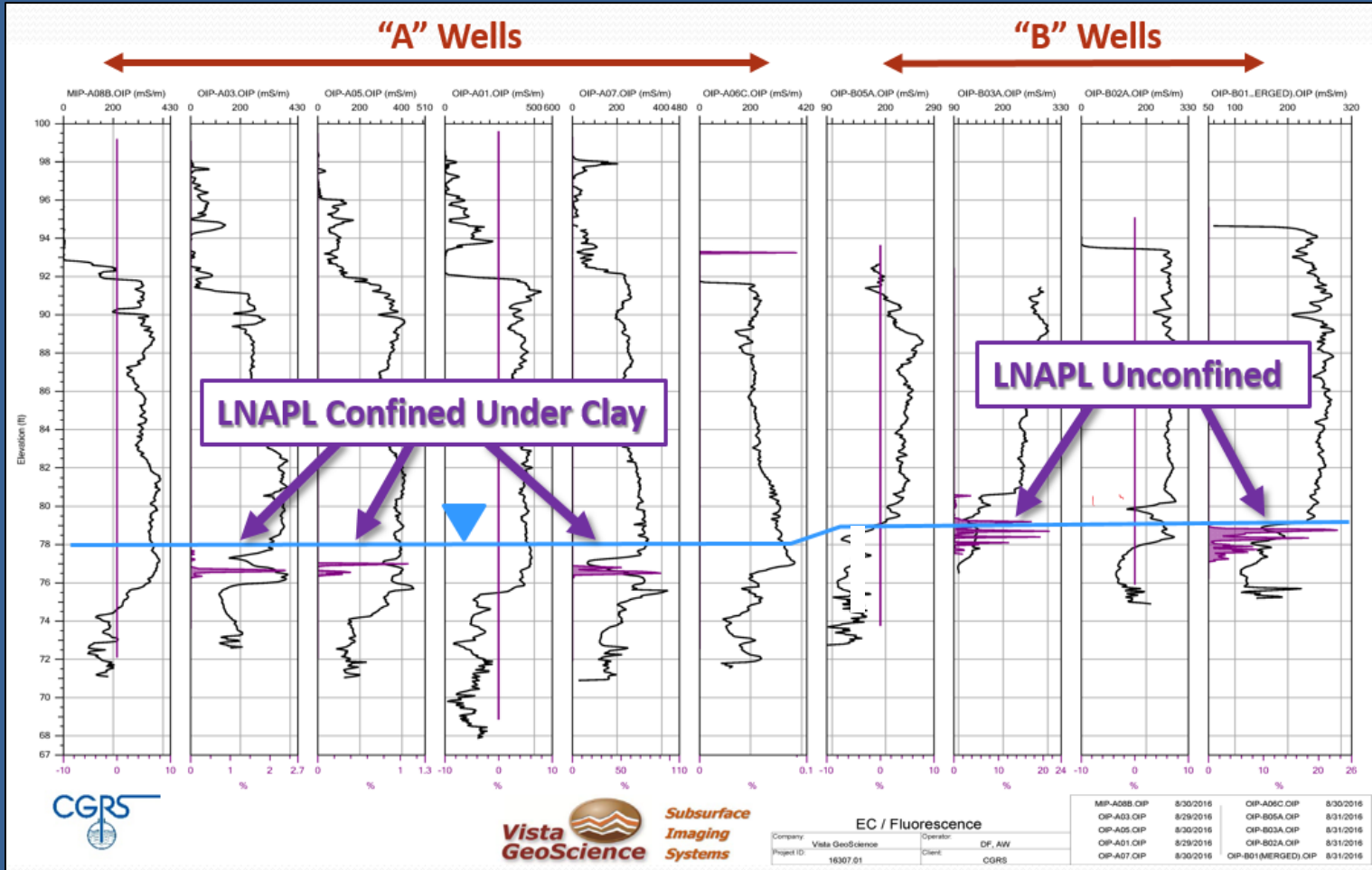


Measurements with an interface probe in the nearby well (DG-28) shows the presence of about 1.4ft of product on top of the groundwater. The interface probe found the contact between the product and groundwater was at an elevation of about 78ft.

At this location the groundwater (+product) is unconfined so that the product thickness in the formation and well are similar.



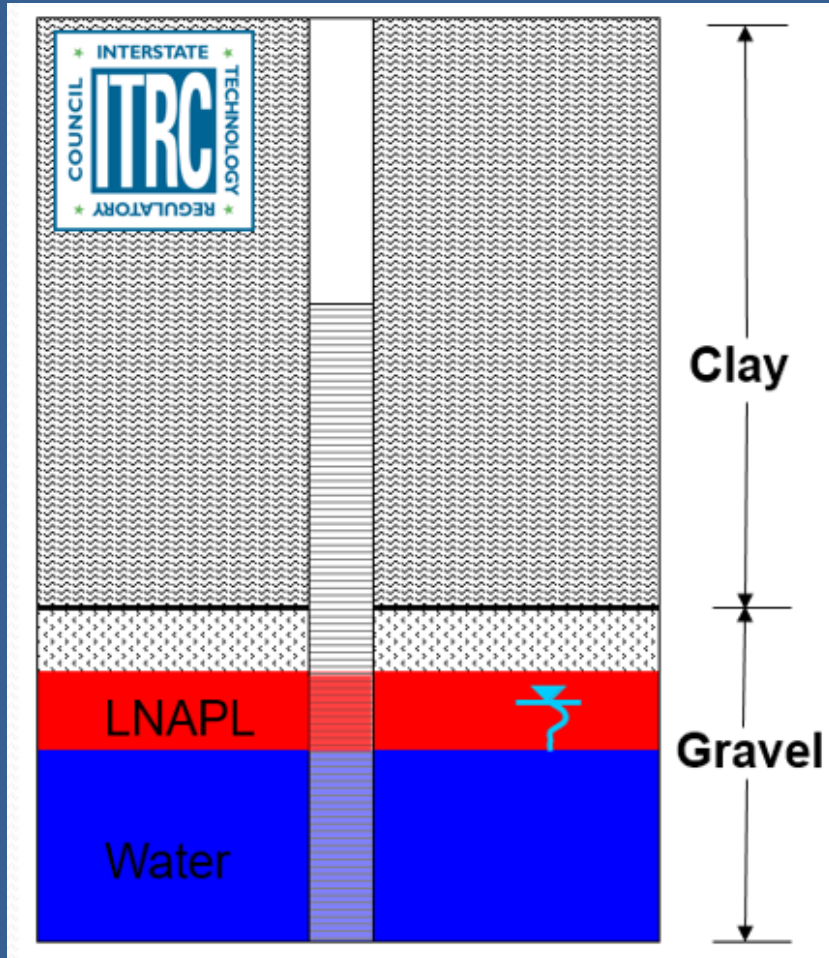
# Field Site: Grand Junction, CO



**Note:** Logs are displayed with equal spacing in the simplified cross sections, not equally spaced on the ground: not to scale.

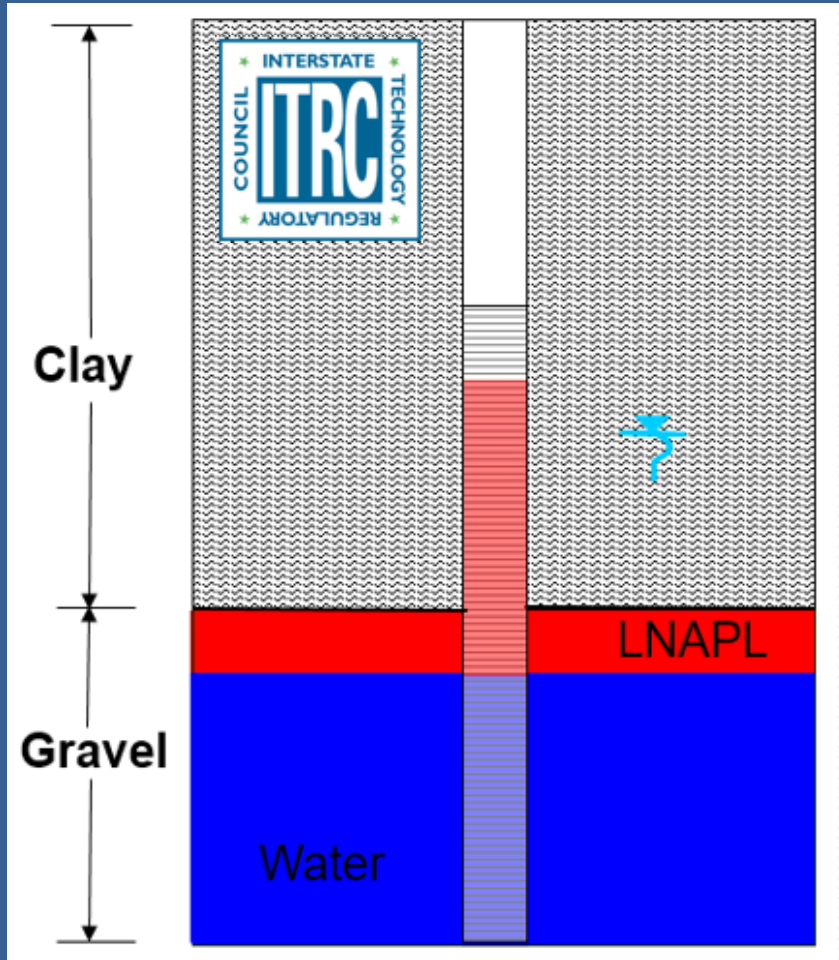


# LNAPL Unconfined Setting



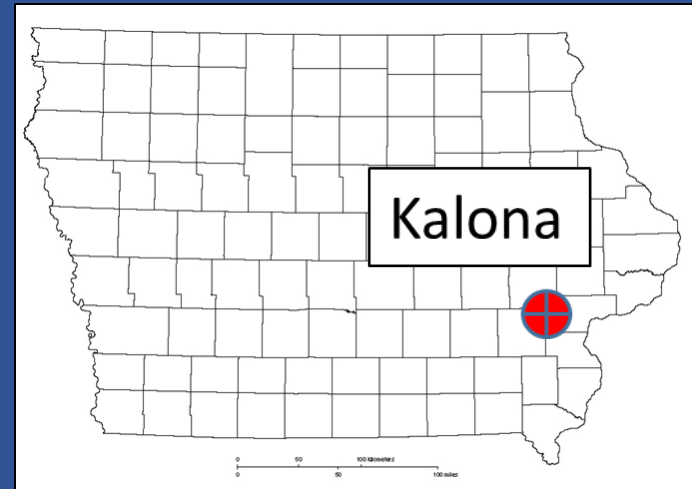
This diagram (after ITRC) shows the behavior of LNAPL between the well and formation under unconfined conditions. This demonstrates that the product thickness in the well is essentially the same as observed in the formation under unconfined conditions. Like the conditions observed on the east side of the site in Grand Junction.

# LNAPL Confined Setting



Again, this diagram (after ITRC) shows the behavior of LNAPL between the well and formation under confined conditions. This demonstrates that the product thickness in the well may be significantly thicker than observed in the formation under confined conditions. Like the conditions observed on the west side of the site in Grand Junction.

# Field Site: Grimm Oil Kalona, Iowa

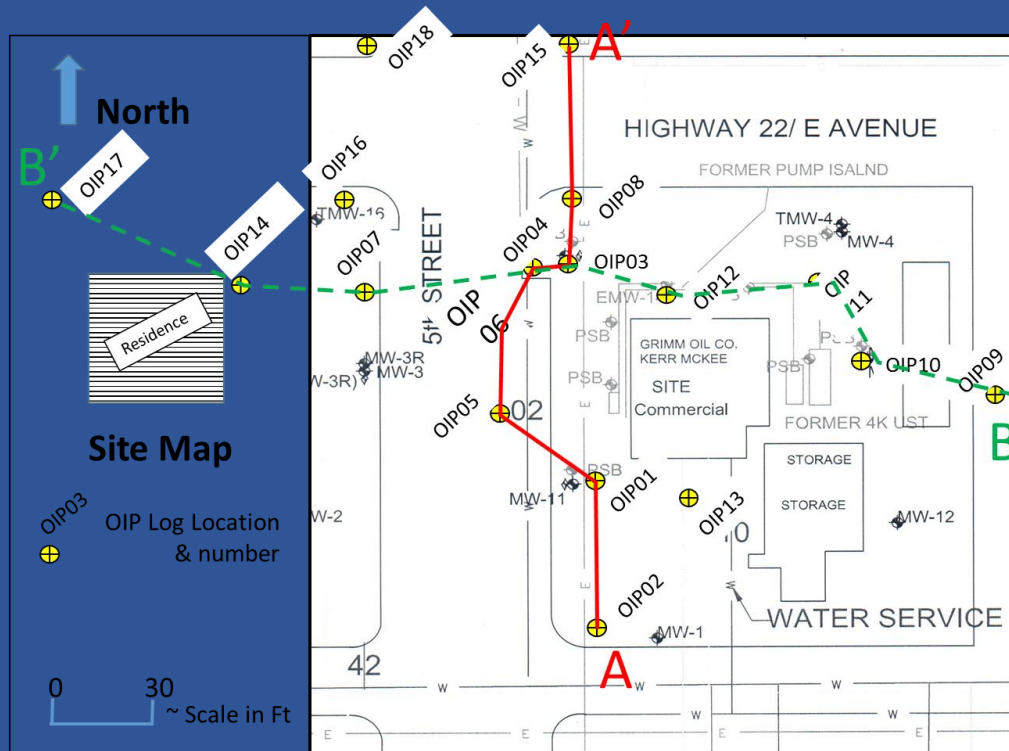


Wes McCall worked with John Coons of Impact7G to run 17 OIP logs across this former gas station in two days. Log depth ranged between about 20 to 27ft. Soil samples were collected adjacent to selected log locations. Field work was directed by James Goodrich (VJ Engineering) and Jeff White (IDNR).



# Field Site: Kalona, Iowa

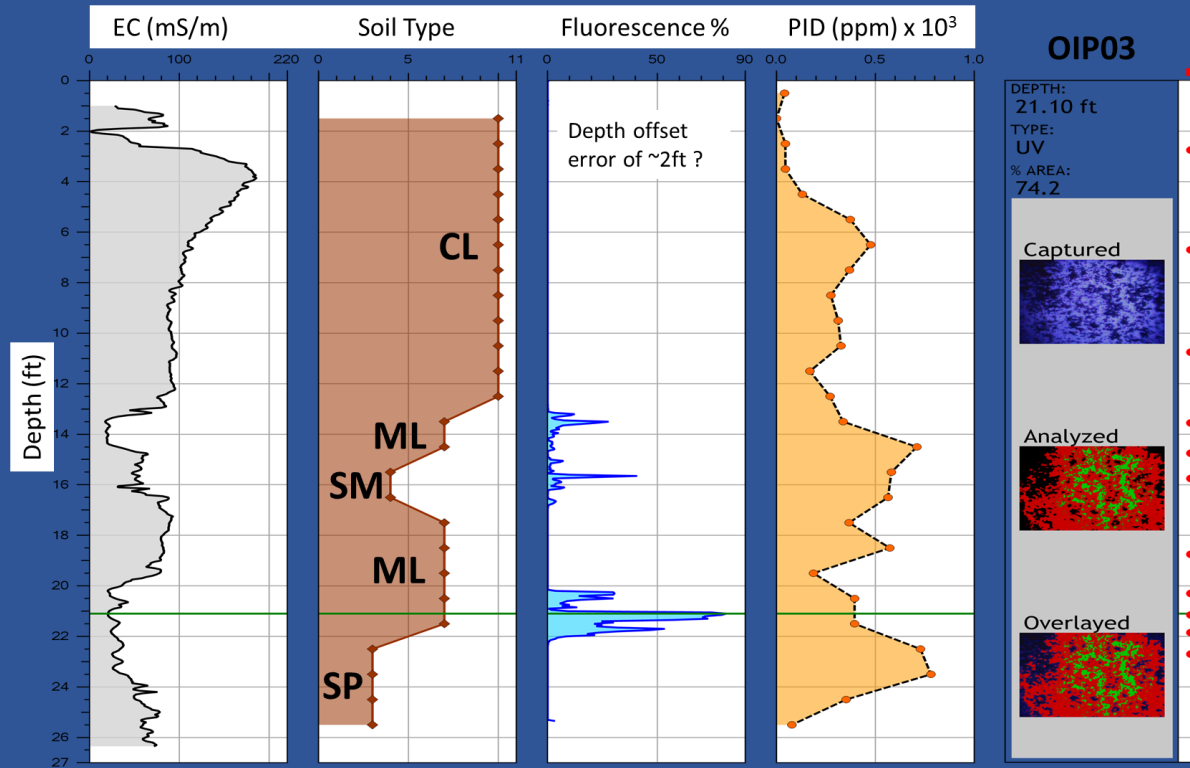
## Site Map



This site map displays the locations of the OIP logs across the site area as well as existing structures and former USTs and pump islands. The logs were later used to make simplified cross sections shown here as N-S cross section A-A' (solid red line) and E-W cross section B-B' (dashed green line).



# Field Site: Kalona, Iowa



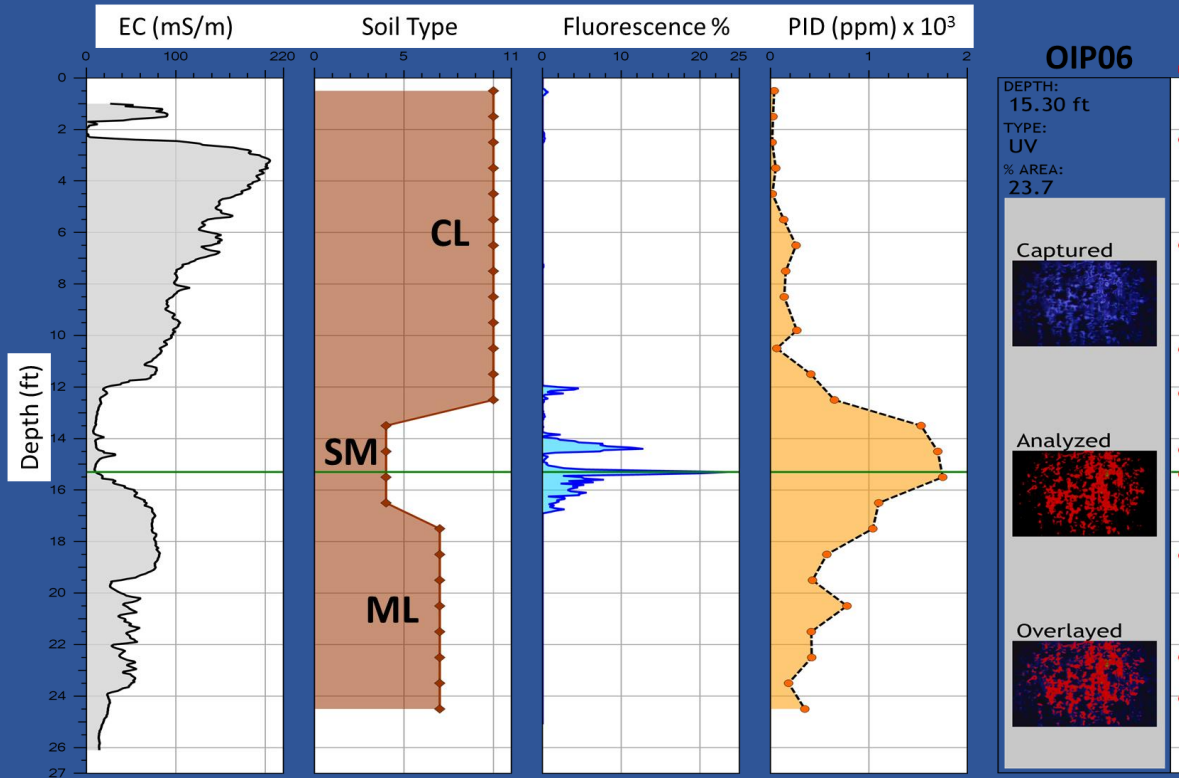
Log OIP-03 was obtained near the former pump island and also near MW # 8. Water level in the well was about 8ft below grade.

Captured UV and analyzed images are shown on the right side of the log for a depth of 21.10ft at this location. The % area Fluorescence was over 70% at this depth.

The EC log indicates the formation has increased sand content between about 13-16ft below grade and again 20-24ft below grade. Visual inspection of soil cores adjacent confirm this.

At this location LNAPL fluorescence was observed across the 13-16ft and 20-22ft intervals where lower EC readings indicating sandy zones of the formation. Also, field screening with a handheld PID was conducted on the core samples. A plot of the PID results shows that high PID response roughly correlates with fluorescence.

# Field Site: Kalona, Iowa



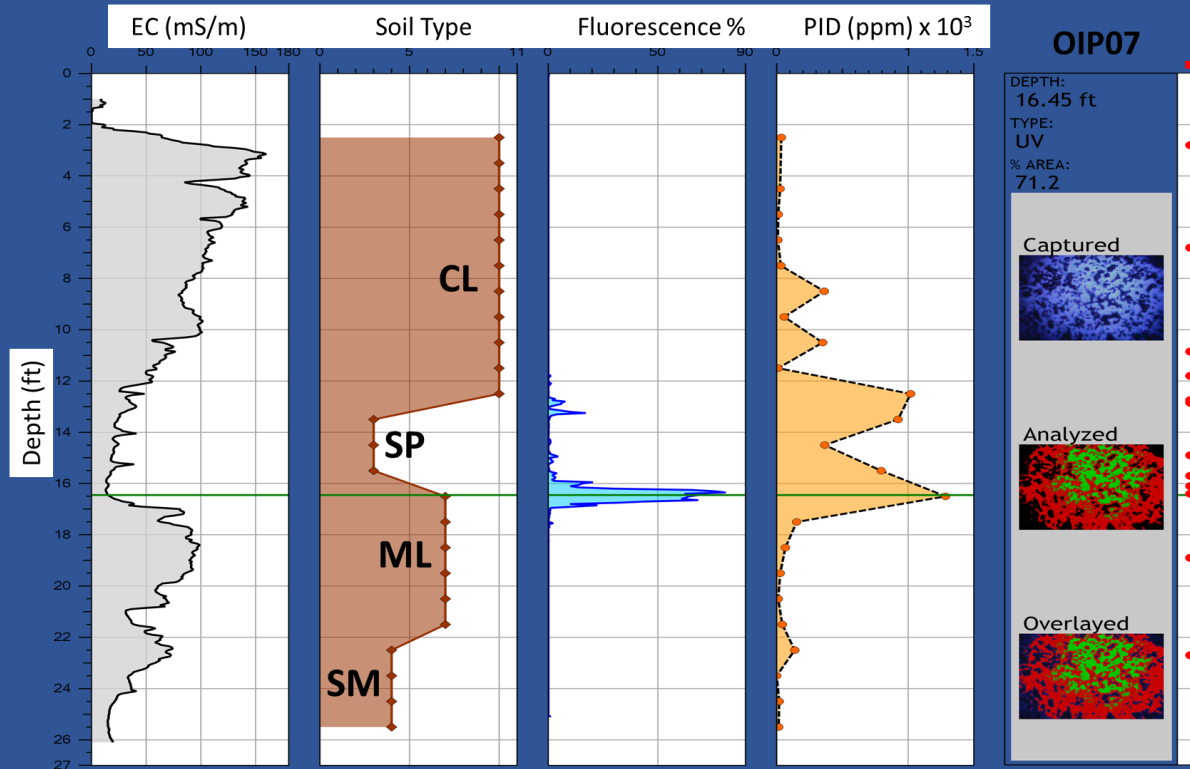
Log OIP06 was obtained in the street adjacent to the municipal water line.

Captured UV and analyzed images are shown on the right side of the log for a depth of 15.30ft at this location. The % area Fluorescence was about 23% at this depth.

The EC log again indicates a sandy zone in the formation between about 12 to 16ft below grade, agreeing with observations made of the adjacent soil cores.

The LNAPL fluorescence observed is near the top and across this sandy interval in the formation.

# Field Site: Kalona, Iowa



Log OIP07 was obtained across 5<sup>th</sup> Street from the former filling station in the edge of the yard of a private residence.

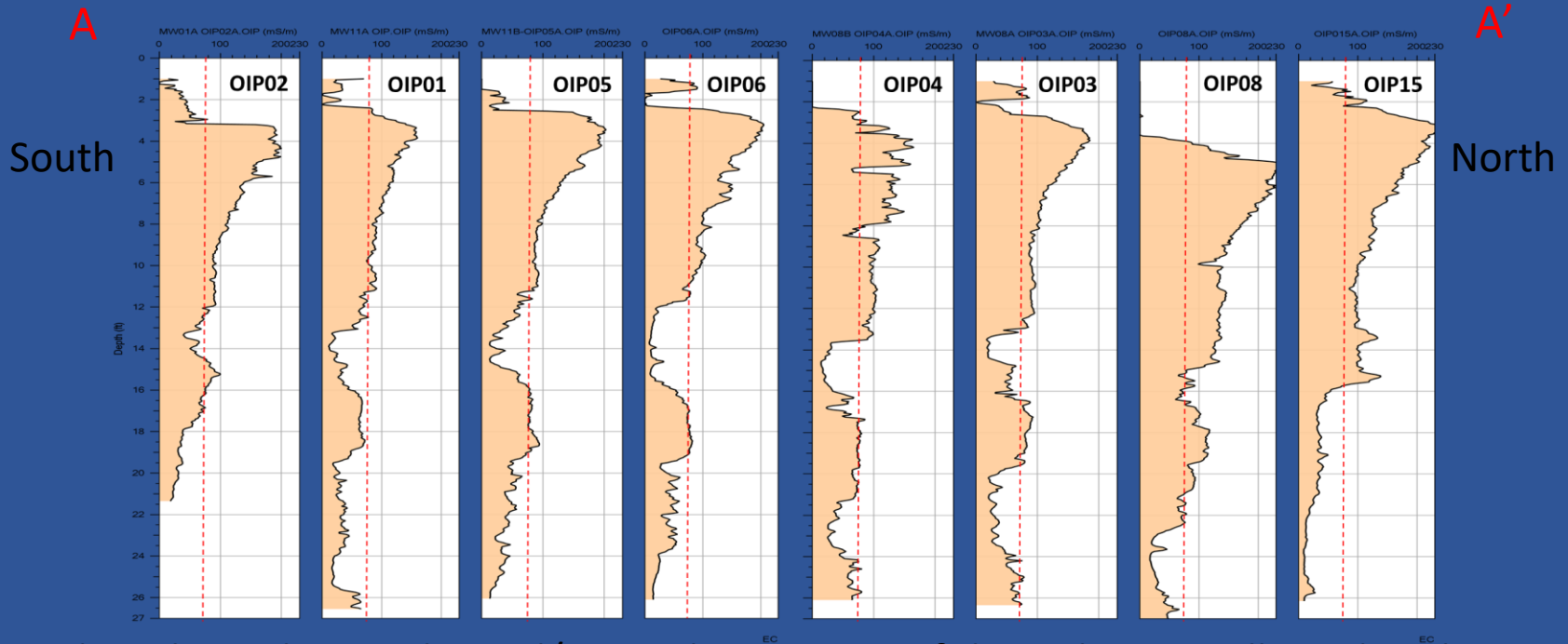
Captured UV and analyzed images are shown on the right side of the log for a depth of 16.45ft at this location. The % area Fluorescence was over 70% at this location/depth.

Again we see that the EC log and soil cores indicate a sandy zone between about 12-16ft depth in the formation.

Also, the LNAPL fuel fluorescence and the highest PID screening results are across this 12-16ft interval. Both methods showing a bifurcation of the LNAPL distribution.

# Field Site: Kalona, Iowa

## Cross Section A-A'



Based on the EC logs and visual/manual inspection of the soil cores collected at the site it was determined for this site that when the bulk formation EC dropped below about 90mS/m the sand content of the formation increased significantly. Higher EC values corresponded with silty-clays ± minor sand content.

A dashed red line is drawn down each cross section at about 90mS/m to help identify zones in the formation above and below this EC level.

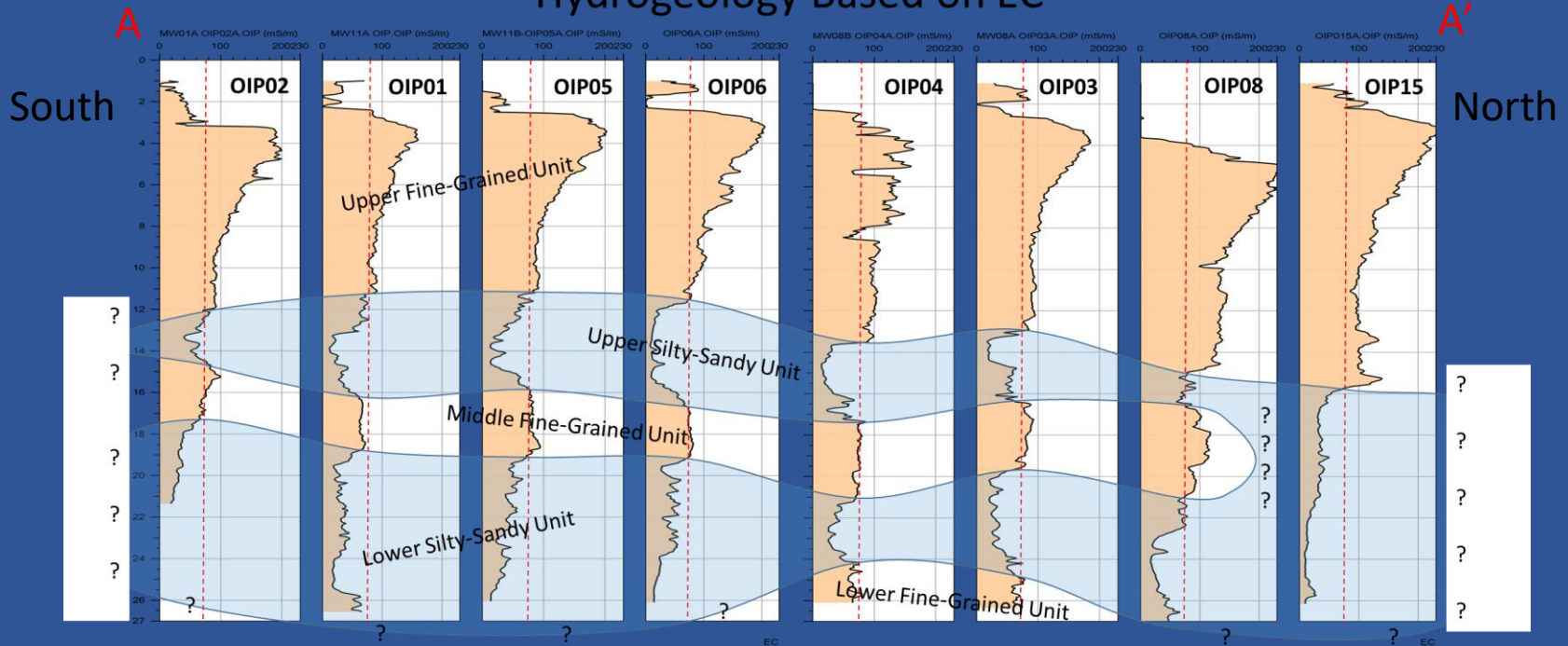
**Note:** Log spacing simplified - not to scale



# Field Site: Kalona, Iowa

## Cross Section A-A'

### Hydrogeology Based on EC



Based off of the EC logs and the continuous cores obtained at 3 locations we are able to make a preliminary interpretation of the site hydrogeology. The sediments at the site are primarily alluvial deposits of the nearby English River.

**Note:** Log spacing simplified - not to scale

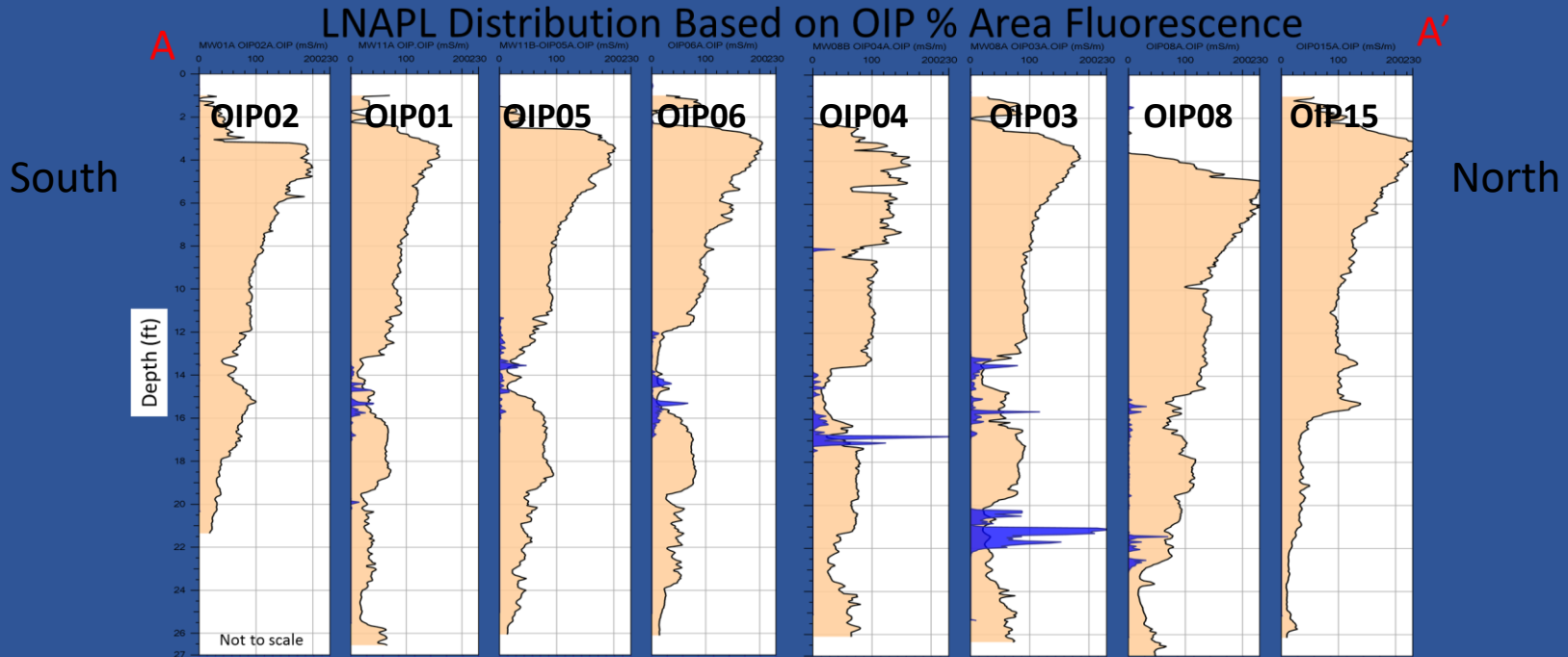






# Field Site: Kalona, Iowa

## LNAPL Fluorescence Over EC



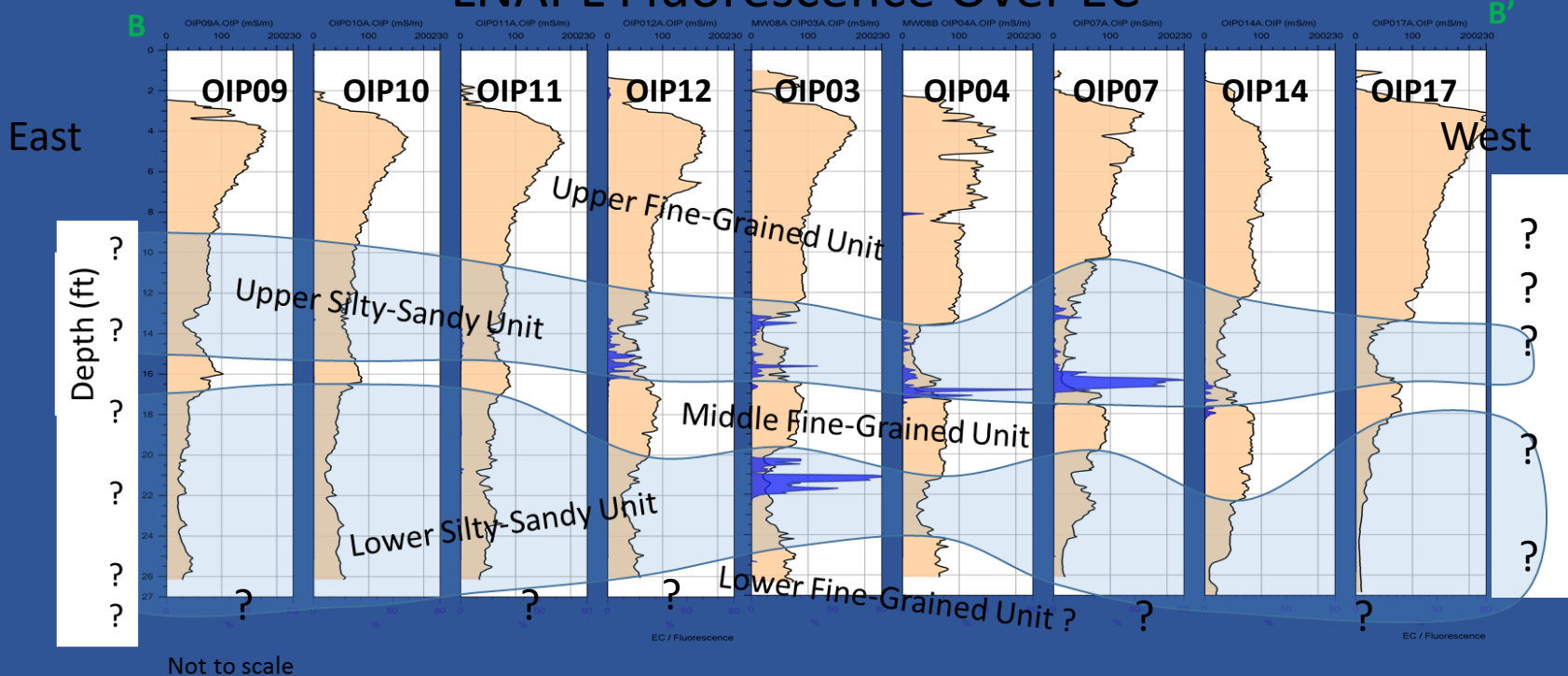
This cross section shows EC with % area fluorescence graphs. This allows us to see that the petroleum LNAPL at the site occurs primarily in the upper silty-sandy unit. This higher permeability zone appears to be the primary migration pathway for LNAPL in the subsurface at this facility.

However, near the pump island (logs OIP03 and OIP08) we see significant fluorescence in the lower silty-sandy unit. This indicates that LNAPL is present well below the local water table (which is ~8ft below grade).

# Field Site: Kalona, Iowa

## Cross Section A-A'

### LNAPL Fluorescence Over EC



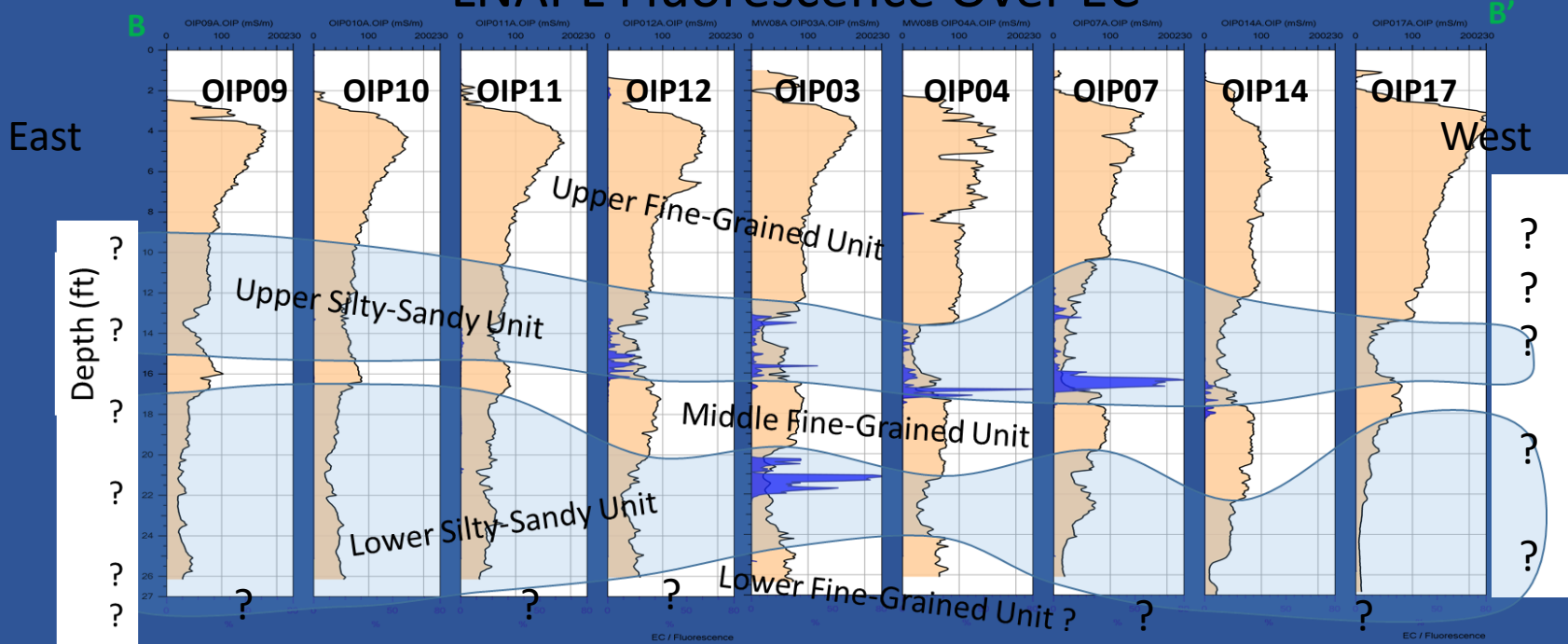
Cross section B-B' showing EC, LNAPL fluorescence and hydrogeologic interpretation based on EC and targeted soil cores.

Again we see that the LNAPL is present primarily in the upper silty-sandy unit, which again appears to be the primary migration pathway at this facility.

# Field Site: Kalona, Iowa

## Cross Section A-A'

### LNAPL Fluorescence Over EC

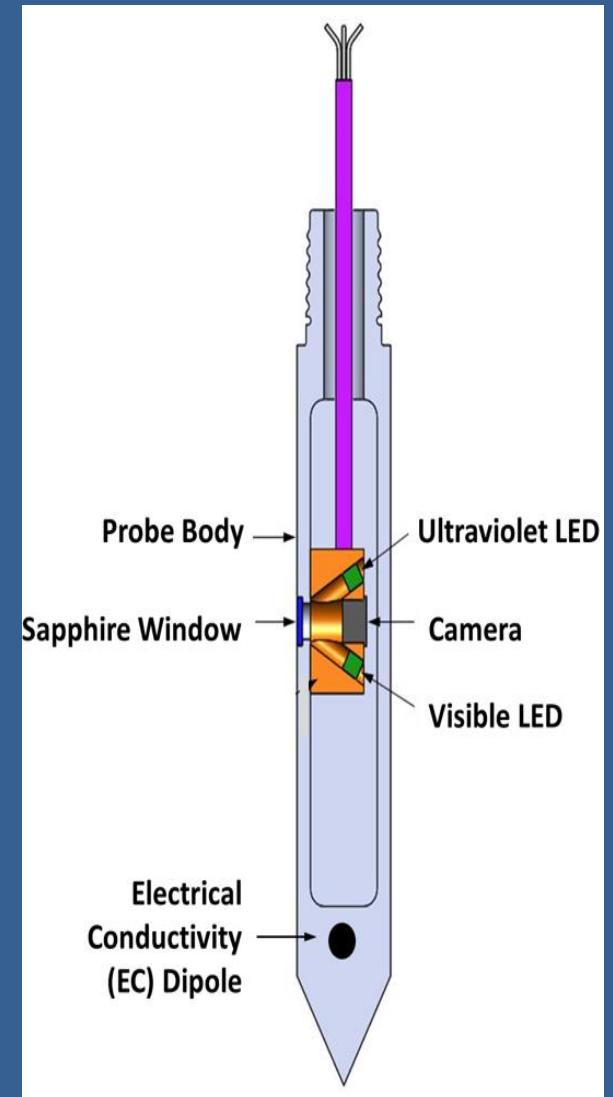


Not to scale

Note log OIP04: A small zone of LNAPL fluorescence is present at a depth of approximately 8ft below grade, coincident with the static water level. It appears that the monitoring well near this location has allowed LNAPL to move up from the 14-16ft zone and enter the more permeable/sandy zone at 8ft through the well screen. As this is located near the municipal water line the hazard and health risk is elevated due to the LNAPLs proximity to the water line. IDNR plans to have this well properly abandoned soon to reduce/eliminate this hazard.

# OIP Summary

- Capable of capturing UV induced fluorescence and visible light images of soil
- Provides % Area fluorescence log of LNAPL hydrocarbons with depth
- Typically, neither dissolved phase hydrocarbons nor chlorinated VOC DNAPLS are detectable
- Image analysis to identify fuel fluorescence in images
- Images can show spatial distribution of hydrocarbons in the soil matrix
- Images are saved and can be visually examined after the log has been completed





# OIP Summary

- Visible light images of the soil may be captured and examined to identify soil texture and color
- EC logs help identify soil types/lithology in many settings (but not always)
- Fluorescence logs in cross section help to define LNAPL distribution in the subsurface
- Combine Fluorescence logs and EC logs to define migration pathways
- May be percussion driven using GH60 series (or smaller) hydraulic hammers.
- For logging only in soils and unconsolidated formations.





Geoprobe Systems

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