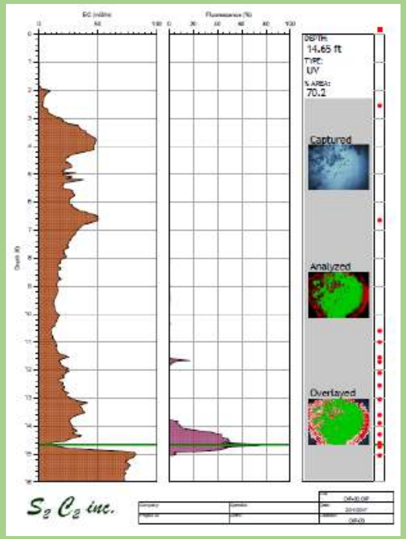
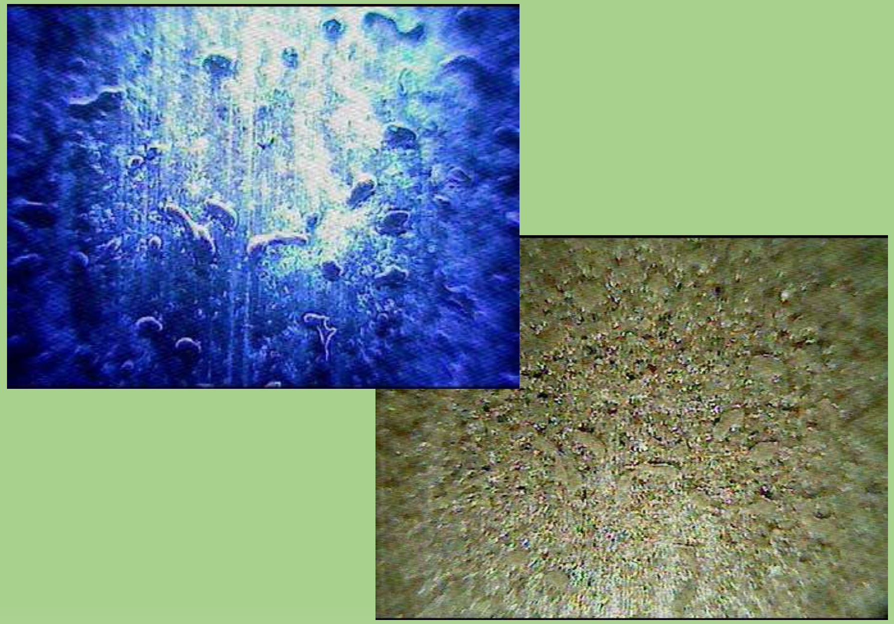
High Resolution Site Characterization Tools
Optical Imaging Profiler (OIP)





Dan Pipp

Geoprobe Systems

High Resolution Site Characterization?

HRSC Tools can include: Direct push sampling and monitoring wells, Field laboratories or other field analytical techniques, direct driven sensors to map contaminants and aquifer characteristics.

Topic Overview

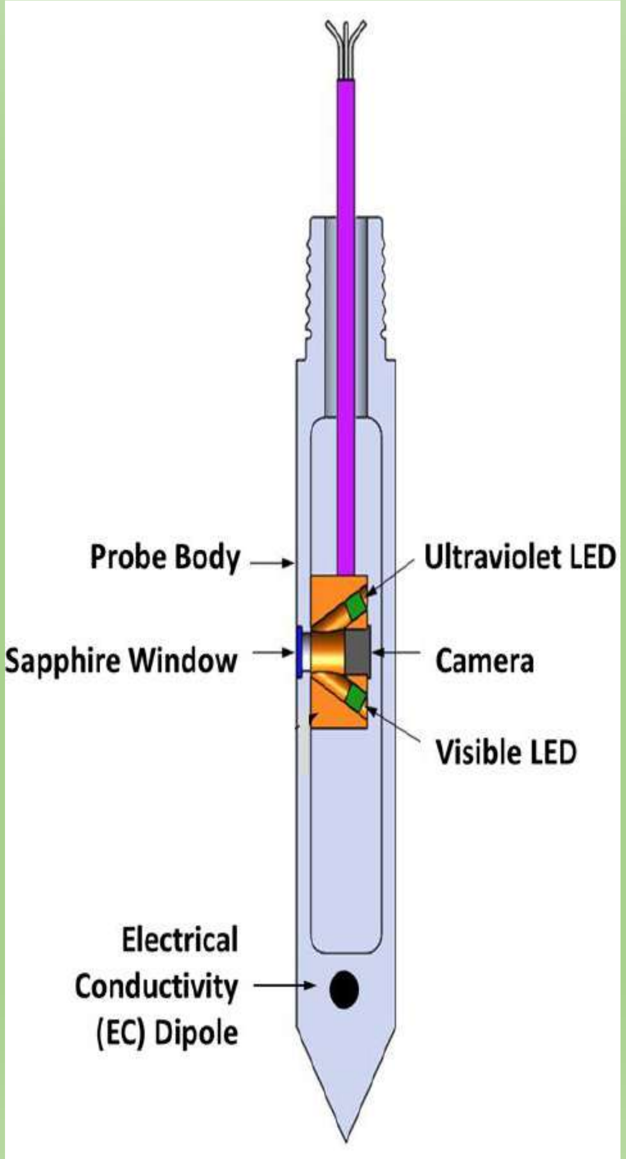
- What is OIP-UV
- The Principles Behind OIP-UV
- Logging with the OIP-UV
- OIP-UV Site Examples
- Other HRSC Tools: HPT and MIP
- MiHPT Site Example

OIP-UV 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 are also be obtained.



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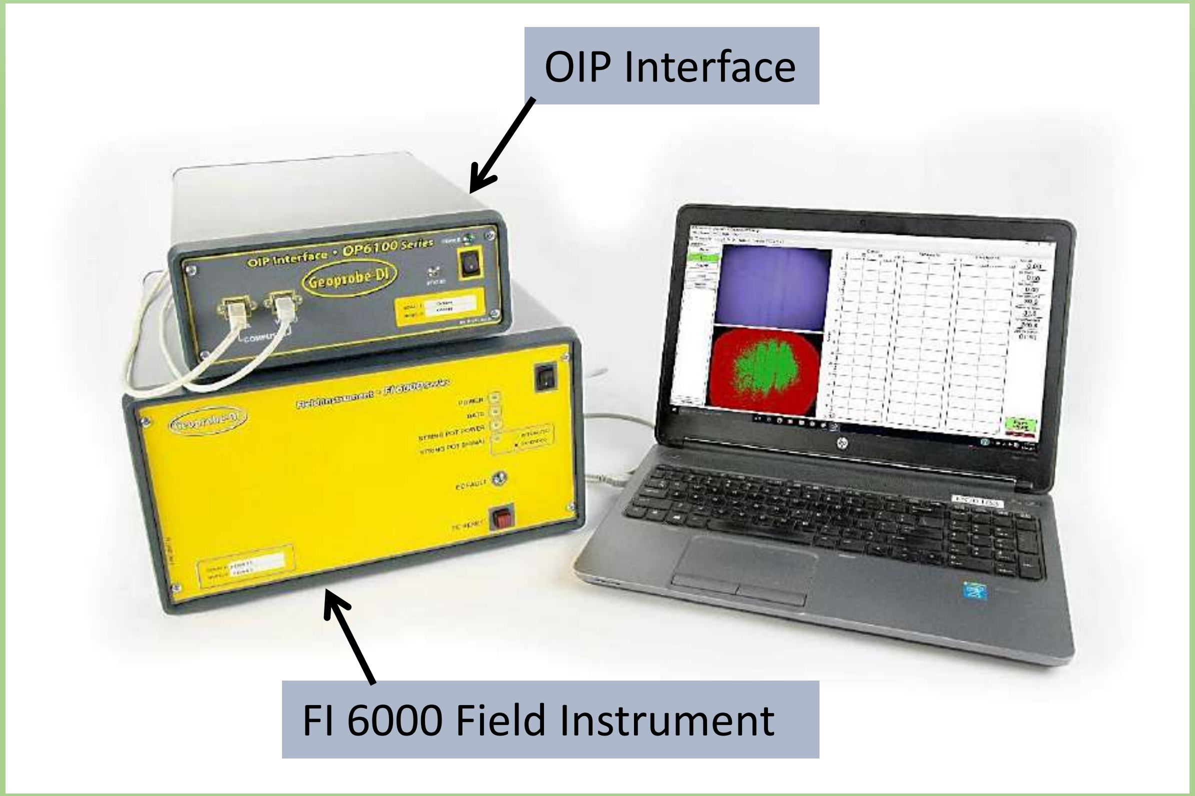
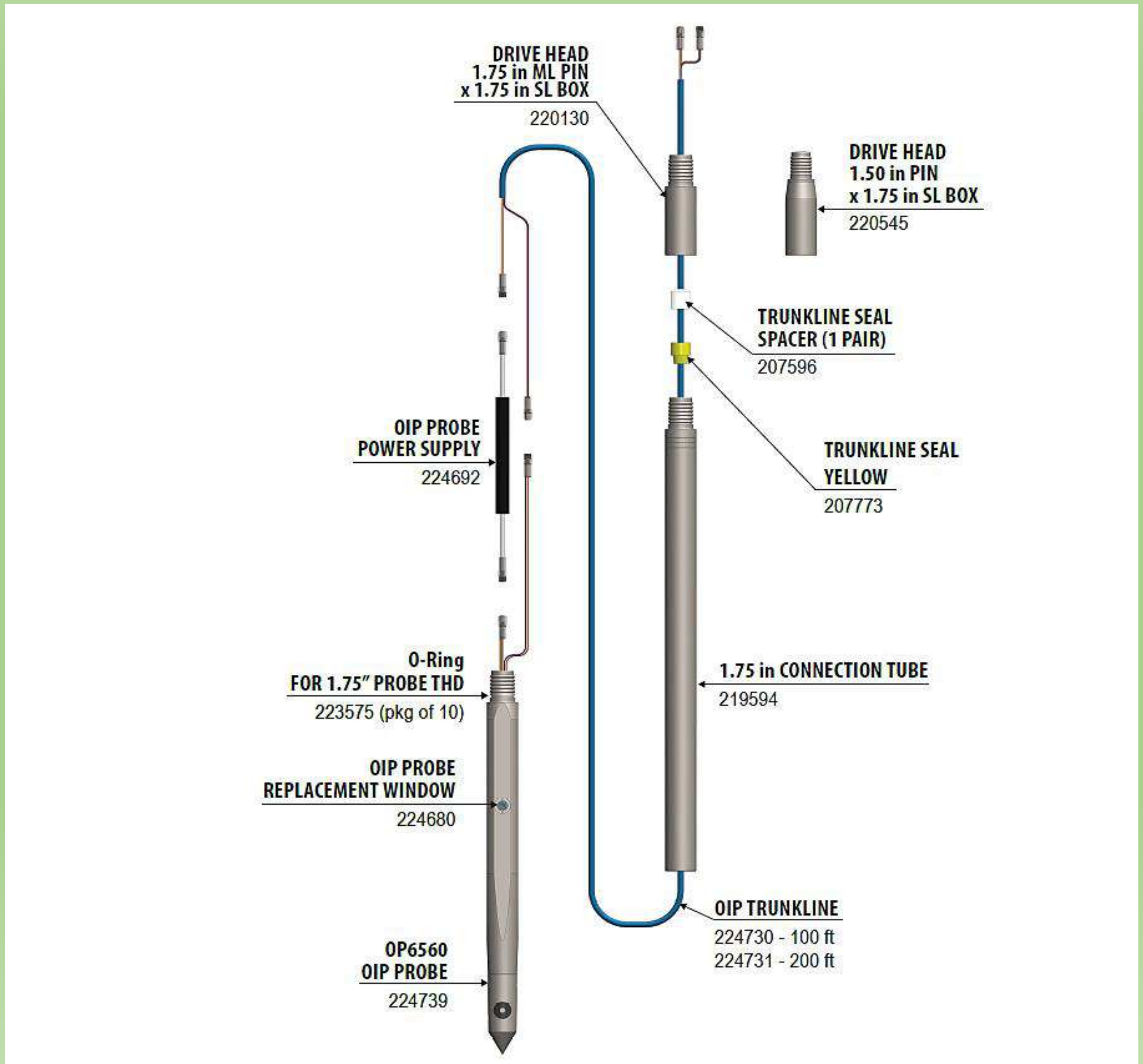
OIP Up-hole Instrumentation



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

OIP Down-hole Tools

OIP
Tool String Diagram



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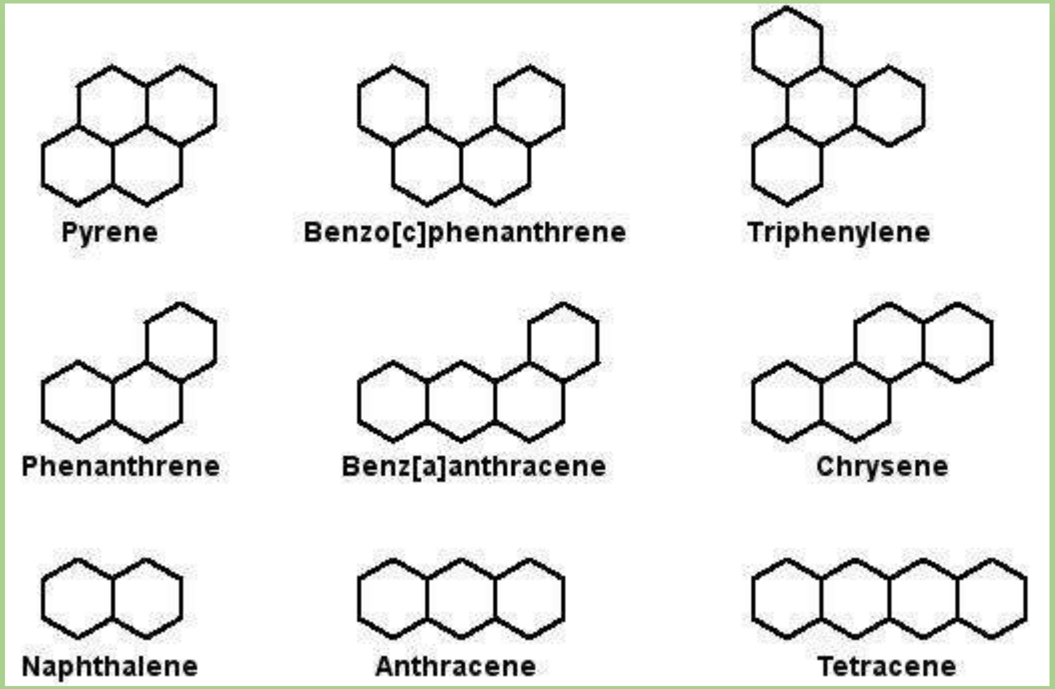
Polycyclic Aromatic Hydrocarbon (PAH) Fluorescence



UV Detectable with a 275nm Source

- Smaller PAH Compounds
  - Gasoline, Jet and Diesel Fuels
  - Mineral, Motor and Crude Oils

None uniform UV Response with 275nm Source

- Larger PAH Compounds
  - Creosote, Coal tar, Bunker Fuels

Will not Fluoresce with 275nm Source

- Chlorinated VOCs
- BTEX
- Dissolved Phase Contaminants

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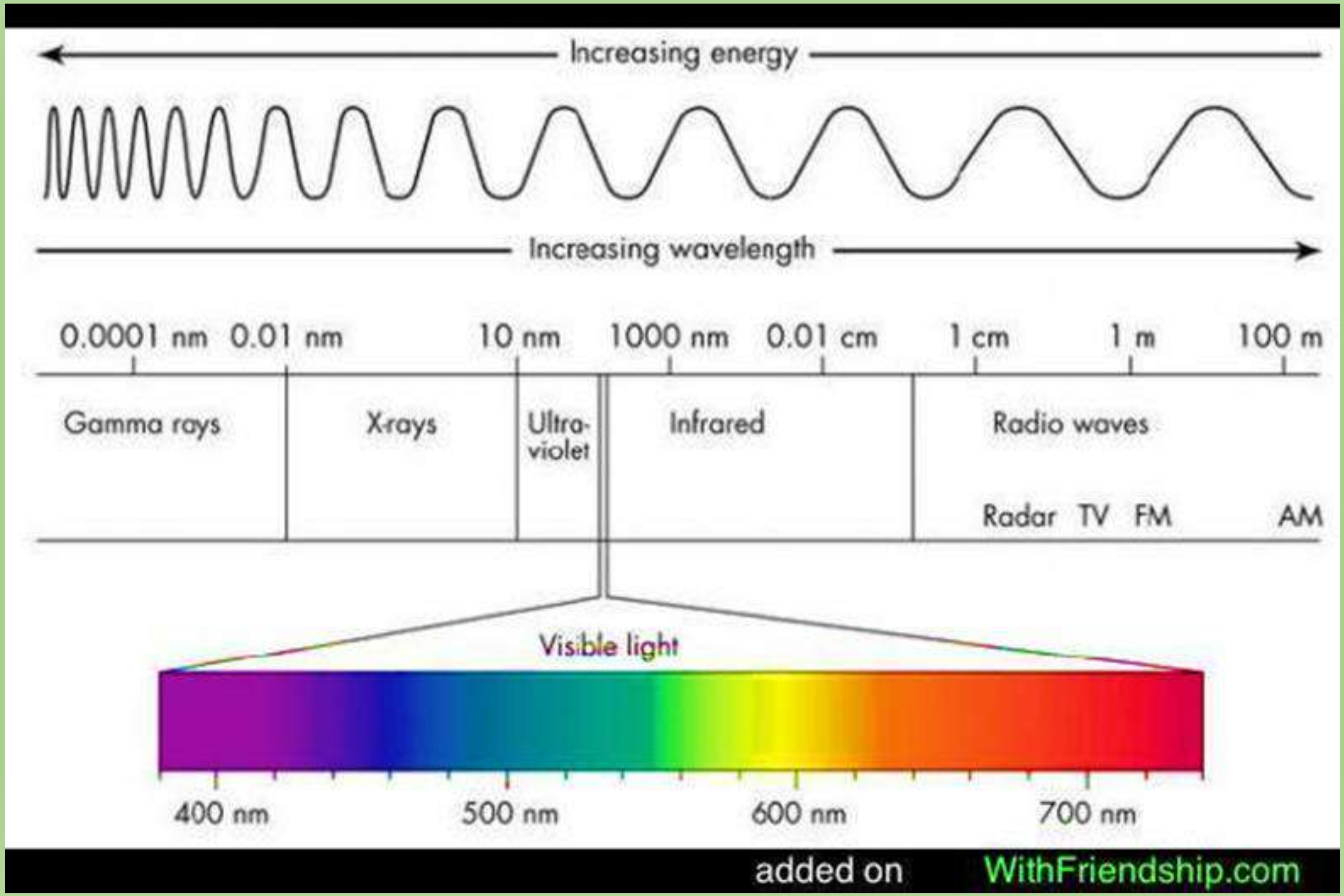
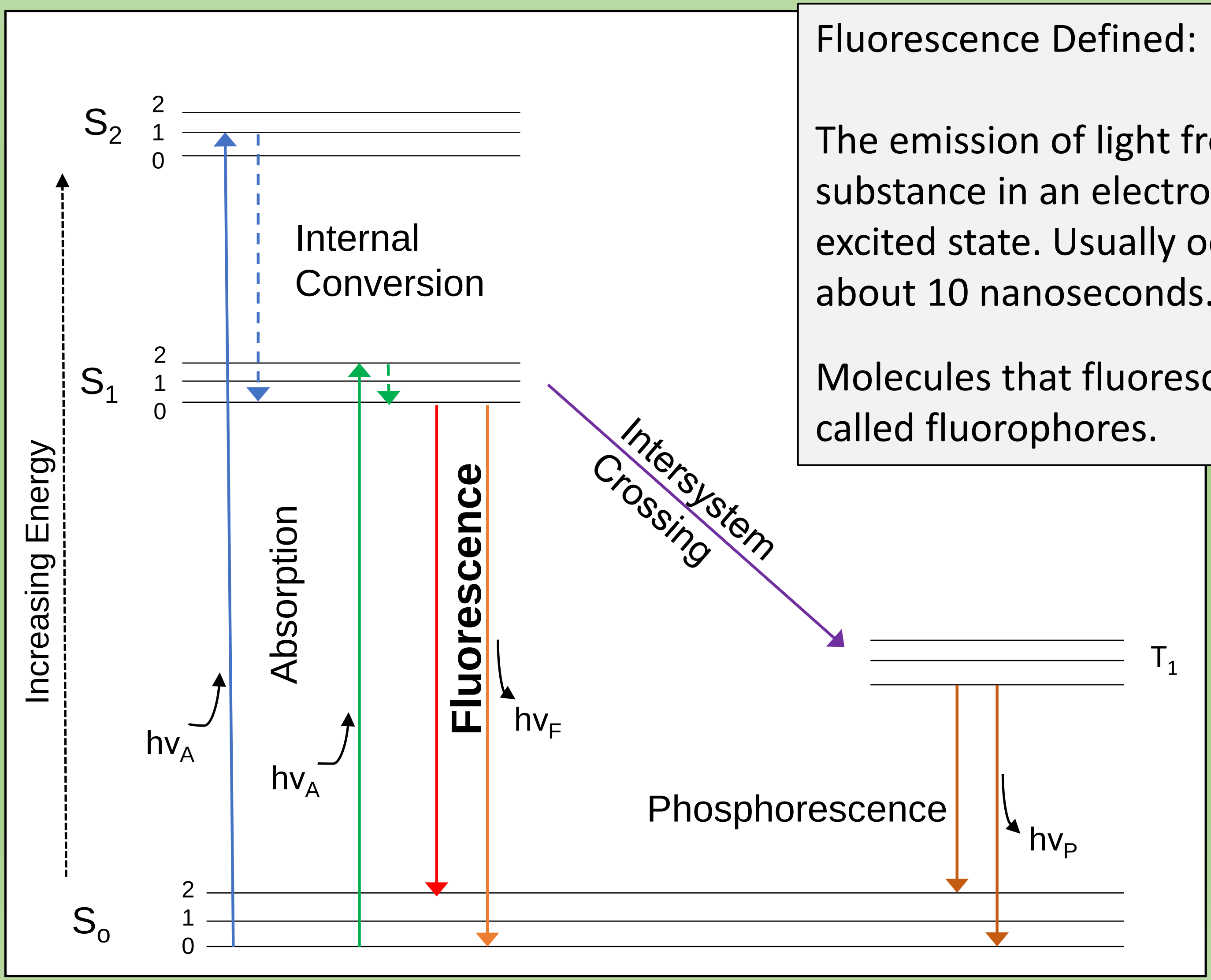
Light Wavelengths



Hue can be directly related to Visible Light and Wavelength

How Fluorescence Occurs

- UV light is absorbed by electrons in PAH molecules
- Electrons move to an excited (higher energy state)
- They lose some energy (move to a higher wavelength) then emit a light photon (fluoresce) to return to their ground state



Fluorescence Defined:

The emission of light from a substance in an electronically excited state. Usually occurs in about 10 nanoseconds.

Molecules that fluoresce are called fluorophores.

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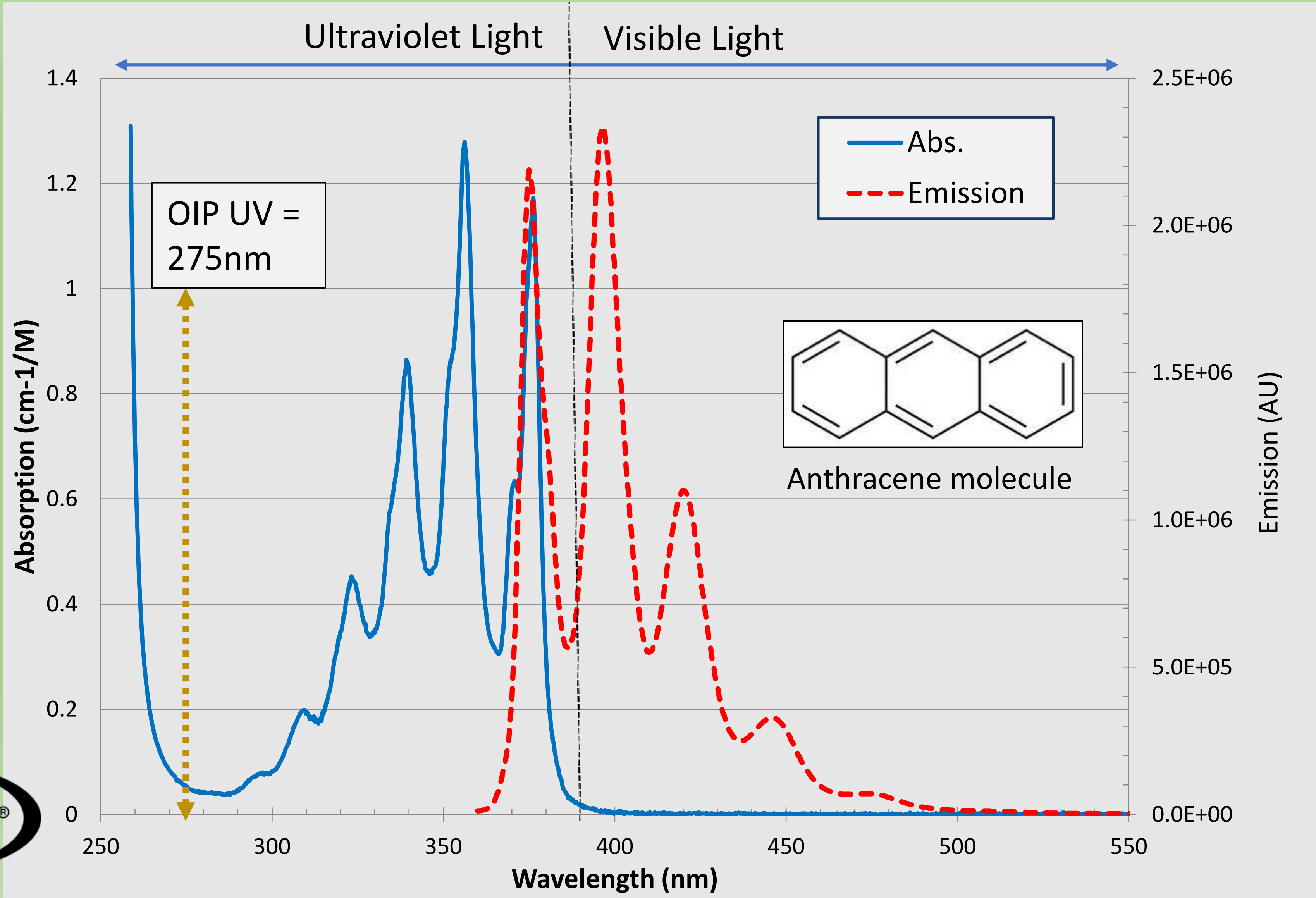
A simplified Jabłoński diagram (after Lakowicz 1999)

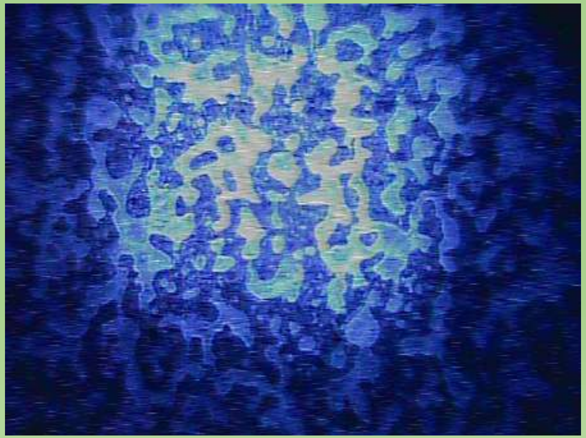
Absorption & Emission Spectra for Anthracene



OIP UV Images

- 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 background image



Typical OIP image of LNAPL fluorescence

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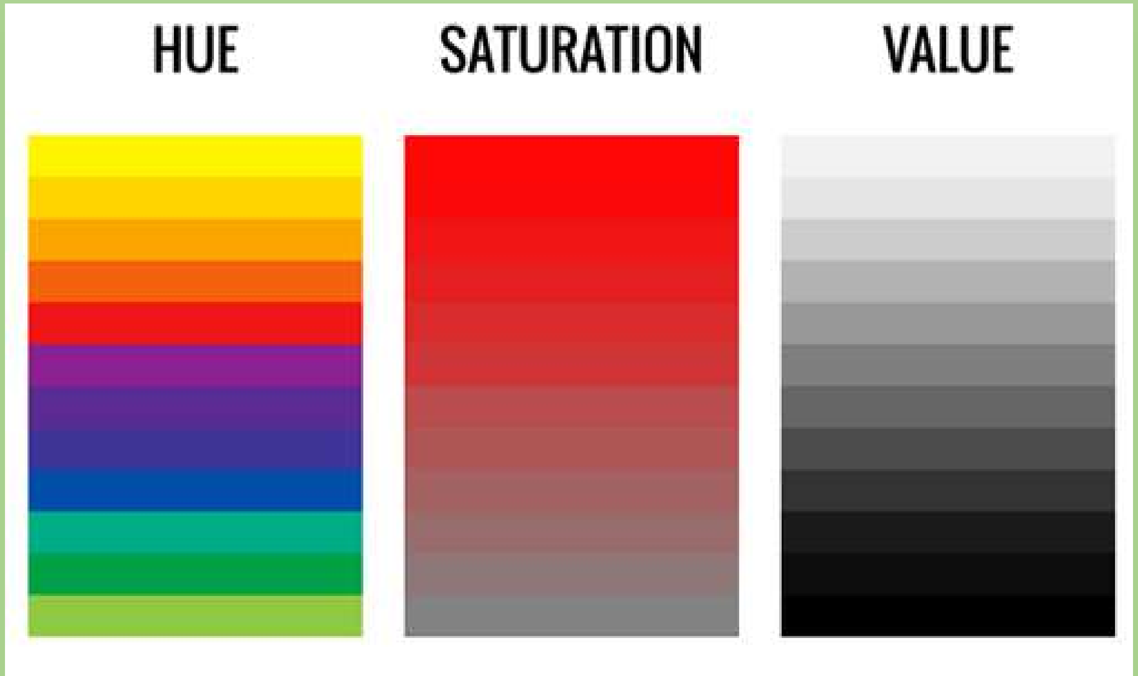
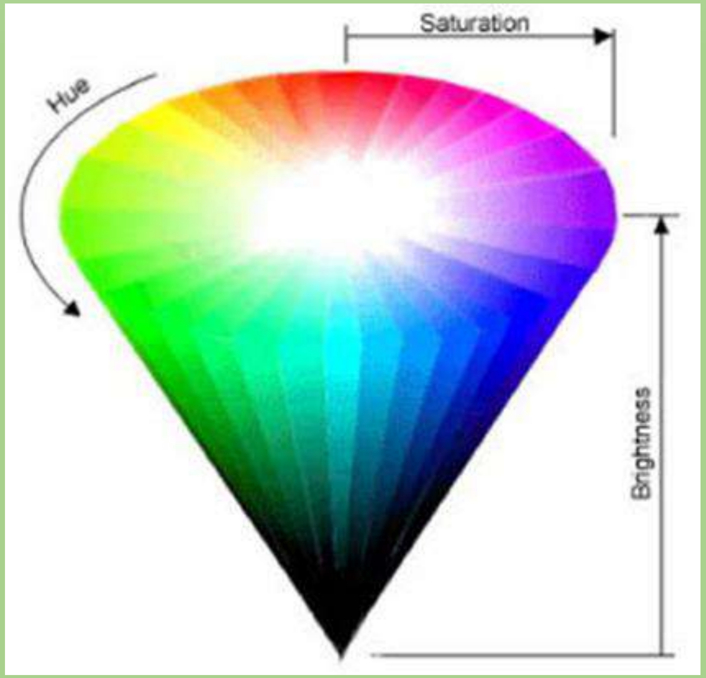
Image Analysis
HSV Color Space





Color defined by Hue, Saturation and Value
HSV

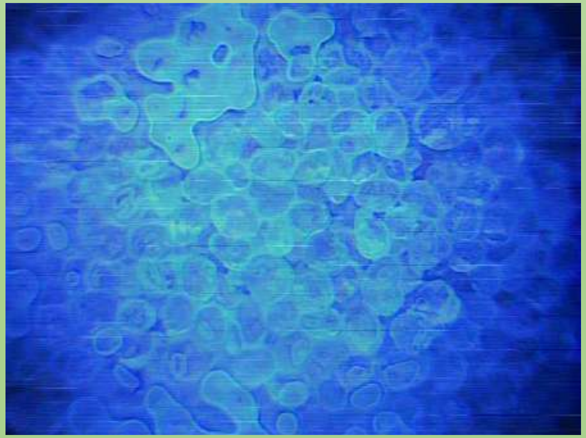
OIP Stills and Visible Images

Fluorescence images of fuel globules in soil

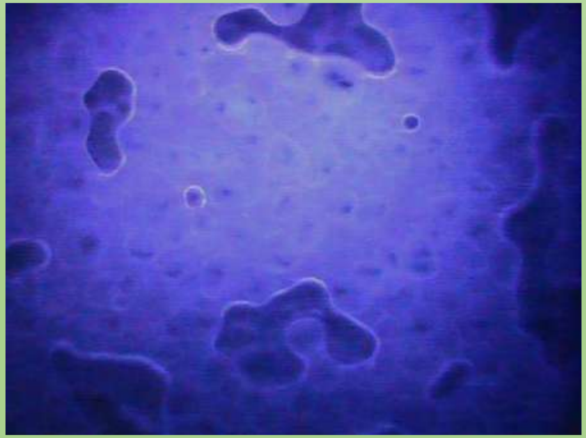
Same image under Visible light
Sand matrix

- UV and Visible still images can be captured at any point during the log
- A UV and Visible image will be capture automatically every time probe advancement is stopped to add a rod to the tool string
- Visible still images can be helpful in assessing soil textures

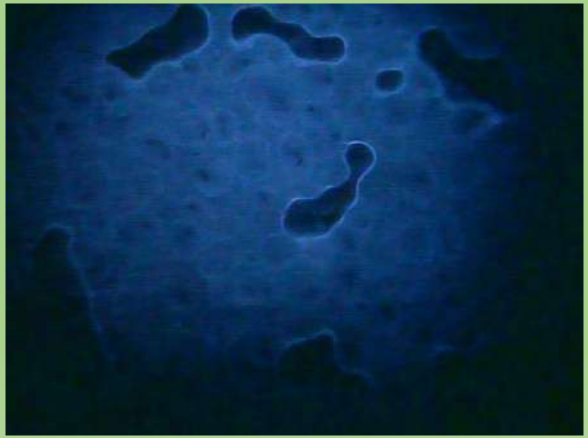
Color Analysis



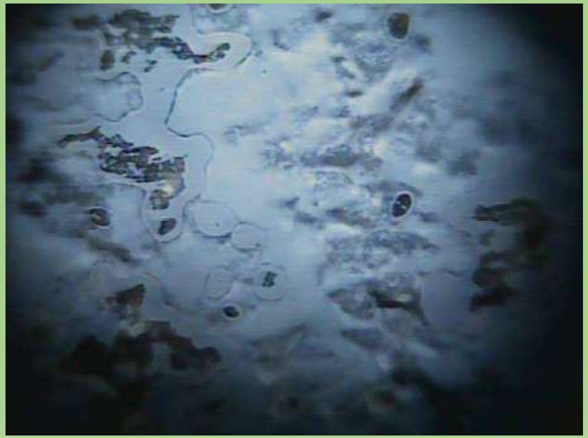
Motor Oil SAE 30



Diesel



Unleaded Gasoline



Crude Oil

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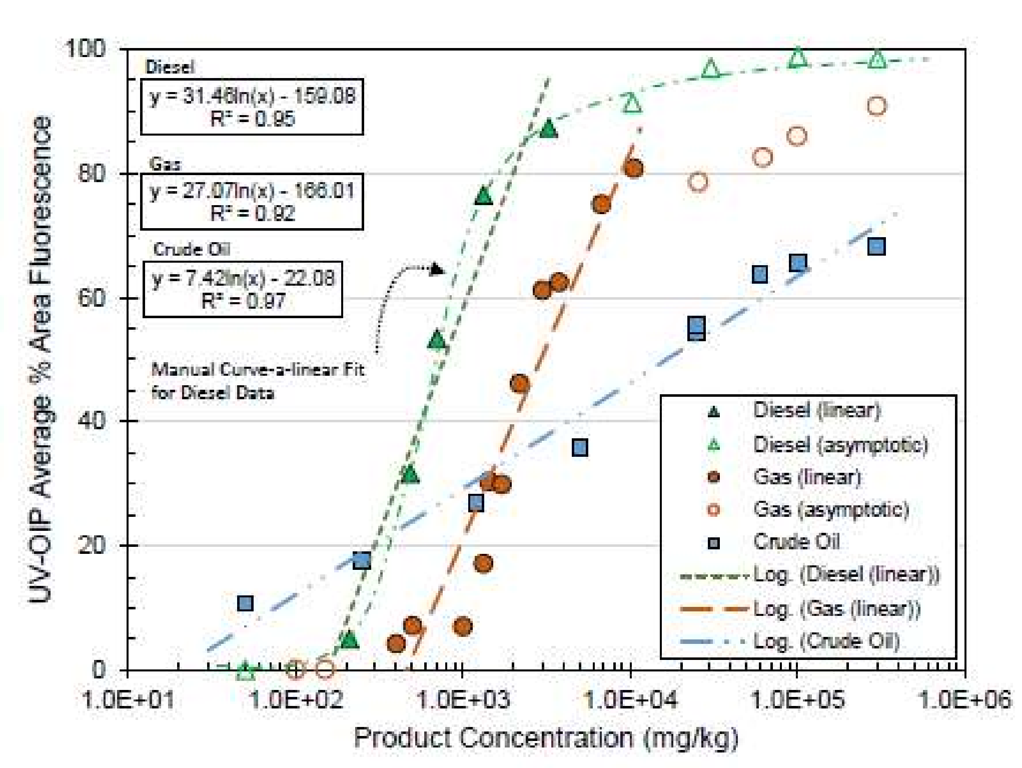
OIP Fuel Fluorescence



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.

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Quality Assurance (QA) Testing

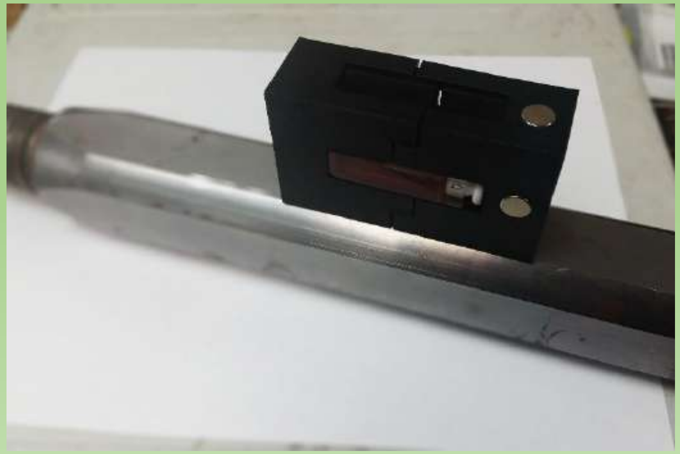
- QA Tests are performed before and after each log
- EC Dipole Test
- Optical Test

Testing the EC Dipole

EC Test Load

OIP Cuvette Holder

Testing the Optical Components and System Response



Optical QA Test

- Image Assessment
  - Visible Target – 1mm Grid
  - Focus and Color Check
- UV Background Assessment
  - Black Box – Blank
- UV Fluorescence Assessment
  - Diesel
  - Motor Oil – SAE 30

Visible Target

Black Box

Diesel Fuel Cuvette

Motor Oil Cuvette

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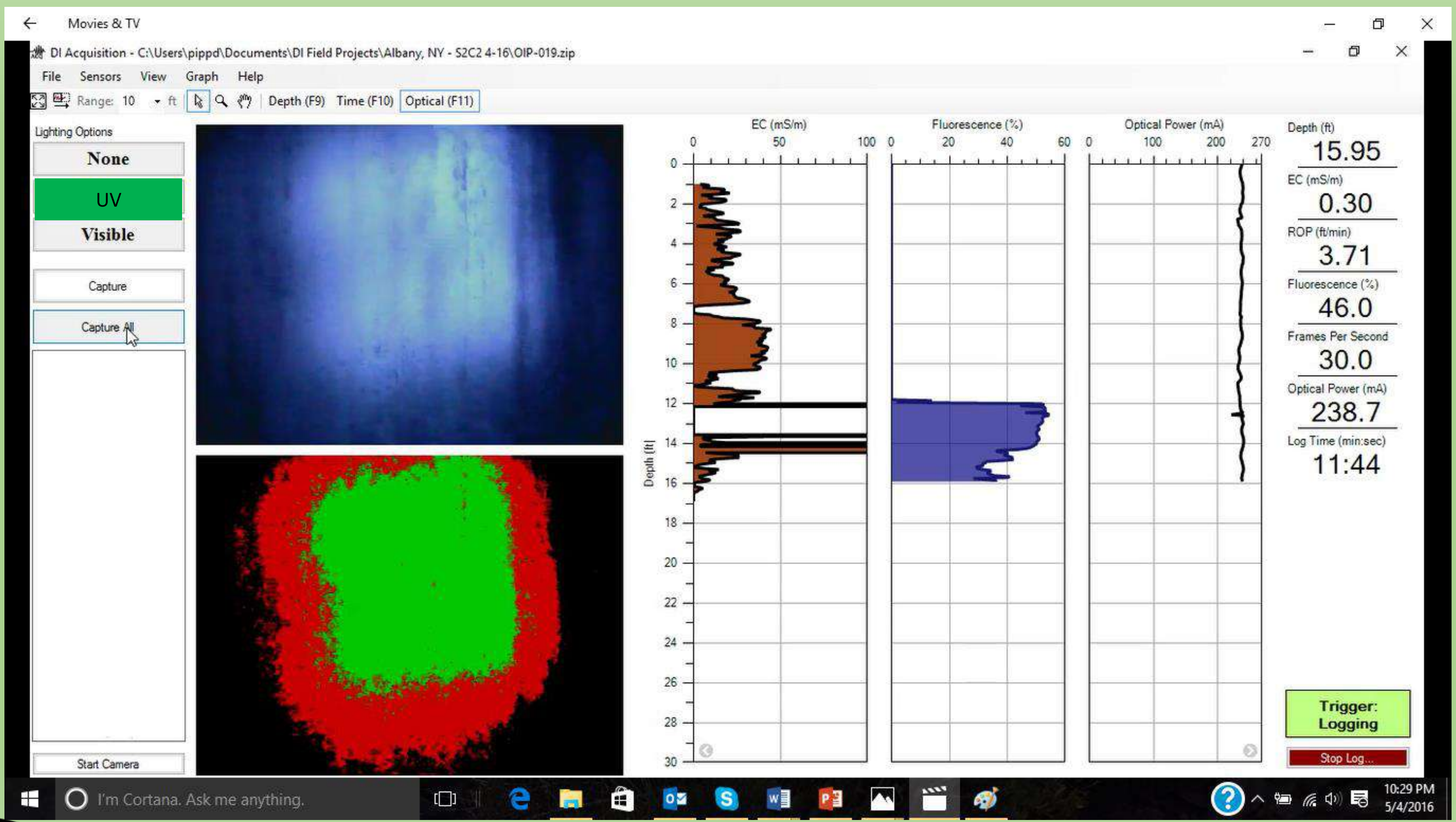
OIP DI Acquisition Software



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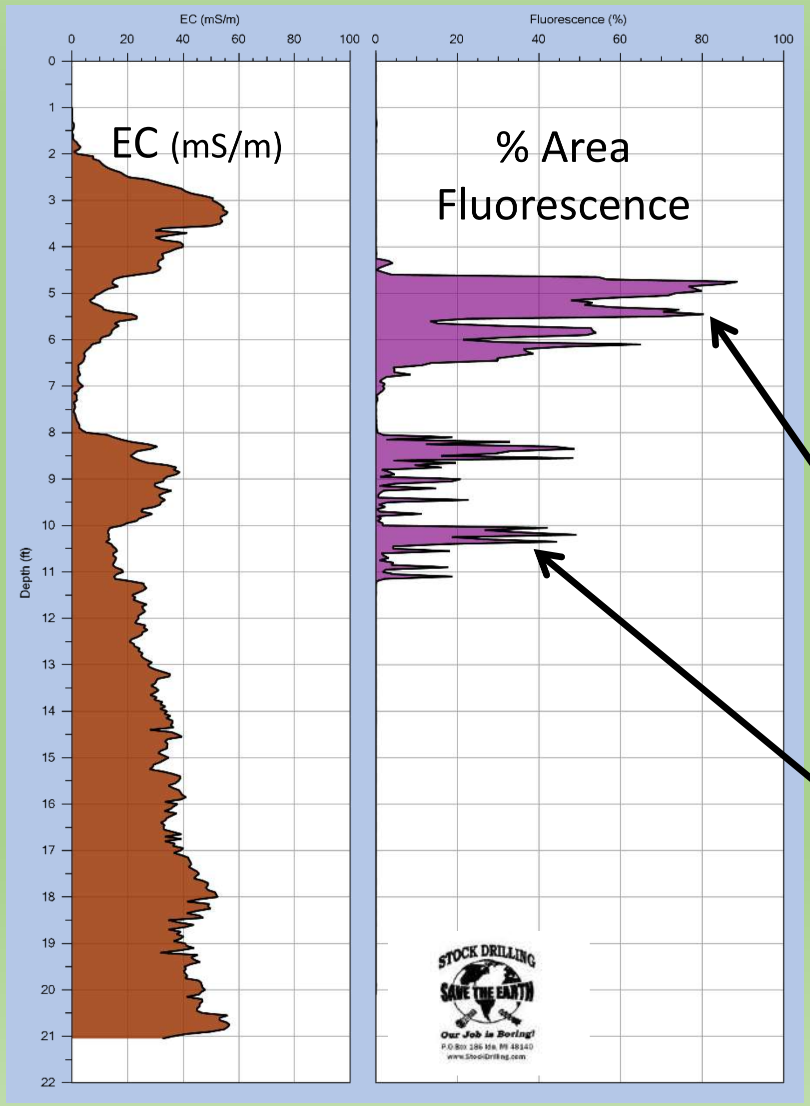
- Requires DI Acquisition 3.0 or newer
- Large log files (200+ MB)

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.

OIP Log GL-19



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

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

Image from 5.0ft

Image from 10.20ft

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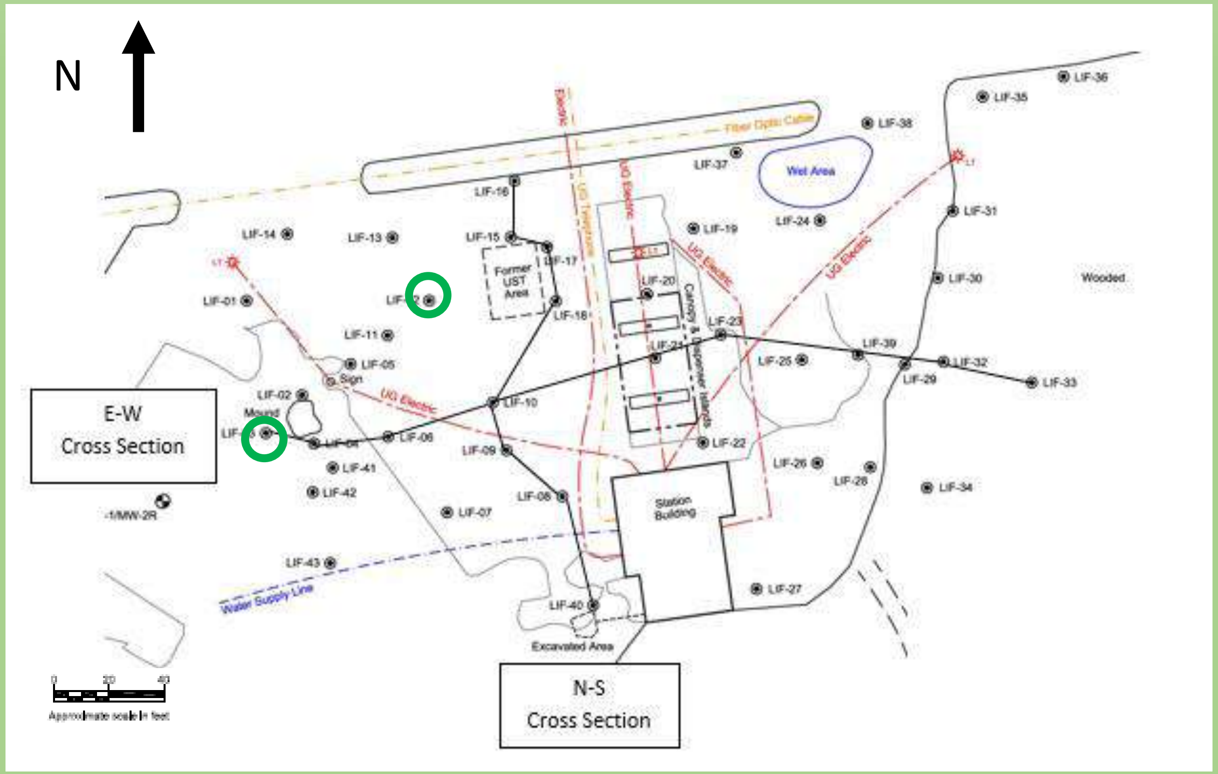
Field Site: Brooklyn, Michigan

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.

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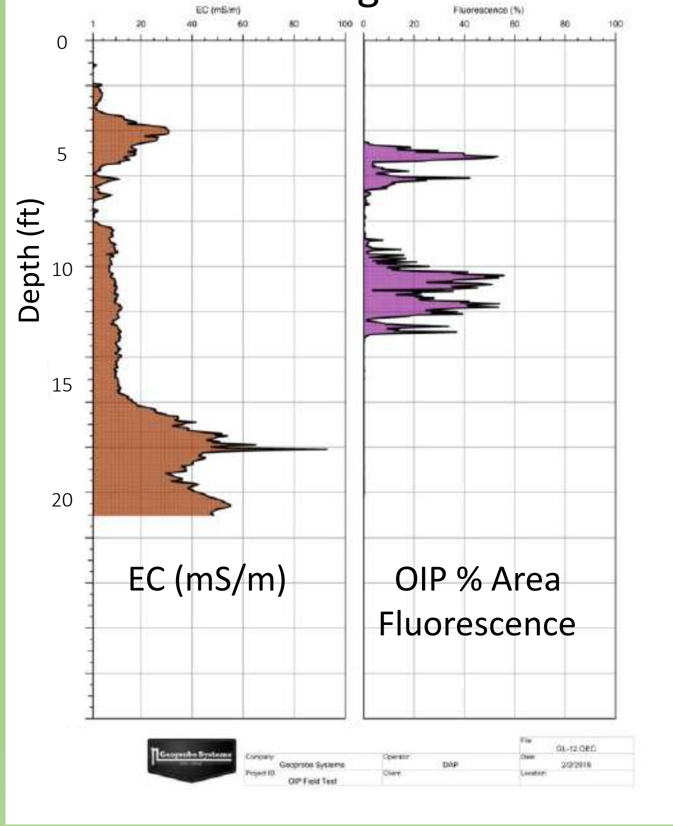
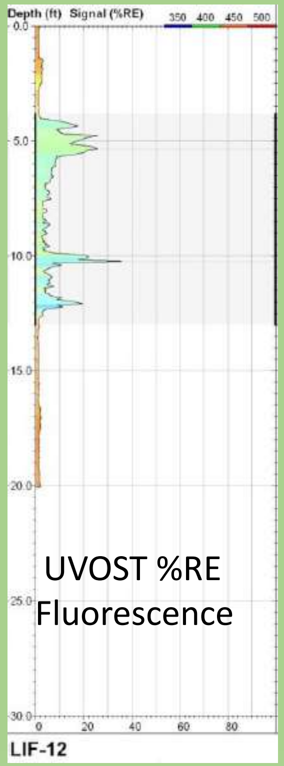
Field Site Data
OIP-EC to UVOST Comparison

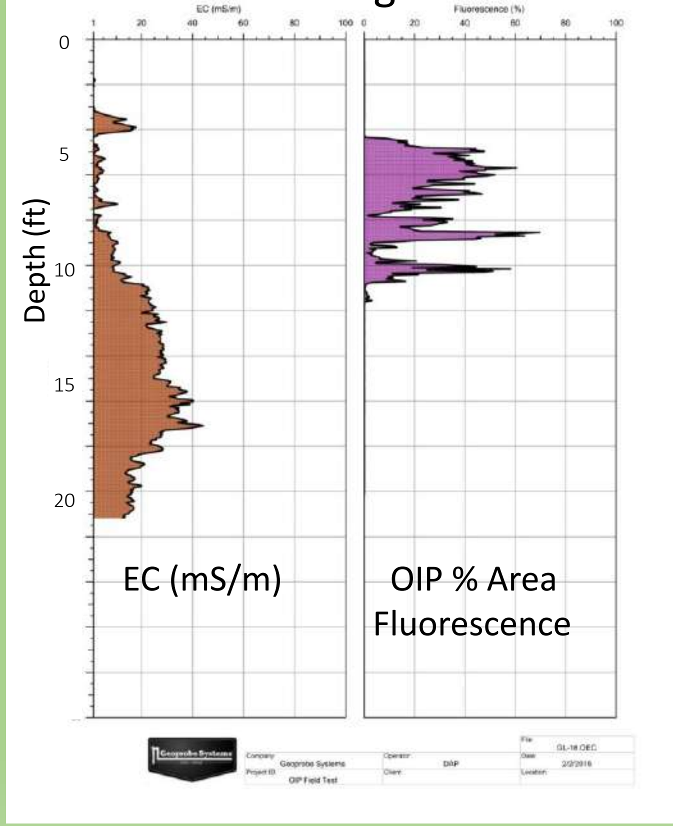
OIP Log 12



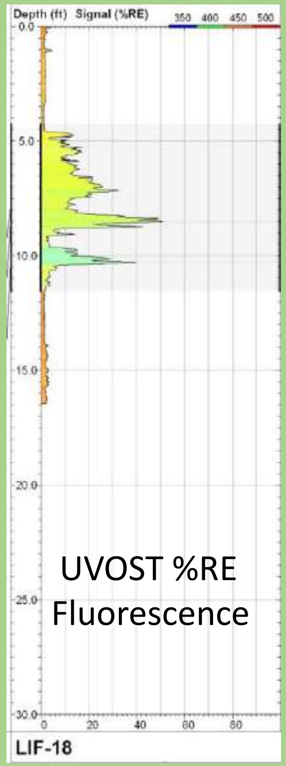
LIF UVOST Log 12



OIP Log 18



LIF UVOST Log 18



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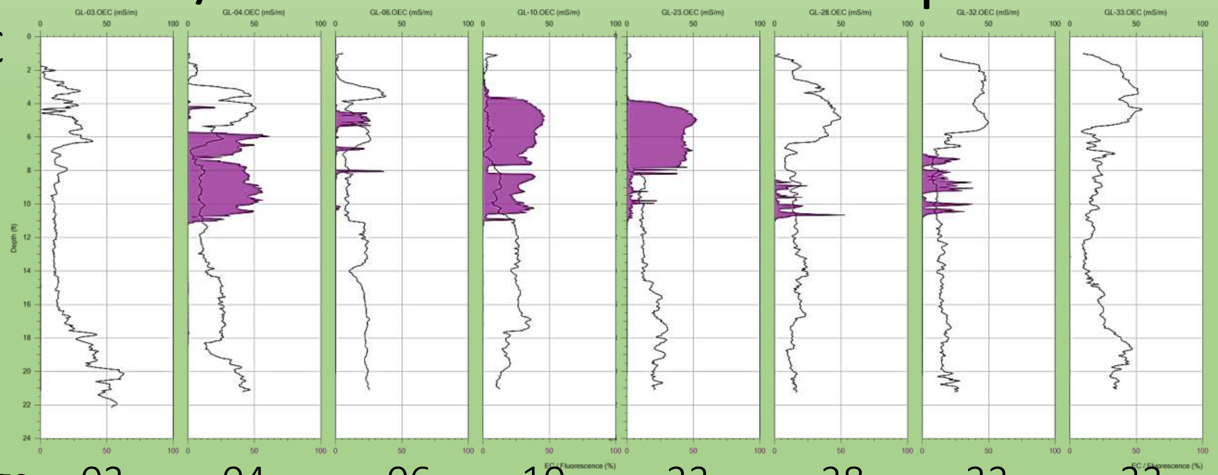
The comparison of logs 12 and 18 show very similar vertical distribution of fluorescence in both the OIP and UVOST technologies.

Field Site Data

OIP/EC to UVOST Comparison

OIP/EC

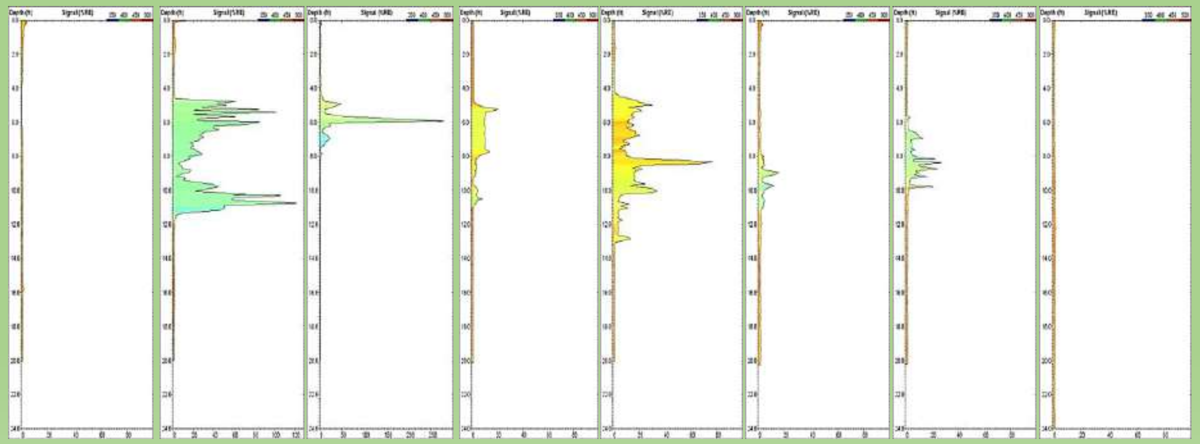
East Side



West Side

Logs: 03 04 06 10 23 28 32 33

LIF UVOST



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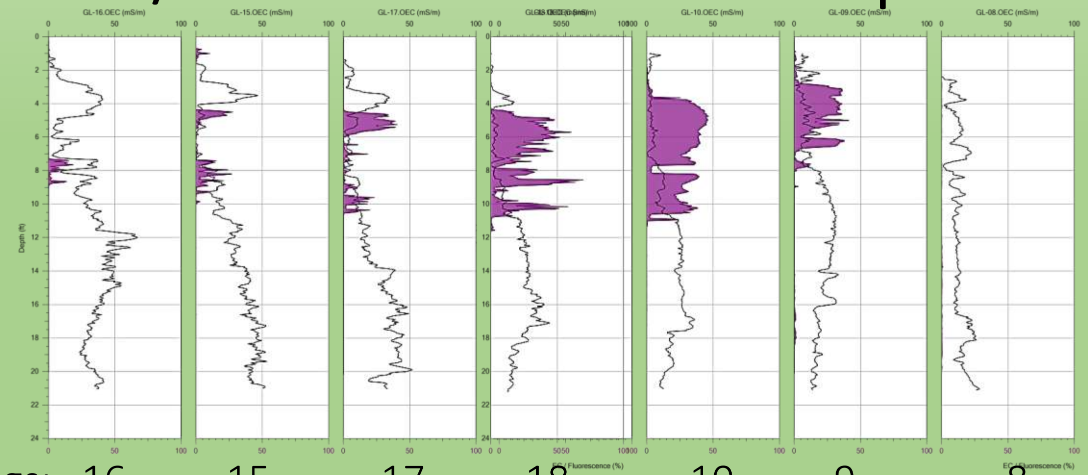
Both technologies display similar vertical and horizontal contaminant distribution.

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

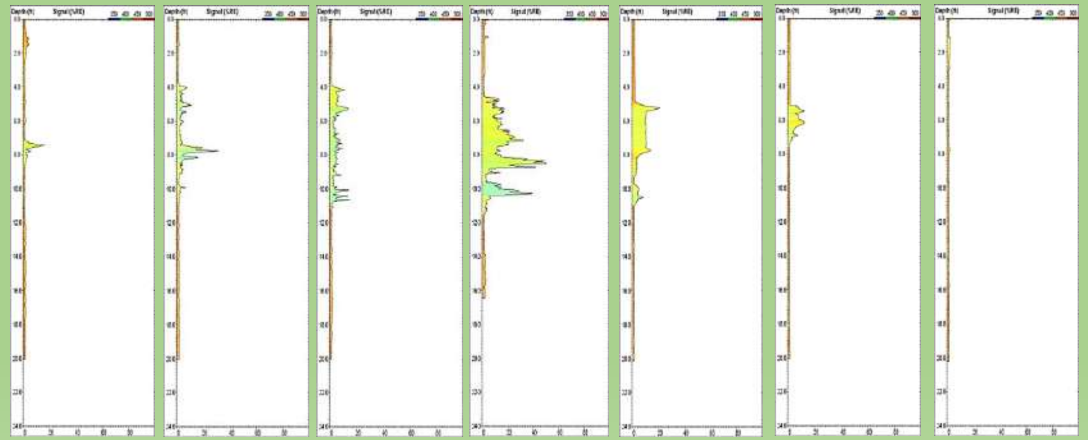
North Side



South Side

Logs: 16 15 17 18 10 9 8

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.

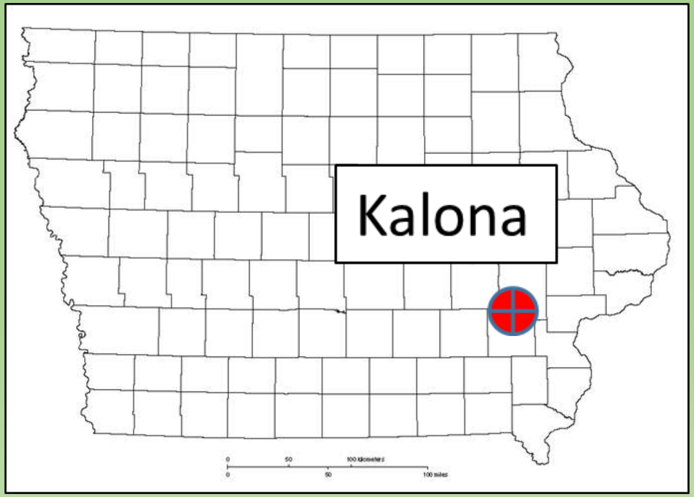
Field Site Example
Grimm Oil Site in Kalona, Iowa

Wes McCall, Geologist, Geoprobe

James Goodrich, Geologist, VJ Engineering

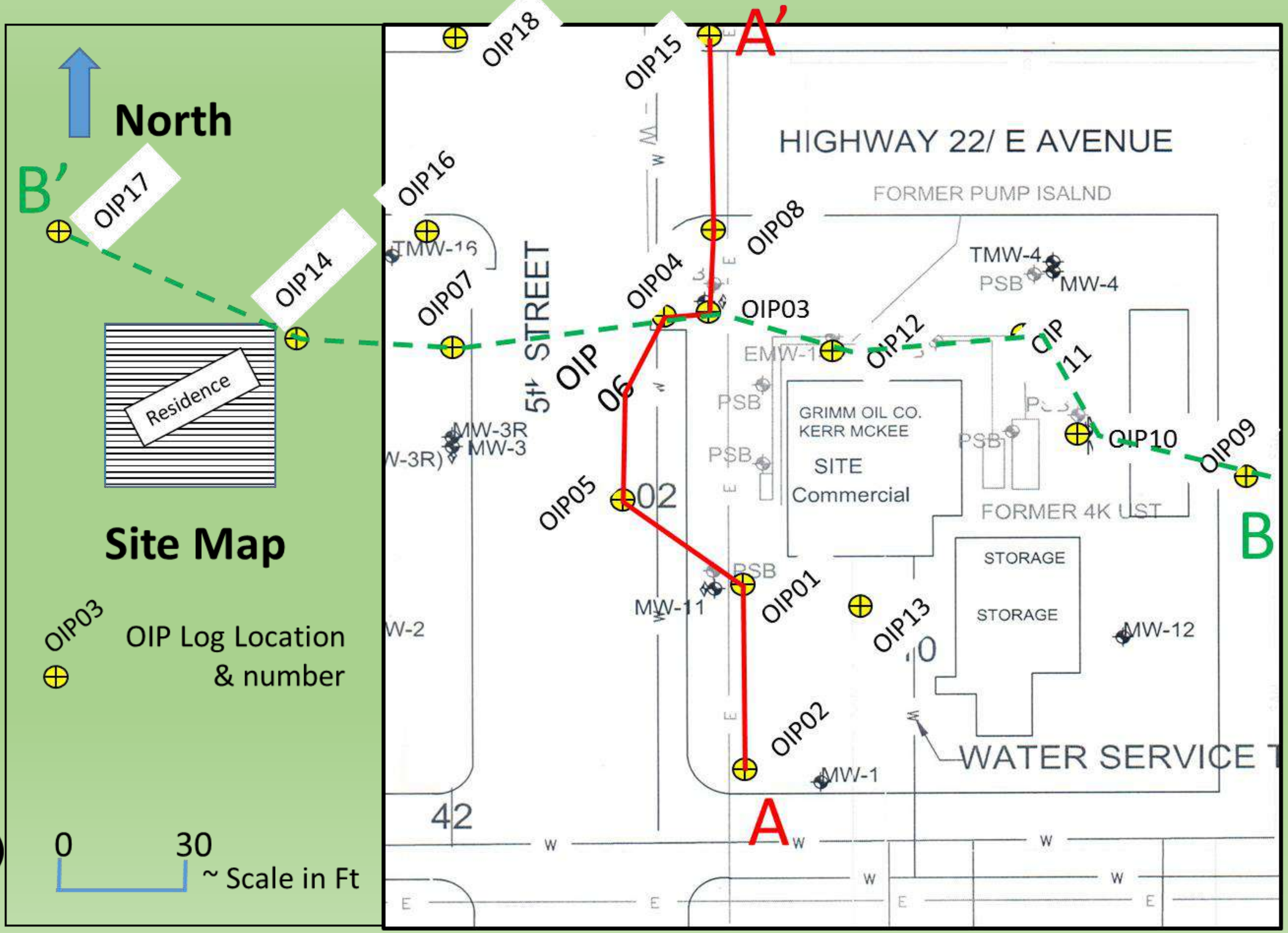
In Coordination with

Jeffrey White, PG, Iowa DNR

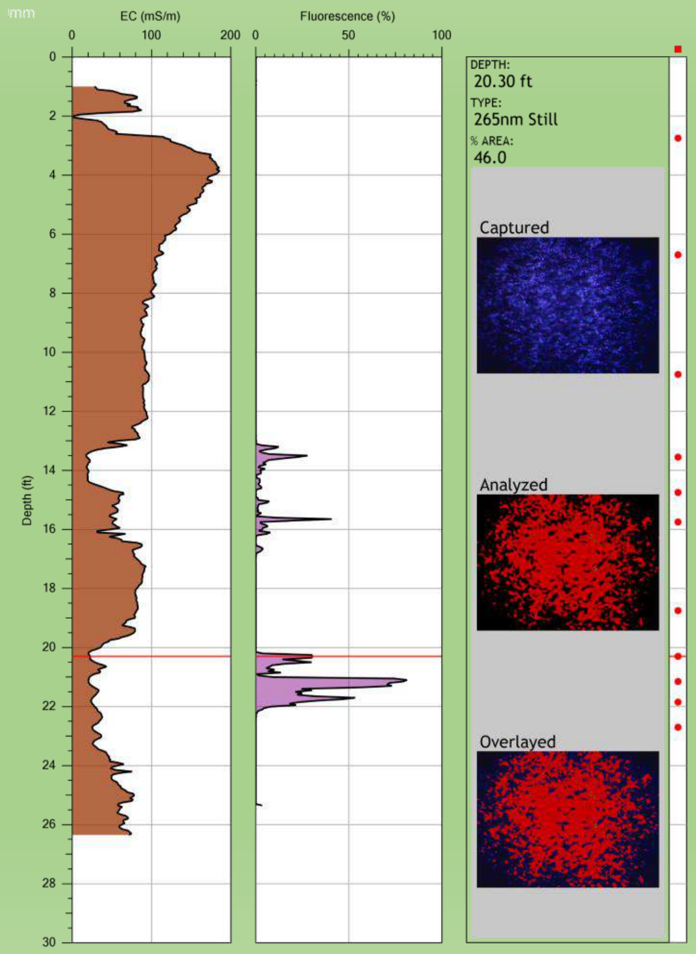


Kalona, Iowa Site Map

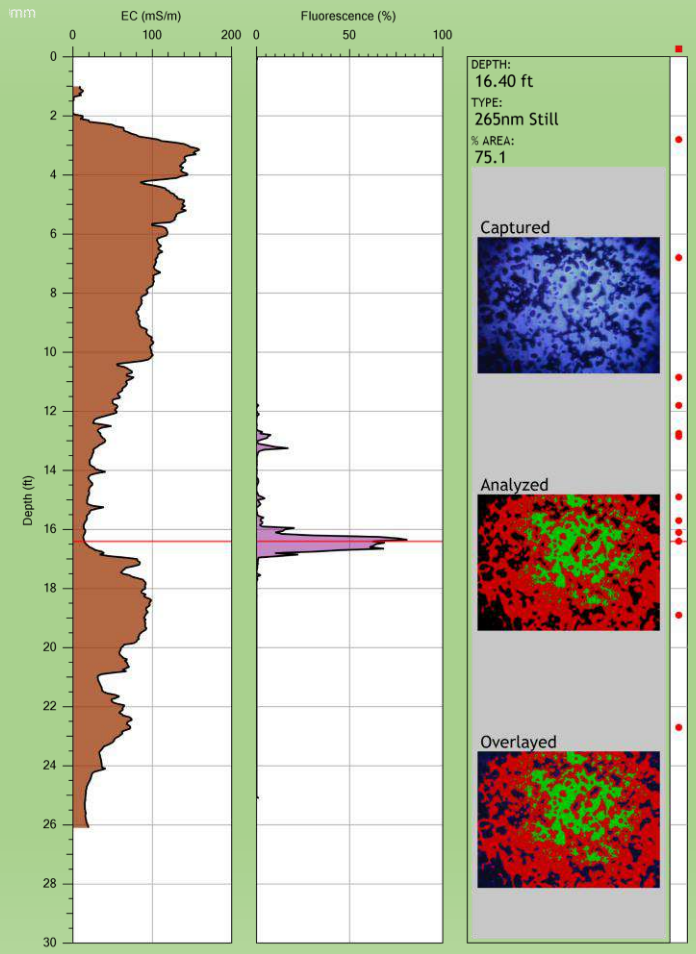
OIP Log Locations and Cross Section Lines



Kalona, Iowa Site Logs



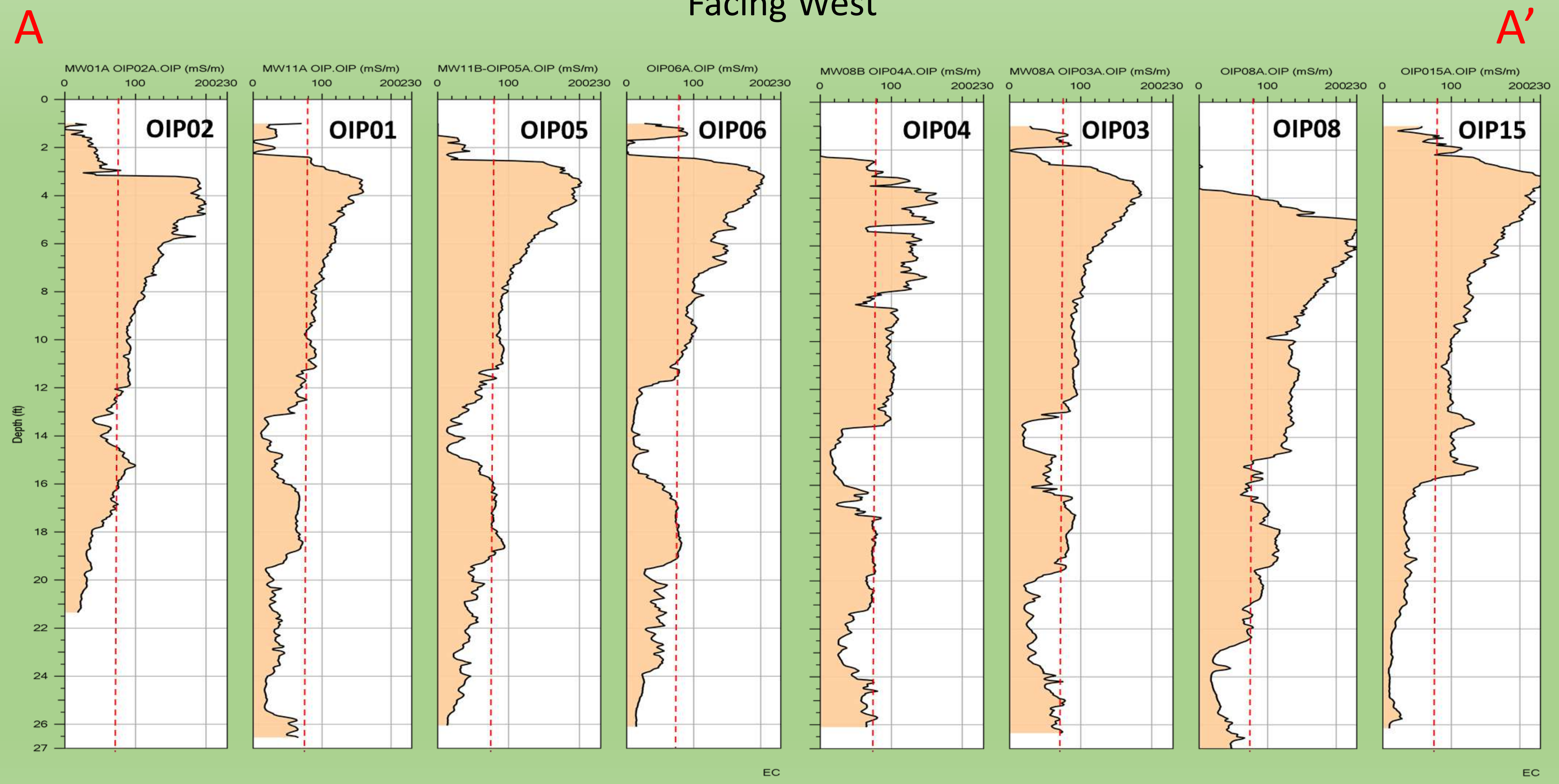
OIP - 03



OIP - 07

Kalona, Iowa Cross Section A-A’

Facing West

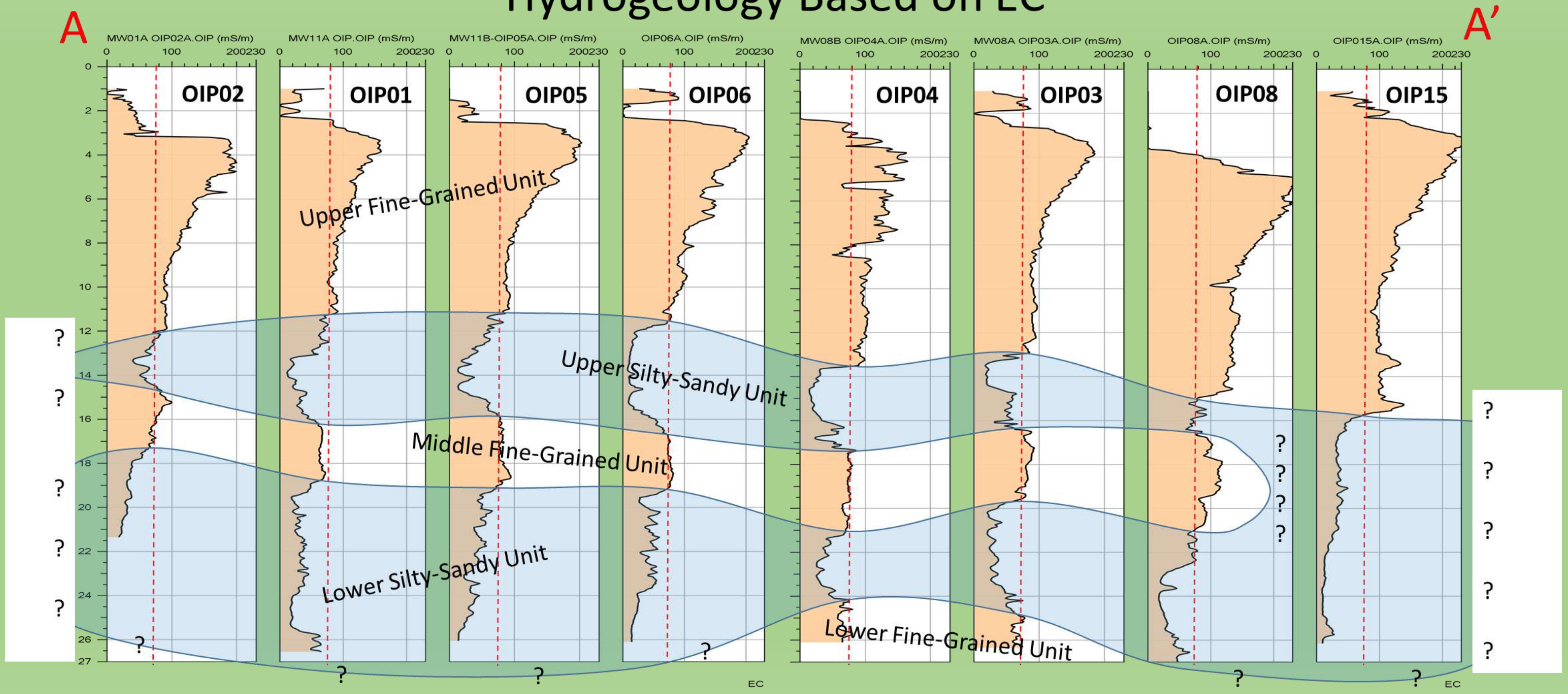


Note: Logs are displayed with equal spacing in the simplified cross sections, not equally spaced on the ground: not to scale.

Grimm Oil Facility, Kalona, Iowa

Cross Section A-A' Facing West

Hydrogeology Based on EC

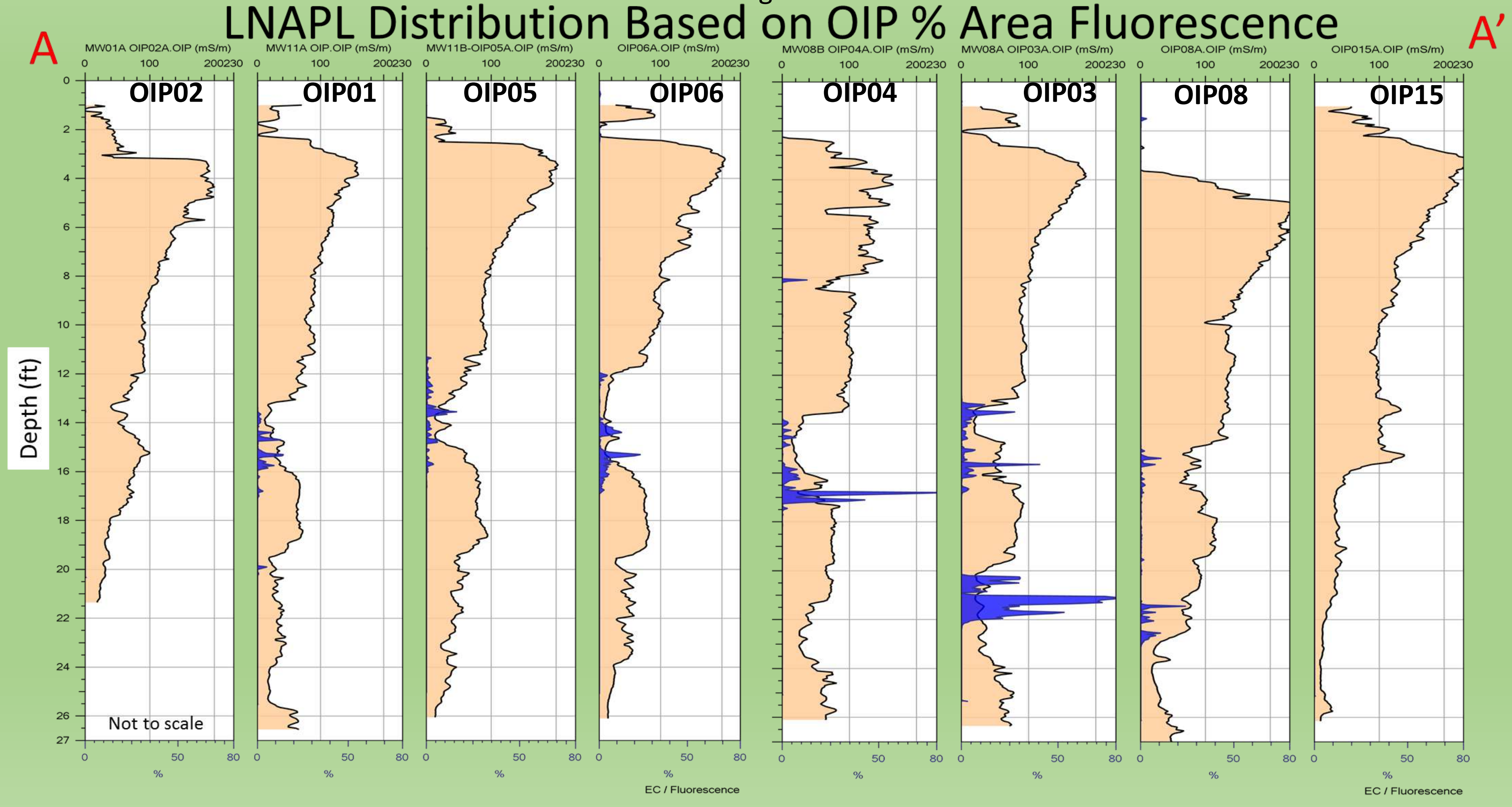


Note: Logs are displayed with equal spacing in the simplified cross sections, not equally spaced on the ground: not to scale.

Grimm Oil Facility, Kalona, Iowa

Cross Section A-A': LNAPL Fluorescence Over EC

Facing West

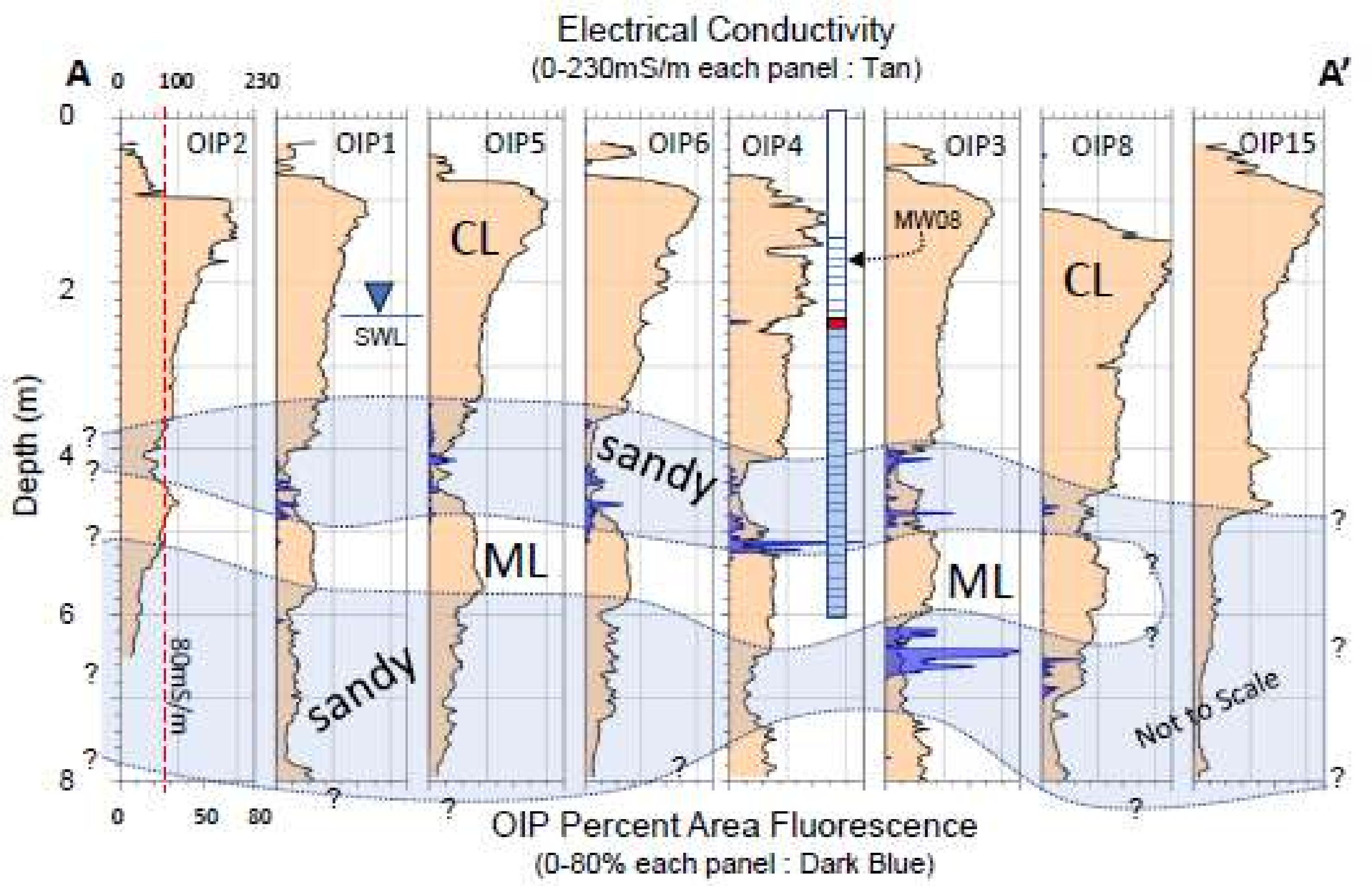


Note: Logs are displayed with equal spacing in the simplified cross sections, not equally spaced on the ground: not to scale.

Grimm Oil Facility, Kalona, Iowa

Cross Section A-A’: LNAPL Fluorescence Over EC

Facing West

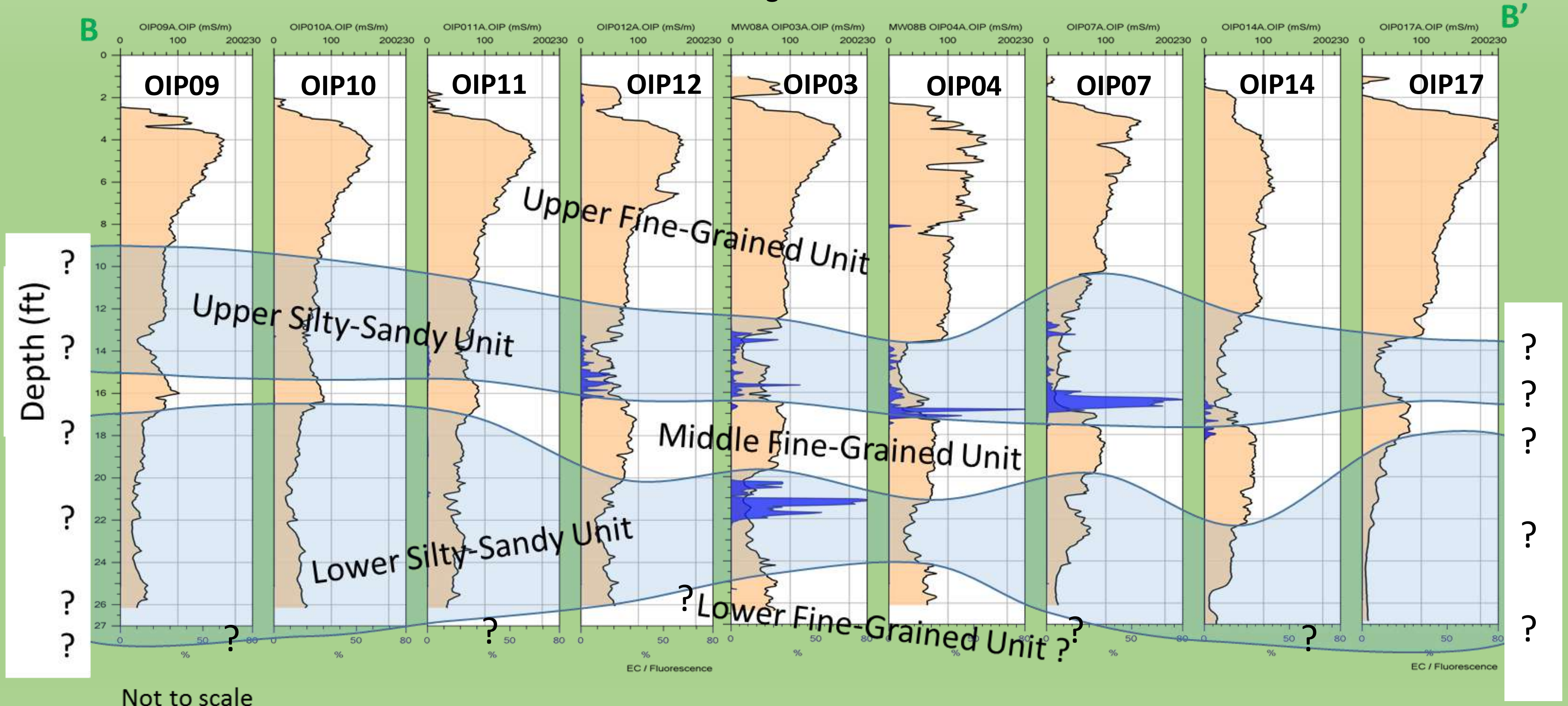


Note: Logs are displayed with equal spacing in the simplified cross sections, not equally spaced on the ground: not to scale.

Grimm Oil Facility, Kalona, Iowa

Cross Section B-B': LNAPL Fluorescence Over EC

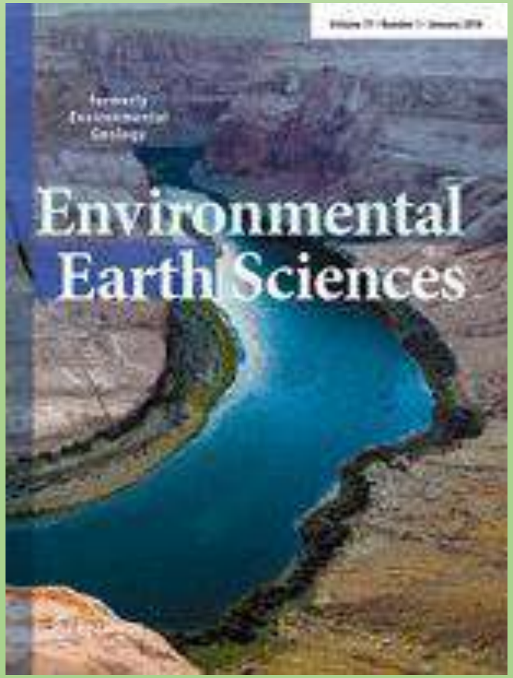
Facing South



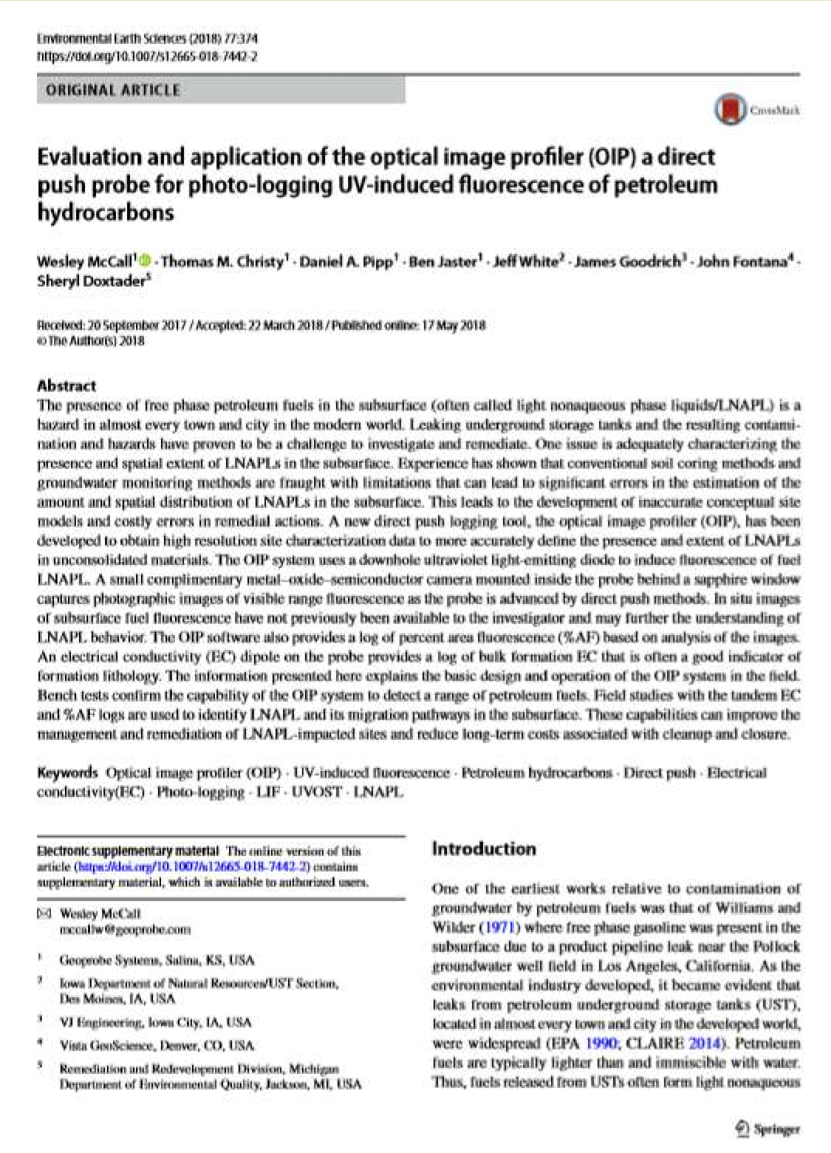
Not to scale

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

OIP Article



May 2018 Publication



Environmental Earth Sciences (2018) 77:374
https://doi.org/10.1007/s12665-018-7442-2

ORIGINAL ARTICLE

CrossMark

Evaluation and application of the optical image profiler (OIP) a direct push probe for photo-logging UV-induced fluorescence of petroleum hydrocarbons

Wesley McCall[1] · Thomas M. Christy[1] · Daniel A. Pipp[1] · Ben Jaster[1] · Jeff White[2] · James Goodrich[3] · John Fontana[4] · Sheryl Doxtader[5]

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Abstract
The presence of free phase petroleum fuels in the subsurface (often called light nonaqueous phase liquids/LNAPL) is a hazard in almost every town and city in the modern world. Leaking underground storage tanks and the resulting contamination and hazards have proven to be a challenge to investigate and remediate. One issue is adequately characterizing the presence and spatial extent of LNAPLs in the subsurface. Experience has shown that conventional soil coring methods and groundwater monitoring methods are fraught with limitations that can lead to significant errors in the estimation of the amount and spatial distribution of LNAPLs in the subsurface. This leads to the development of inaccurate conceptual site models and costly errors in remedial actions. A new direct push logging tool, the optical image profiler (OIP), has been developed to obtain high resolution site characterization data to more accurately define the presence and extent of LNAPLs in unconsolidated materials. The OIP system uses a downhole ultraviolet light-emitting diode to induce fluorescence of fuel LNAPL. A small complimentary metal–oxide–semiconductor camera mounted inside the probe behind a sapphire window captures photographic images of visible range fluorescence as the probe is advanced by direct push methods. In situ images of subsurface fuel fluorescence have not previously been available to the investigator and may further the understanding of LNAPL behavior. The OIP software also provides a log of percent area fluorescence (%AF) based on analysis of the images. An electrical conductivity (EC) dipole on the probe provides a log of bulk formation EC that is often a good indicator of formation lithology. The information presented here explains the basic design and operation of the OIP system in the field. Bench tests confirm the capability of the OIP system to detect a range of petroleum fuels. Field studies with the tandem EC and %AF logs are used to identify LNAPL and its migration pathways in the subsurface. These capabilities can improve the management and remediation of LNAPL-impacted sites and reduce long-term costs associated with cleanup and closure.

Keywords Optical image profiler (OIP) · UV-induced fluorescence · Petroleum hydrocarbons · Direct push · Electrical conductivity(EC) · Photo-logging · LIF · UVOST · LNAPL

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s12665-018-7442-2) contains supplementary material, which is available to authorized users.

✉ Wesley McCall
mccallw@geoprobe.com

1 Geoprobe Systems, Salina, KS, USA
2 Iowa Department of Natural Resources/UST Section, Des Moines, IA, USA
3 VJ Engineering, Iowa City, IA, USA
4 Vista GeoScience, Denver, CO, USA
5 Remediation and Redevelopment Division, Michigan Department of Environmental Quality, Jackson, MI, USA

Introduction

One of the earliest works relative to contamination of groundwater by petroleum fuels was that of Williams and Wilder (1971) where free phase gasoline was present in the subsurface due to a product pipeline leak near the Pollock groundwater well field in Los Angeles, California. As the environmental industry developed, it became evident that leaks from petroleum underground storage tanks (UST), located in almost every town and city in the developed world, were widespread (EPA 1990; CLAIRE 2014). Petroleum fuels are typically lighter than and immiscible with water. Thus, fuels released from USTs often form light nonaqueous

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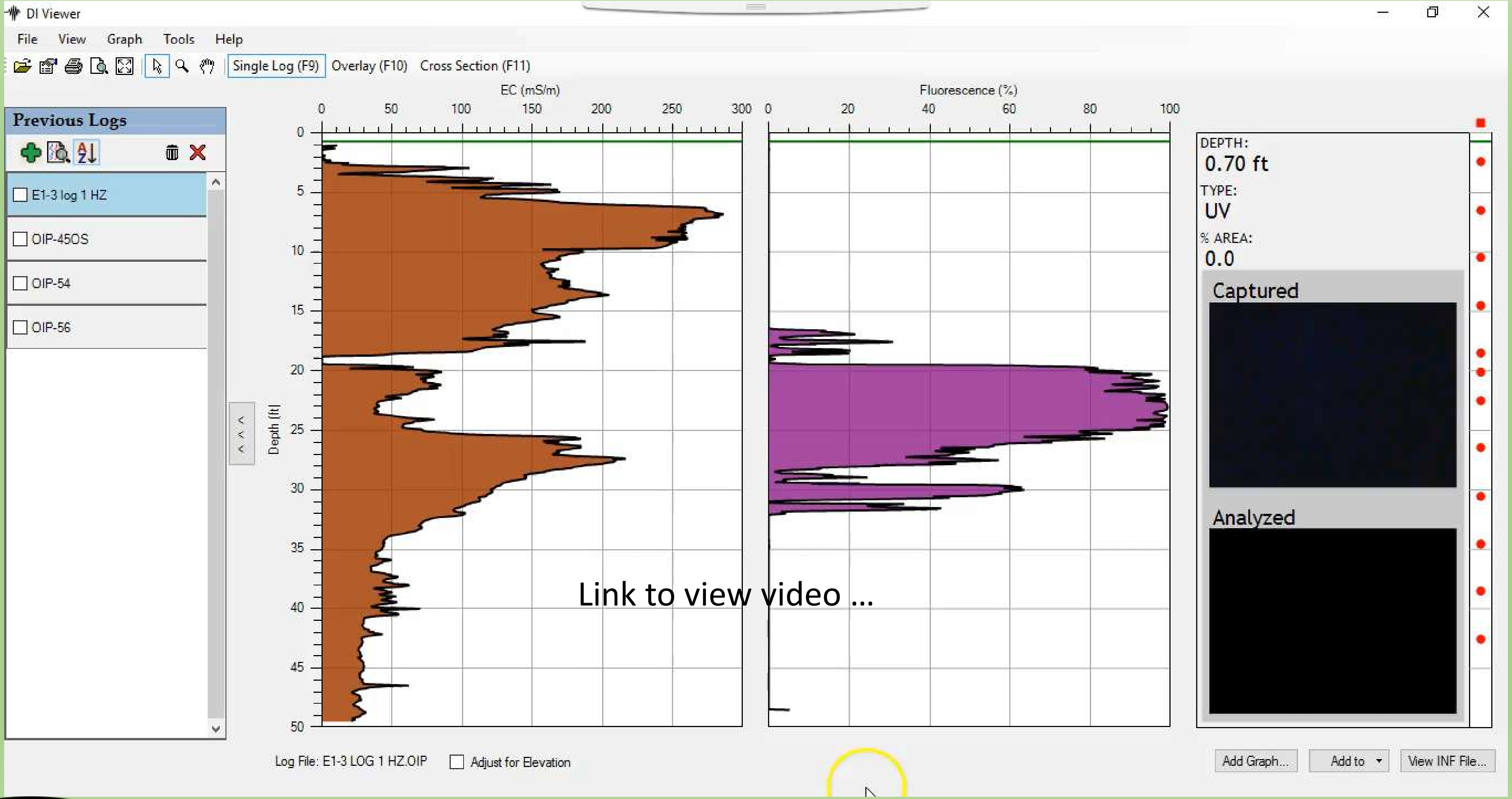
Viewing OIP Logs – DI Viewer



Coming OIP Enhancements
OIP-G & OIP-HPT

520nm
Green Laser Diode
For use with
Coal Tar
Creosote
Bunker Fuels

520nm Green Laser Diode
combined with IR LED

OiHPT - Addition of HPT to OIP
(UV & G) Probes for Permeability
Measurements

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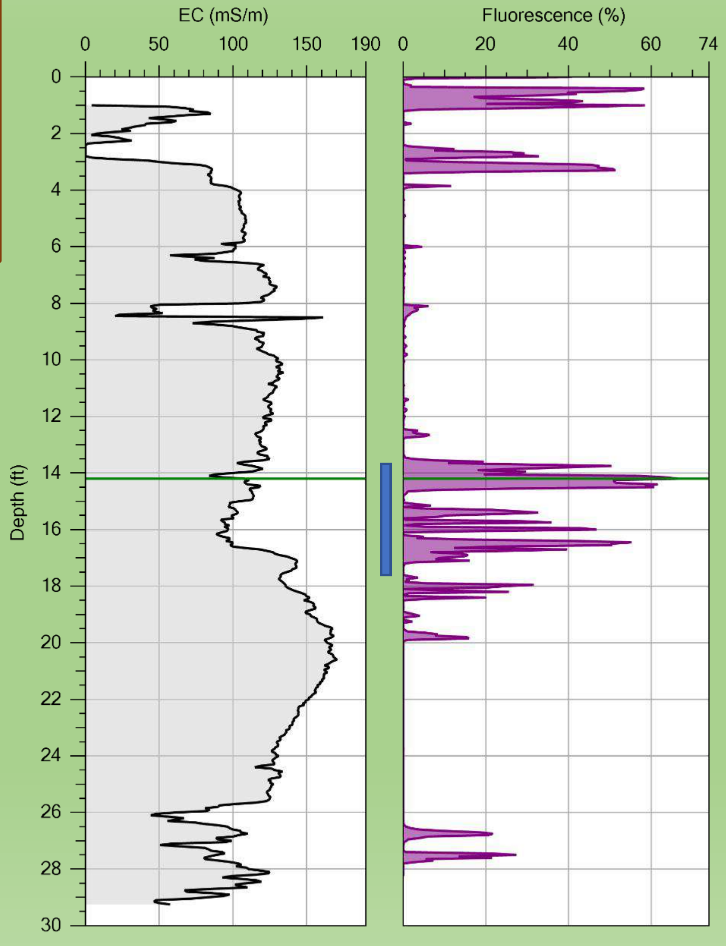
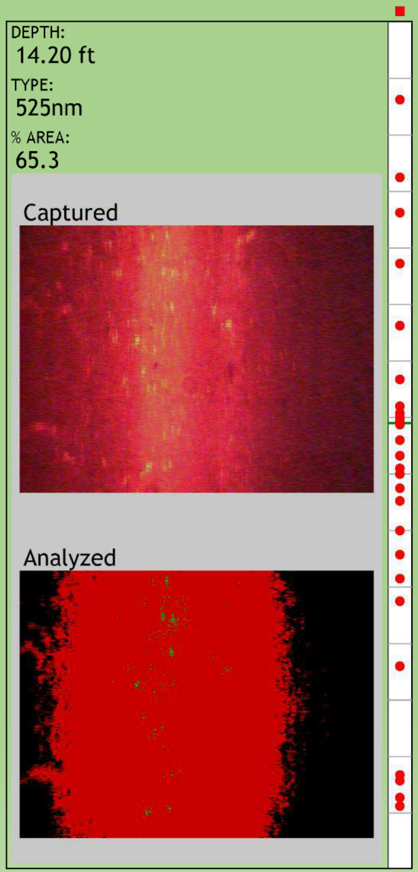
OIP-G Log
Wellington, KS MGP

Wellington MGP, circa 1896

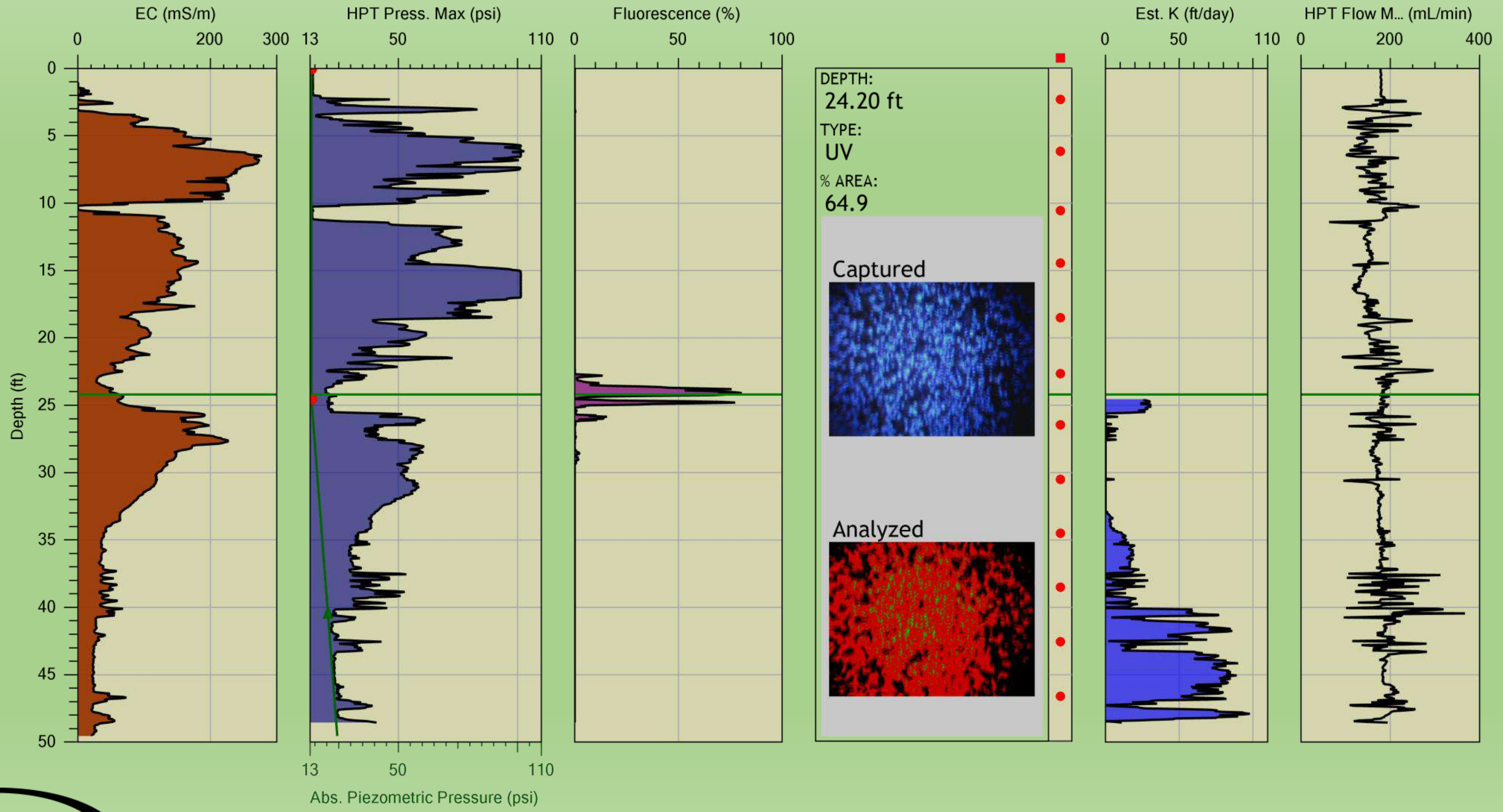




Coal Tar DNAPL

DT22 Core from 13.5ft-17.5ft pored off Coal Tar DNAPL which separated from water overnight

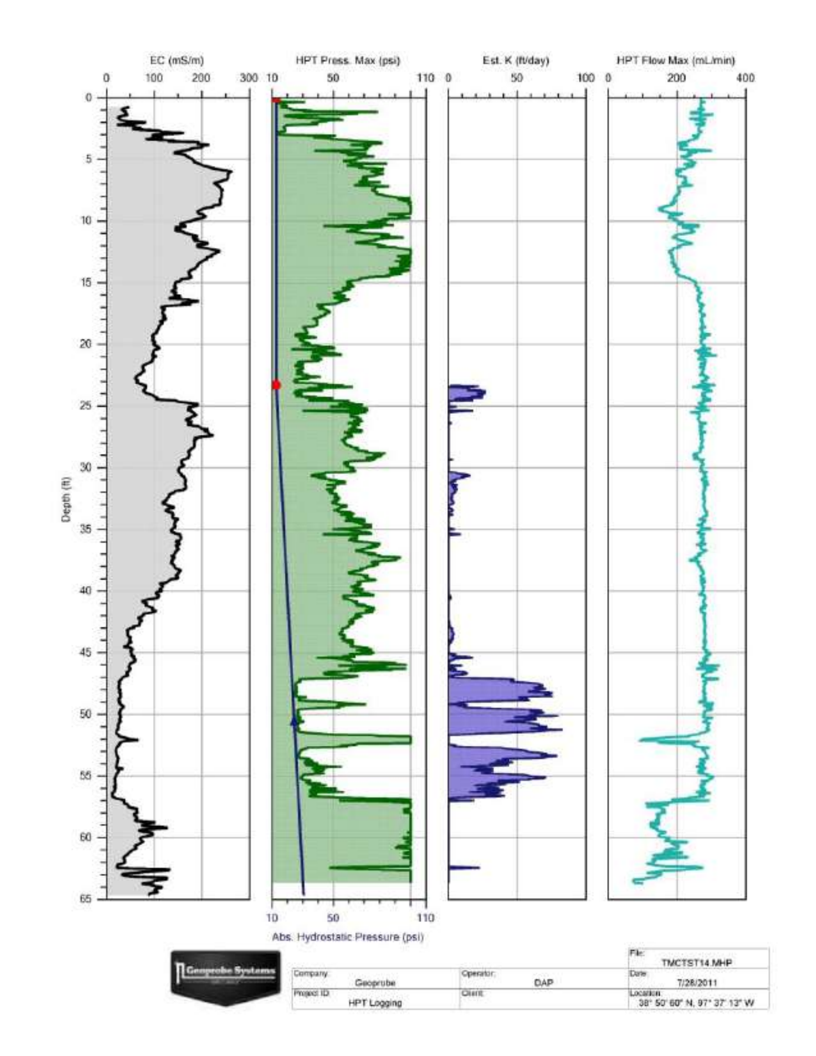
OiHPT-UV Log



Map the presence of (residual) NAPL knowing how it is affected by permeability and contaminant migration pathways.

Other HRSC Tools:
Hydraulic Profiling Tool (HPT)

- Graphs EC, HPT Pressure & Flow
- Calculates Hydrostatic Profile and Estimated Hydraulic Conductivity (K)
- True Measurement of Formation Permeability
- Calculate an estimate of GW Specific Conductance



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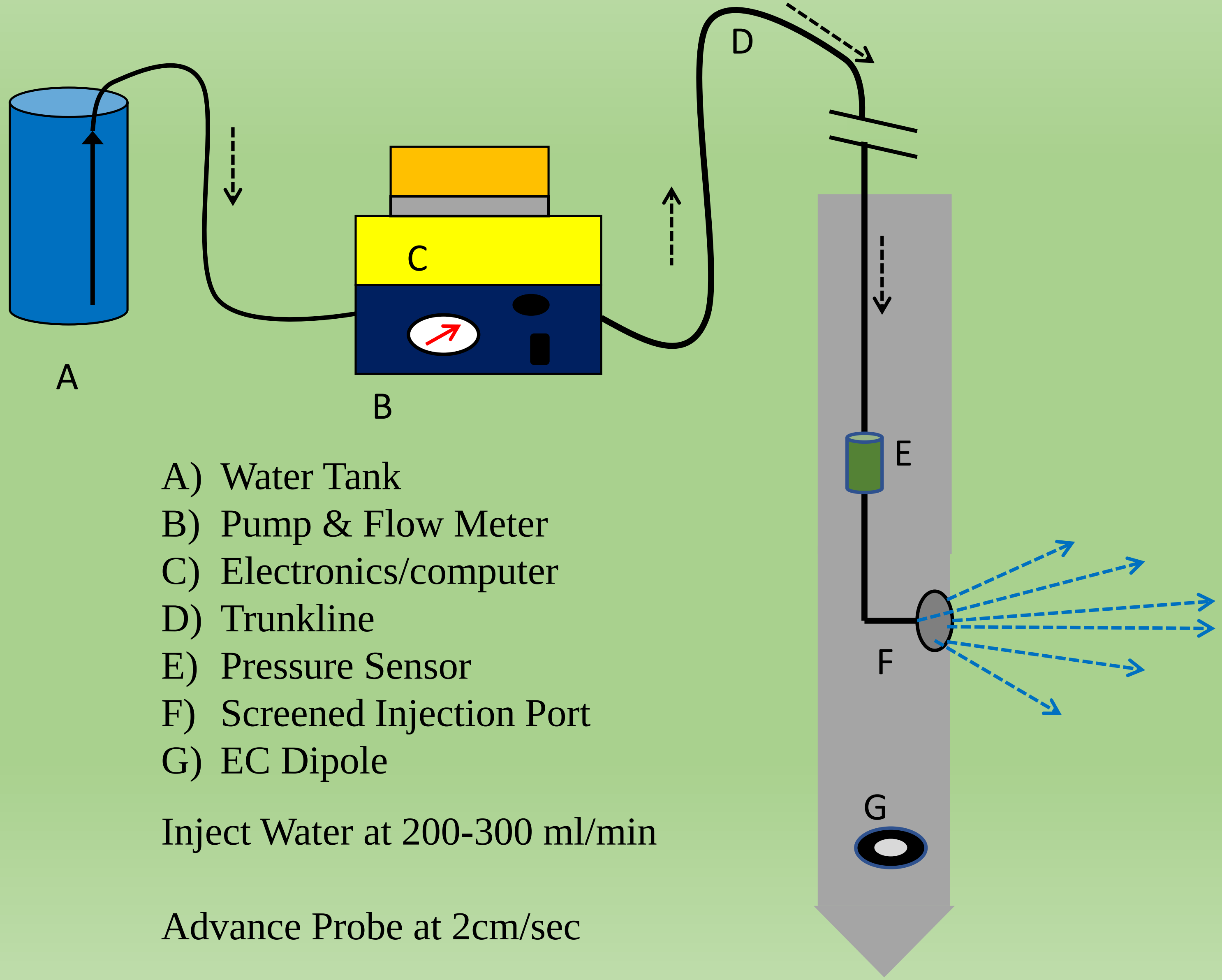
HPT Principles of Operation



A) Water Tank
B) Pump & Flow Meter
C) Electronics/computer
D) Trunkline
E) Pressure Sensor
F) Screened Injection Port
G) EC Dipole

Inject Water at 200-300 ml/min

Advance Probe at 2cm/sec

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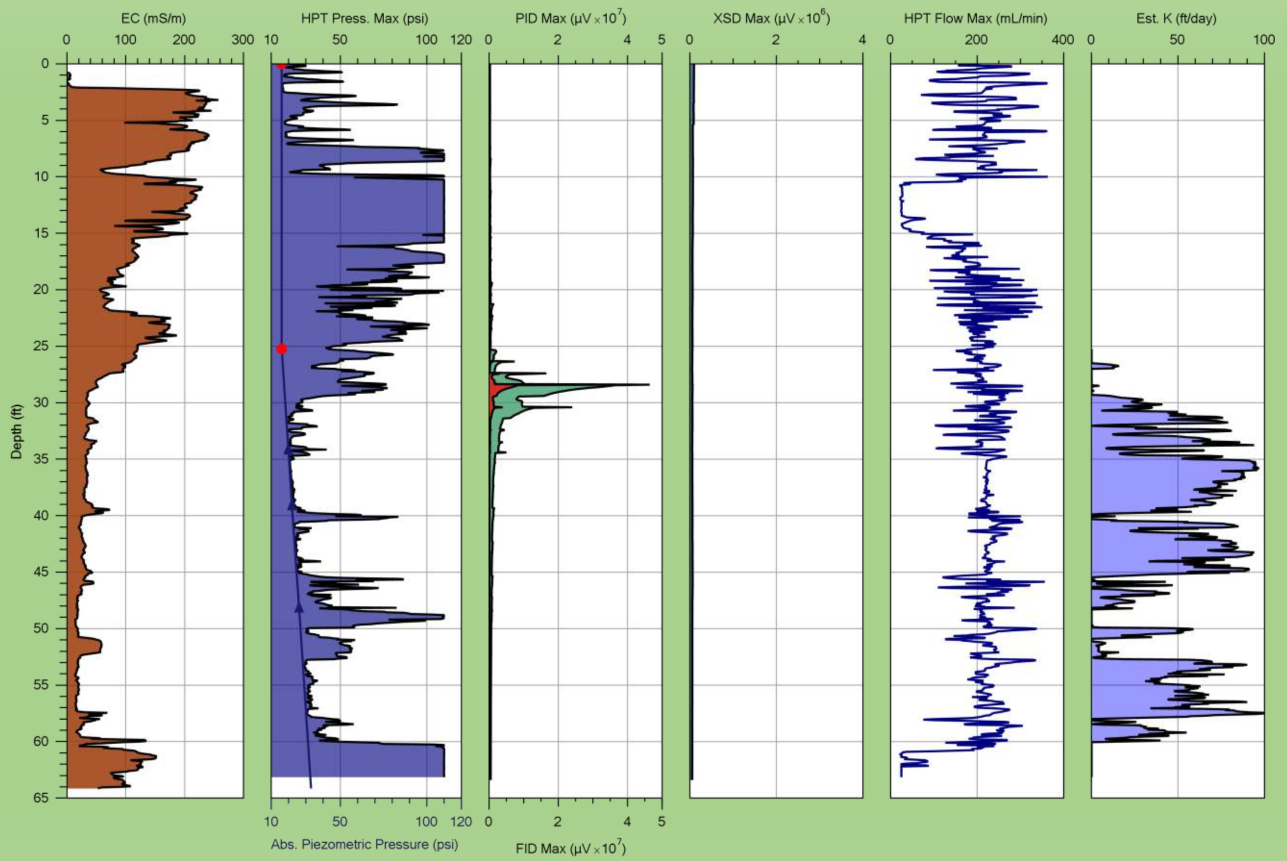
Other HRSC Tools:
Membrane Interface Probe (MIP)



Mapping of Dissolved to Free Phase volatile organic compounds (VOCs) along with EC and HPT lithology characterization

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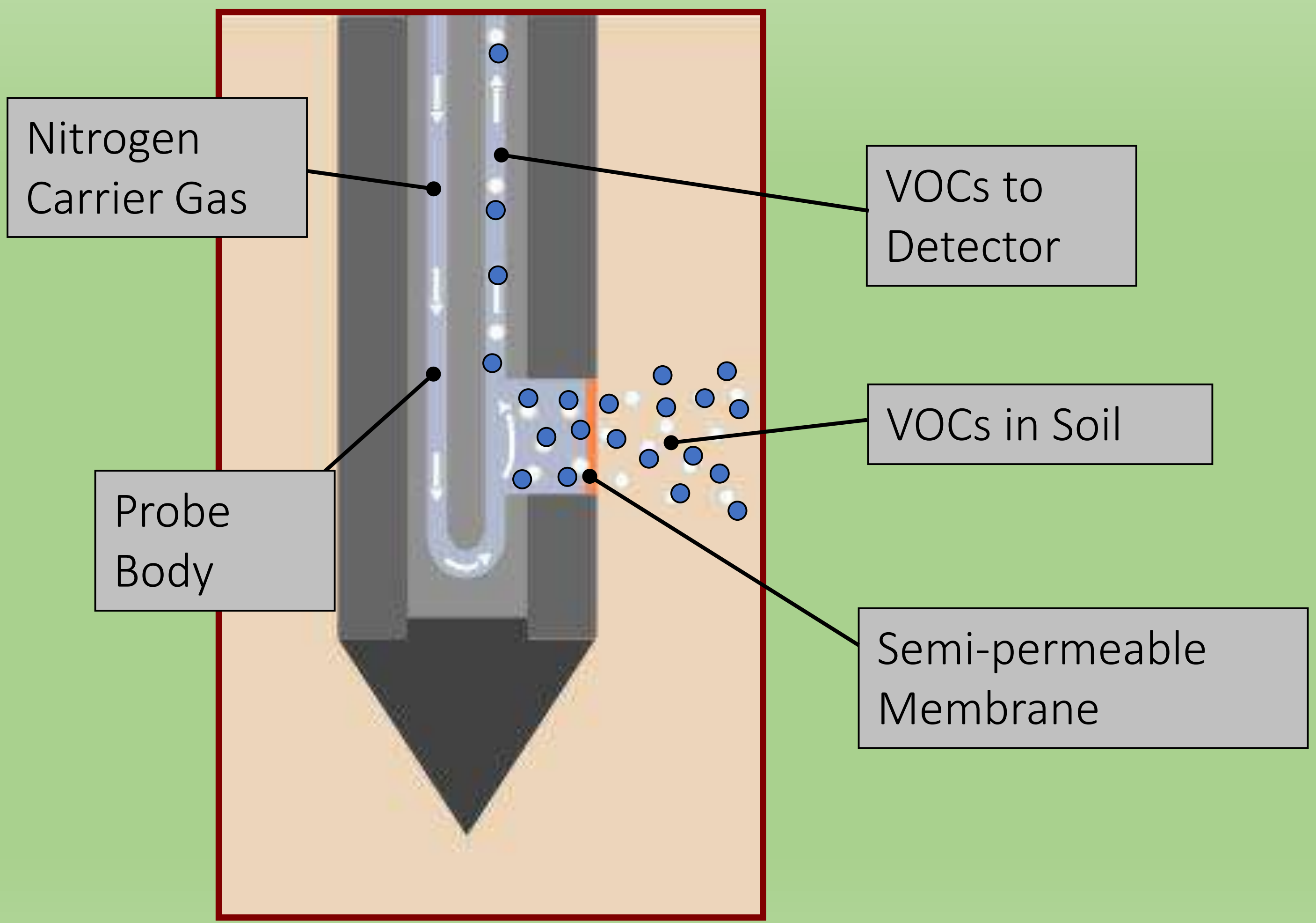
MIP Theory of Operation



Under a Concentration Gradient VOCs move across the Membrane via diffusion and then are carried to the Detector at the surface in an Inert Carrier Gas

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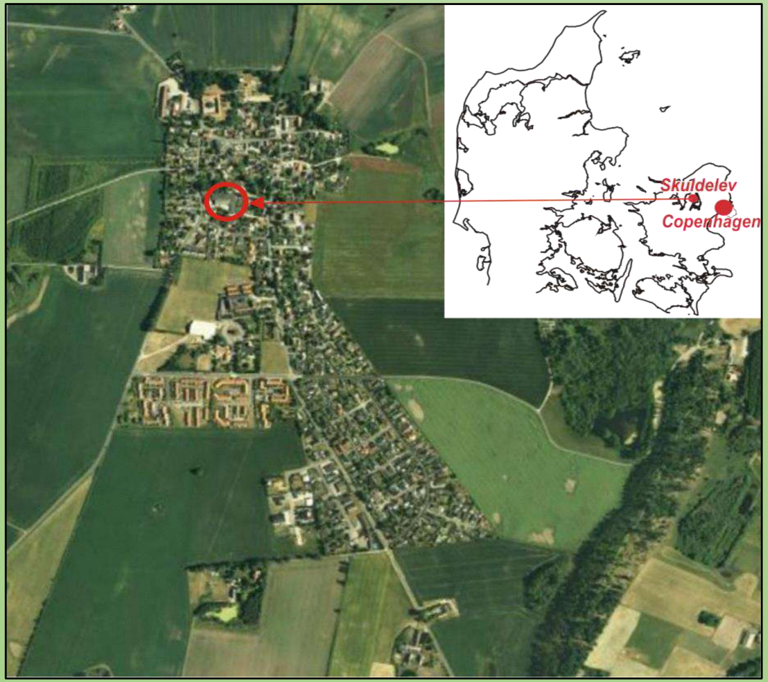
MiHPT Field Site Example: Skuldelev, Denmark



Here the insert map shows that Skuldelev is located about one hour west of Copenhagen in Denmark. A small community in the pastoral countryside.

Glaciated Region

Site underlain by glacial till and related unconsolidated deposits

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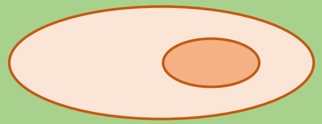
Skuldelev, DK Site Map

MiHpt Log X - - - -

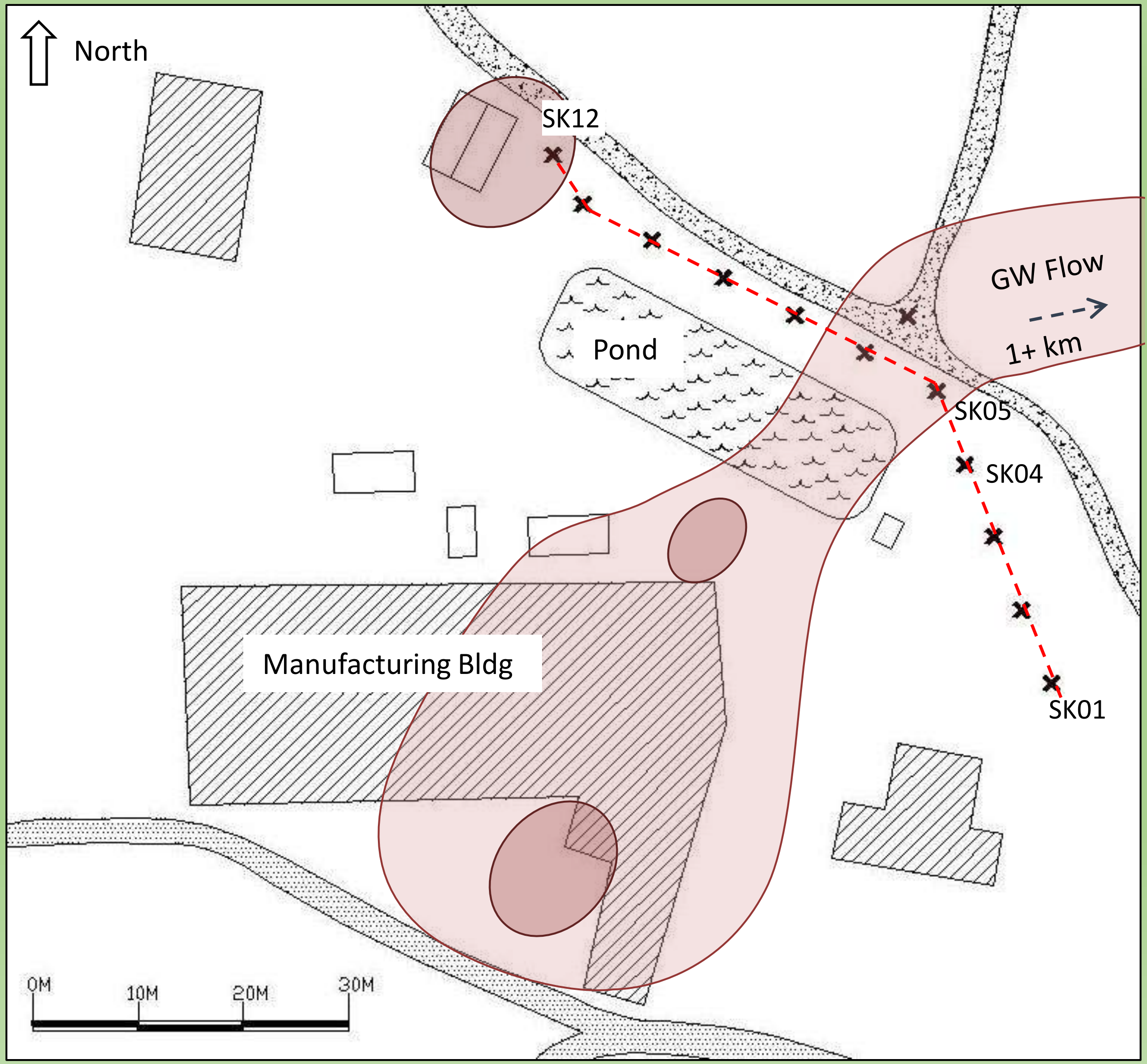
Cross section Line

GW Plume & Hot Spot



PCE, TCE, DCE & VC

Previous work with the MIP system and Electrical conductivity logs was not able to distinguish between the coarse grained materials and fine grained materials in the subsurface as observed with targeted soil cores.



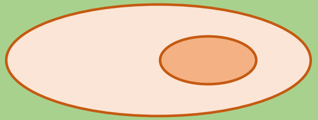
Logs are spaced 8 m (~25ft) apart.

Skuldelev, DK Site Map

MiHpt Log X - - - -

Cross section Line

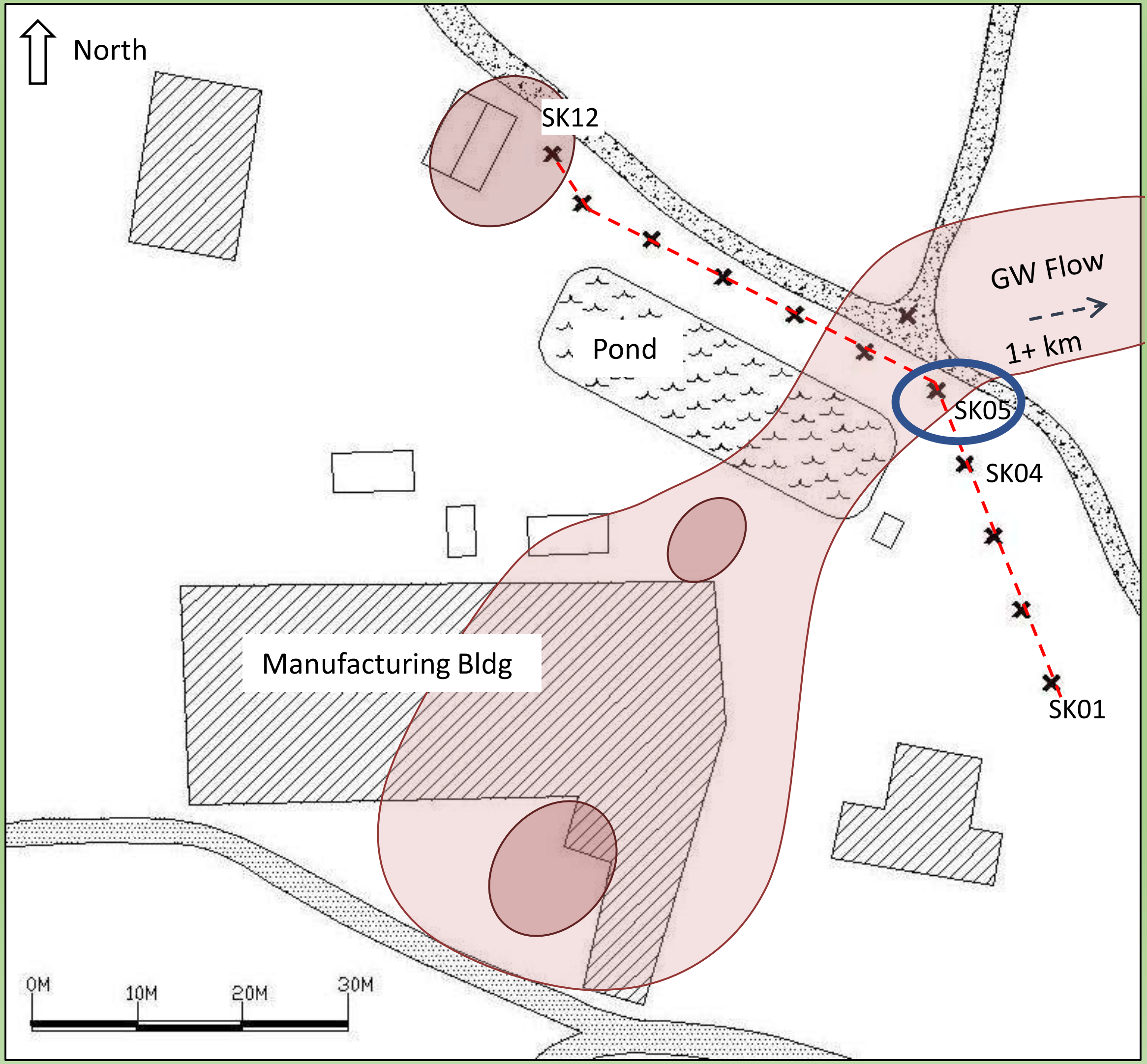
GW Plume & Hot Spot



PCE, TCE, DCE & VC

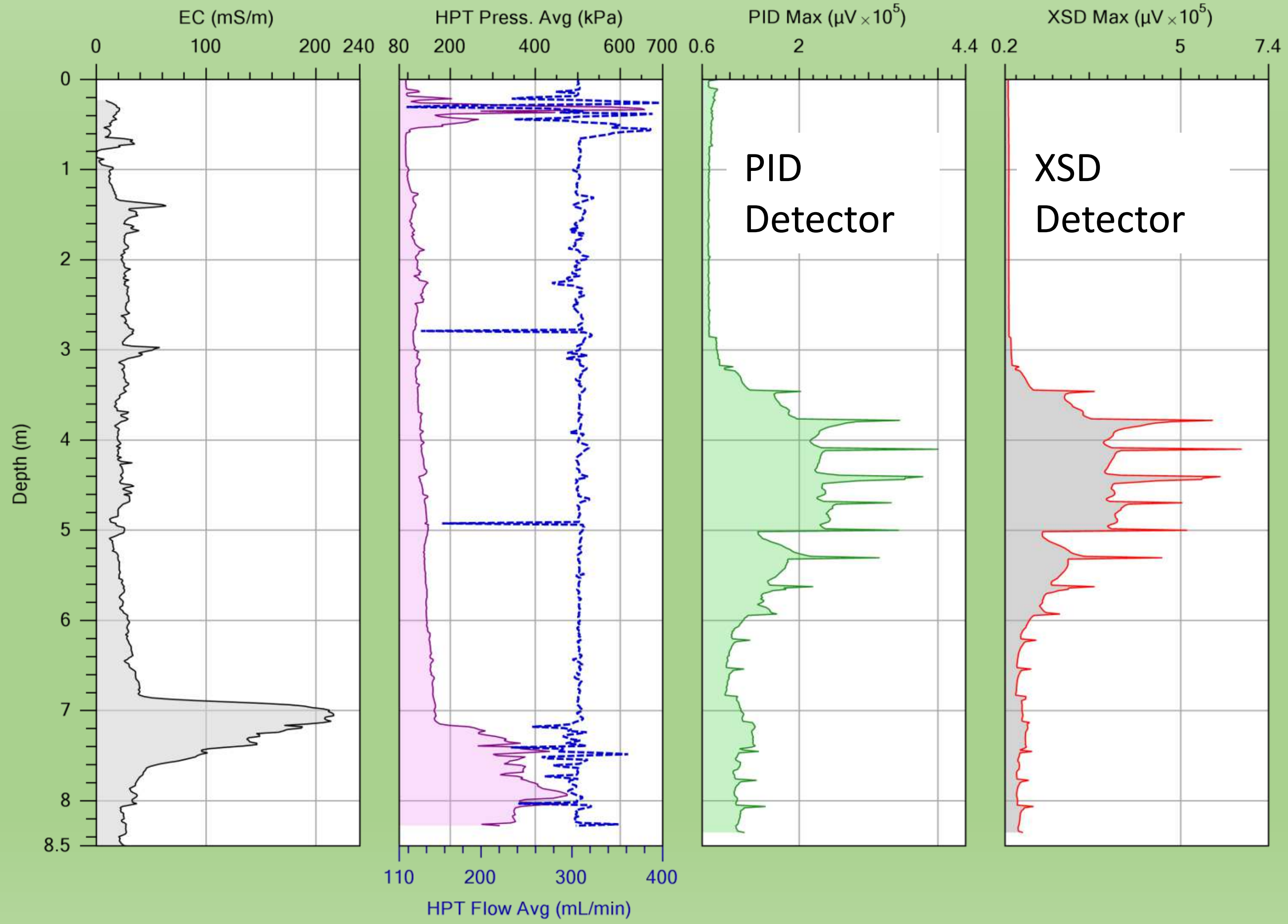
Logs in the transect were placed about 8 meters (25ft) apart.

We have been looking at data from the SK05 log at Skuldelev …



Logs are spaced 8 m (~25ft) apart.

MiHpt Log SK05



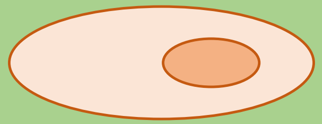
As well as the detector logs for contaminant level and distribution. Here we see the chlorinated VOC contaminants are located within the sandy aquifer material at this location. Now … Where did we run this log ?

Skuldelev, DK Site Map

MiHpt Log X - - - - -

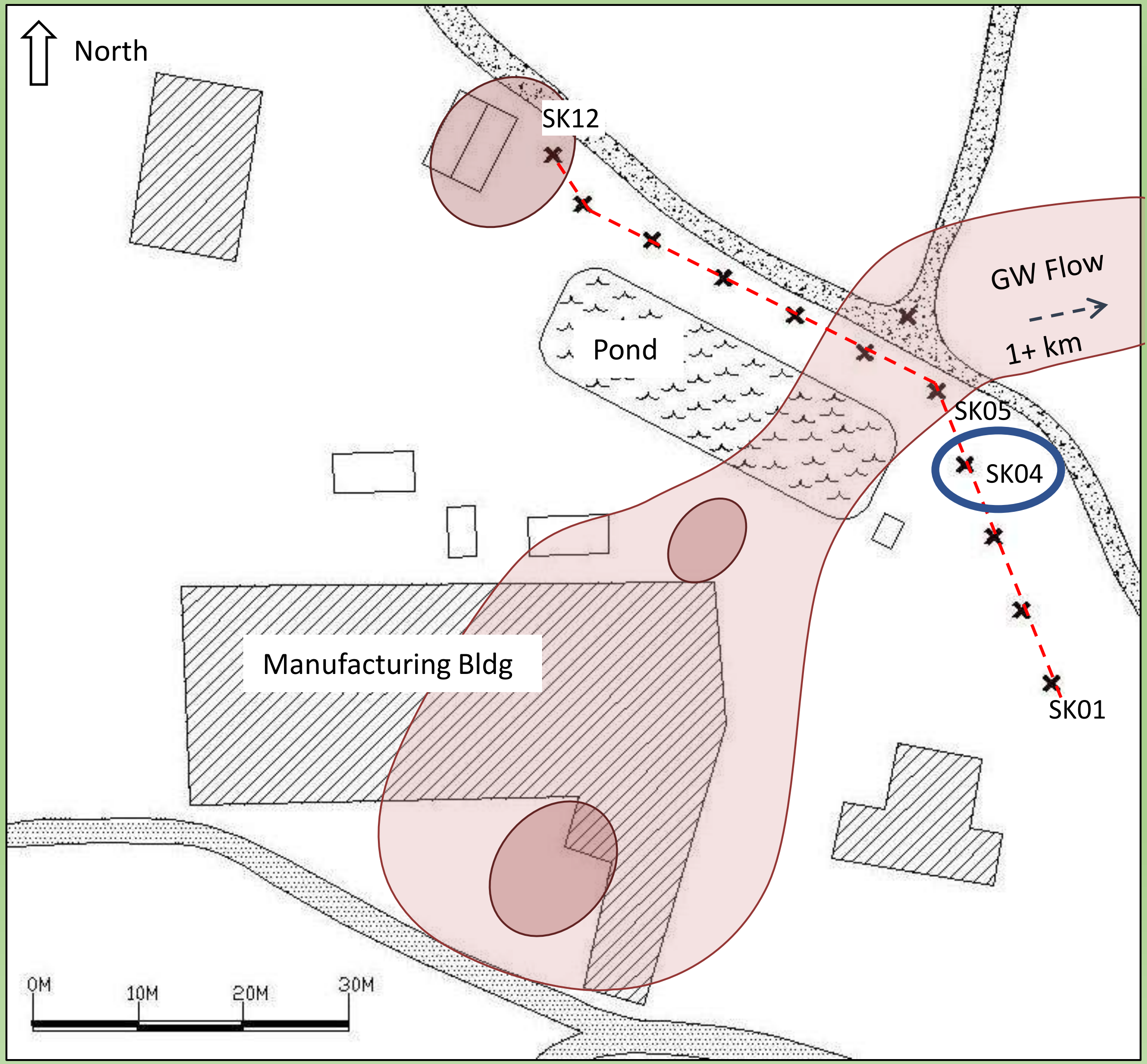
Cross section Line

GW Plume & Hot Spot



PCE, TCE, DCE & VC

Now let's look at results for the SK04 log, just outside of the main groundwater plume body.

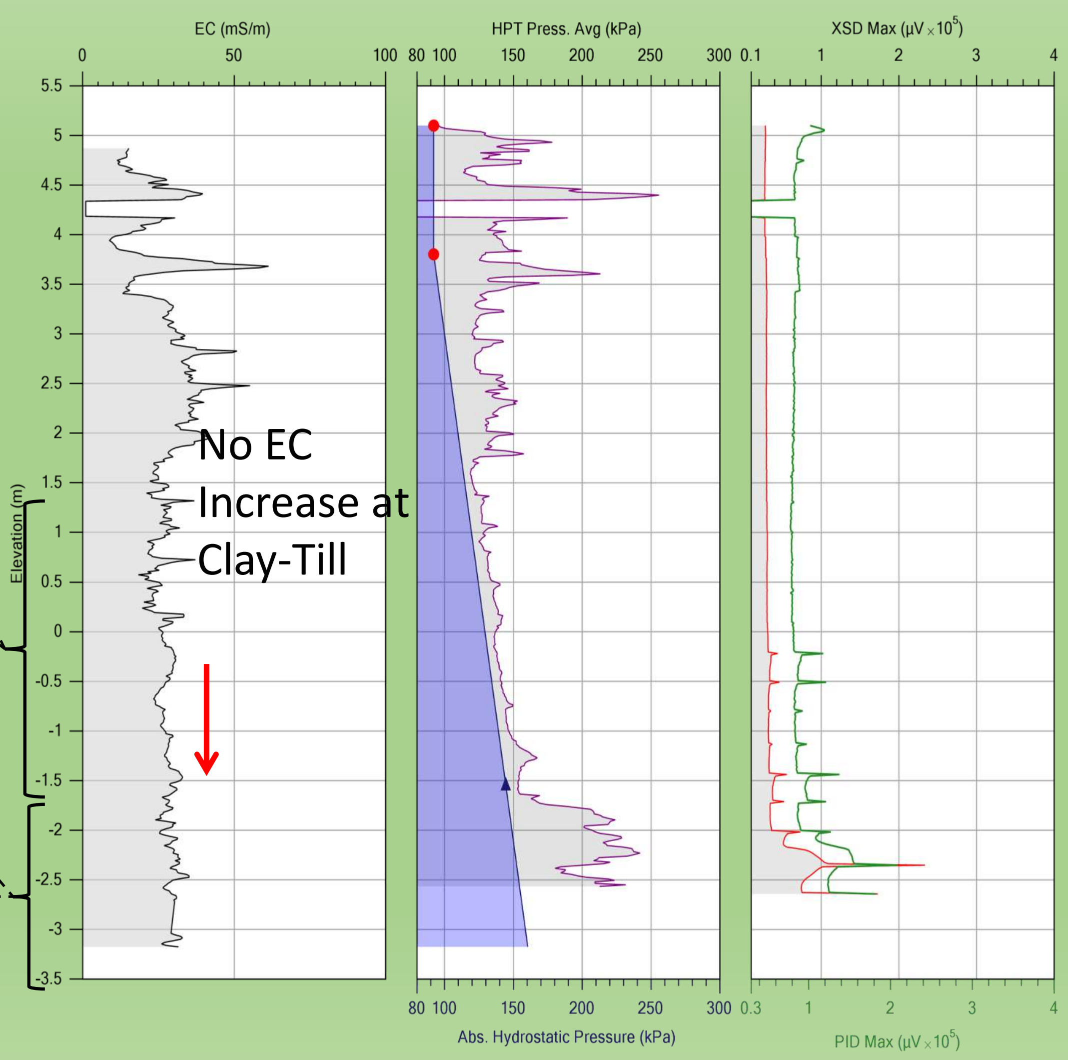


Logs are spaced 8 m (~25ft) apart.

MiHpt Log SK04

Sand & Gravel

Clay-Till

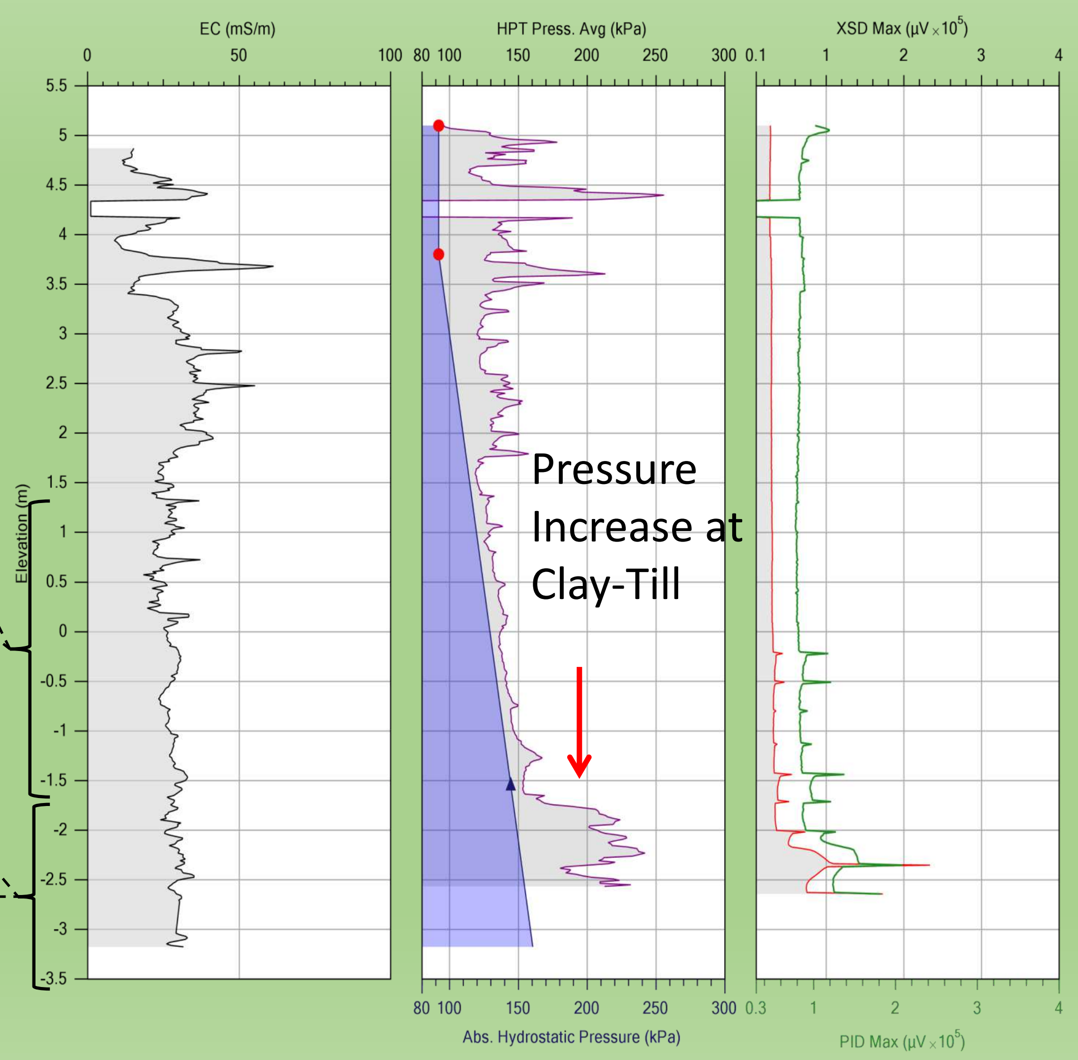


At Skuldelev the EC of the clay-till was essentially the same as the EC of sands and gravels. So maybe that EC peak at the SK05 log was an anomaly?

MiHpt Log SK04

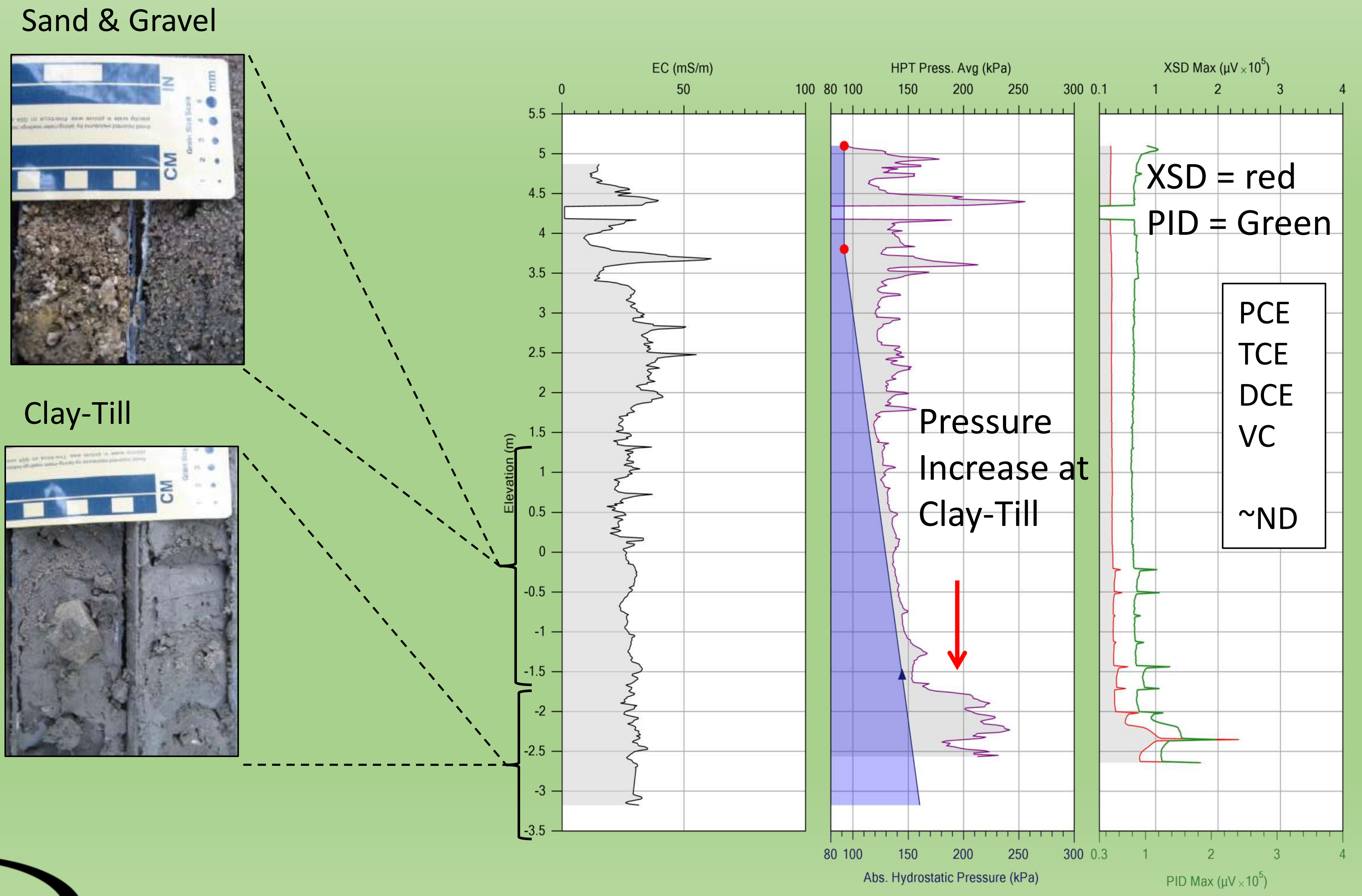
Sand & Gravel

Clay-Till



However, the HPT pressure increased significantly in the clay-till.

MiHpt Log SK04



At this location outside of the main groundwater plume the halogen specific detector (XSD) found only minor detects of contamination.

Skuldelev, DK Site Map

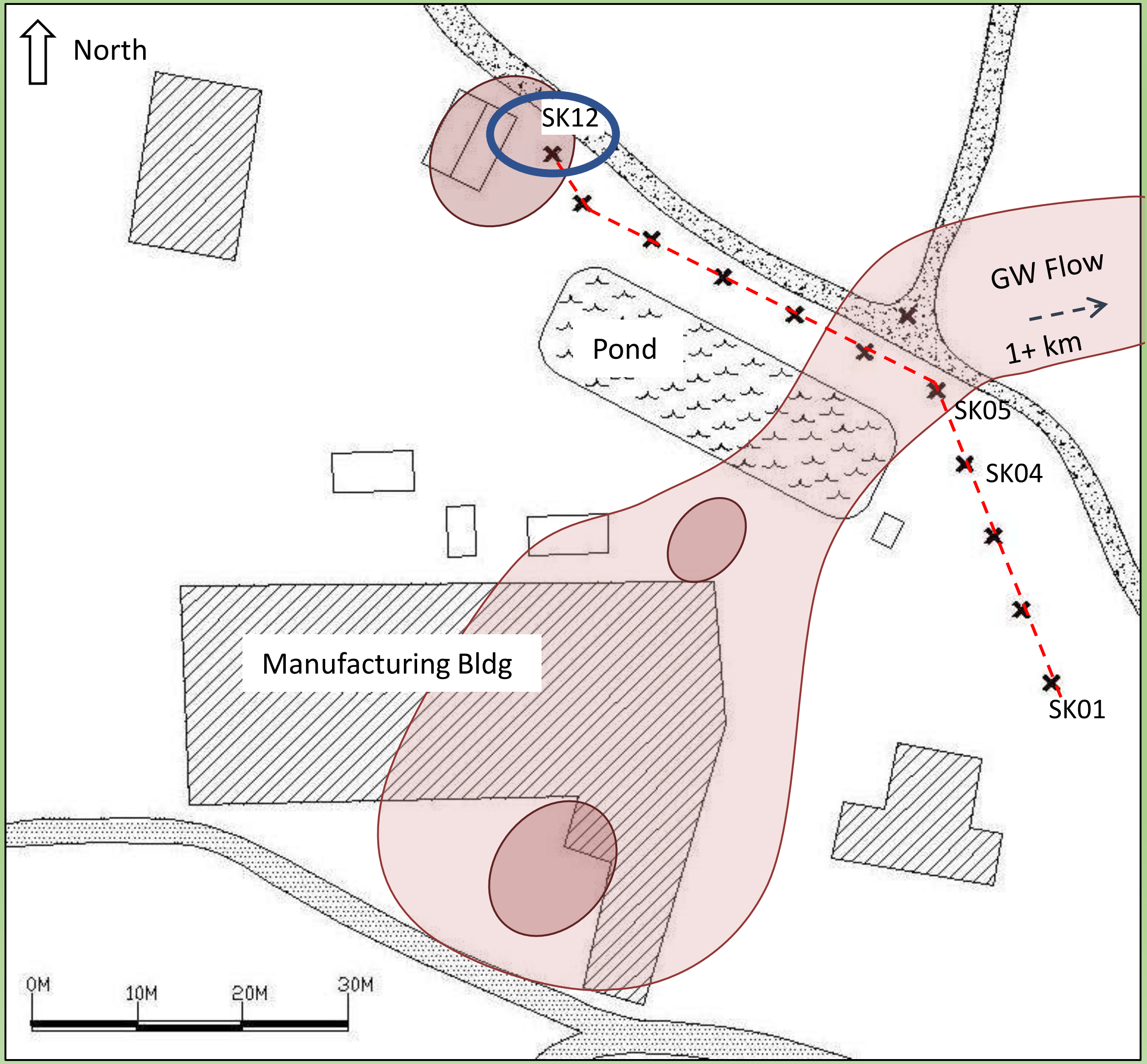
MiHpt Log X - - - - -

Cross section Line

GW Plume & Hot Spot

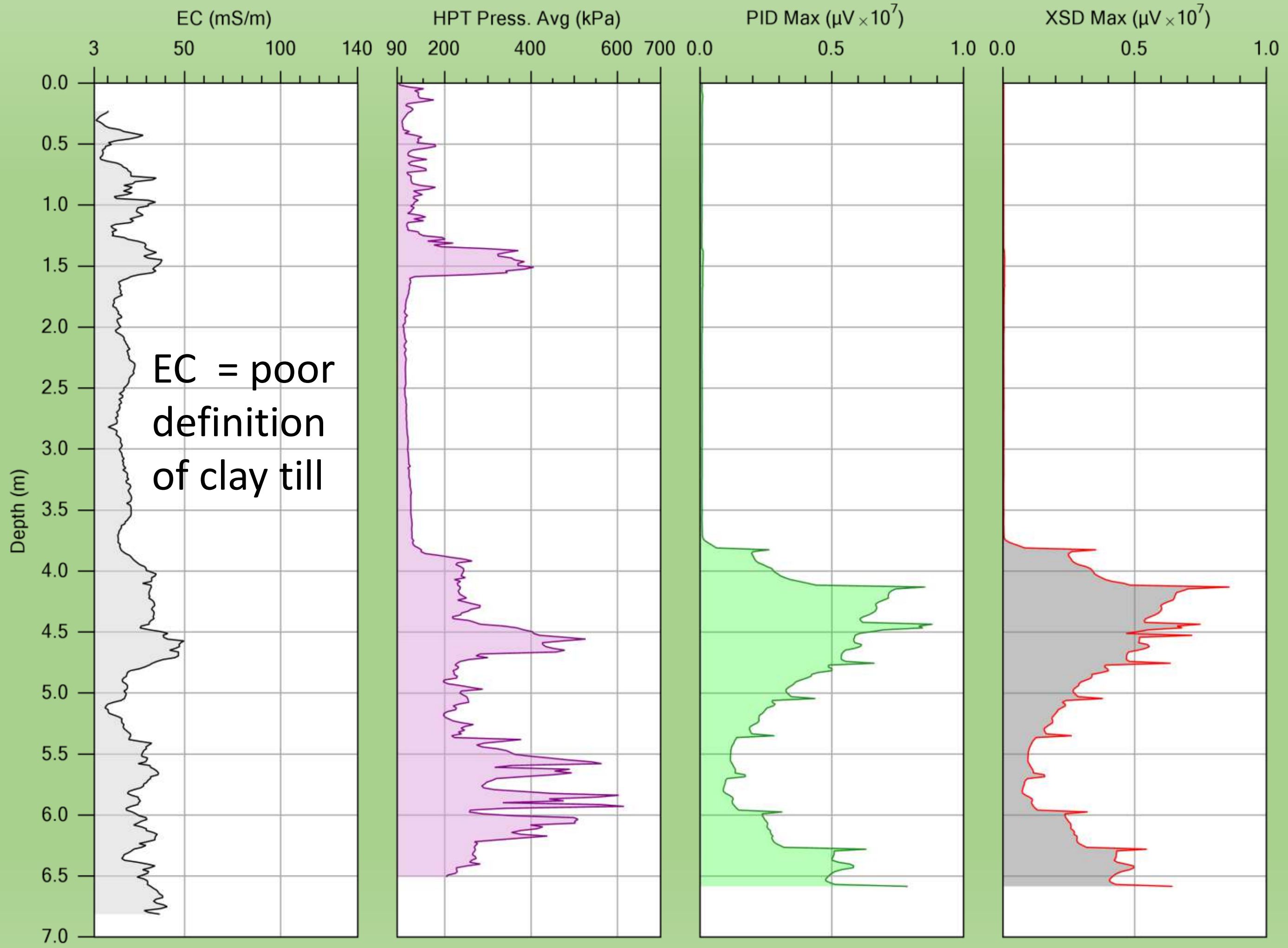
PCE, TCE, DCE & VC

Now let's look at the SK12 location log …

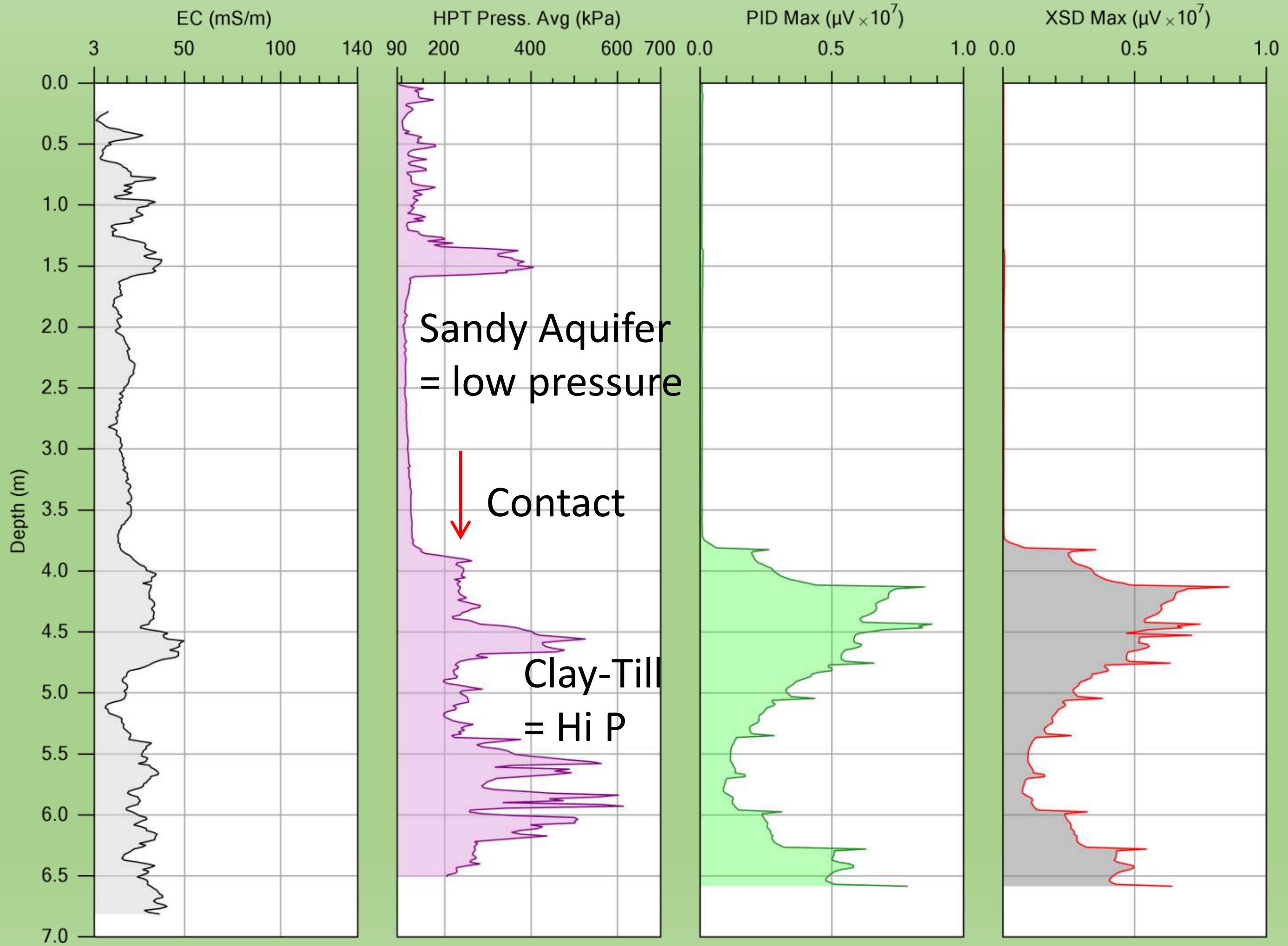


Logs are spaced 8 m (~25ft) apart.

MiHpt Log SK12



MiHpt Log SK12



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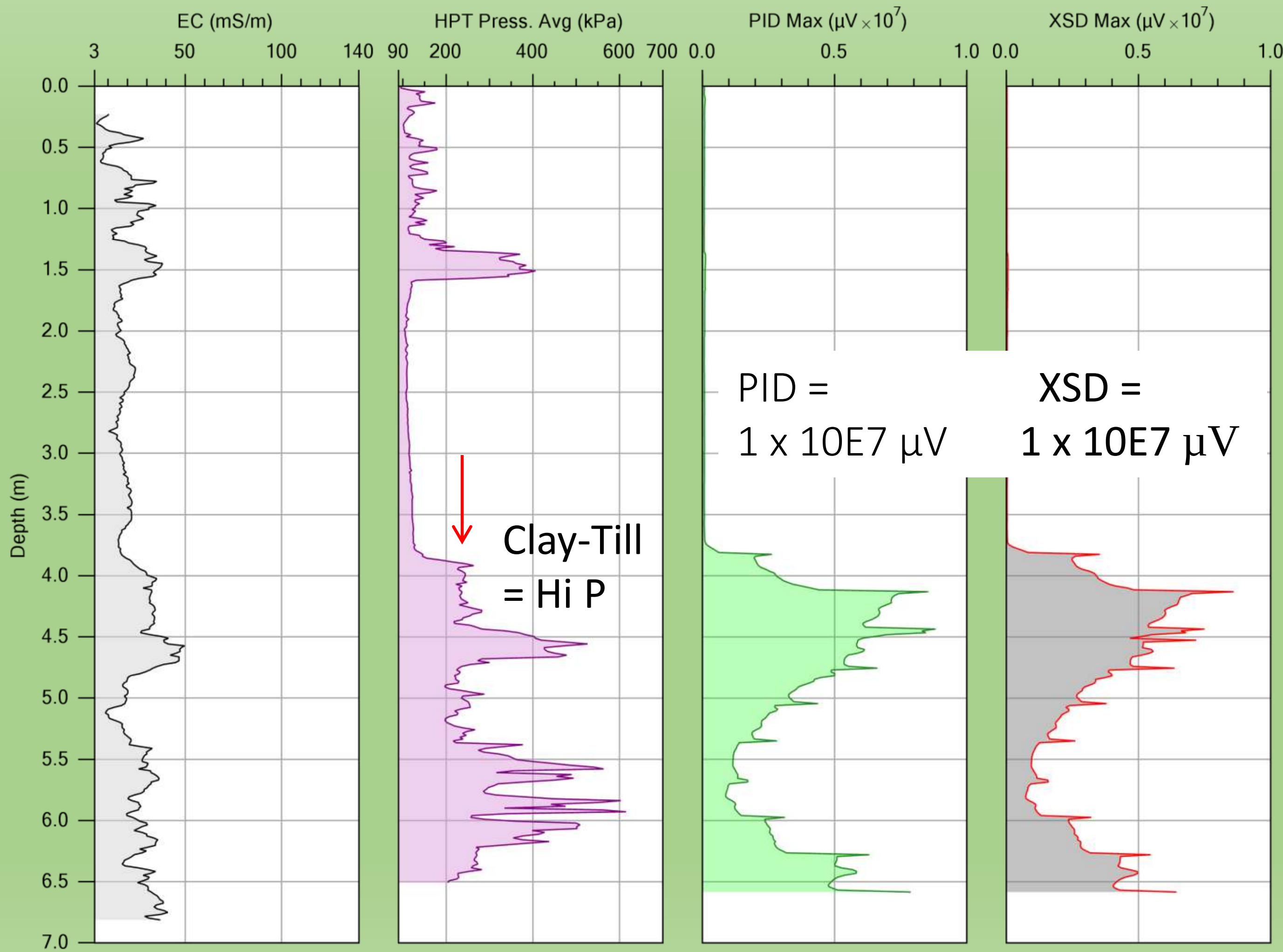
MiHpt Log SK12



Notice that the detector responses are almost exclusively in the clay-till at this location. The detector responses are high, almost at the maximum of the detector range for both detectors.

Skuldelev Cross Section Map

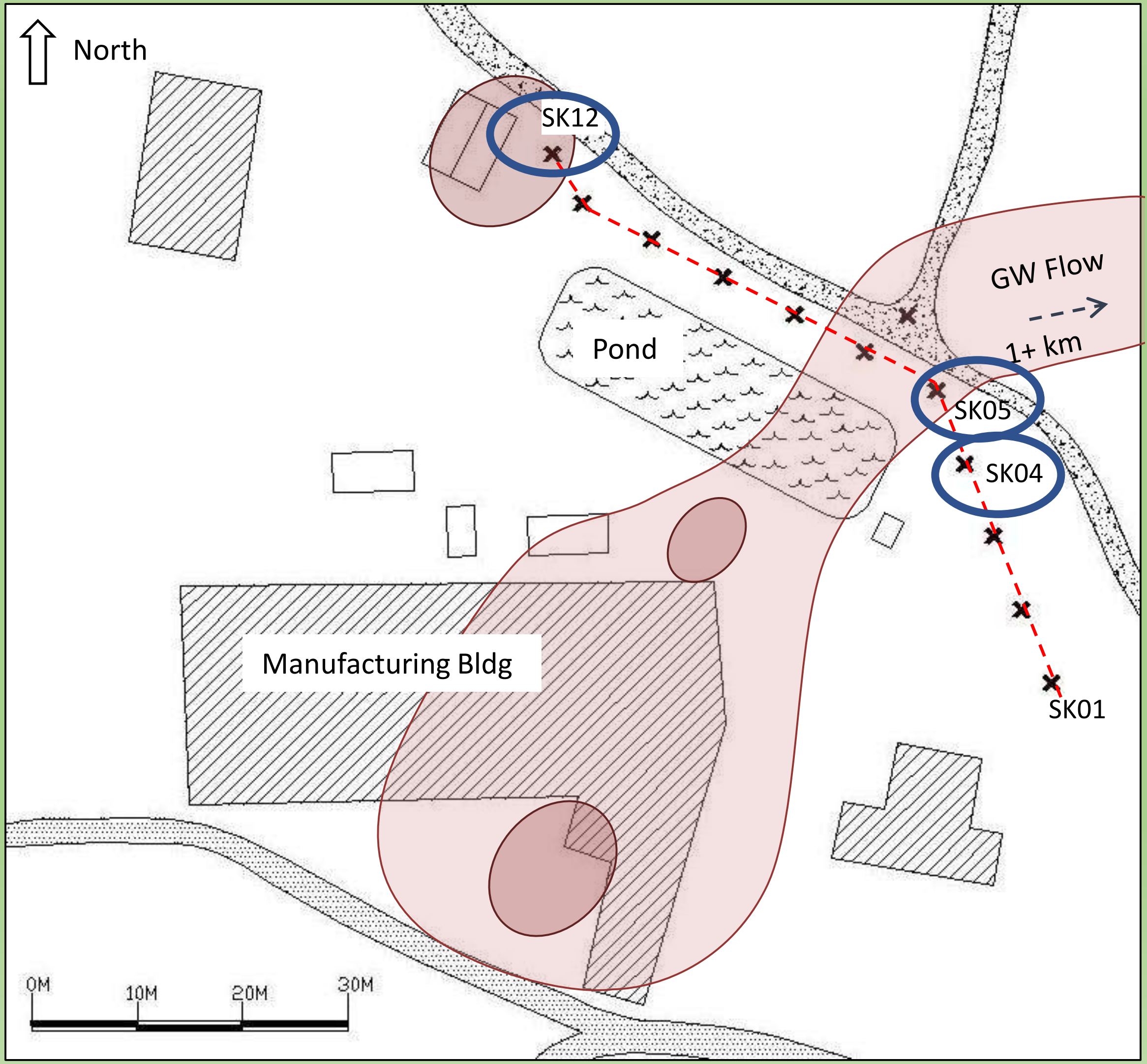
MiHpt Log X - - - - -

Cross section Line

GW Plume & Hot Spot

PCE, TCE,
DCE & VC

Back at the site map, we have looked at the SK12, SK05 and SK04 logs …



Logs are spaced 8 m (~25ft) apart.

Skuldelev Cross Section Map

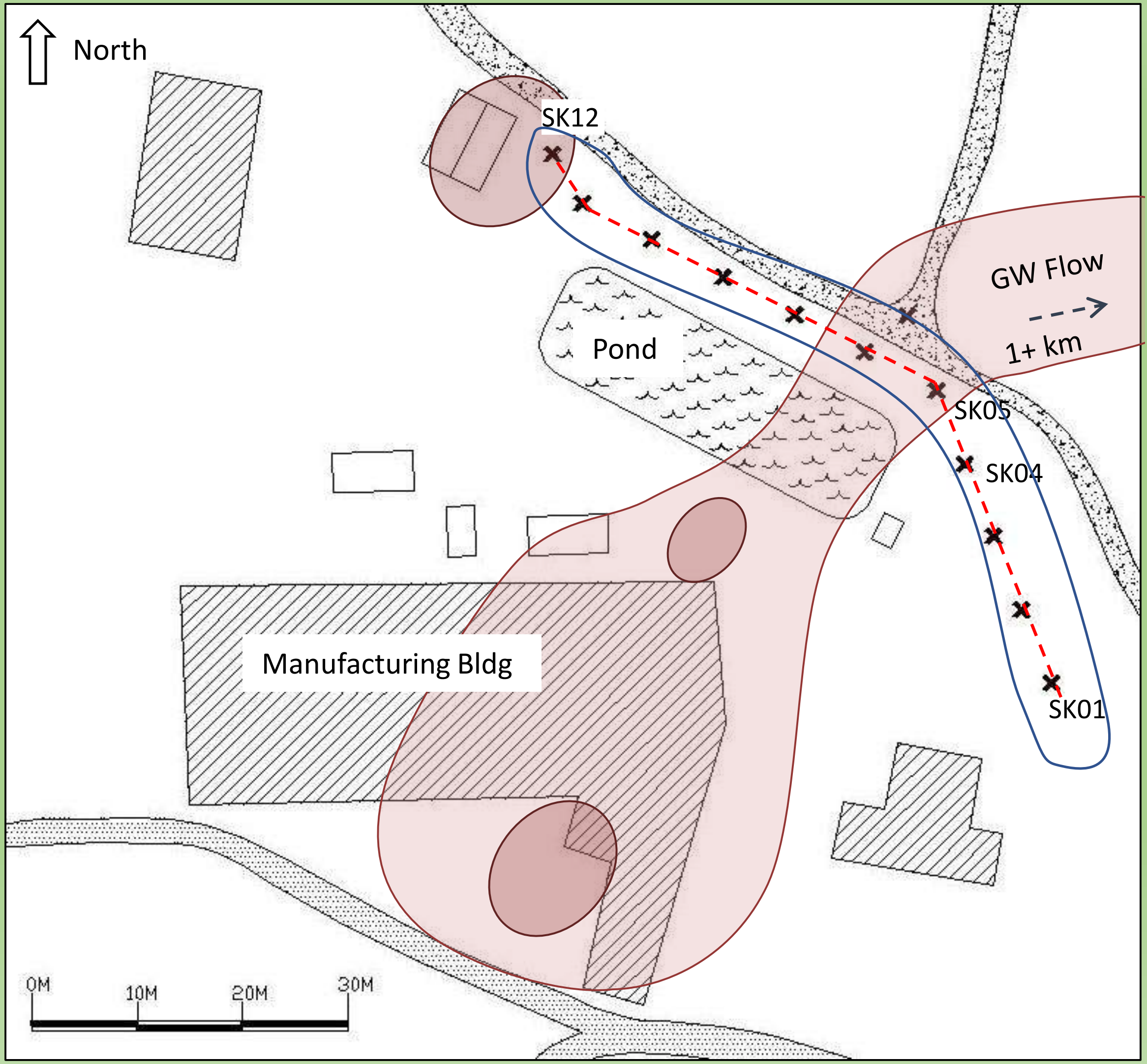
MiHpt Log X - - - -

Cross section Line

GW Plume & Hot Spot

PCE, TCE, DCE & VC

Now, let's look at a cross section of HPT pressure, looking from the northeast to the south west.

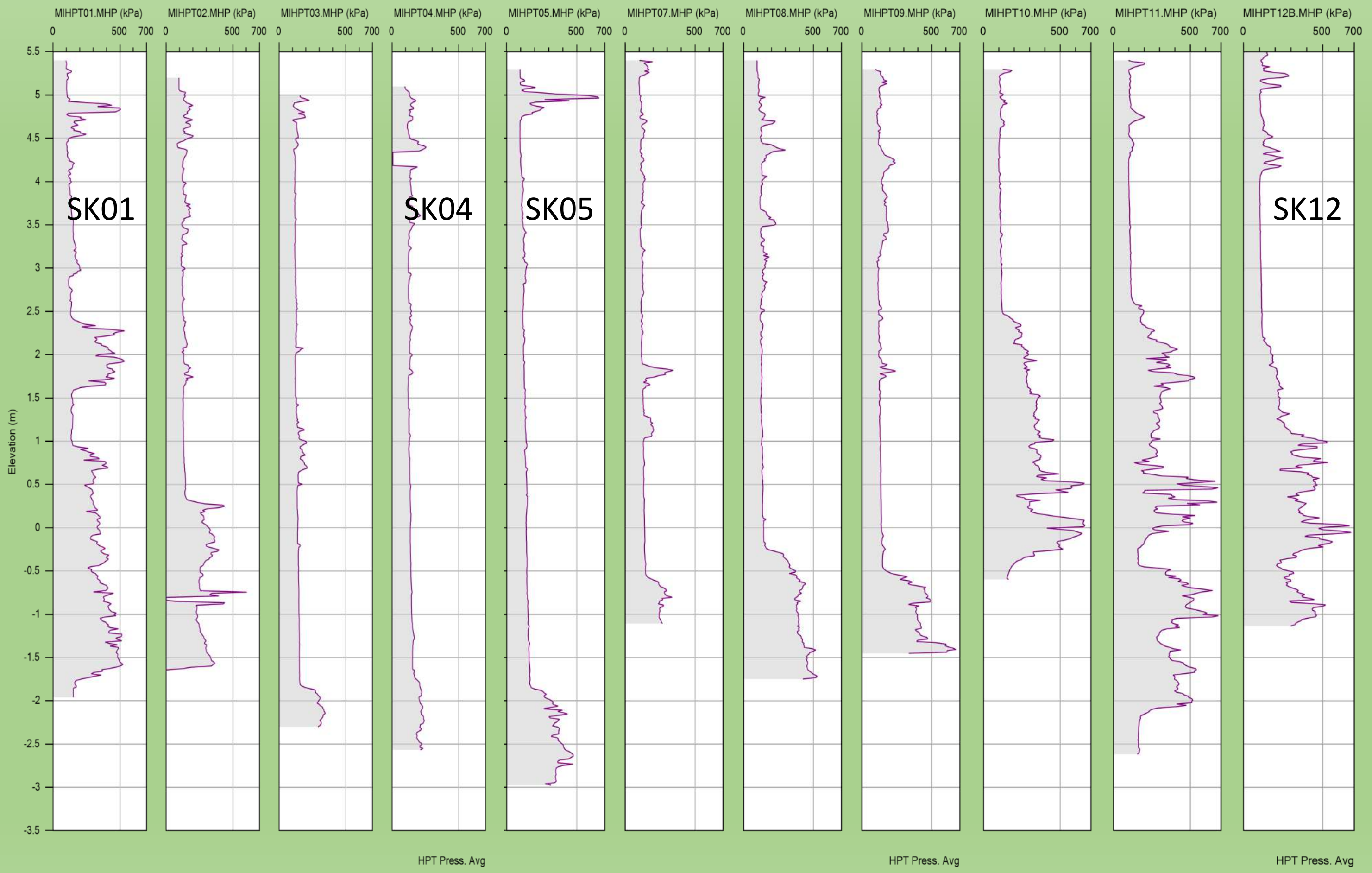


Logs are spaced 8 m (~25ft) apart.

Skuldelev HPT Pressure Cross Section

(Elevation Corrected)

East West



(Facing ~ Southwest)

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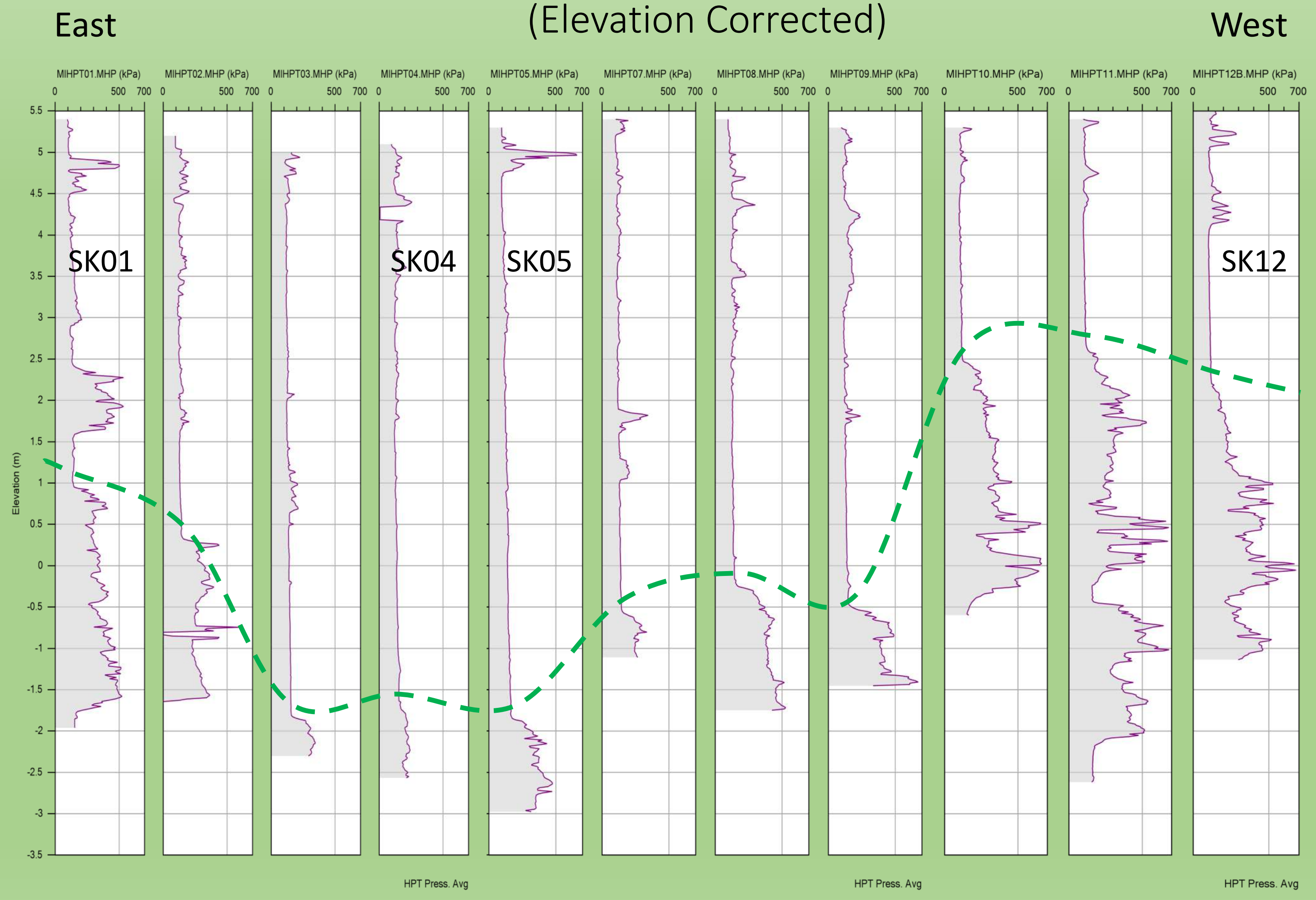
We can see the top of the clay-till in the subsurface across the site where the HPT pressure increases in each log.

Skuldelev HPT Pressure Cross Section

(Elevation Corrected)

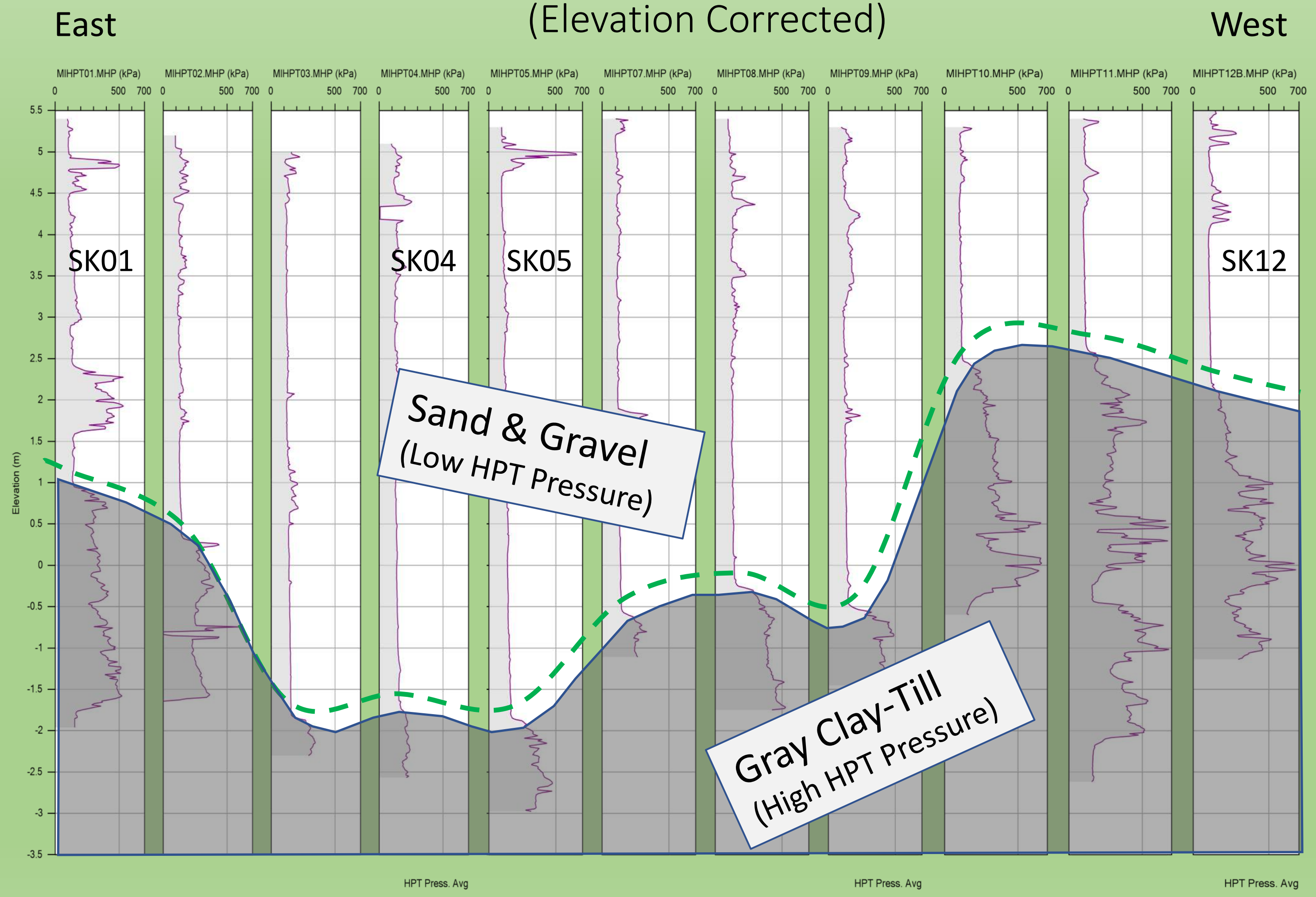


(Facing ~ Southwest)

If we draw a line between each log connecting the elevation where the HPT pressure increases we define a surface of contact …

Skuldelev HPT Pressure Cross Section

(Elevation Corrected)



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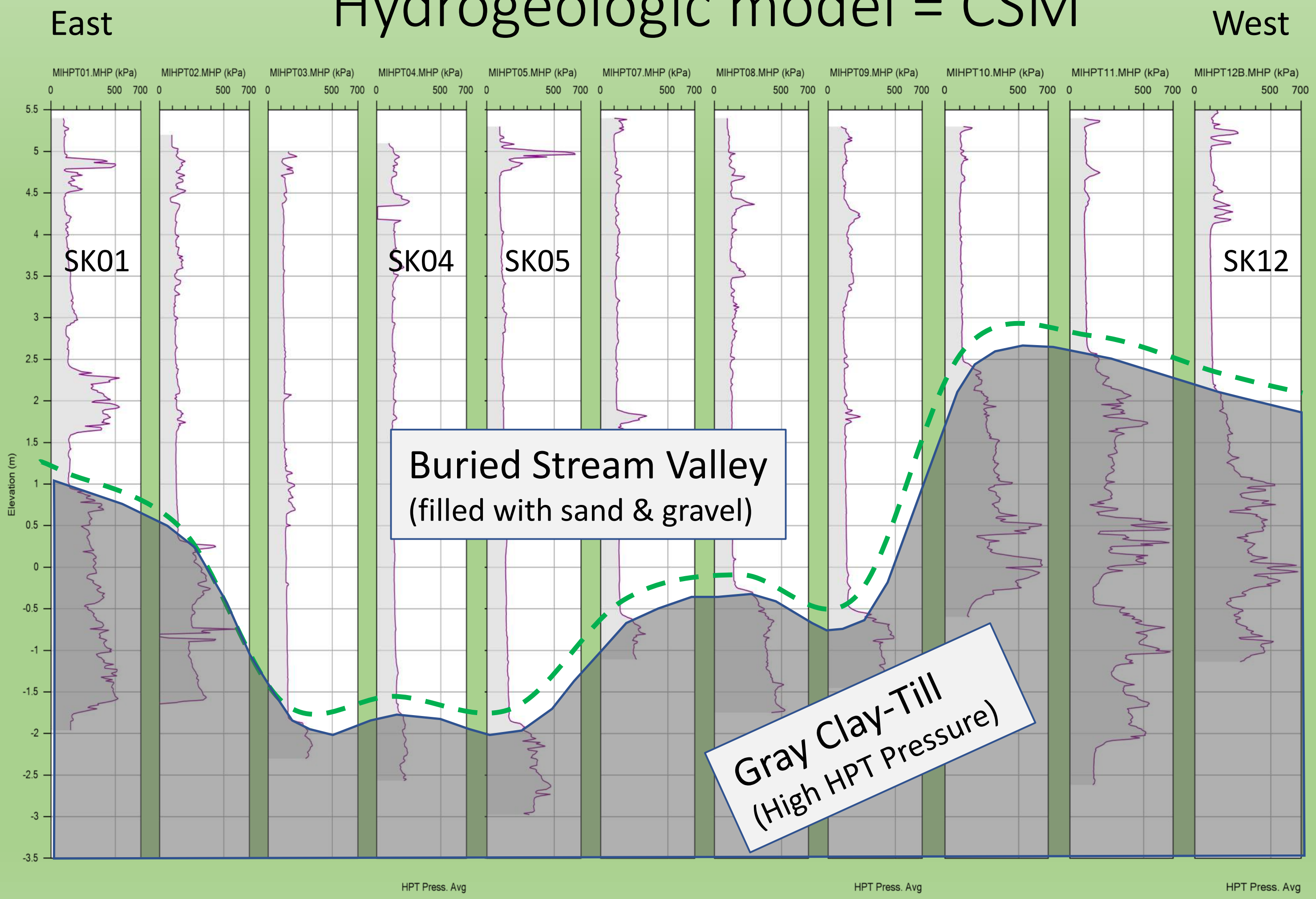
This surface separates the top of the high pressure clay-till from the low pressure, sands and gravels (Aquifer materials). Looking at the profile it looks like a cross section of a stream valley.

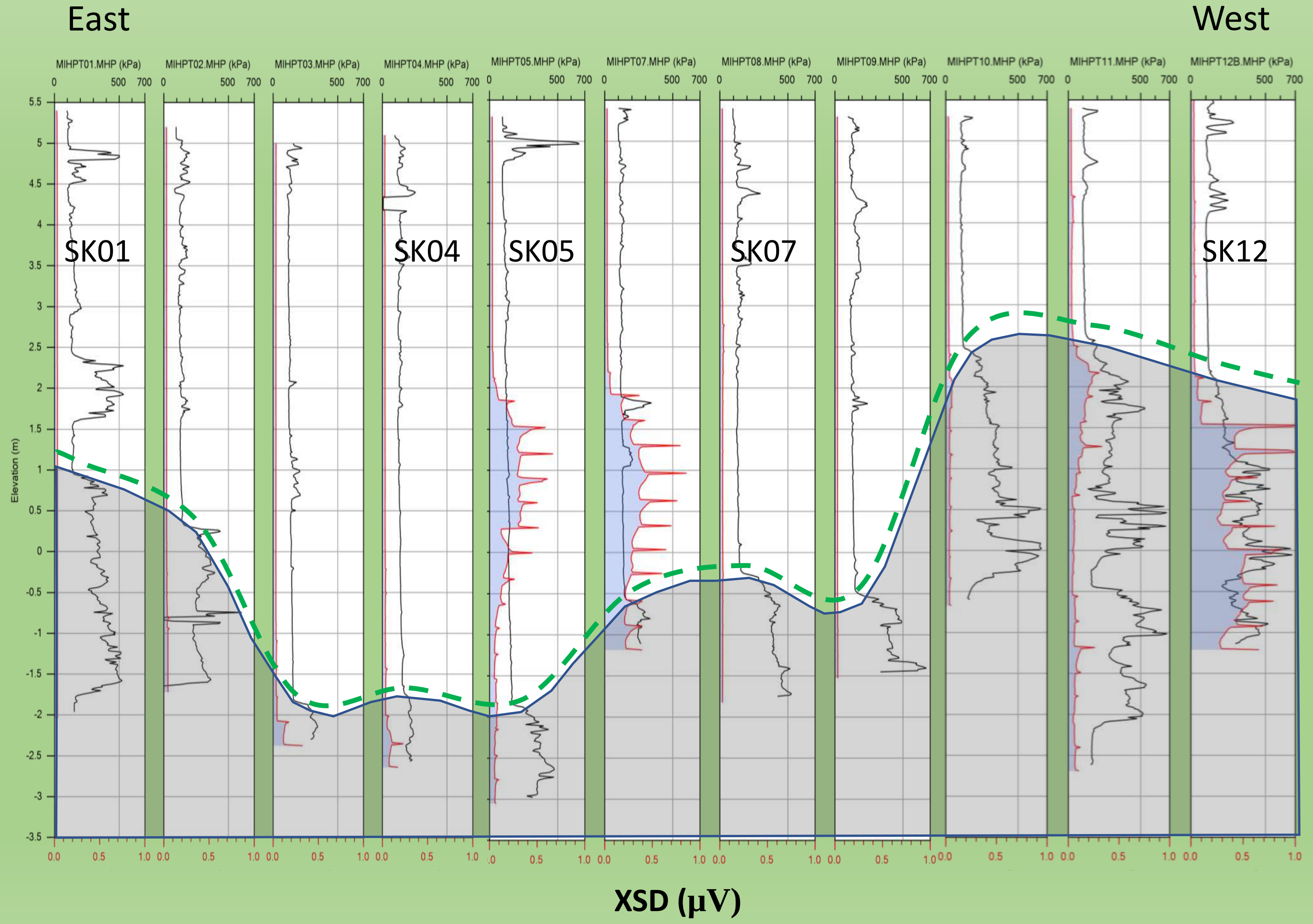
Skuldelev HPT Pressure Cross Section =

Hydrogeologic model = CSM



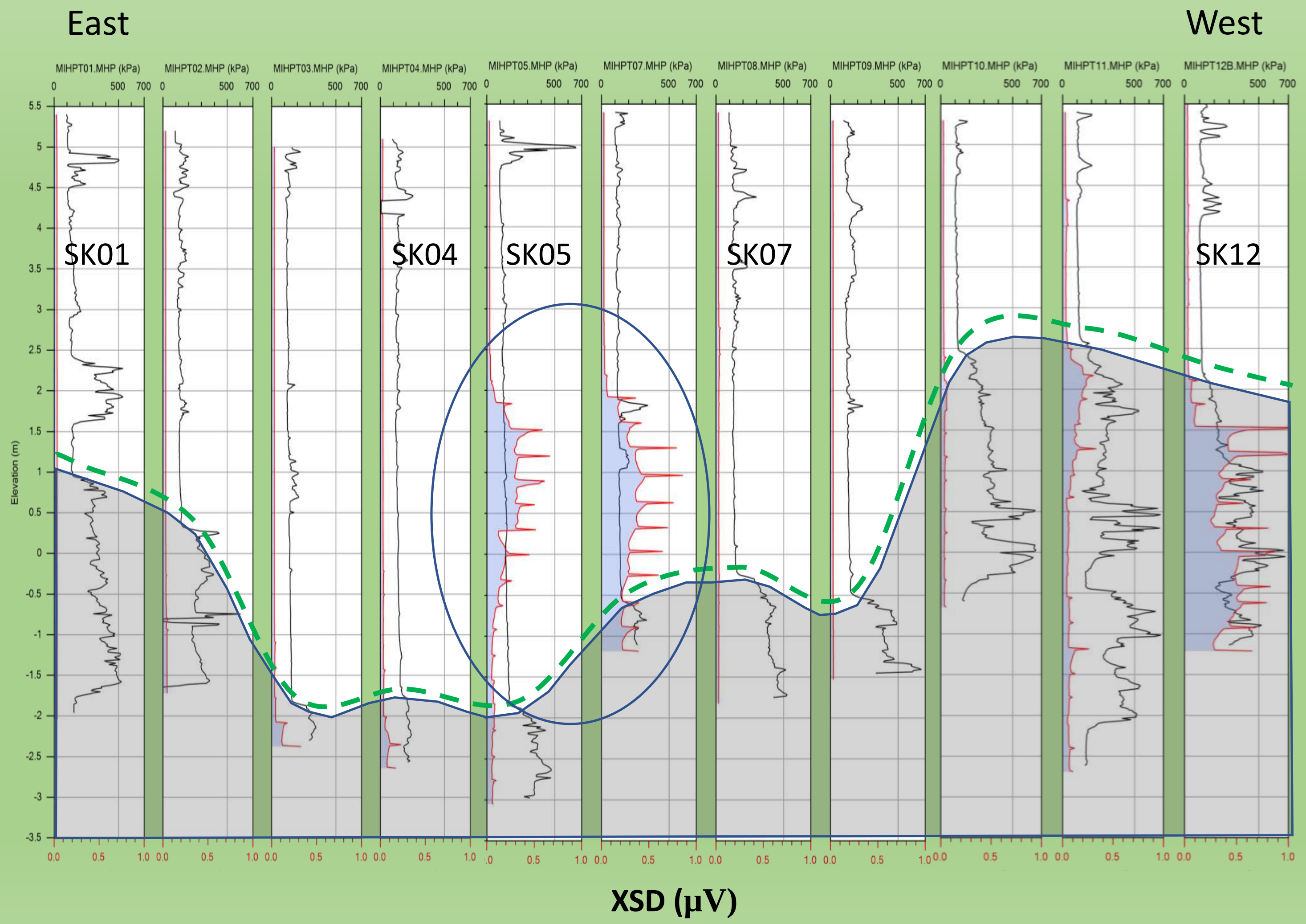
It appears that a post-glacial stream eroded a small valley in the surface of the clay-till that was later filled with sand and gravel, probably from outwash streams as the glaciers receded. Now we have created a detailed hydrogeologic model of the subsurface based on the HPT pressure logs. This becomes the foundation for our hydrogeologic conceptual site model (CSM).

HPT Pressure and XSD Cross Section



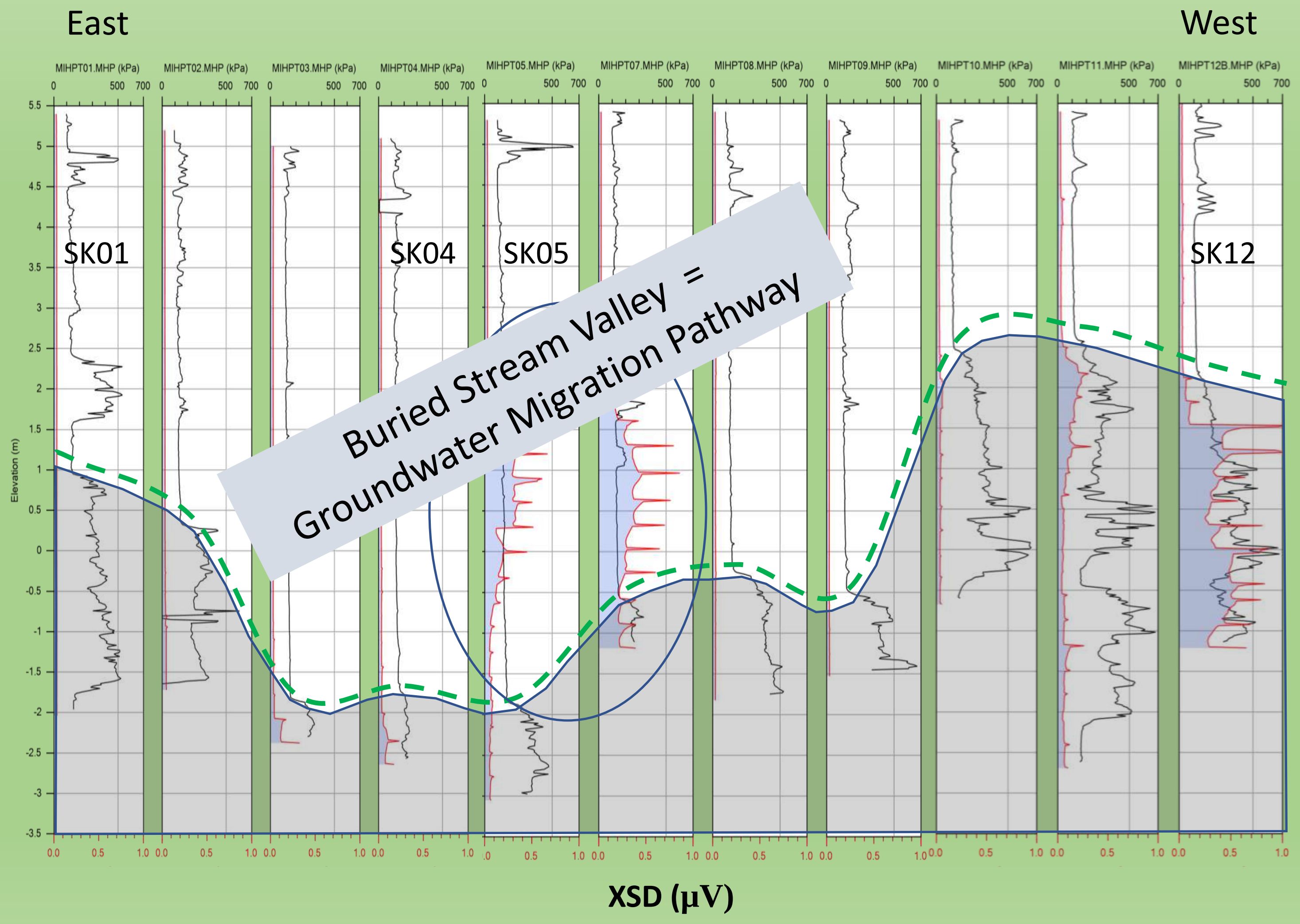
In this hydrogeologic cross section the MIP XSD detector response (red with blue fill) for chlorinated VOCs has been placed over the HPT pressure logs (black) at each location.

HPT Pressure and XSD Cross Section



It becomes apparent that the CVOC groundwater plume is migrating down the buried stream valley at locations SK05 and SK07. This was not understood until we had run the HPT logs and constructed this HPT pressure cross section.

HPT Pressure and XSD Cross Section



It becomes apparent that the CVOC groundwater plume is migrating down the buried stream valley at locations SK05 and SK07. This was not understood until we had run the HPT logs and constructed this HPT pressure cross section.

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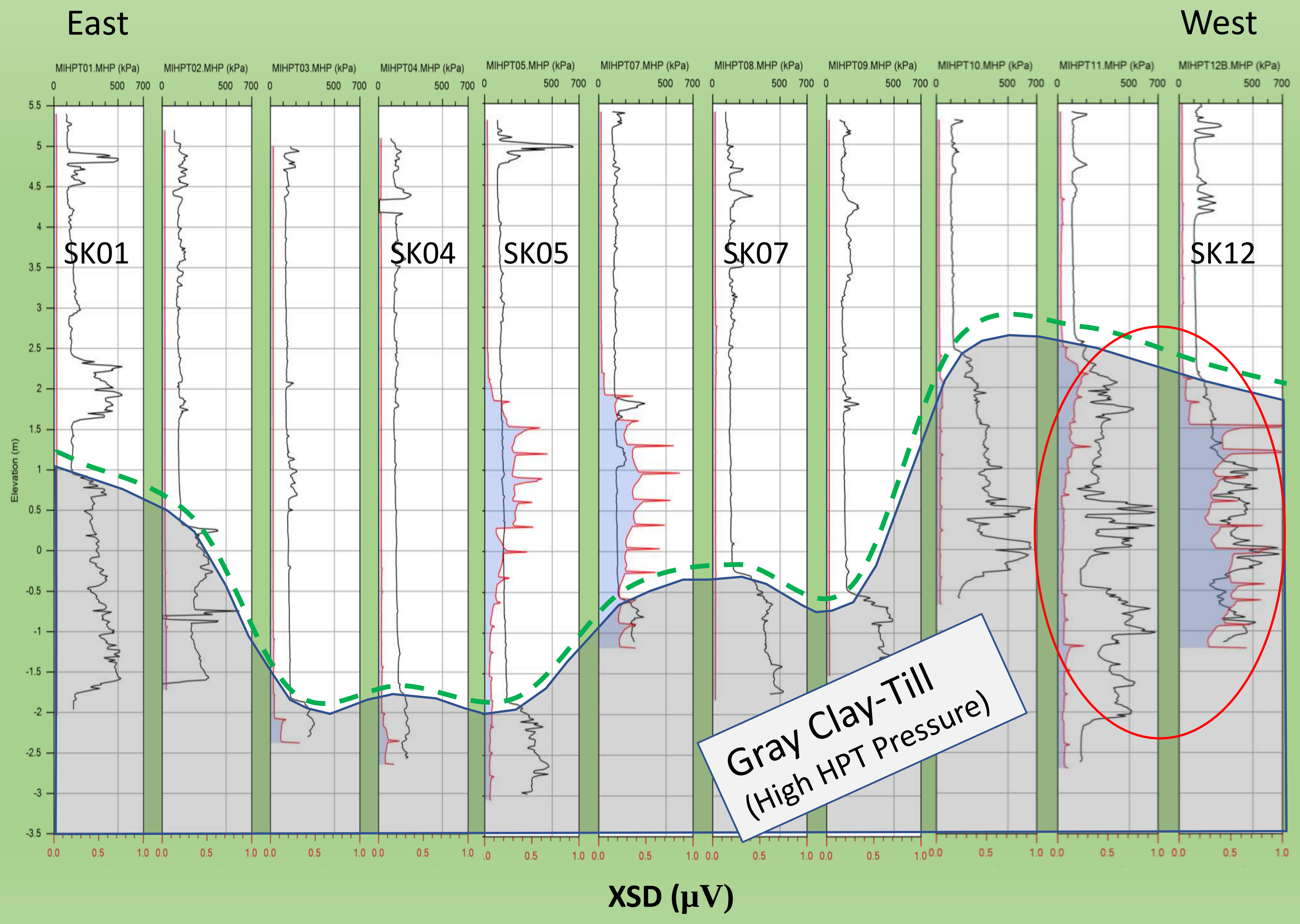
HPT Pressure and XSD Cross Section



Over at the west end of the cross section (SK11 & SK12) CVOC contamination is present in the clay-till. This "hot spot" formed as the result of a sewer leak after solvents were disposed of in the facility sewer, and is not associated with the groundwater plume.

Skuldelev, DK Site Map

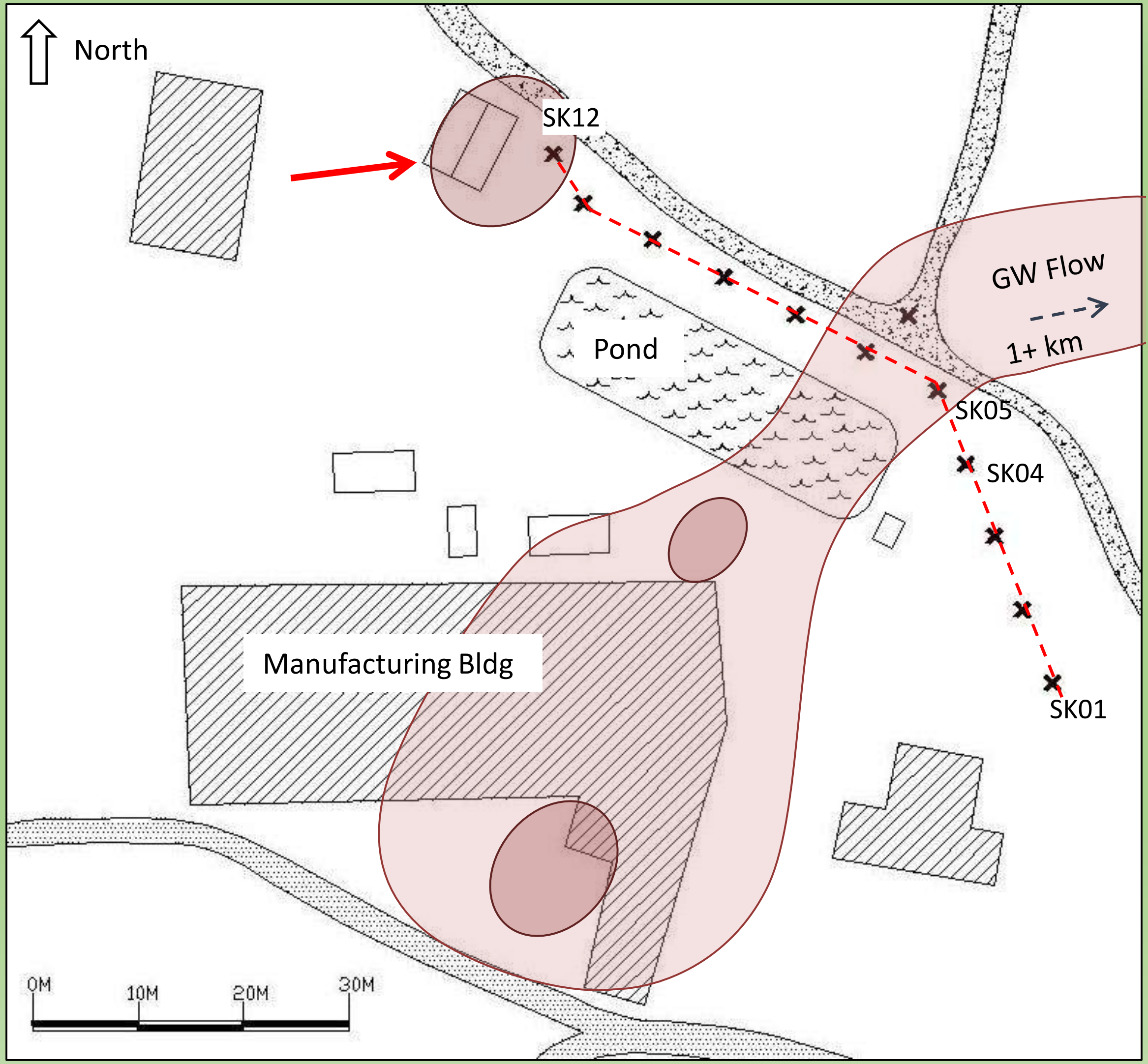
MiHpt Log X - - - - -

Cross section Line

GW Plume & Hot Spot

PCE, TCE, DCE & VC

Here is the hot spot at SK12 shown on the map (red arrow).



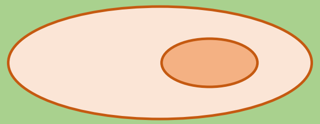
Logs are spaced 8 m (~25ft) apart.

Skuldelev Site Map

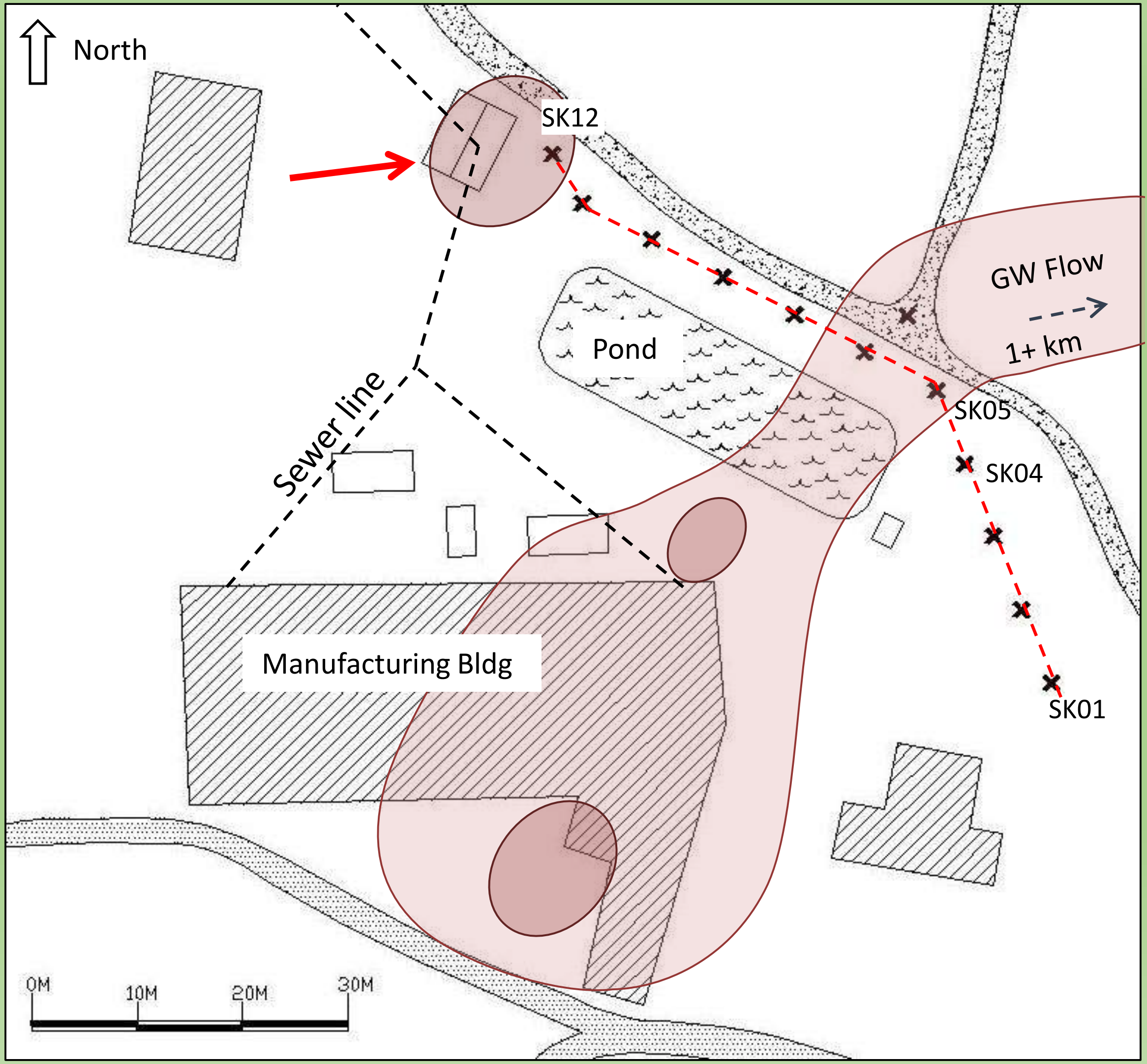
MiHpt Log X - - - -

Cross section Line

GW Plume & Hot Spot

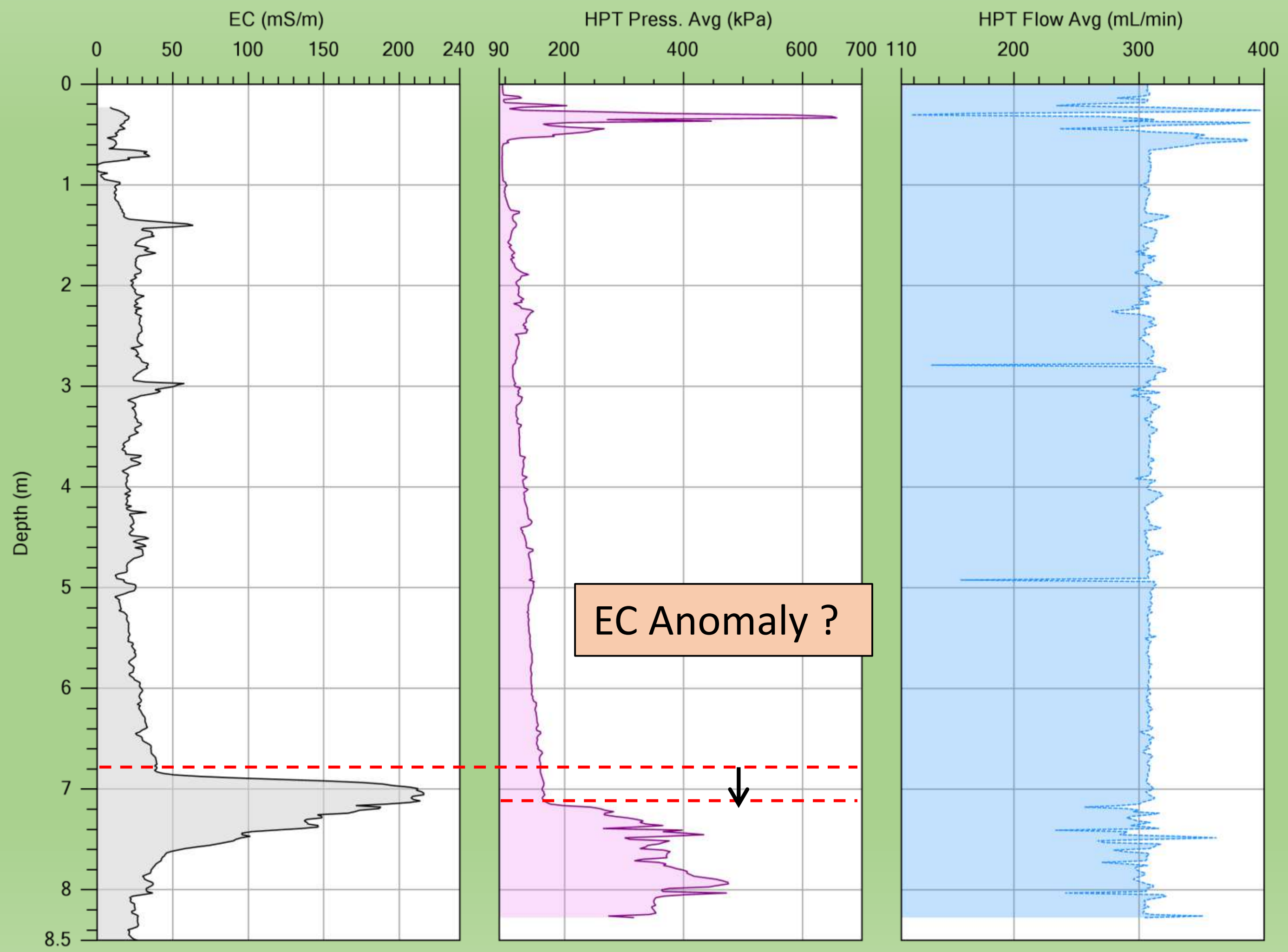


Here the sewer line juncture where the leak occurred that resulted in the hot spot at SK12 is shown on the map (red arrow). Sewer lines/back filled ditches led to vapor intrusion in some homes.



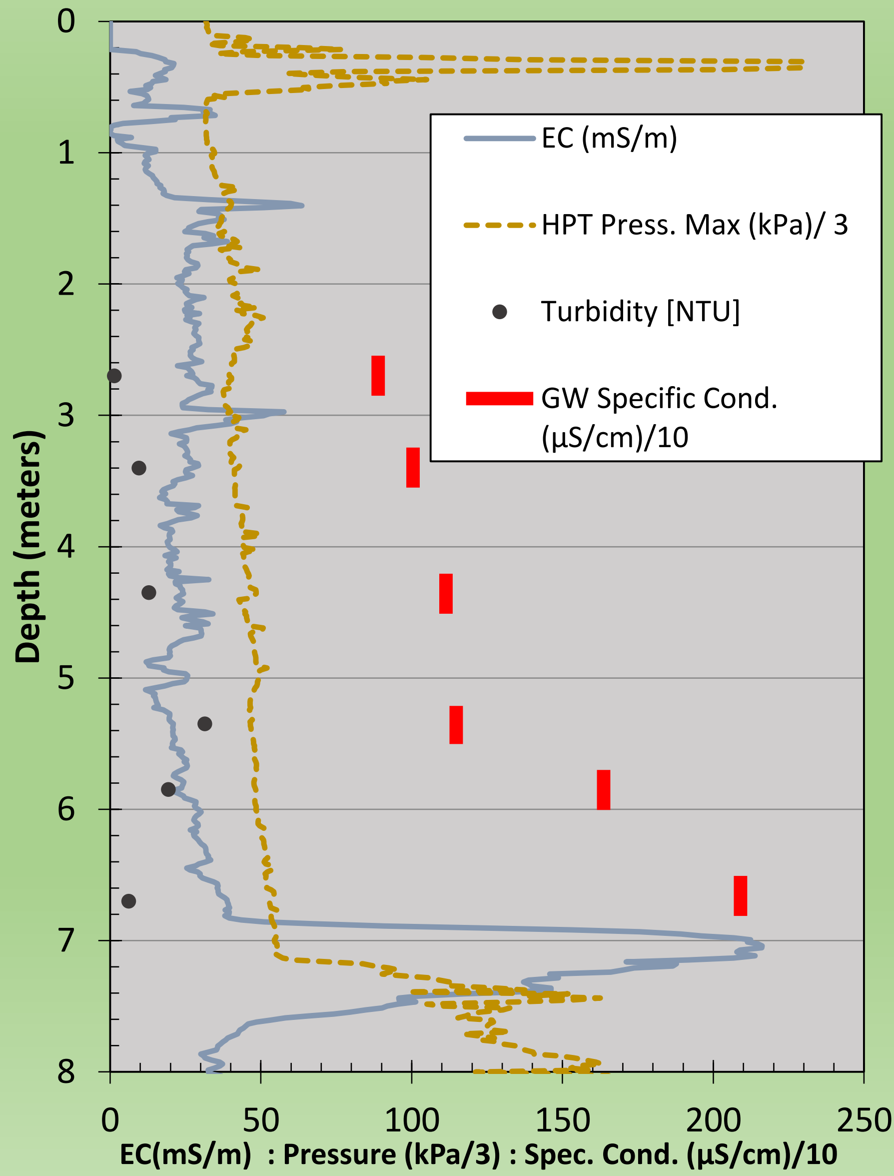
Logs are spaced 8 m (~25ft) apart.

SK05 HPT Log from Skuldelev



When EC increases before HPT pressure, it may indicate an EC anomaly, caused by ionic contaminants.

SK05 Location

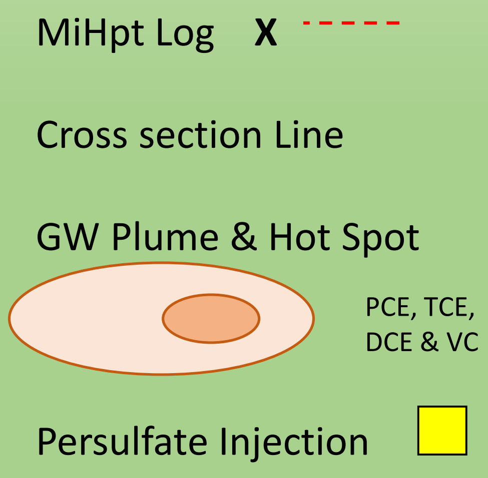


EC & HPT Pressure

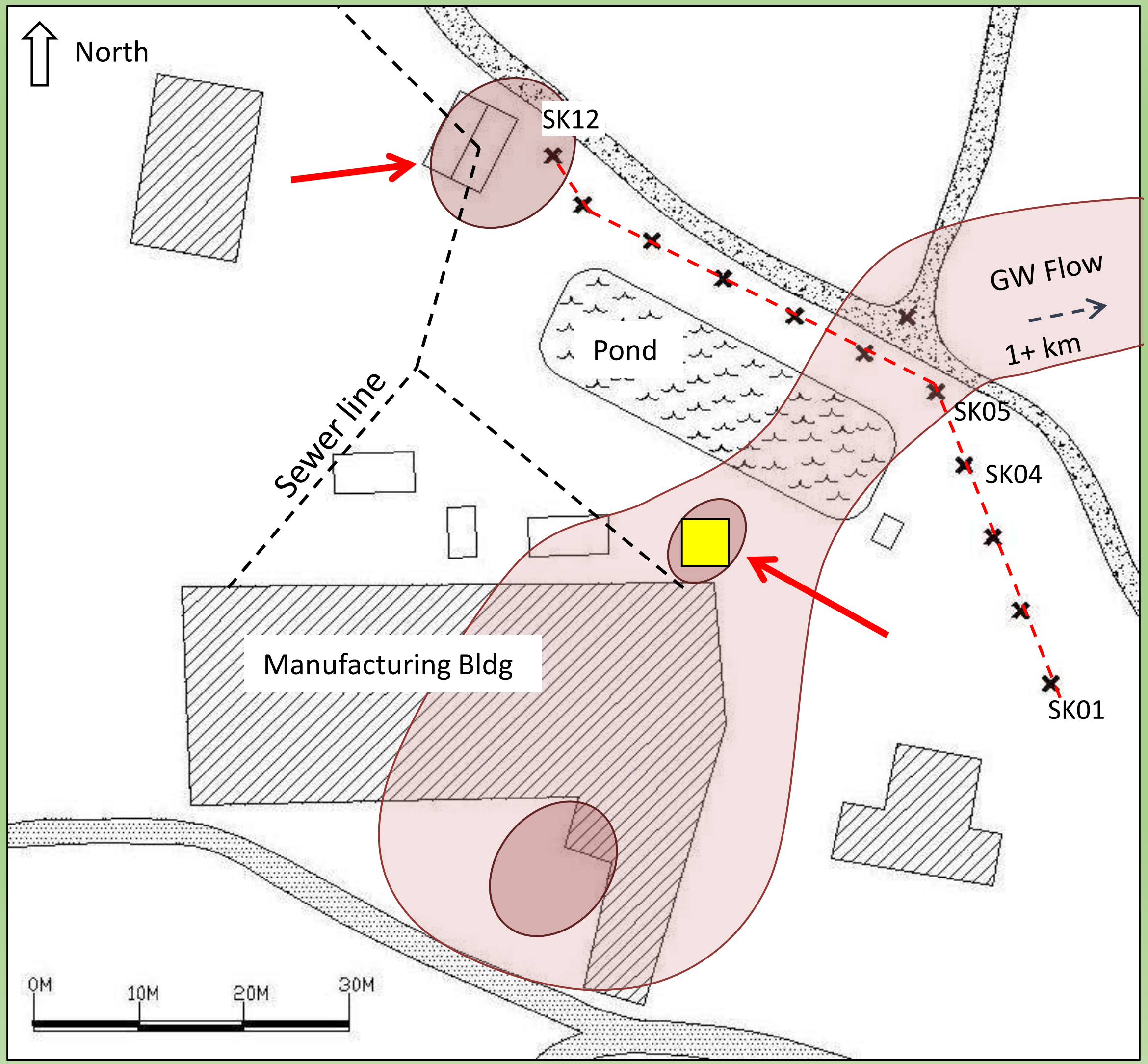
Groundwater specific conductance

We conducted groundwater profile sampling at SK05 for CVOCs with SP16 groundwater samplers. The 30 cm (1 ft) piezometer screens were developed prior to sampling. Water quality parameters, including specific conductance, were monitored to stability at each interval. Here we see the specific conductance is increasing as we approach the EC anomaly. This suggests that an ionic contaminant in the formation is causing an increase in the bulk formation electrical conductivity.

Skuldelev, DK Site Map



During discussions with the NIRAS project managers (Klaus Weber and Anders Christensen) we learned that a pilot study with persulfate injection had been conducted at one of the DNAPL hot spots upgradient of the MiHpt cross section.



Logs are spaced 8 m (~25ft) apart.

Skuldelev, DK Site Map

MiHpt Log X - - - - -

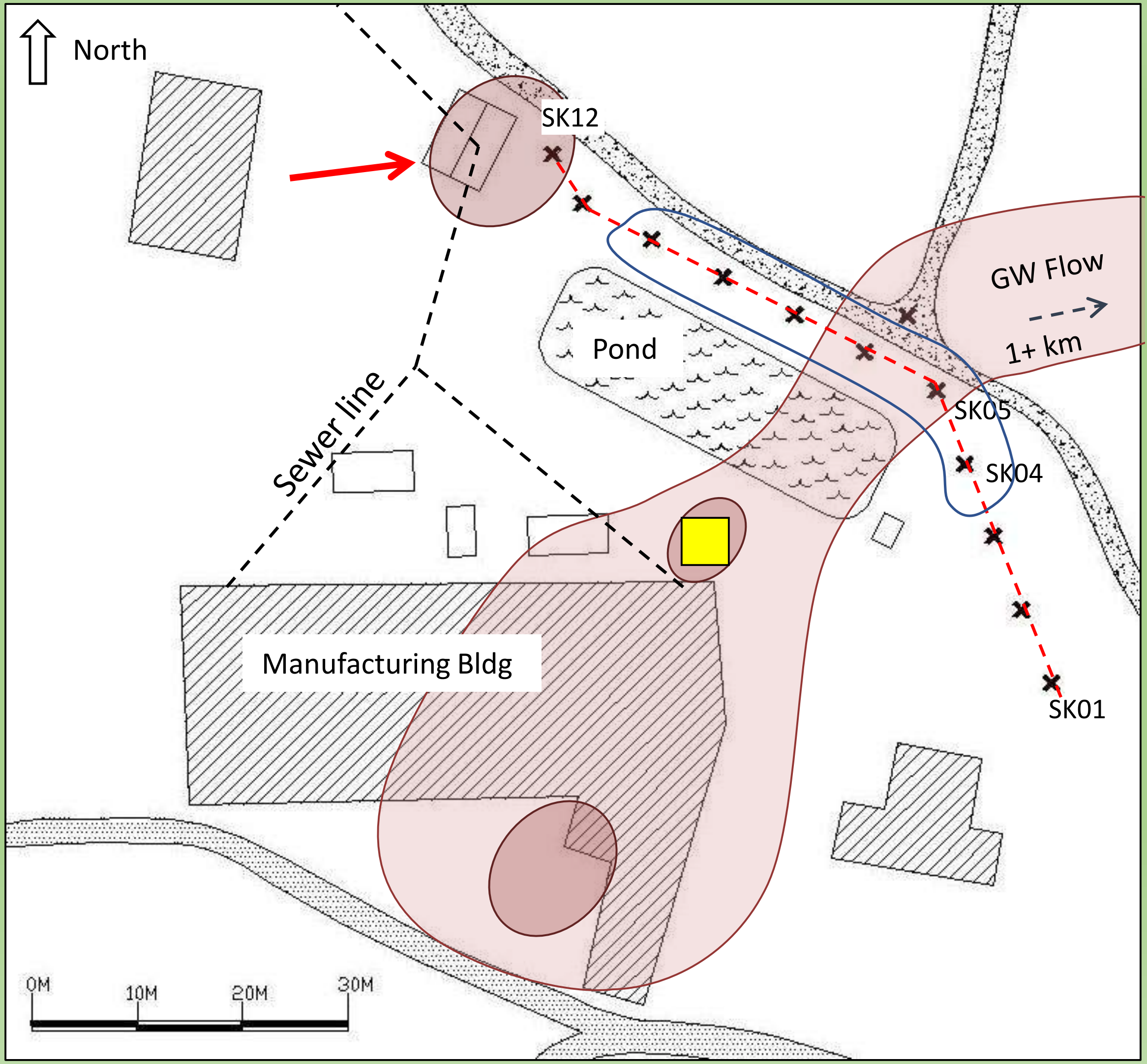
Cross section Line

GW Plume & Hot Spot

PCE, TCE, DCE & VC

Persulfate Injection

Now, let's look at a cross section from SK04 over to the SK10 location, focusing on EC and HPT pressure.



Logs are spaced 8 m (~25ft) apart.

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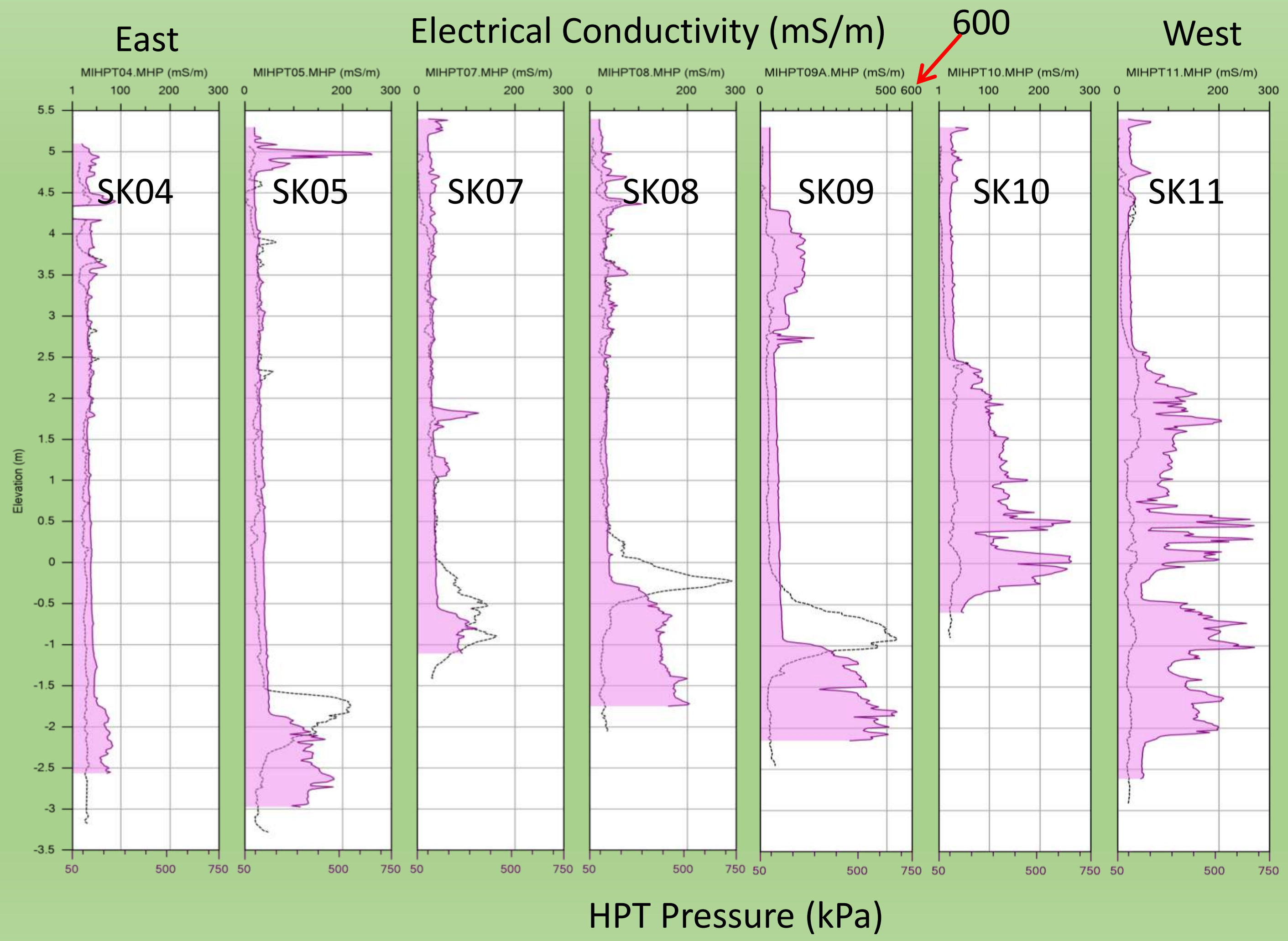
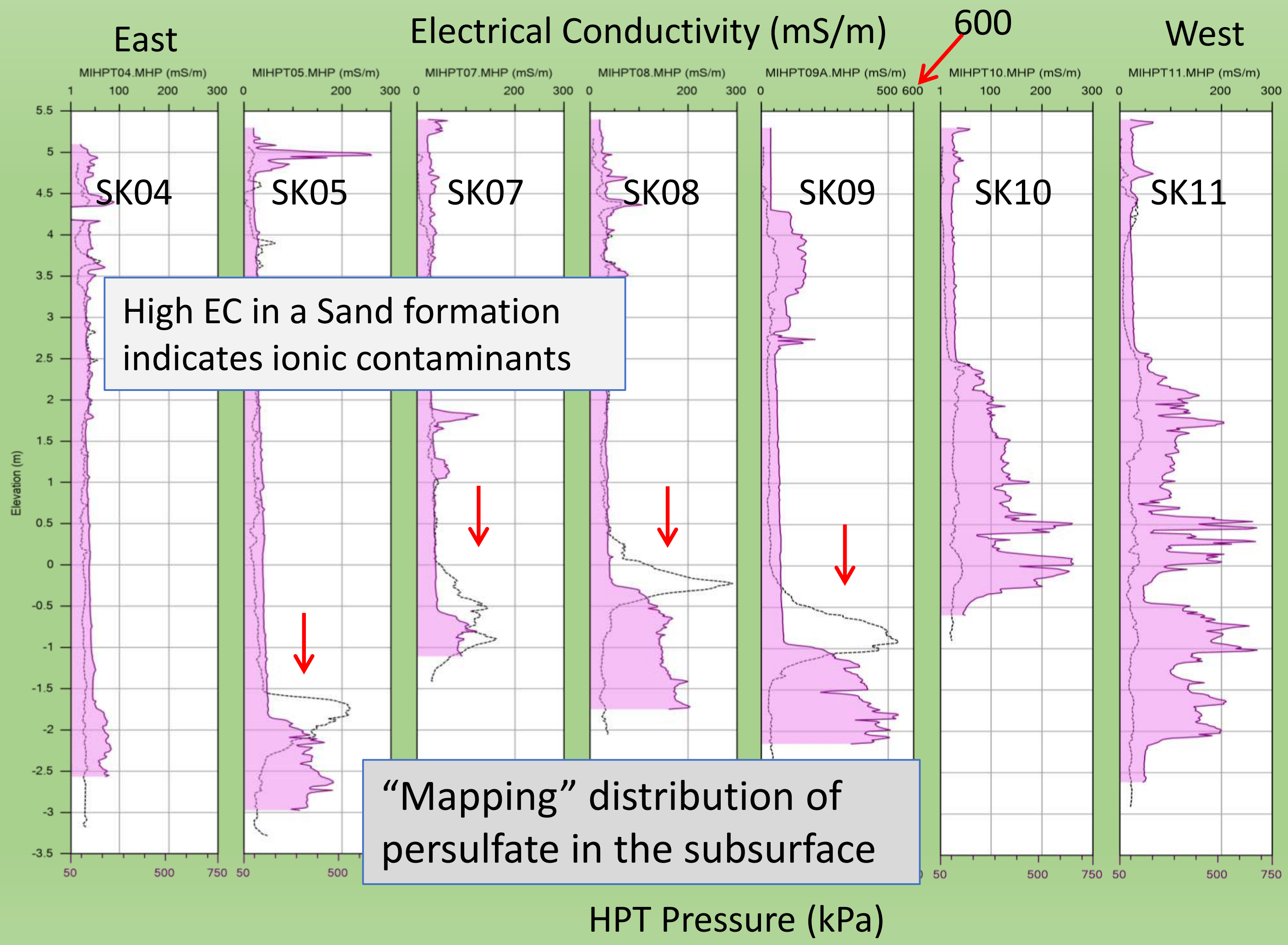
Cross Section with HPT Pressure & EC



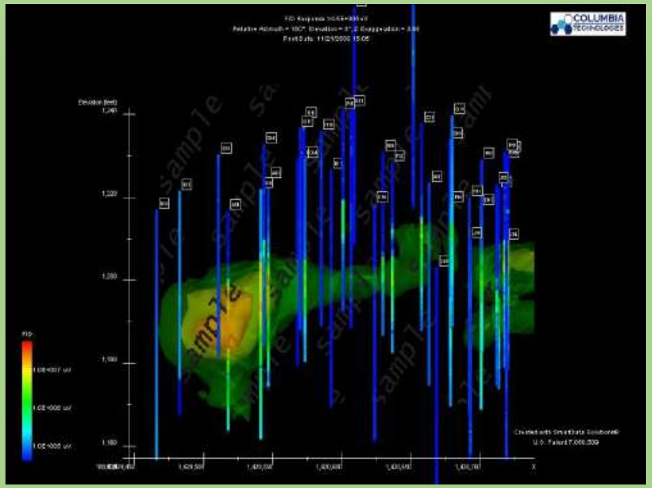
HPT pressure is in purple and EC is black dashed line. Background EC at SK04 and SK10 & 11 are relatively flat, and below HPT pressure.

Cross Section with HPT Pressure & EC



However, between the SK05 to SK09 locations we see that EC clearly increases above the clay-till. In several cores across the area we observed a “basal conglomerate” at the boundary between the clay-till and the overlying sands and gravels.

Conclusions



- They are not silver bullets.
- These tools accelerate the understanding of PAH and VOC contaminant plumes and highlight migration pathways and contaminant storage and back diffusion zones.
- Define LNAPL source areas and VOC dissolved phase extents.
- High resolution plume mapping can…
  - Frequently reduce remediation costs by remediating only the impacted soils/groundwater as defined by the plume shape.
  - Greatly improve remediation effectiveness.
- Help guide soil/groundwater sampling and MW installation.
  - You still need run analytical for contaminant type and concentration confirmation.

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