Laser-Induced Fluorescence (LIF)

Effective Technology Allowing Efficient Investigation and Cleanup of Hydrocarbon Contaminated Sites

E-Brochure

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WCEC
2008

Traditional Investigation Methods

1) Test Hole Investigation
2) Monitoring Well Network
3) Vapor Survey
4) Membrane Interface Probe (MIP)

WCEC Notes:

An overview of current investigation methods. With the exception of the MIP probe, these methods have been standard to environmental investigations over the past 20+ years. All of these methods look at all four phases of contamination outlined on the next slide.

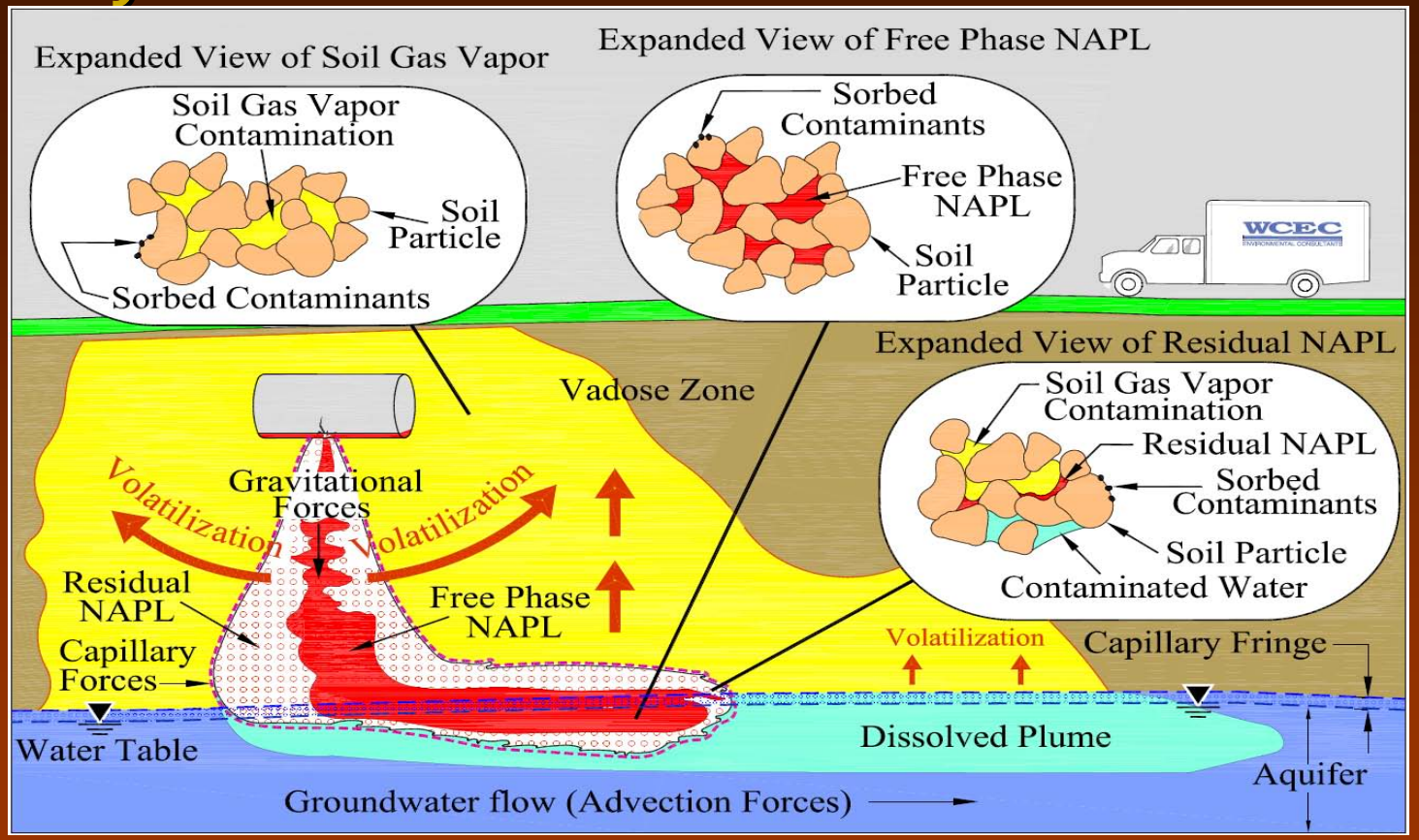
Hydrocarbon Contaminant Phases

1) Vapor Phase
2) Adsorbed Phase
3) Dissolved Phase (APL)
4) Non-Aqueous Phase Liquids (NAPL)
    a. free phase (mobile)
    b. residual

WCEC Notes:

The four hydrocarbon contamination phases. The traditional investigation methods previously outlined are effective at locating and defining the first three phases of contamination; they are ineffective at locating and defining the fourth phase – NAPL. LIF only sees NAPL which is unique to the environmental field. This ability allows investigations to focus on the source of the problem (NAPL) rather than the symptom of the problem (vapor phase, adsorbed phase, dissolved phase). This ability allows environmental professionals to make better and more efficient site decisions.

Hydrocarbon Contaminant Phases



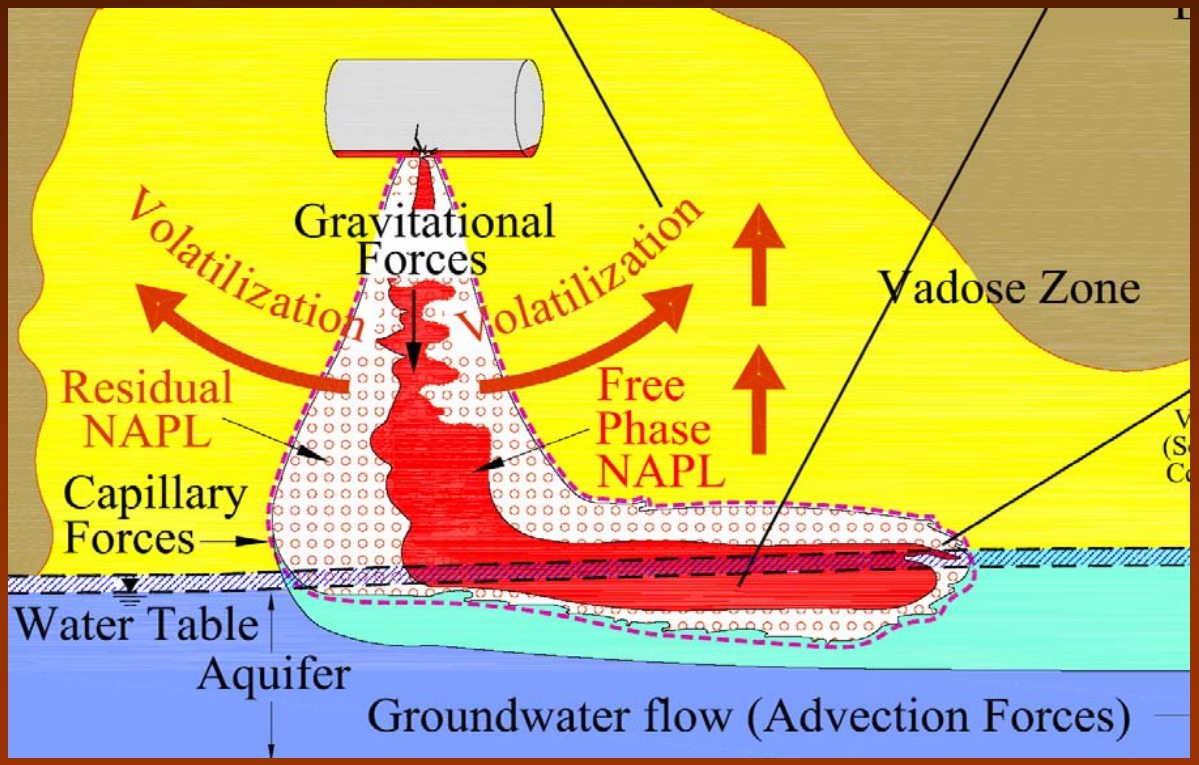
WCEC Notes:

The key to this conceptual cross section is that petroleum contamination in soil gas vapor or water is made up of individual molecules of hydrocarbon compounds such as benzene, naphthalene, etc. Free phase NAPL and residual NAPL are both NAPL. Both are solvent-based and connected together in an organic matrix of millions of other hydrocarbons. The difference between free phase and residual NAPL is free phase is continuous and capable of migration, where residual is discontinuous and adheres to soil particles via capillary forces and thus generally not capable of migration.

Key to LIF ⟶ Identifies NAPL

Understanding the positioning of NAPL is prerequisite for:

- Effective remediation design
- Efficient use of cleanup funds



WCEC Notes:

The key to LIF is it allows environmental professionals to quickly and accurately define the extent of NAPL at contaminated sites. This information alone is invaluable in making efficient decisions regarding how and if corrective actions are needed. In the conceptual example above, only the free phase and residual phase NAPL need to be removed for effective cleanup. It is now clearly understood that the soil gas vapor and dissolved contamination will attenuate if its source is removed.

Total LIF/UVOST™ Projects

WCEC Notes:

LIF/UVOST projects completed in the last 10 years.

Minnesota Pollution Control Agency (MPCA) Developments

- 2007 Second Party Review of Remediation Program
  - Reason: high costs/low return of current remediation systems
  - Conclusion: lack of NAPL fate/transport understanding
- Outcome - NAPL definition required prior to remediation
  - Updating MPCA Guidance Documents to require NAPL definition

MPCA Contact:
Paul Stock -Remediation Coordinator
(218) 846-0473
Paul.Stock@state.mn.us

WCEC Notes:

This is a MPCA overview of LIF use and contact information. Paul Stock encourages people in this industry to contact him to discuss the importance of understanding NAPL position prior to attempting any cleanup.

LIF Technology Review

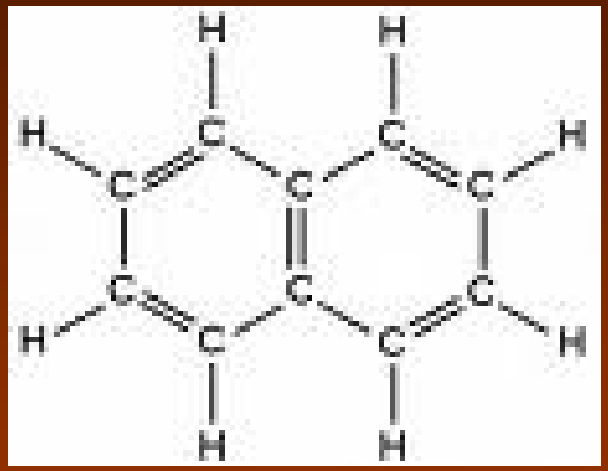
Laser-Induced Fluorescence (LIF)

- Ultra-Violet Optical Screening Tool (UVOST™)
- Utilizes push probe
- Direct-sensing tool
- Real-time log
- Rapid assessment – 200-500 ft per day
- Detects free phase & residual NAPL
- Does not see dissolved or vapor phase

WCEC Notes:
For LIF, WCEC uses the UVOST, which has an ultra-violet laser. Any NAPL (free phase or residual) in the soil will fluoresce under UV light. It is a direct sensing tool. Everything is optical - no soil or groundwater sampling – with real time logs. It is delivered via push probe, covering 200-500 ft per day. Since this does not see dissolved or vapor phase (too dilute), WCEC trained professional can define the NAPL plume and focus on the source.

Why does NAPL Fluoresce?

- It contains organic solvent-based polycyclic aromatic hydrocarbons (PAHs)
- PAHs fluoresce under UV excitation



Naphthalene

WCEC Notes:

Polycyclic aromatic hydrocarbons (PAHs), which are found in NAPL, are the part of the NAPL that fluoresce. The PAHs in diesel are different than the PAHs in gasoline, etc. Naphthalene is one example of a PAH. (Kerosene is mainly naphthalene.) Diesel contains a relatively high concentration of PAHs, and thus fluoresces very well.

UVOST™ & SPOC

Computer with real-time log

- UV laser light
- Fiber optic cable in rods
- SPOC: Shock-Protected Optical Compartment
- Sapphire window

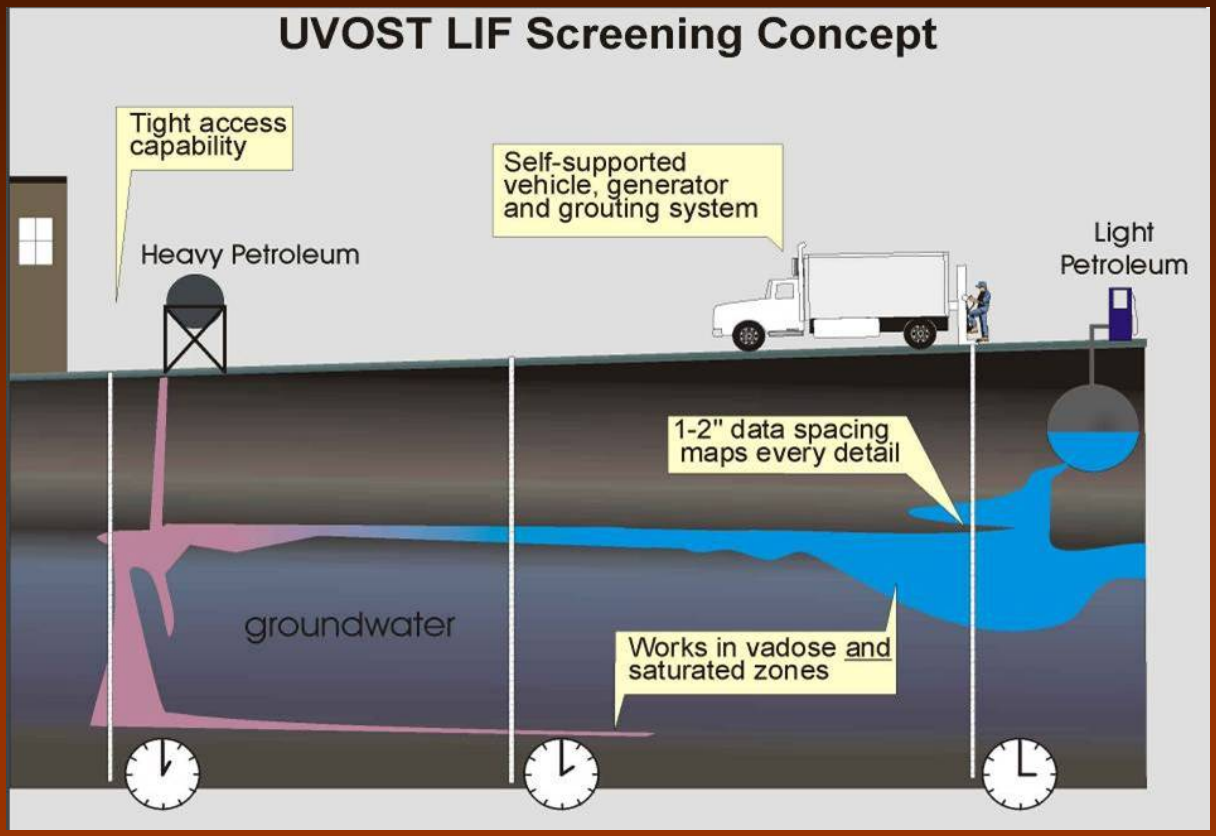
WCEC Notes:

The rods are pre-strung with a fiber optic cable, which is attached to the SPOC. UV laser light travels through the cable to the SPOC and exits through the sapphire window. The SPOC is water tight and allows the probe to be hammered without affecting the data. As the SPOC is pushed down, any NAPL in the soil at the window will fluoresce. This fluorescence travels back up the rods through the same cable to the detection equipment.

Screening Concept

- Grid layout
- 25 -30’ apart
- Detection levels typically <100 ppm
- Only “sees” what’s at window
- Above & below the saturated zone
- No drag-down
- _____

  Depth Limitations
- geologic obstructions
- push probe depth



WCEC Notes:

LIF investigation: borings are conducted in a grid pattern across the site, ~25’-30’ apart. Depending on the product and soil type, contamination (as low as 10-20 ppm) will fluoresce. LIF works above and below the saturated zone. Since the probe only makes one push into the ground to complete the log, contamination does not get “dragged down” as can happen when rods are pulled up and pushed down through a highly contaminated zone.

Applications & Limitations

Detectable Products

- gasoline
- diesel
- jet (kerosene)
- motor oil
- hydraulic fluids
- cutting fluids

May also see:

- coal tar
- creosote (wood treatment)

Doesn't see

- polychlorinated bi-phenyls (PCBs)
- chlorinated hydrocarbons

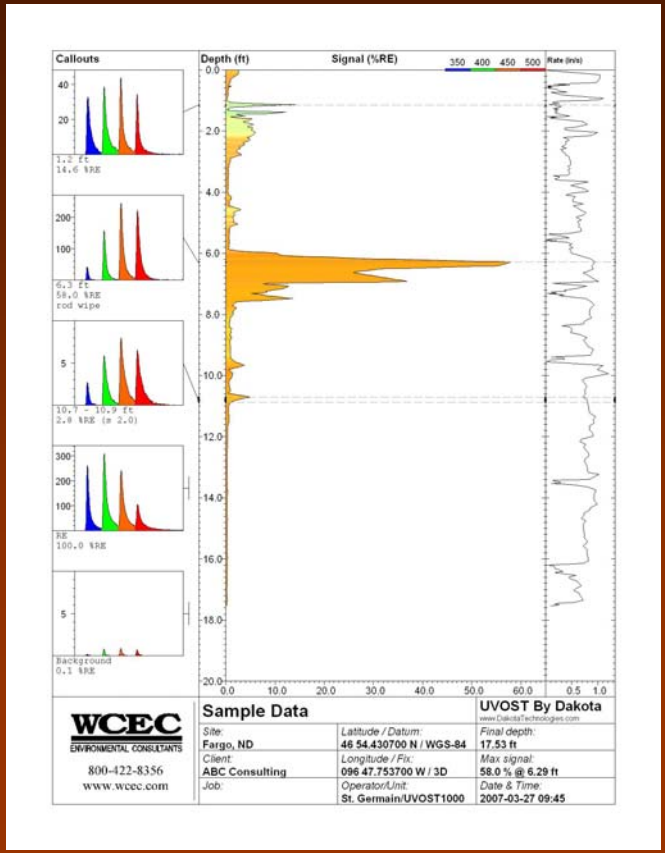
False Positives

- organic matter
- calcite

WCEC Notes:

How well LIF "sees" a product sometimes depends on soil type and age. For example, weathered gasoline in clay may be difficult to detect. However, diesel is not affected by soil or age and fluoresces well.

Example LIF Log



- Continuous data (1″)
- Semi-Quantitative → %RE
- Qualitative → Product Type
- Waveforms (callouts)
- Response ~linear

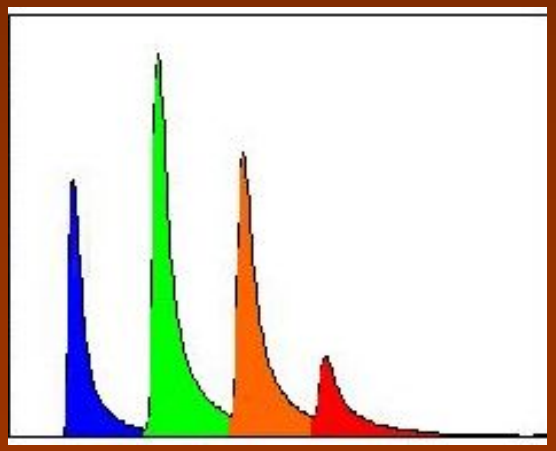
- QA/QC (each push)
  - Reference Emitter Check
  - Background Check

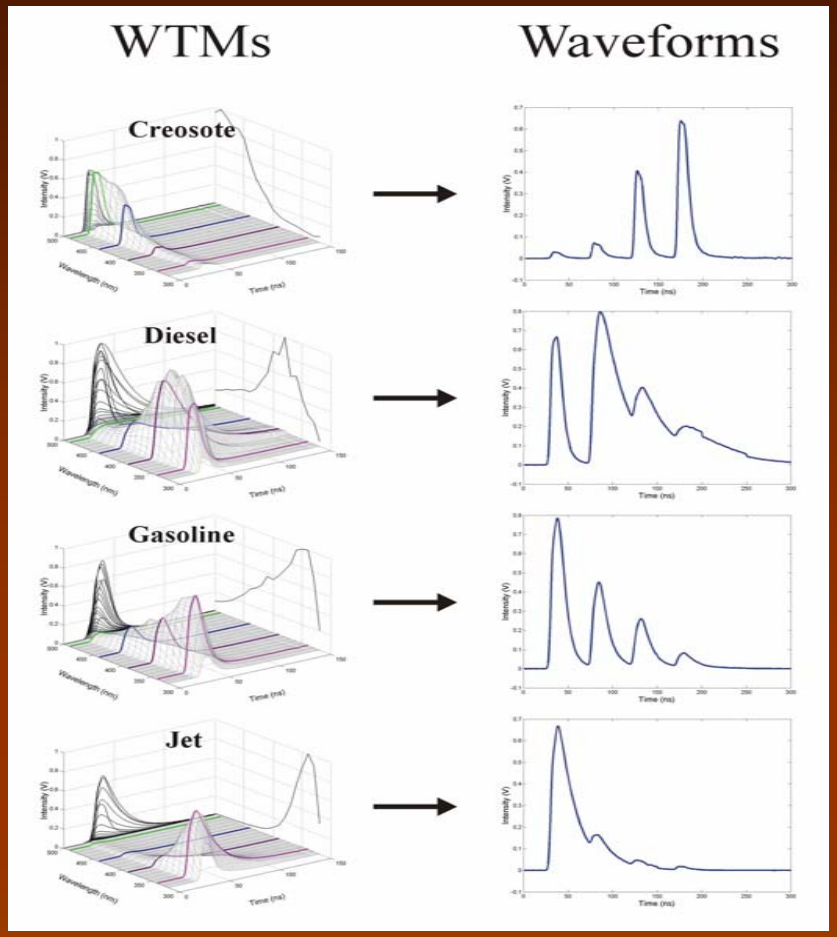
WCEC Notes:

On the log: depth is vertical; fluorescence intensity is horizontal. The SPOC is pushed at a rate of 0.8 in/sec, giving fluorescence data every inch. Before each push, a reference (reference emitter or RE) is checked and the background is checked. Data is given as a comparison to our RE as %RE rather than parts per million (semi-quantitative). Product type can be determined from the callout at that depth (left side of log) (qualitative).

Waveforms for Various Products

350 nm (UV) → blue
400 nm (violet) → green
450 nm (blue) → orange
500 nm (green) → red



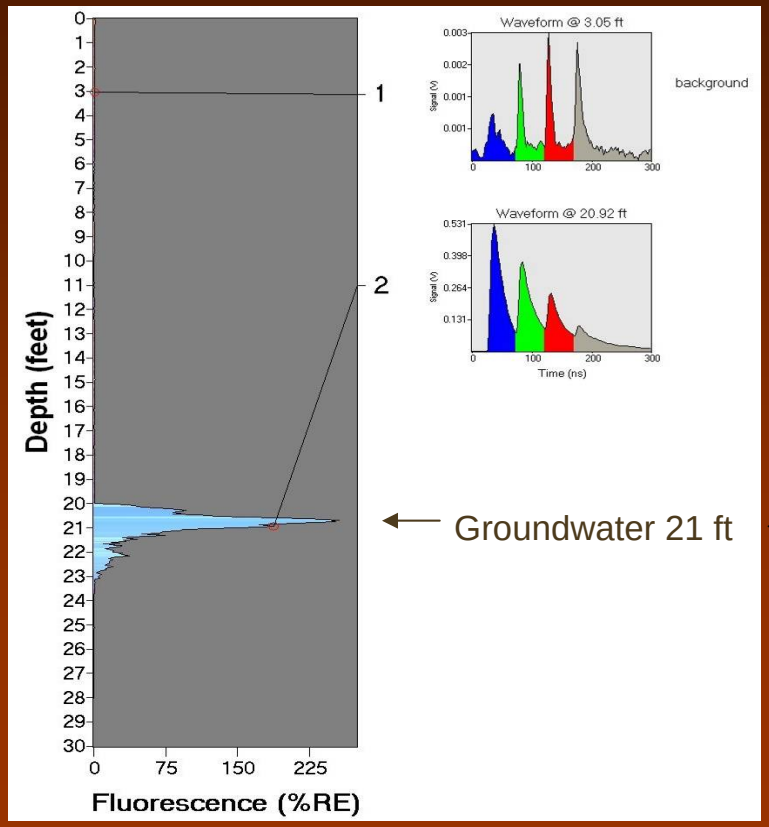


WCEC Notes:

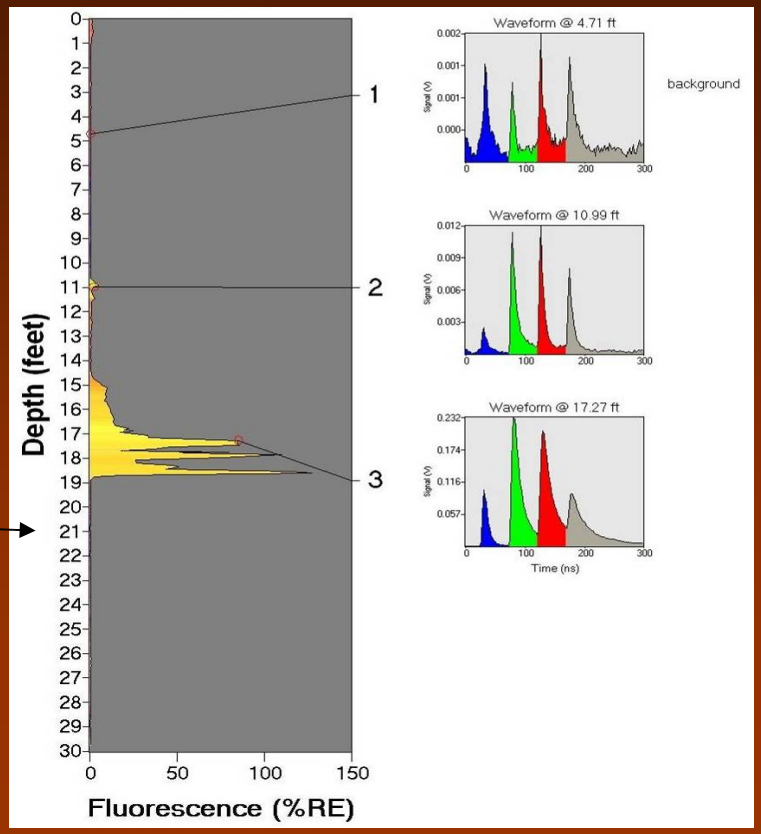
Here's how the waveforms compare for different products. Note the differences in peak height (fluorescence intensity) and thickness of the peaks (decay fluorescence). The colors used for the peaks on the waveforms were chosen by the manufacturer.

Example Logs from a Gasoline Site

Source Area



Perimeter



WCEC Notes:

In these UVOST logs, the fluorescence intensity of gasoline appears as blue and diesel appears as yellow. The source area boring was completed in the worst case site area and shows a classic near water table distribution of NAPL. The perimeter boring was completed near an adjacent property with a source of diesel contamination. Notice the diesel NAPL has not yet reached the water table.

When to use LIF

- Prior to site remediation
  - Evaluate NAPL position (horizontal and vertical)
  - Focus Remediation Effort on NAPL (source)
- Remediation system currently operating
  - Test effectiveness
  - Evaluate current NAPL position
- Investigation
  - Evaluate magnitude of source area
  - Reduce number of MWs and test holes
  - Identify products, differentiate between RPs

LIF Case Studies

- Site 1: Complex NAPL Migration
- Site 2: Submerged NAPL

WCEC Notes:

A review of two unique case studies where LIF was utilized. Both sites are going to active remediation, and LIF was utilized to define the vertical and horizontal extent of NAPL prior to determining the most effective remediation technology and completing a pilot test. More case study data is easily available upon request.

Site 1 - Site Background

FIGURE 2b: Detailed Site Map Showing Monitoring Wells and Water Supply Wells

WCEC

WCEC Notes:

This is a sandy site with inter-bedded layers of silt. The water table is approximately 40 feet below grade. There are benzene impacts to two municipal wells.

Dissolved Benzene Plume

WCEC Notes:

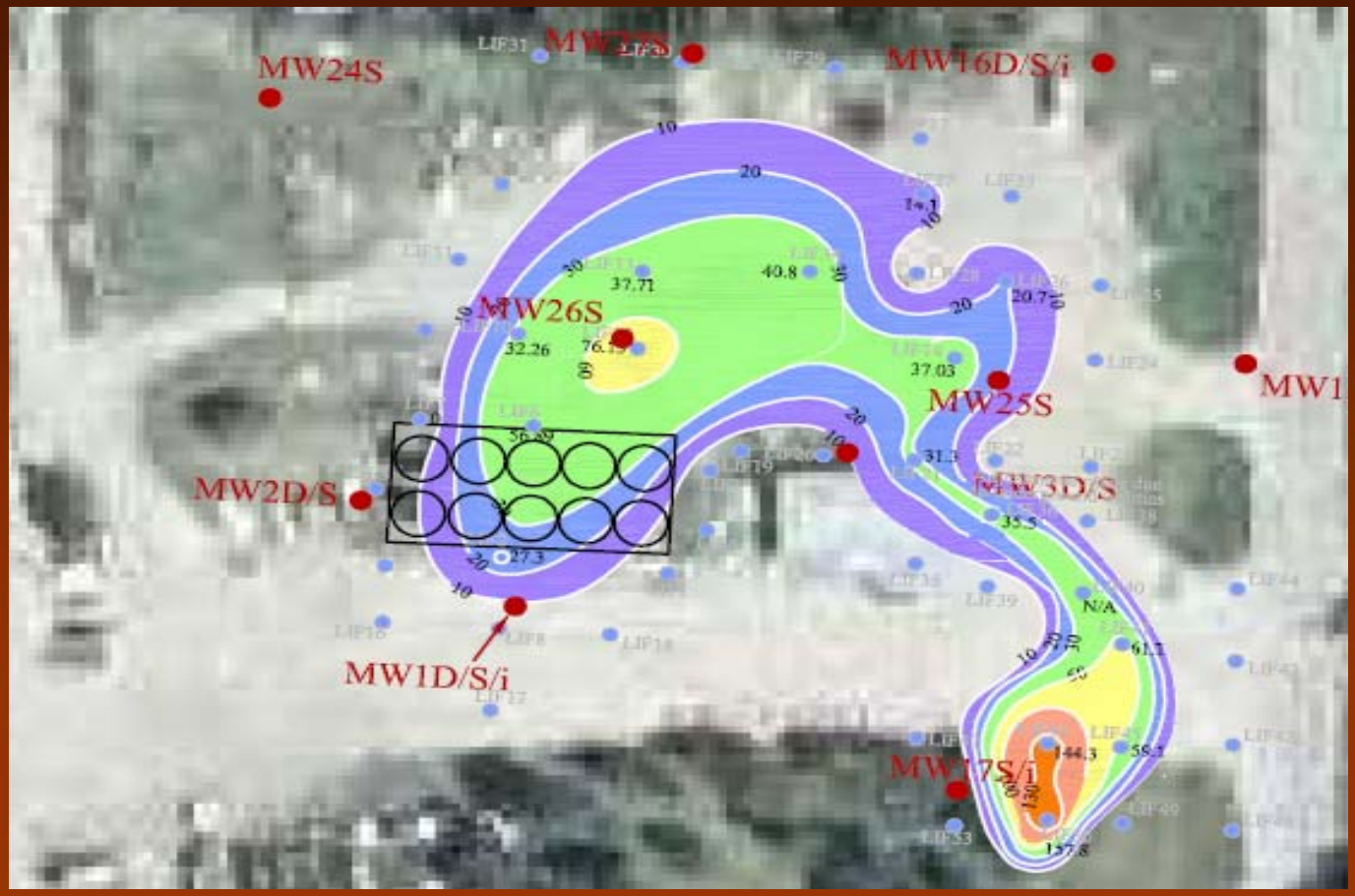
A large dissolved benzene plume was defined via laboratory analysis of discrete water samples. The definition of this plume lead to the identification of the responsible party. Since the symptom of the problem had been defined, it was time to move to the next phase and define the source of the problem.

NAPL vs Dissolved Benzene Plume

WCEC Notes:

WCEC completed an LIF 30 foot grid at the site and defined the vertical and horizontal extent of NAPL.

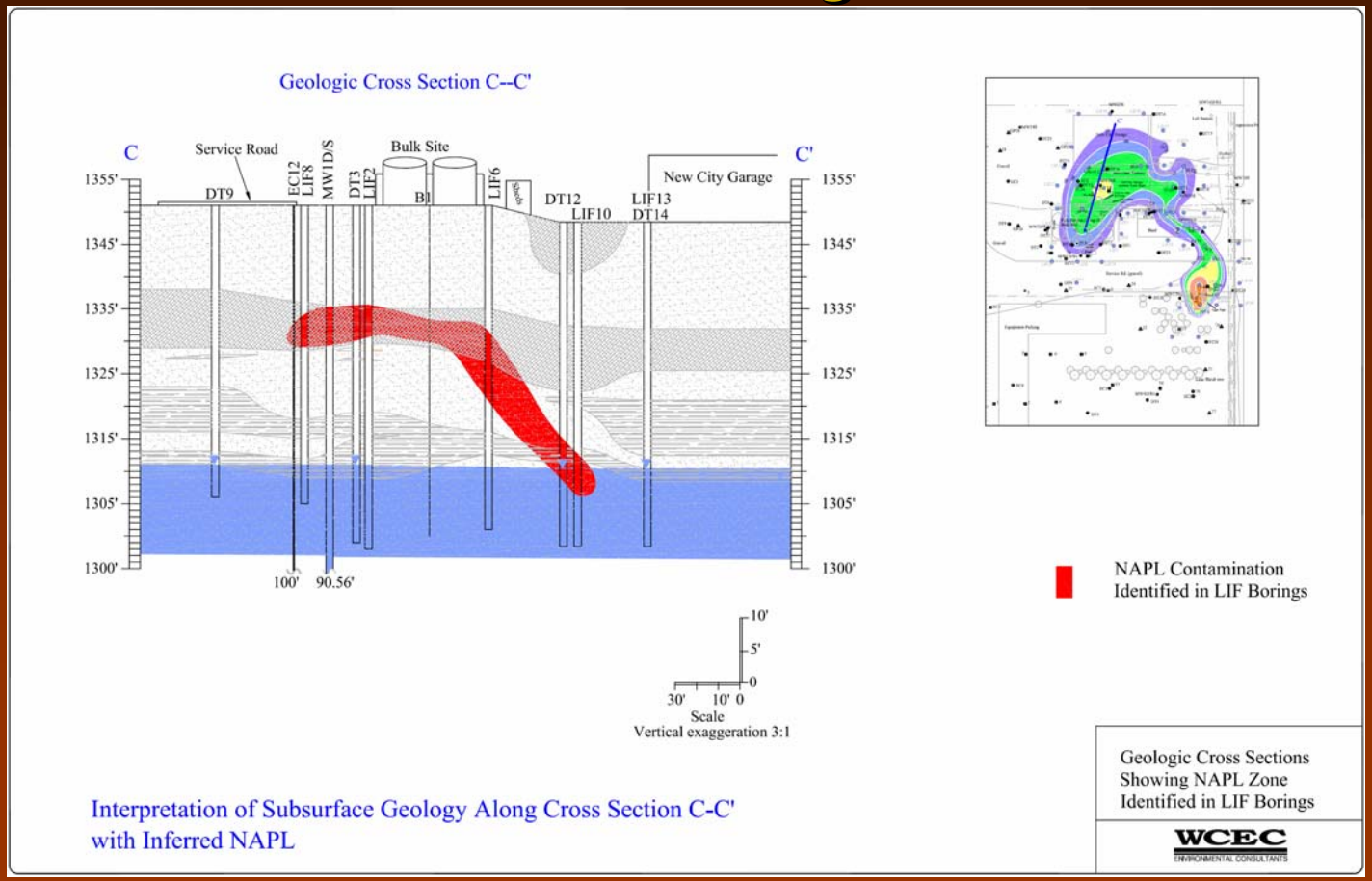
Defined NAPL



WCEC Notes:

A blow up of the NAPL plume without the dissolved plume. The red areas are the worst case areas with the highest % response. Natural groundwater flow is to the S-SE. A municipal well was recently installed to the SW, and pumping of that well pulled the mobile NAPL in that direction. The northerly migration near the bulk site is explained on the next slide.

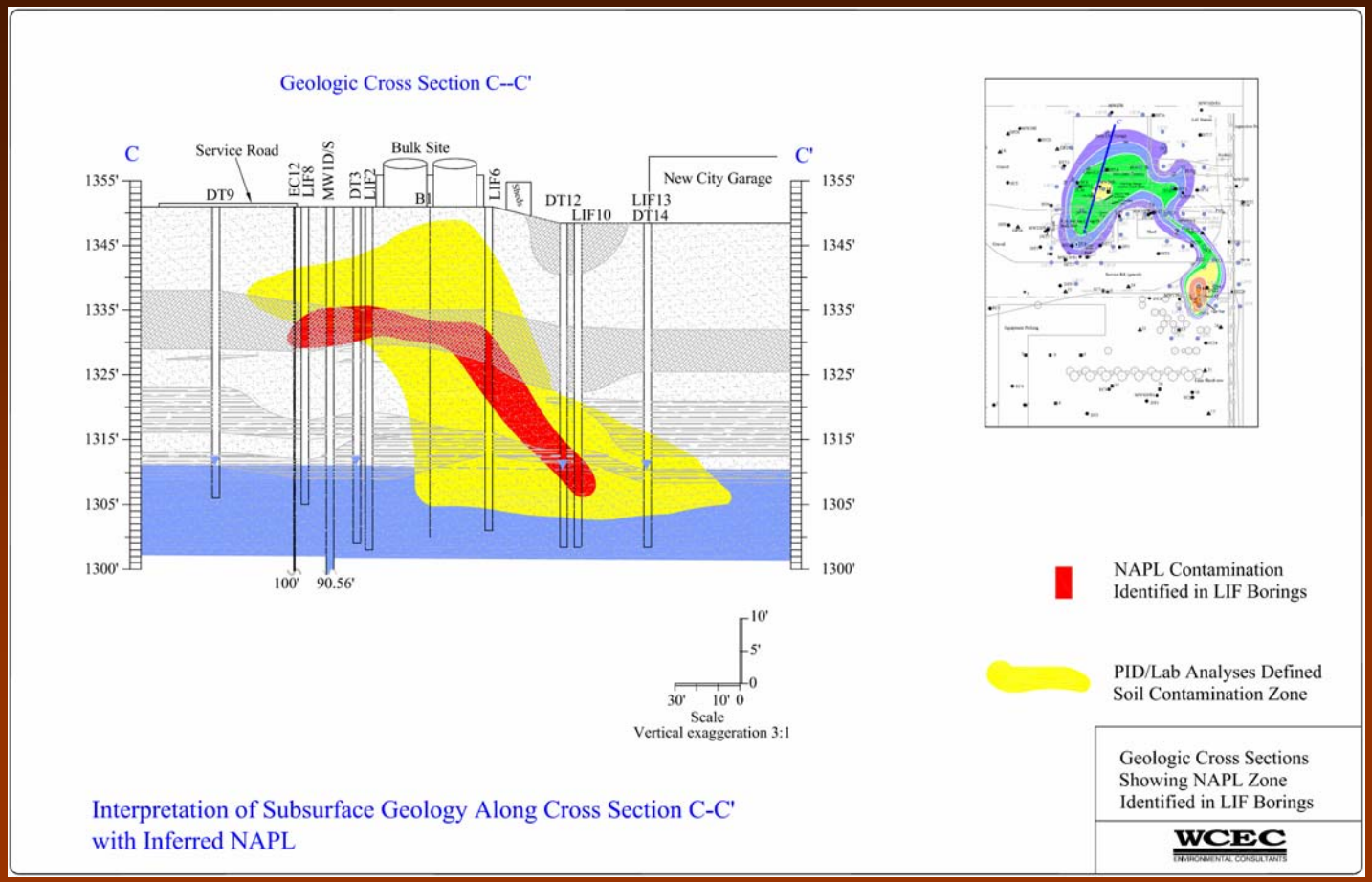
NAPL Vertical Migration



WCEC Notes:

The red indicates NAPL across the C-C' cross section. This NAPL is in the residual phase as it is no longer mobile and is adhered to soil particles. Based on the residual footprint remaining from the release, the release quickly migrated downward until it hit the silty till layer that is tilted to the north, where product flowed to the north until it eventually migrated through the silty layer and eventually impacted the water table. At that point, further NAPL migration was influenced by natural and, later, induced ground water flow.

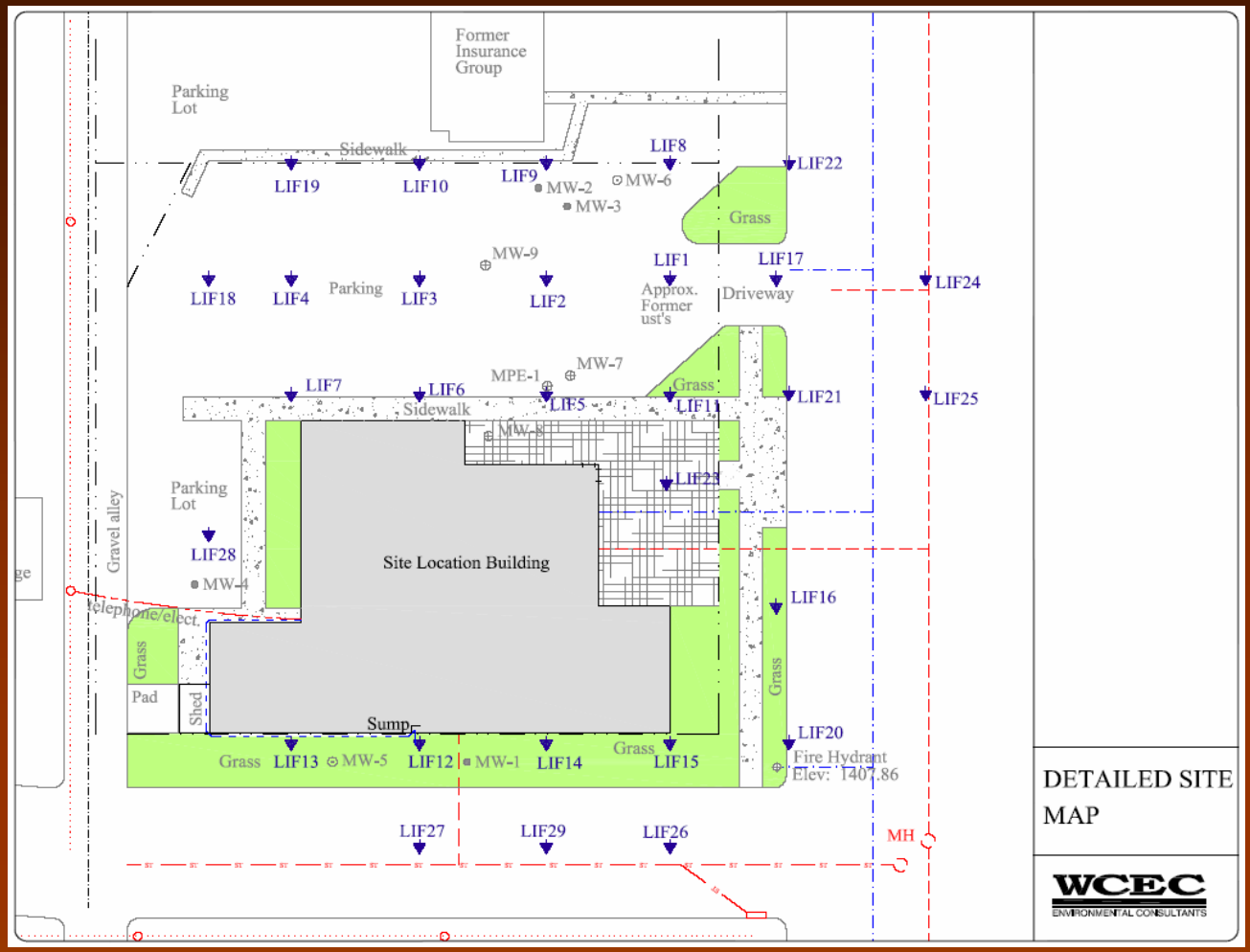
NAPL Vertical Migration



WCEC Notes:

Same cross section, but with the defined soil gas vapor plume. Again, I like to call it the source of the problem (NAPL, in red) and the symptom of the problem (soil gas vapor, in yellow). The ability to see just the NAPL is now allowing us to focus our remediation efforts only on the source.

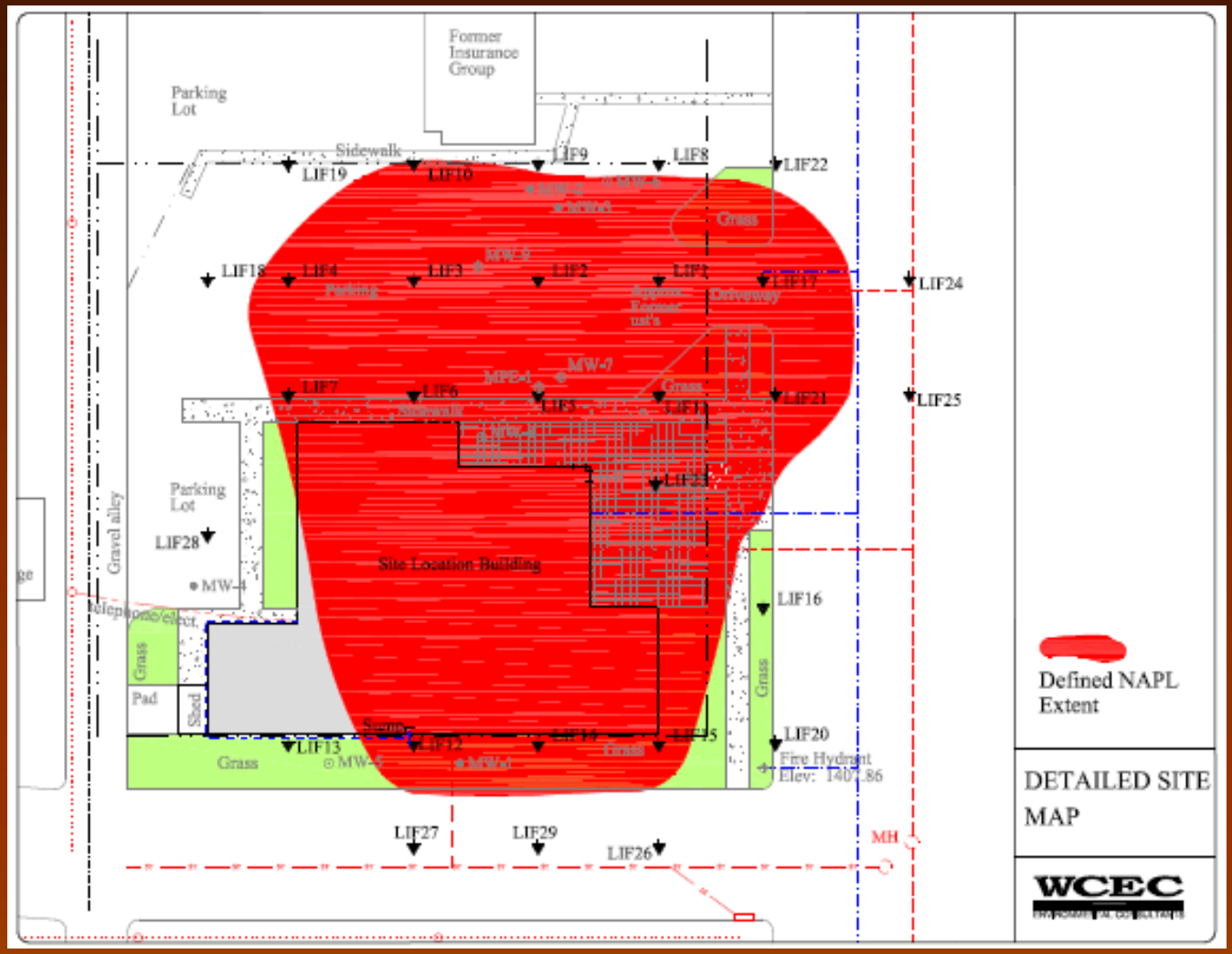
Site 2 - Site Background



WCEC Notes:

This site is a fine textured site with inter-bedded layers of sand. Several feet of free product were identified in monitoring wells at the site. When WCEC took over this "problem site," the first step was to complete a grid of LIF borings at the site.

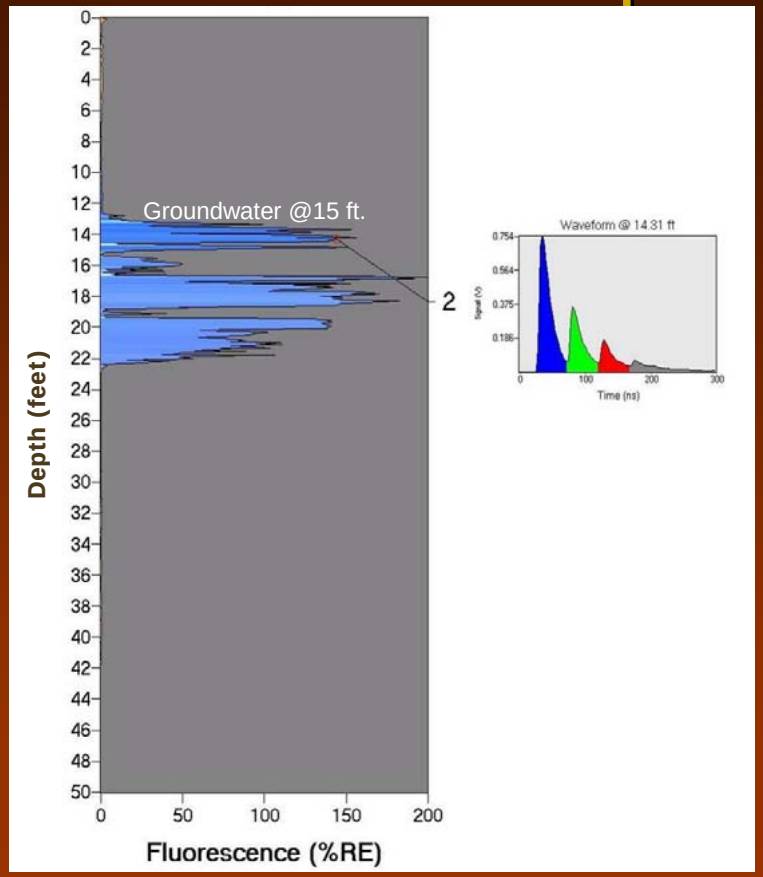
Defined NAPL Extent

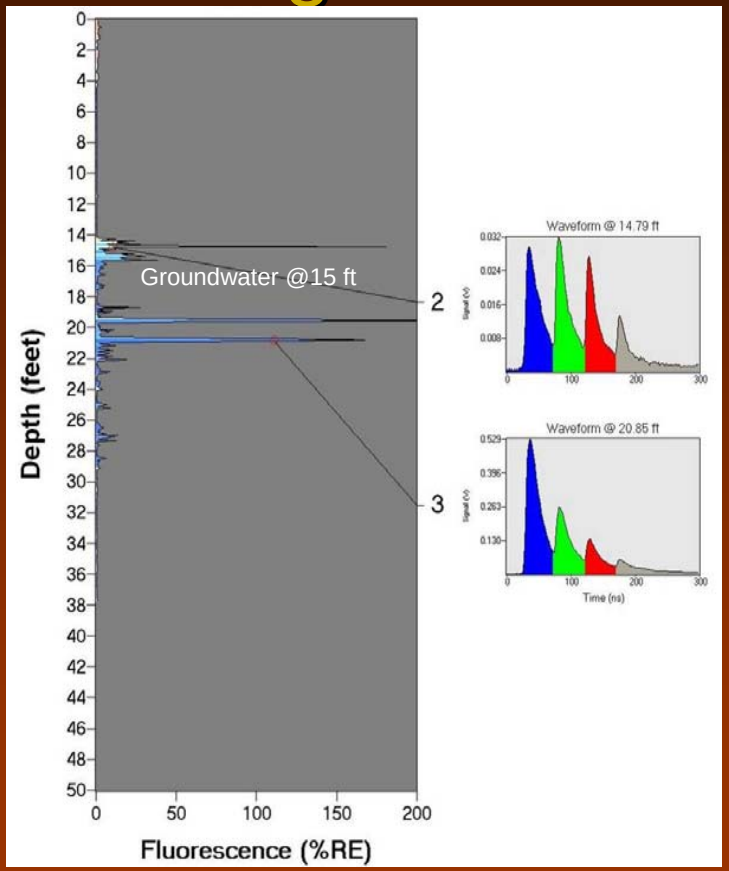


WCEC Notes:

The LIF work identified the vertical and horizontal extent of NAPL (in red). Most likely, this was the first time that anyone understood what the problem was at this site.

Example LIF Site Logs

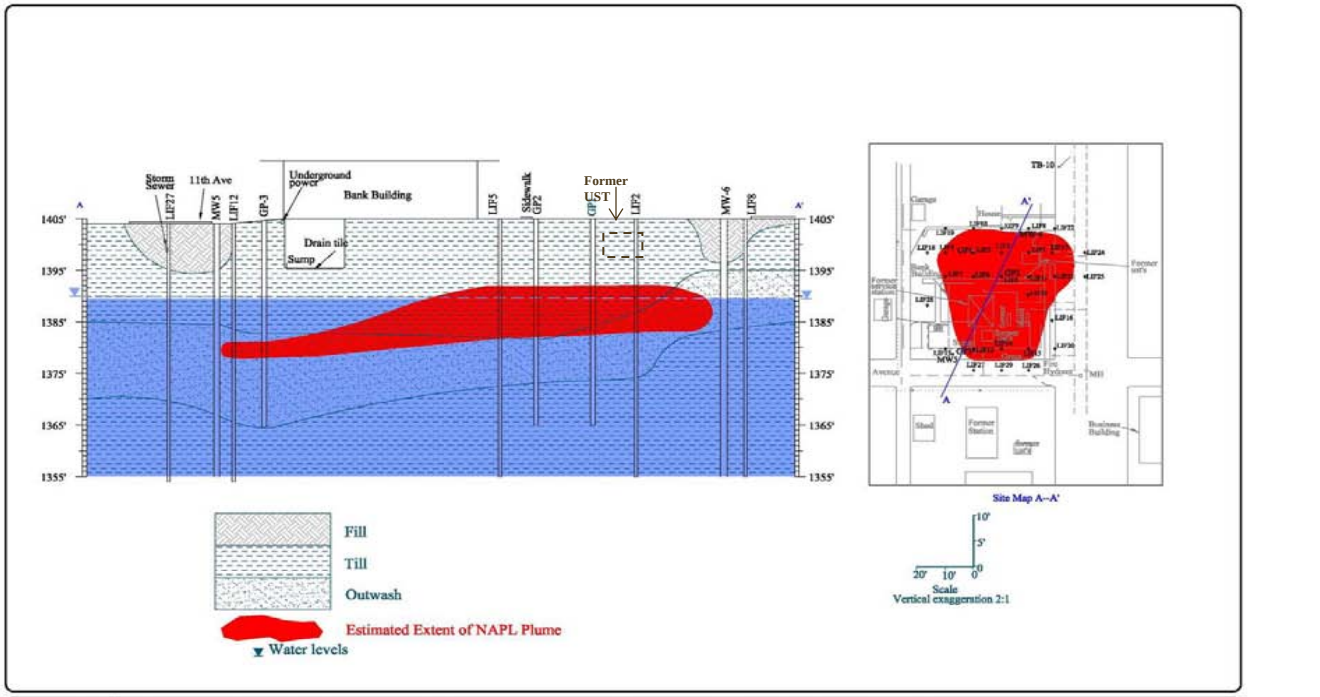




WCEC Notes:

Here are examples of two LIF logs from this site. I have several examples of the source area log, on the left where NAPL is present well below the water table (15 feet below grade). The perimeter boring on the right shows thin bands of the most highly concentrated NAPL at the site. What we found is that this perimeter log shows migration of NAPL in sandy fractures within the clayey matrix; thus, by default the LIF provides a snapshot of the geology at this site.

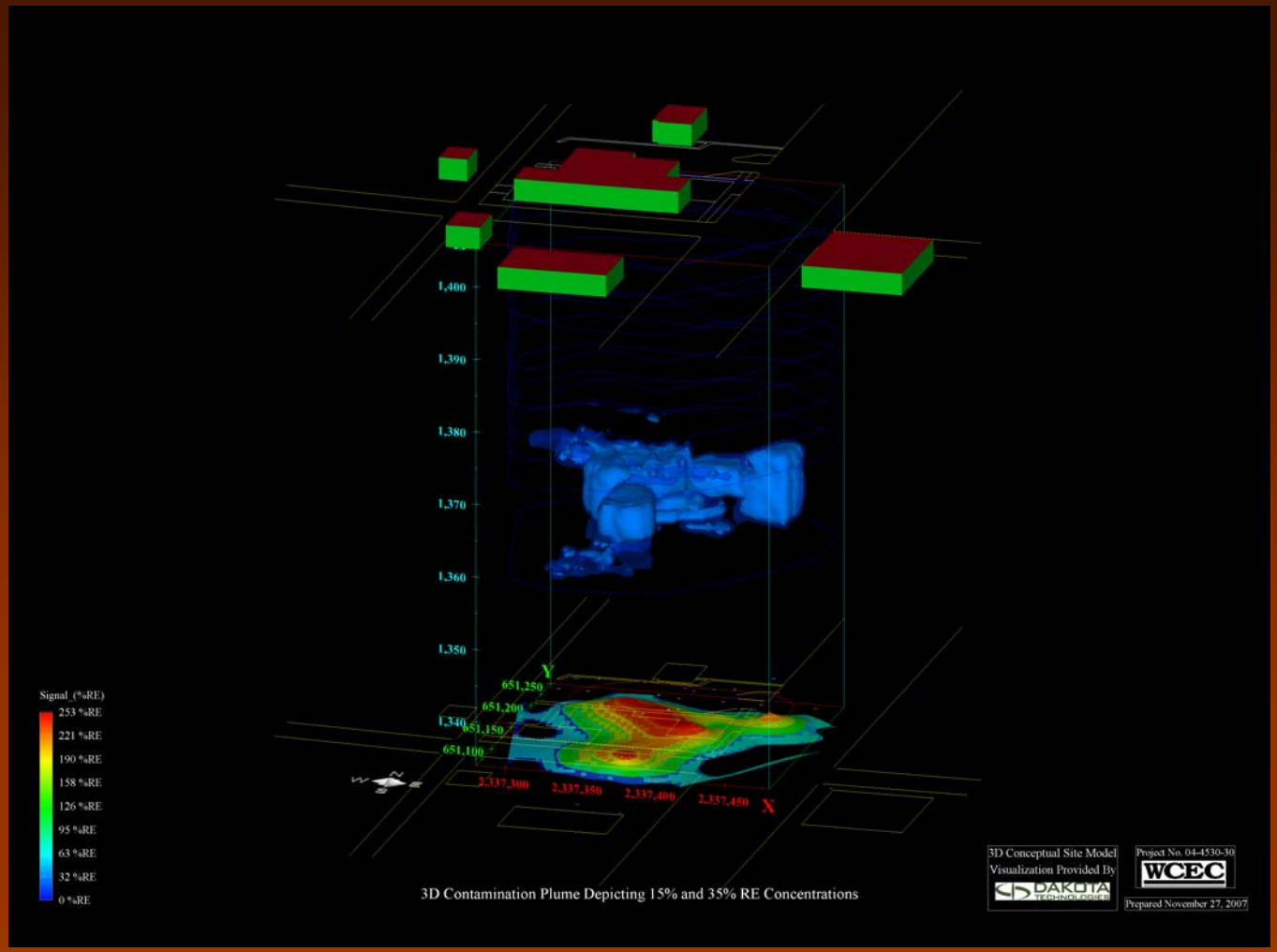
Submerged NAPL



WCEC Interpretation of Subsurface Geology Along Cross Section A-A' with Inferred NAPL Plume

WCEC Notes:

A-A' cross section of the NAPL plume. The horizontal and vertical NAPL migration is extremely visable. Approximately 80% of the NAPL is located beneath the water table, which leads to several challenges when selecting remediation strategies. Excavation is not an option at the site due to the location of the NAPL plume in relation to expensive site structures. As a result, WCEC recently completed a multi-phase extraction (MPE) pilot test and successfully lowered the water table below the defined vertical extent of NAPL and exposed that NAPL to vapor extraction. Information like this is invaluable in determining High Potential Future Costs (HPFC).



3D Contamination Plume Depicting 15% and 35% RE Concentrations

WCEC Notes:

This is a 3D depiction of the NAPL plume (blue) at this site. Notice the area of vertical and horizontal migration and the location of the A-A' Cross Section.

Benefits of LIF/UVOST™

- Product identification
- Instantaneous/continuous data
- Focus on source, not symptom
- Efficient – no lab sampling, fast paced, focused remediation, well-informed decisions
- Geoprobe™ deliverable
- Typically 200-500 feet/day
- Prerequisite for effective remediation design

Questions?

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