Positive Application of ASTM Guidance for the Occurrence and Mobility of NAPL in Sediment

Sediment Management Working Group Sponsor Forum

November 14, 2024

Emma Applegate
Dan Canavan, PG
Jeffrey Hale, PG

KLEINFELDER
Bright People. Right Solutions.

Site and Sediment Characteristics

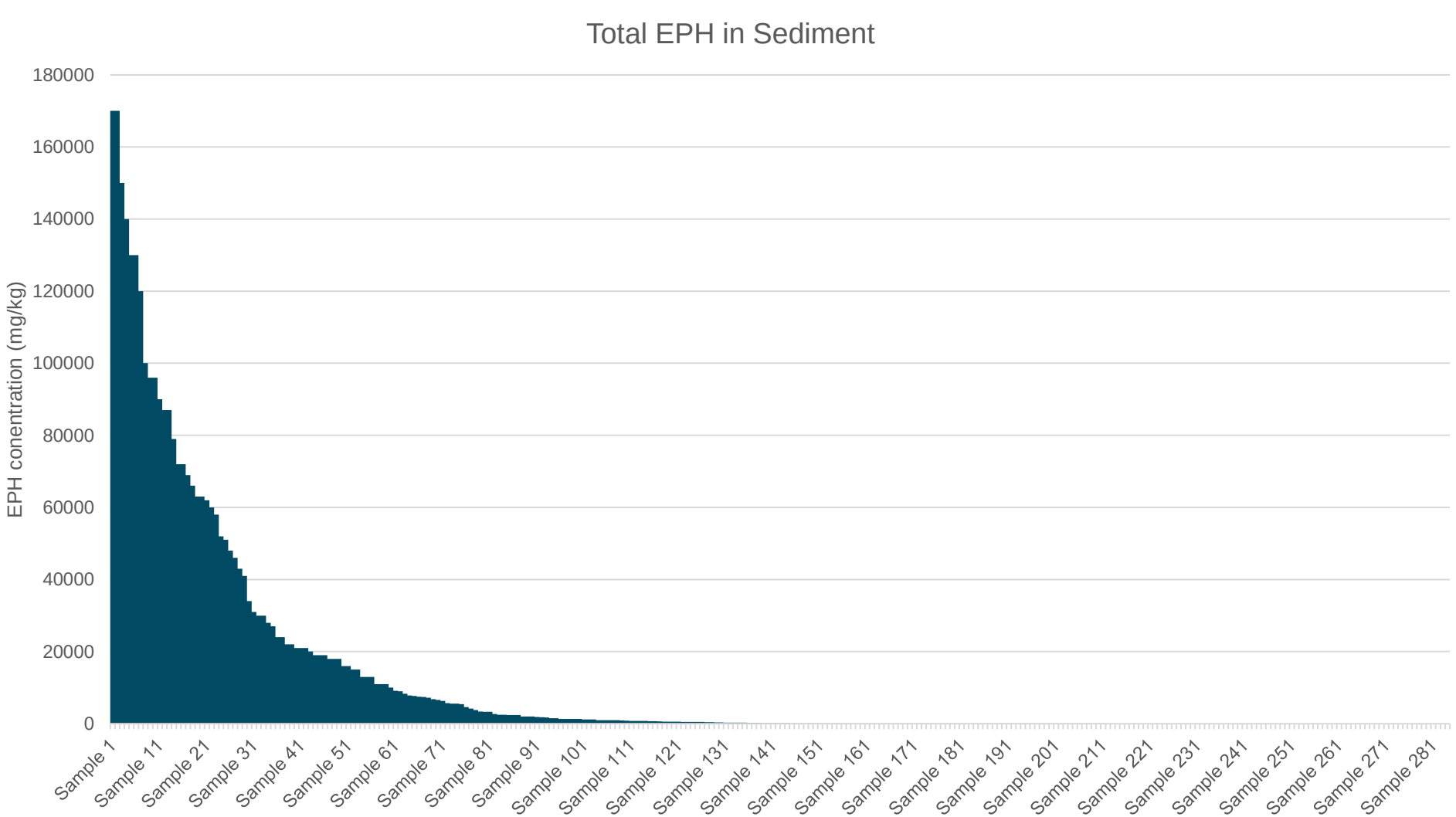
Site Setting

- Active oil refinery
- Tidally influenced creek
- Stream reshaped & dredged over time
- Highly modified shoreline
- Flow largely comprised of non-contact cooling water

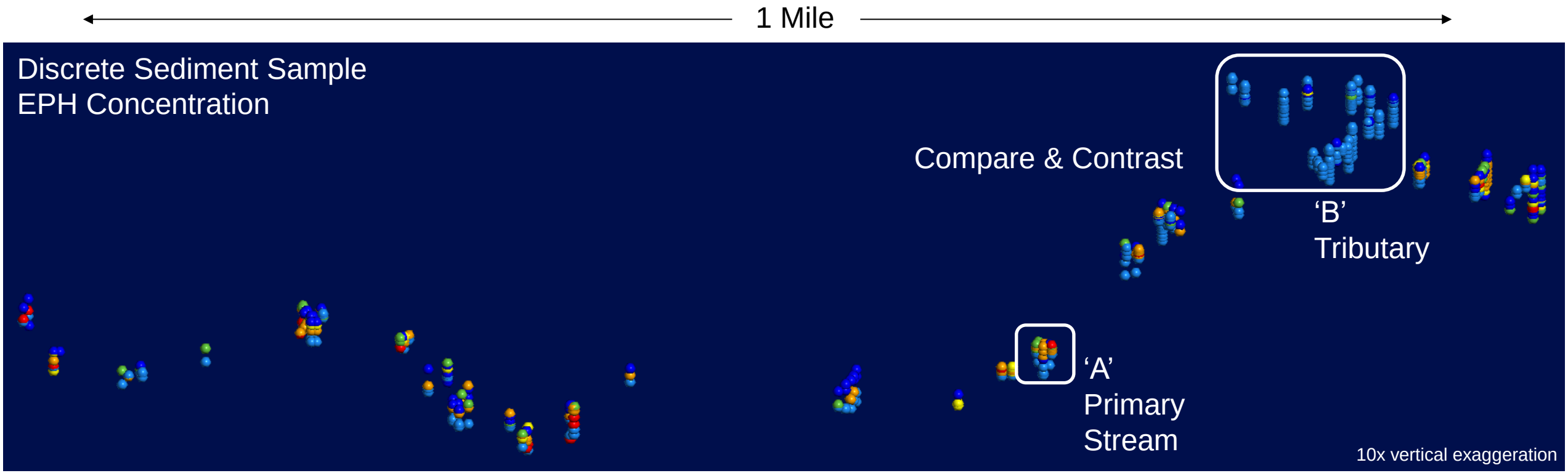
Sediments

- Strata: weathered red shale, peat, and silt
- Target interval: non-plastic silt ≤15 feet
- EPH concentrations ≤170,000 mg/kg
- Initial NAPL saturation 0.21% to 35.89%
- NAPL conductivity 0.0 to 1.4 x 10^{-8} cm/s

Site and Sediment Characteristics



Site and Sediment Characteristics



>100,000 mg/kg >30,000 mg/kg >20,000 mg/kg >10,000 mg/kg >1,000 mg/kg <1,000 mg/kg

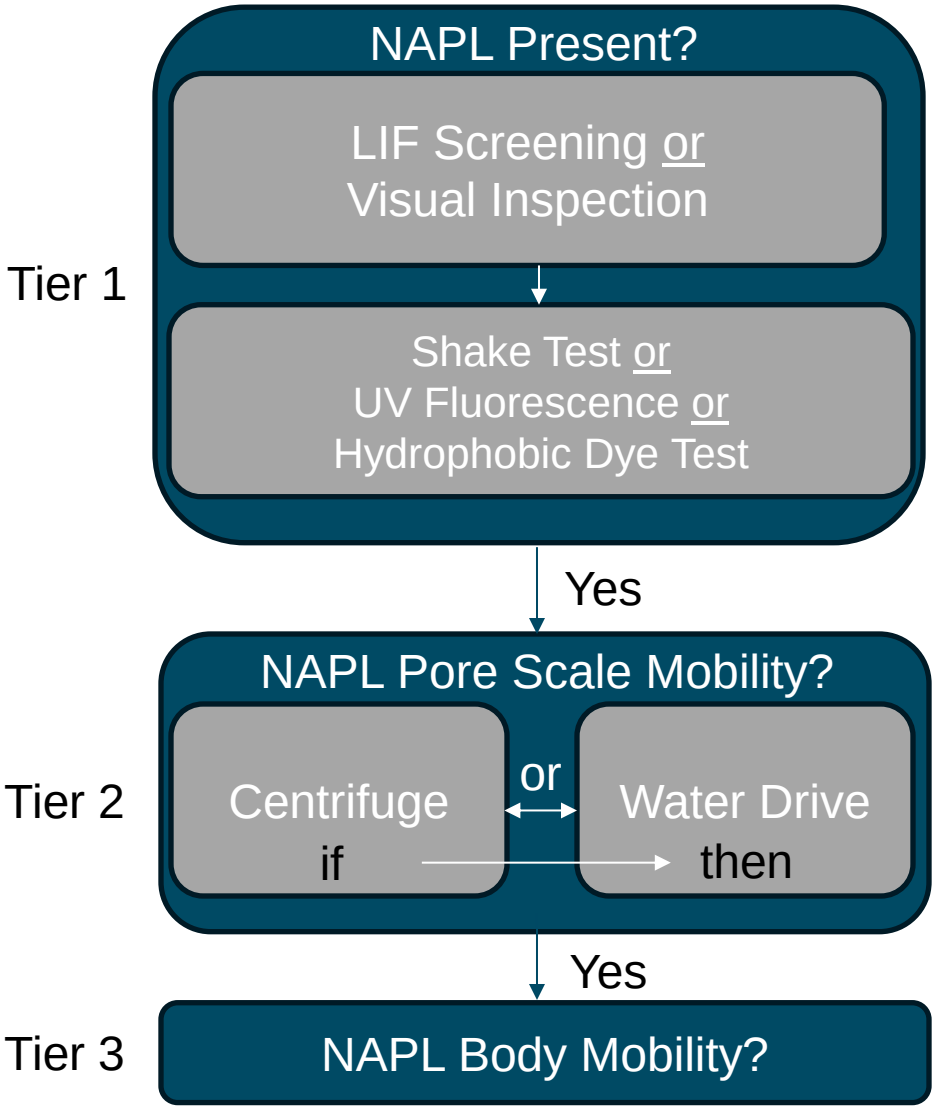
ASTM Standard Guides for NAPL Mobility and Migration in Sediment

- E3268-21 – Sample Collection, Field Screening, and Sample Handling
- E3281-21a – Screening Process to Categorize Samples for Laboratory NAPL Mobility Testing
- E3282-22 – Evaluation Metrics

ASTM Standard Guides for NAPL Mobility and Migration in Sediment

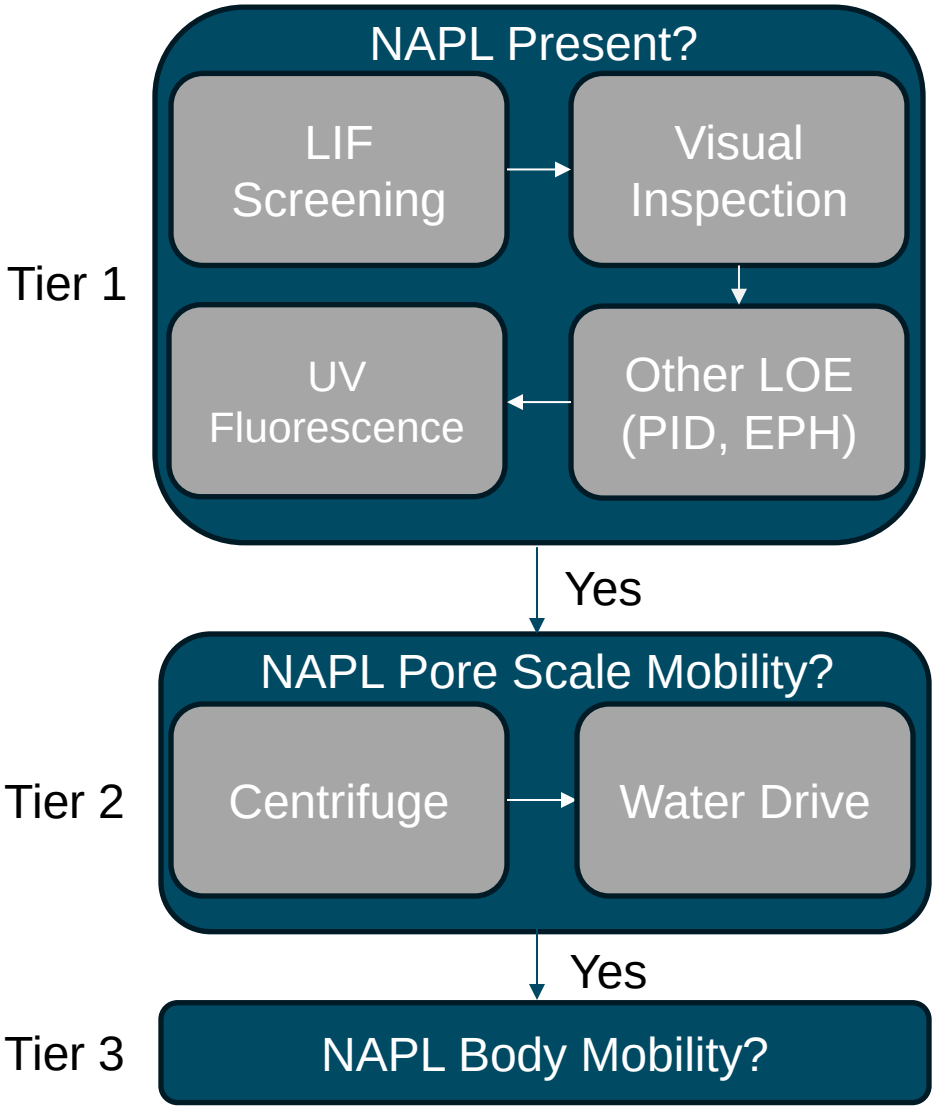
- Systematic process to evaluate NAPL presence & mobility in sediment
- Procedures include:
  - Sediment sample collection
  - Sample processing
  - Visual observation
  - LIF screening
  - UV/white light photography
  - Mobility testing
  - Mobility weight of evidence approach

NAPL Mobility and Migration in Sediments – Evaluation Metrics (ASTM E3282-22)



- **Tier 1** – Field Testing for NAPL Presence
  - Screen with LIF or visual inspection
  - Confirm with shake test method or UV photography or hydrophobic dye test
  - End Point #1 if no NAPL identified
- **Tier 2** – Pore Scale Lab Mobility Evaluation
  - Evaluate NAPL mobility in pores interior to NAPL body
  - Can choose centrifuge or water drive
  - If mobile by centrifuge proceed to water drive
  - End Point # 2 if NAPL immobile at pore scale
- **Tier 3** – NAPL Body Scale Migration Evaluation
  - NAPL body expansion / migration
  - End Point #3 if NAPL body is immobile

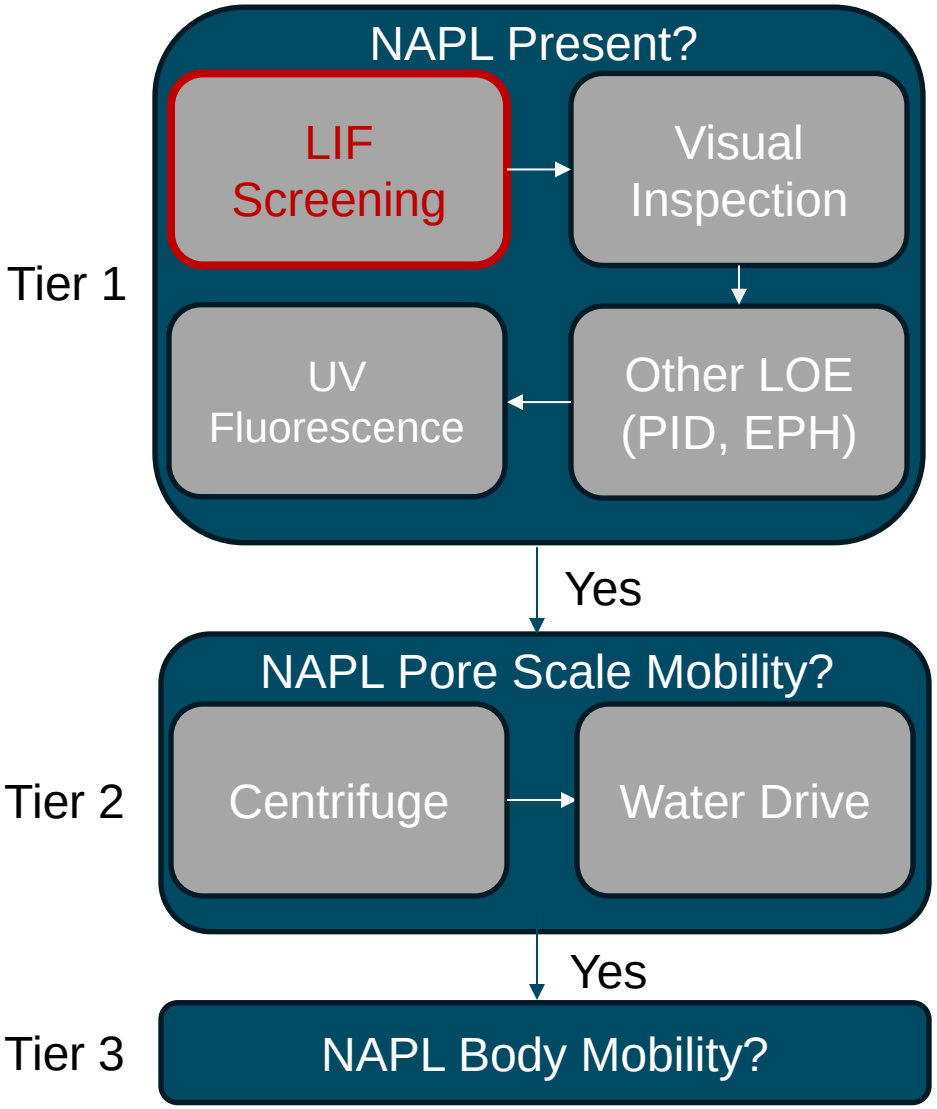
NAPL Mobility and Migration in Sediments – Evaluation Metrics (Modified Approach)

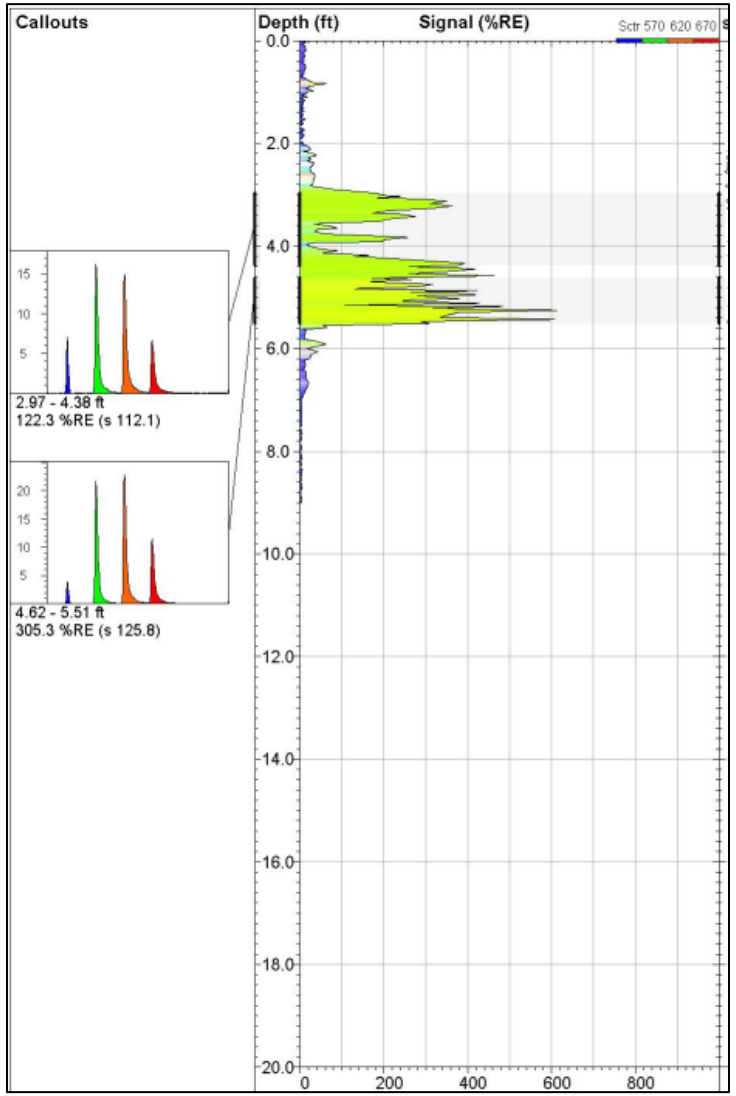


- **Tier 1** – Field Testing for NAPL Presence
  - Evaluate multiple lines of evidence sequentially
  - Exclude shake test due to bias
    - Commonly produces sheen in absence of other indicators
    - Liberates molecules that coalesce to form sheen/film
  - Replace with other indicators (e.g., PID, EPH)
  - UV fluorescence photography strong differentiator
  - End Point #1 if no visual nor UV evidence of NAPL

- **Tier 2** – Pore Scale Lab Mobility Evaluation
  - Apply centrifuge first (most likely to liberate NAPL)
  - Apply water drive if NAPL liberated by centrifuge (more representative of field conditions)

Tier 1 – Field Testing for NAPL Presence
LIF Measurements

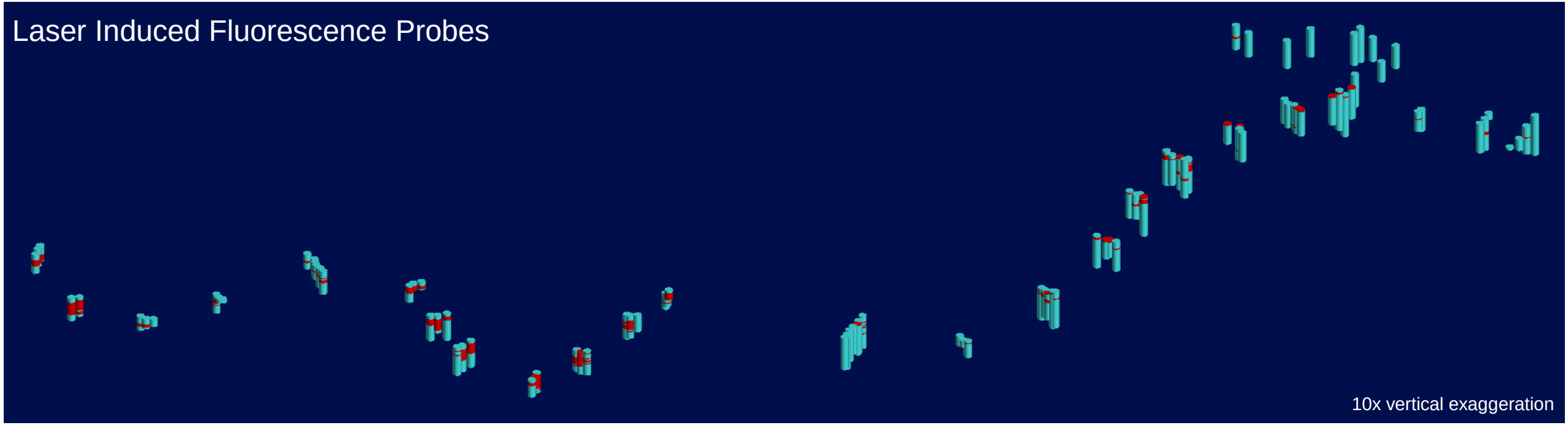




- High data density and spatial coverage
- Indirect indicator with less ‘stand-alone’ certainty
- Should be supported by other lines of evidence
- Subject to interferences
- Beware of exaggerated amplitude scale (%RE)

Tier 1 – Field Testing for NAPL Presence
LIF Measurements

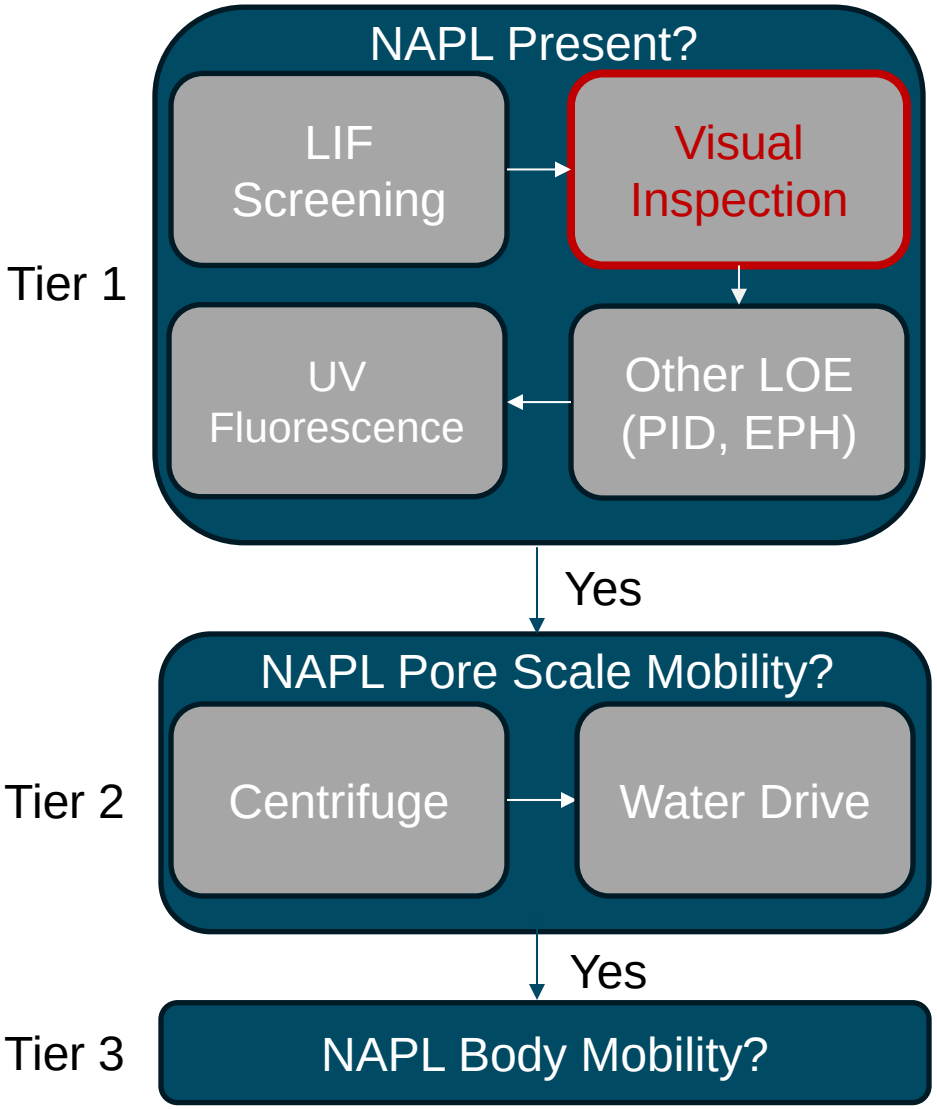
1 Mile



>120% RE <120% RE

Observations of “No Visual Evidence of NAPL” exclusively <120% RE intervals

Tier 1 – Field Testing for NAPL Presence
Visual Observation

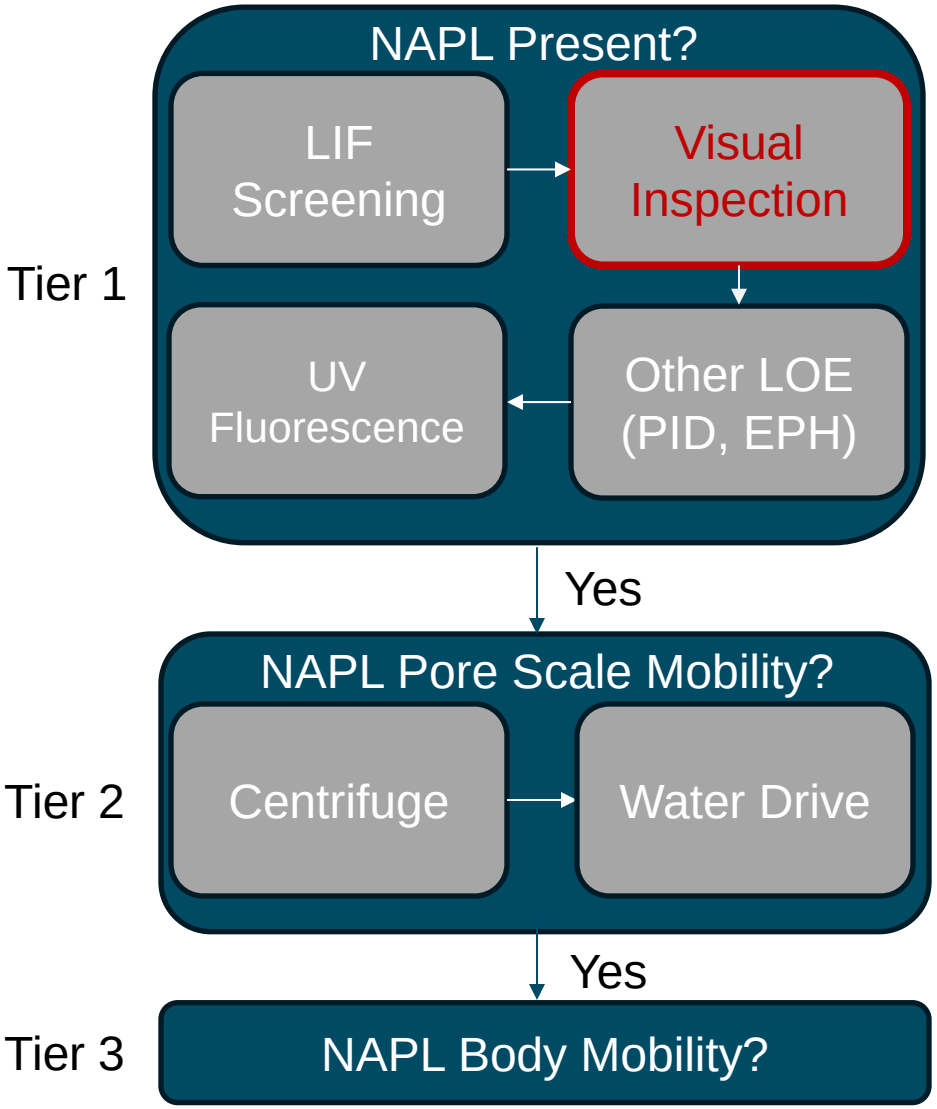


Definitions / Categories

- **No visual evidence** – no sheen or NAPL is observed
- **Sheen** – sheen present; NAPL not observed
- **Blebs** – droplets of NAPL; matrix not visually contaminated or saturated (typically immobile)
- **Coated** – sediment grains coated with NAPL; unsaturated pores
- **Saturated** – pores saturated with NAPL; may freely drain

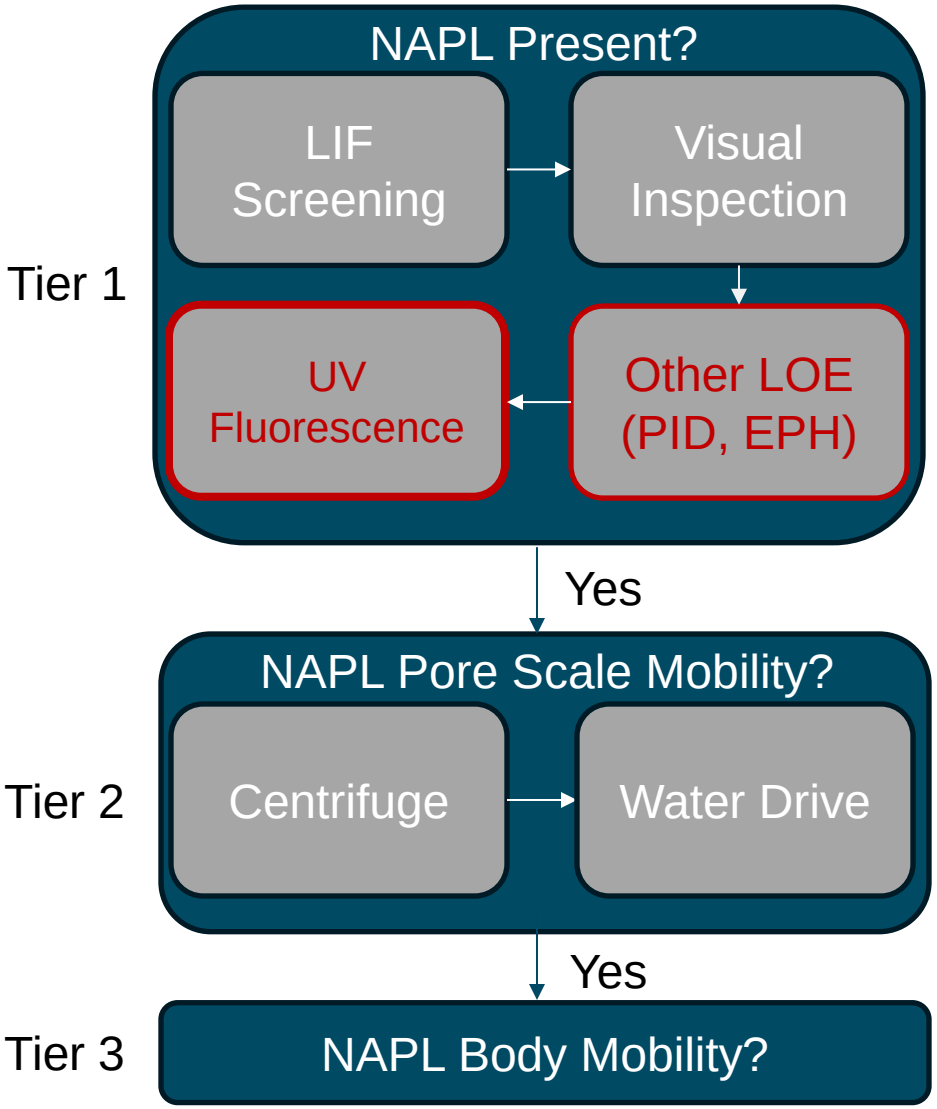
Tier 1 – Field Testing for NAPL Presence
Visual Observation

Tier 1 – Field Testing for NAPL Presence
Visual Observation

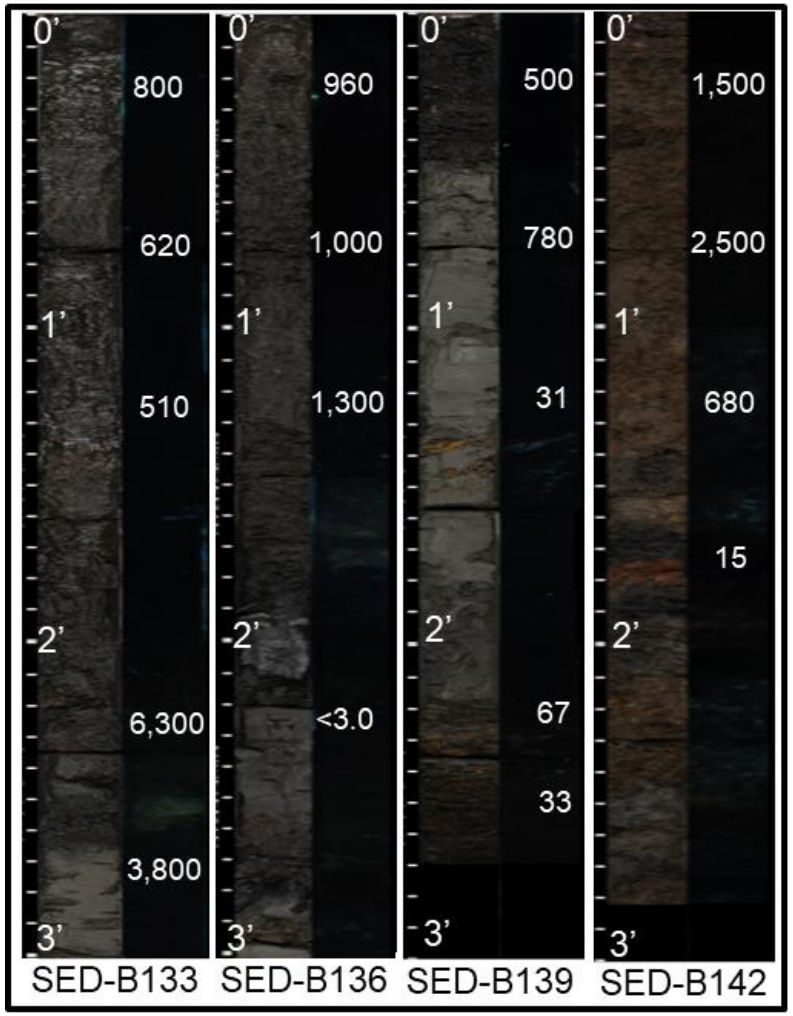


- Difficult to discern NAPL from black silt
- Difficult to discern pore saturation in fine-grained sediments with potential oil-particle aggregates
- “No visual evidence” easily discernible in some sediments
- Visible NAPL saturation in sample with 23.7% initial NAPL saturation by Dean-Stark method

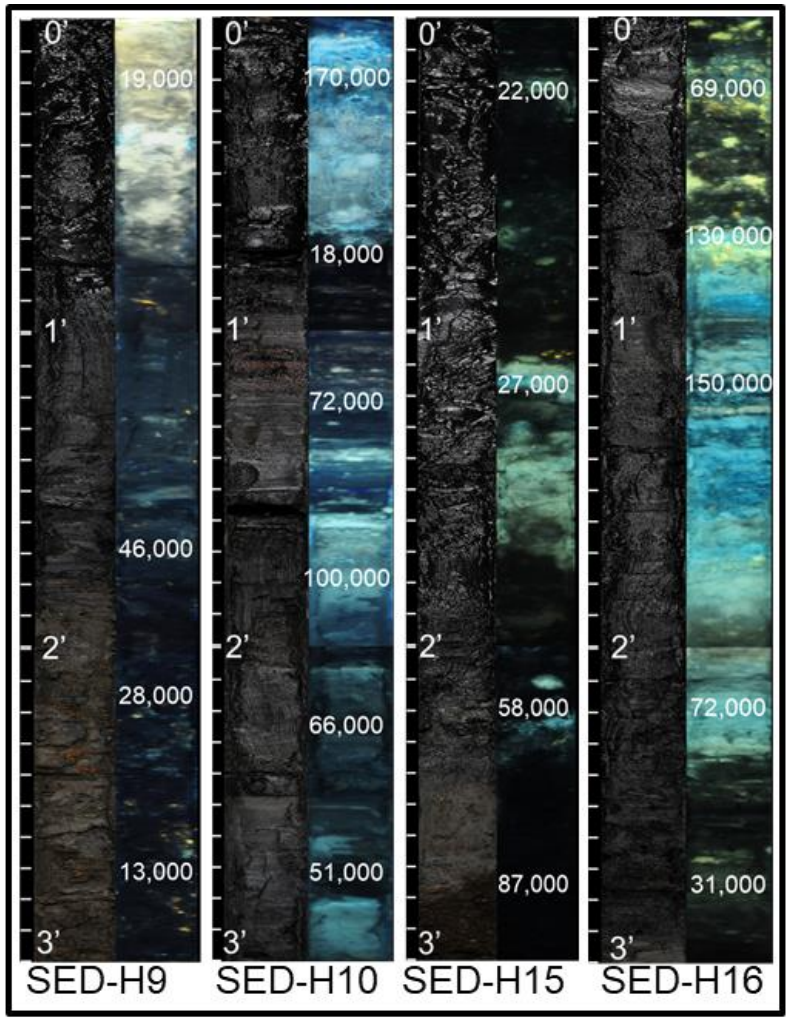
Tier 1 – Field Testing for NAPL Presence other LOE and UV



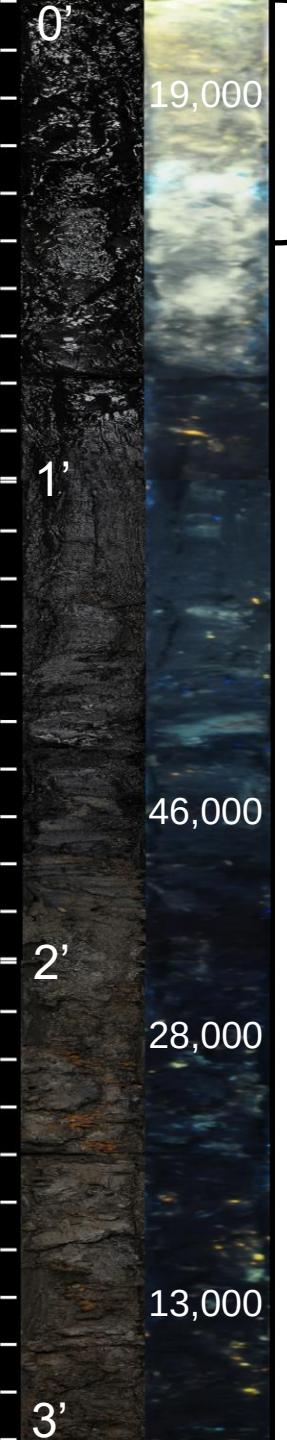
Absence of NAPL by UV

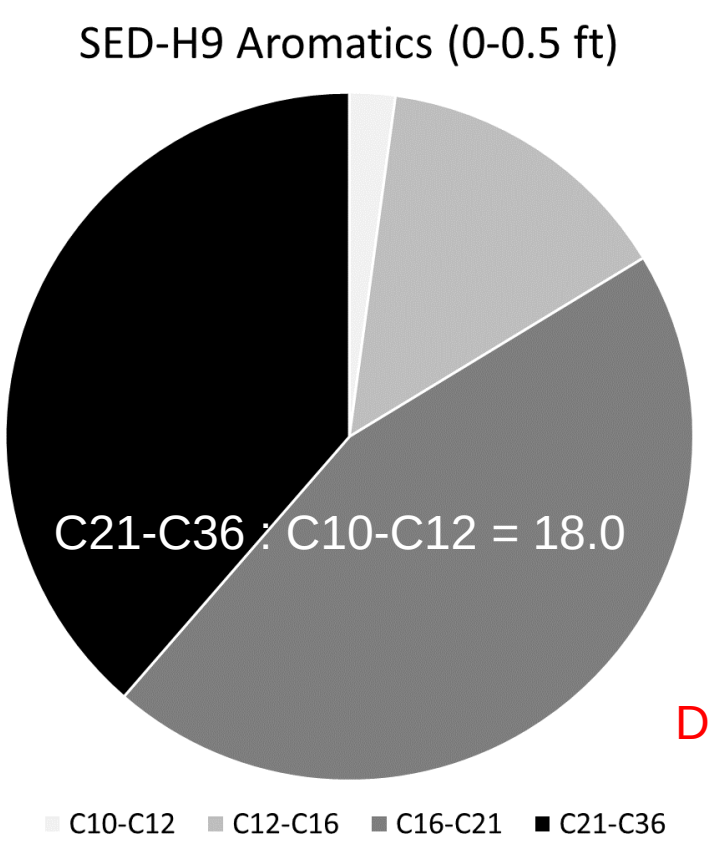


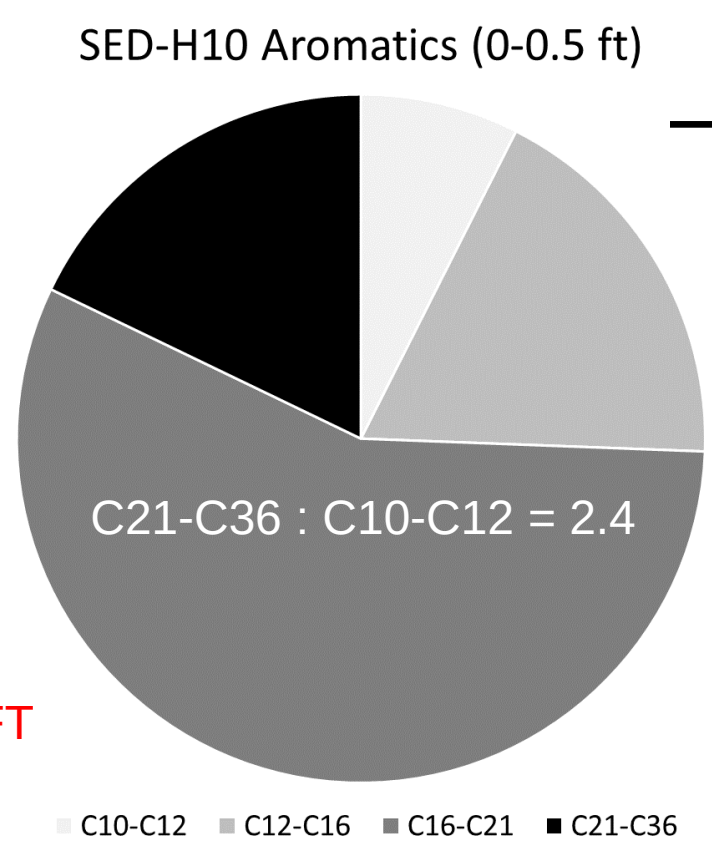
Presence of NAPL by UV

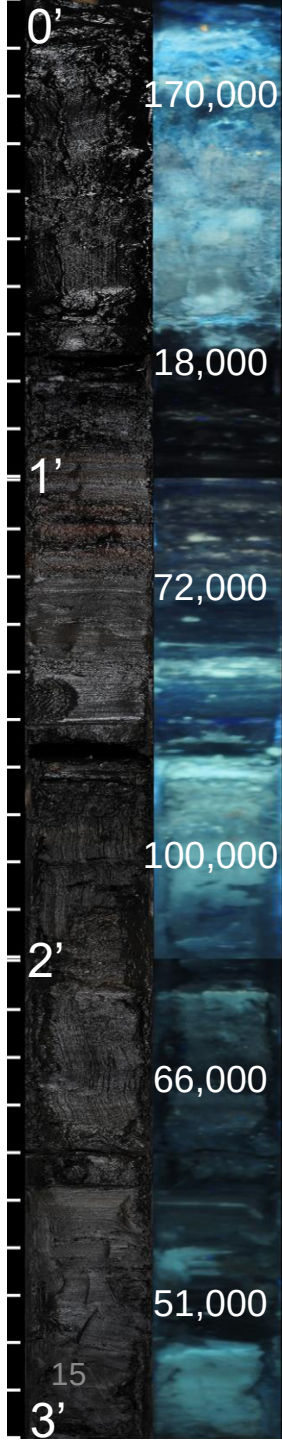


EPH concentration superimposed: <3.0 to 170,000 mg/kg







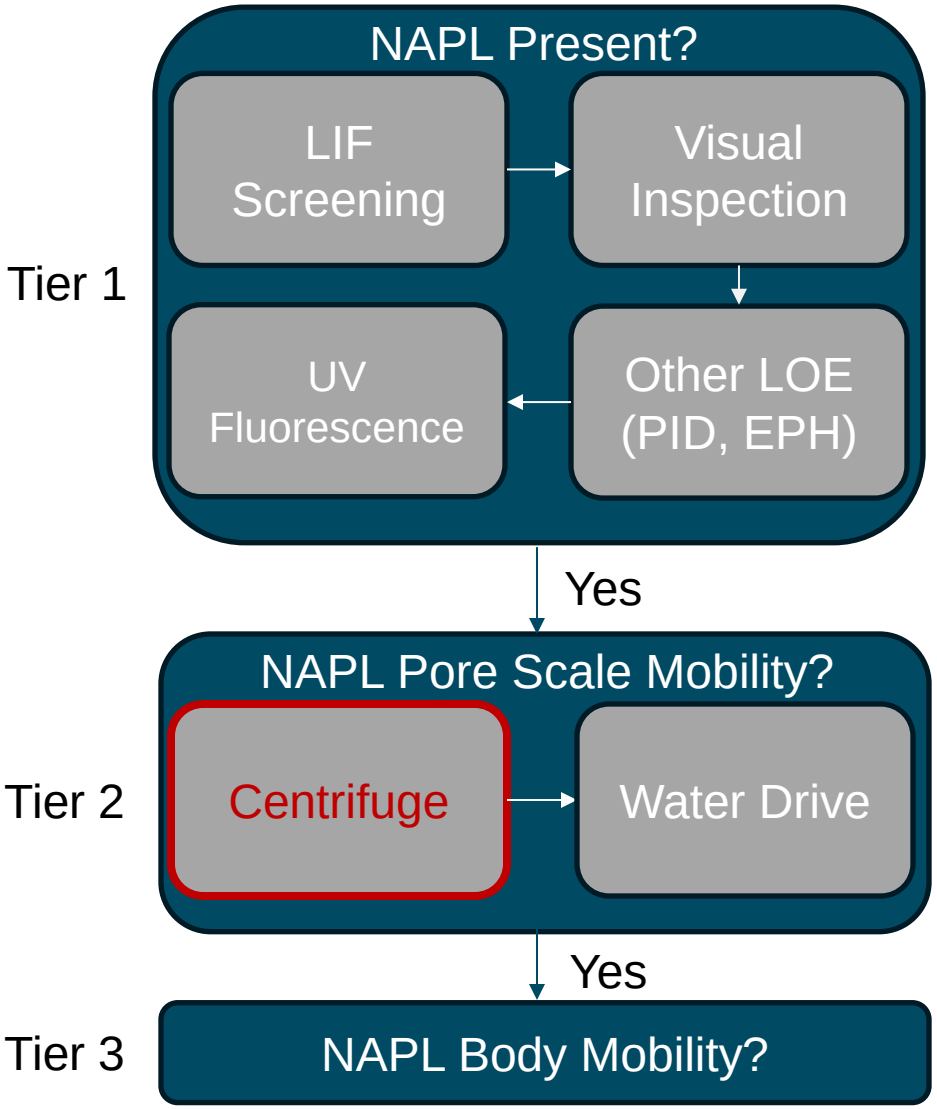


DRAFT

Fluorescence Color Versus Molecular Characteristics

API Gravity	Fluorescence Color	Interpretation
<15	Brown	Higher Molecular Weight PAHs (Greater Specific Gravity)
15-25	Orange	
25-35	Yellow to Cream	
35-45	White	Lower Molecular Weight PAHs (Lesser Specific Gravity)
>45	Blue-White to Violet	

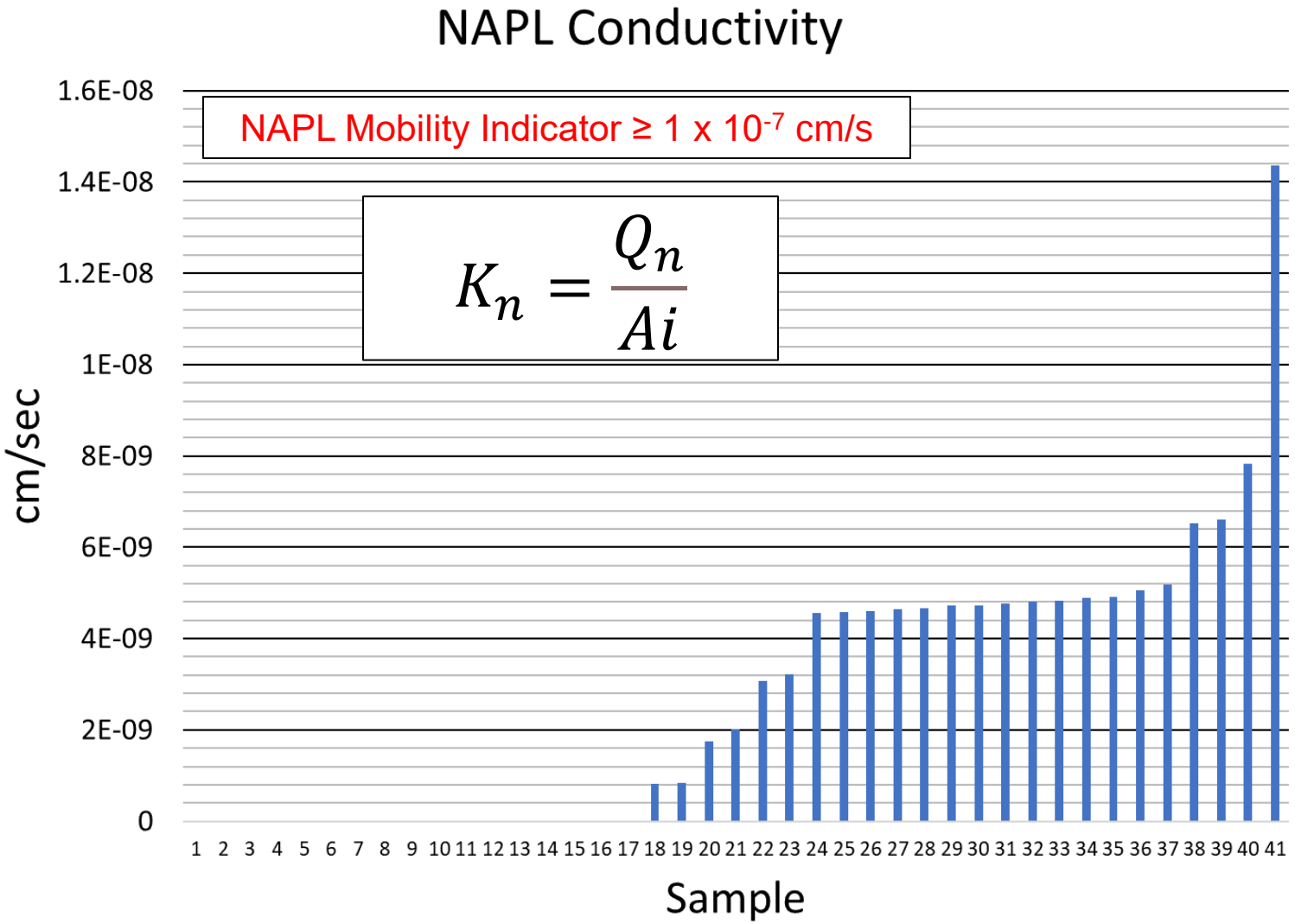
Tier 2 – Pore Scale Lab Mobility Testing
Weight of Evidence NAPL Mobility Evaluation



- Centrifugal force 25X gravity for ten hours
- Site-specific temperatures due to cooling water discharge / potential reduced viscosity
- Pre-centrifuge (initial) NAPL and water saturation (Dean-Stark)
- Post-centrifuge NAPL and water saturation (Dean-Stark)
- Description of fluid extruded from the sample
- NAPL effective conductivity

Tier 2 – Pore Scale Lab Mobility Testing
Weight of Evidence NAPL Mobility Evaluation

- K_n = effective conductivity of NAPL (cm/sec)
- Q_n = average NAPL flow rate from sample during centrifuge (cm^3/sec)
- A = area of discharge from test sample (orthogonal to the flow) (cm^2)
- i = hydraulic gradient imposed during test (dimensionless)



Tier 2 – Pore Scale Lab Mobility Testing
Weight of Evidence NAPL Mobility Evaluation

Lines of Evidence Used In NAPL Mobility Scoring				Weight of Evidence	
Initial NAPL Saturation	NAPL Saturation Reduction After Centrifuge (25g - 10 hours)	NAPL Expressed During Centrifuge (25g - 10 hours)	NAPL Effective Conductivity	NAPL Mobility Score Sum	Interpretation
> 30% = +1	≥ 10% = +1	NAPL Expressed = 0	≥10^{-7} cm/s = +1	≥ 0 = mobile	
10 - 30% = 0	< 10% = -1	Not Expressed = -1	<10^{-7} cm/s = -1	< 0 = immobile	
< 10% = -1					

Tier 2 – Pore Scale Lab Mobility Testing
Weight of Evidence NAPL Mobility Evaluation

Sediment Sample Information		Lines of Evidence Used In NAPL Mobility Scoring				Weight of Evidence	
		Initial NAPL Saturation	NAPL Saturation Reduction After Centrifuge (25g - 10 hours)	NAPL Expressed During Centrifuge (25g - 10 hours)	NAPL Effective Conductivity	NAPL Mobility Score Sum	Interpretation
Sample ID	Depth (ft-bss)	> 30% = +1 10 - 30% = 0 < 10% = -1	≥ 10% = +1 < 10% = -1	NAPL Expressed = 0 Not Expressed = -1	≥10^{-7} cm/s = +1 <10^{-7} cm/s = -1	≥ 0 = mobile < 0 = immobile	
SED-H1	1.65-1.75	-1	-1	-1	-1	-4	Immobile
SED-H2	0.35-0.45	-1	-1	0	-1	-3	Immobile
SED-H3	0.55-0.65	-1	-1	0	-1	-3	Immobile
SED-H3	1.25-1.35	1	-1	0	-1	-1	Immobile
SED-H4	1.35-1.45	-1	-1	0	-1	-3	Immobile
SED-H5	0.05-0.15	-1	-1	-1	-1	-4	Immobile
SED-H5	3.1-3.2	-1	-1	-1	-1	-4	Immobile
SED-H7	2.8-2.9	0	-1	-1	-1	-3	Immobile
SED-H7	3.3-3.4	0	-1	-1	-1	-3	Immobile
SED-H8	1.7-1.8	0	-1	0	-1	-2	Immobile
SED-H8	2.8-2.9	0	-1	0	-1	-2	Immobile
SED-H9	0.3-0.4	0	-1	0	-1	-2	Immobile
SED-H9	0.4-0.5	-1	-1	0	-1	-3	Immobile
SED-H10	0.05-0.15	0	-1	0	-1	-2	Immobile
SED-H11	1.2-1.3	-1	-1	0	-1	-3	Immobile
SED-H11	1.65-1.75	-1	-1	0	-1	-3	Immobile
SED-H11	2.0-2.1	0	-1	0	-1	-2	Immobile
SED-H13	1.25-1.35	-1	-1	-1	-1	-4	Immobile
SED-H13	3.15-3.25	0	-1	-1	-1	-3	Immobile
SED-H15	1.1-1.2	0	-1	0	-1	-2	Immobile
SED-H16	0.7-0.8	-1	-1	0	-1	-3	Immobile
SED-H16	0.15-0.25	-1	-1	-1	-1	-4	Immobile
SED-H16	1.4-1.5	0	-1	0	-1	-2	Immobile
SED-H17	0.7-0.8	-1	-1	-1	-1	-4	Immobile
SED-H17	4.5-4.6	-1	-1	-1	-1	-4	Immobile

Sediment Sample Information		Lines of Evidence Used In NAPL Mobility Scoring				Weight of Evidence	
		Initial NAPL Saturation	NAPL Saturation Reduction After Centrifuge (25g - 10 hours)	NAPL Expressed During Centrifuge (25g - 10 hours)	NAPL Effective Conductivity	NAPL Mobility Score Sum	Interpretation
Sample ID	Depth (ft-bss)	> 30% = +1 10 - 30% = 0 < 10% = -1	≥ 10% = +1 < 10% = -1	NAPL Expressed = 0 Not Expressed = -1	≥10^{-7} cm/s = +1 <10^{-7} cm/s = -1	≥ 0 = mobile < 0 = immobile	
SED-H18	1.8-1.9	0	-1	0	-1	-2	Immobile
SED-H18	2.55-2.65	-1	-1	0	-1	-3	Immobile
SED-B132	1.6-1.7	-1	-1	0	-1	-3	Immobile
SED-B133	2.5-2.6	0	-1	0	-1	-2	Immobile
SED-B136	1.7-1.8	-1	-1	-1	-1	-4	Immobile
SED-B136	8.7-8.8	-1	-1	0	-1	-3	Immobile
SED-B136	9.1-9.2	-1	-1	-1	-1	-4	Immobile
SED-B138	8.0-8.1	-1	-1	-1	-1	-4	Immobile
SED-B139	6.2-6.3	-1	-1	0	-1	-3	Immobile
SED-B141	0.0-0.1	-1	-1	-1	-1	-4	Immobile
SED-B141	1.0-1.1	-1	-1	-1	-1	-4	Immobile
SED-B141	5.0-5.1	-1	-1	-1	-1	-4	Immobile
SED-B141	6.0-6.1	-1	-1	0	-1	-3	Immobile
SED-B141	8.4-8.5	-1	1	0	-1	-1	Immobile
SED-B141	11.0-11.1	-1	1	0	-1	-1	Immobile
SED-B142	0.0-0.1	-1	-1	0	-1	-3	Immobile
SED-B142	1.0-1.1	-1	-1	-1	-1	-4	Immobile
SED-B142	2.15-2.25	-1	-1	-1	-1	-4	Immobile
SED-B142	5.3-5.4	-1	1	0	-1	-1	Immobile
SED-B143	8.1-8.2	-1	-1	0	-1	-3	Immobile
SED-O2	14.5 - 14.6	0	-1	0	-1	-2	Immobile
SED-O2	16.4-16.5	-1	-1	0	-1	-3	Immobile
SED-O3	15.1-15.2	-1	-1	0	-1	-3	Immobile

- 48 Samples Tested
- 25 Locations

Tier 2 – Pore Scale Lab Mobility Testing
Weight of Evidence NAPL Mobility Evaluation

Sediment Sample Information		Lines of Evidence Used In NAPL Mobility Scoring				Weight of Evidence	
		Initial NAPL Saturation	NAPL Saturation Reduction After Centrifuge (25g - 10 hours)	NAPL Expressed During Centrifuge (25g - 10 hours)	NAPL Effective Conductivity	NAPL Mobility Score Sum	Interpretation
Sample ID	Depth (ft-bss)	> 30% = +1 10 - 30% = 0 < 10% = -1	≥ 10% = +1 < 10% = -1	NAPL Expressed = 0 Not Expressed = -1	≥10^{-7} cm/s = +1 <10^{-7} cm/s = -1	≥ 0 = mobile < 0 = immobile	
SED-H1	1.65-1.75	-1	-1	-1	-1	-4	Immobile
SED-H2	0.35-0.45	-1	-1	0	-1	-3	Immobile
SED-H3	0.55-0.65	-1	-1	0	-1	-3	Immobile
SED-H3	1.25-1.35	1	-1	0	-1	-1	Immobile
SED-H4	1.35-1.45	-1	-1	0	-1	-3	Immobile
SED-H5	0.05-0.15	-1	-1	-1	-1	-4	Immobile
SED-H5	3.1-3.2	-1	-1	-1	-1	-4	Immobile
SED-H7	2.8-2.9	0	-1	-1	-1	-3	Immobile
SED-H7	3.3-3.4	0	-1	-1	-1	-3	Immobile
SED-H8	1.7-1.8	0	-1	0	-1	-2	Immobile
SED-H8	2.8-2.9	0	-1	0	-1	-2	Immobile
SED-H9	0.3-0.4	0	-1	0	-1	-2	Immobile
SED-H9	0.4-0.5	-1	-1	0	-1	-3	Immobile
SED-H10	0.05-0.15	0	-1	0	-1	-2	Immobile
SED-H11	1.2-1.3	-1	-1	0	-1	-3	Immobile
SED-H11	1.65-1.75	-1	-1	0	-1	-3	Immobile
SED-H11	2.0-2.1	0	-1	0	-1	-2	Immobile
SED-H13	1.25-1.35	-1	-1	-1	-1	-4	Immobile
SED-H13	3.15-3.25	0	-1	-1	-1	-3	Immobile
SED-H15	1.1-1.2	0	-1	0	-1	-2	Immobile
SED-H16	0.7-0.8	-1	-1	0	-1	-3	Immobile
SED-H16	0.15-0.25	-1	-1	-1	-1	-4	Immobile
SED-H16	1.4-1.5	0	-1	0	-1	-2	Immobile
SED-H17	0.7-0.8	-1	-1	-1	-1	-4	Immobile
SED-H17	4.5-4.6	-1	-1	-1	-1	-4	Immobile

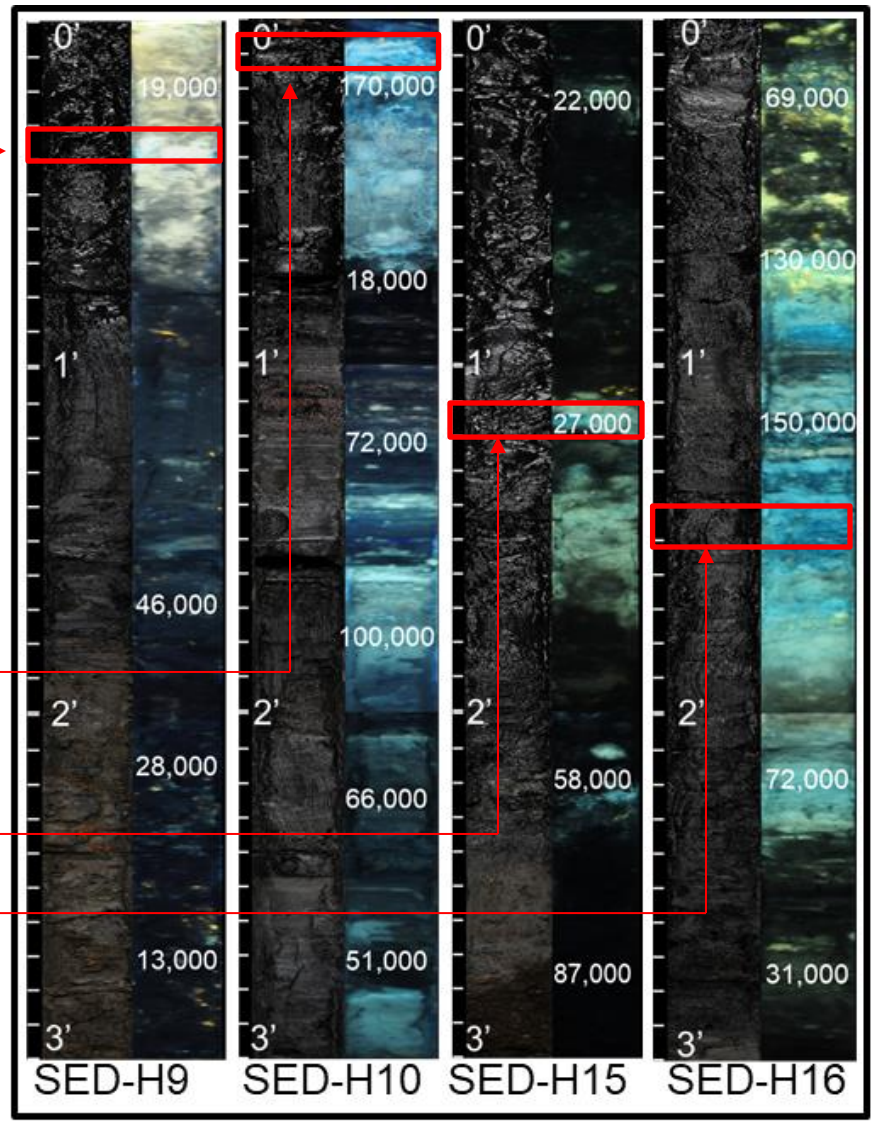
Initial NAPL Sat

23.7% (visual)

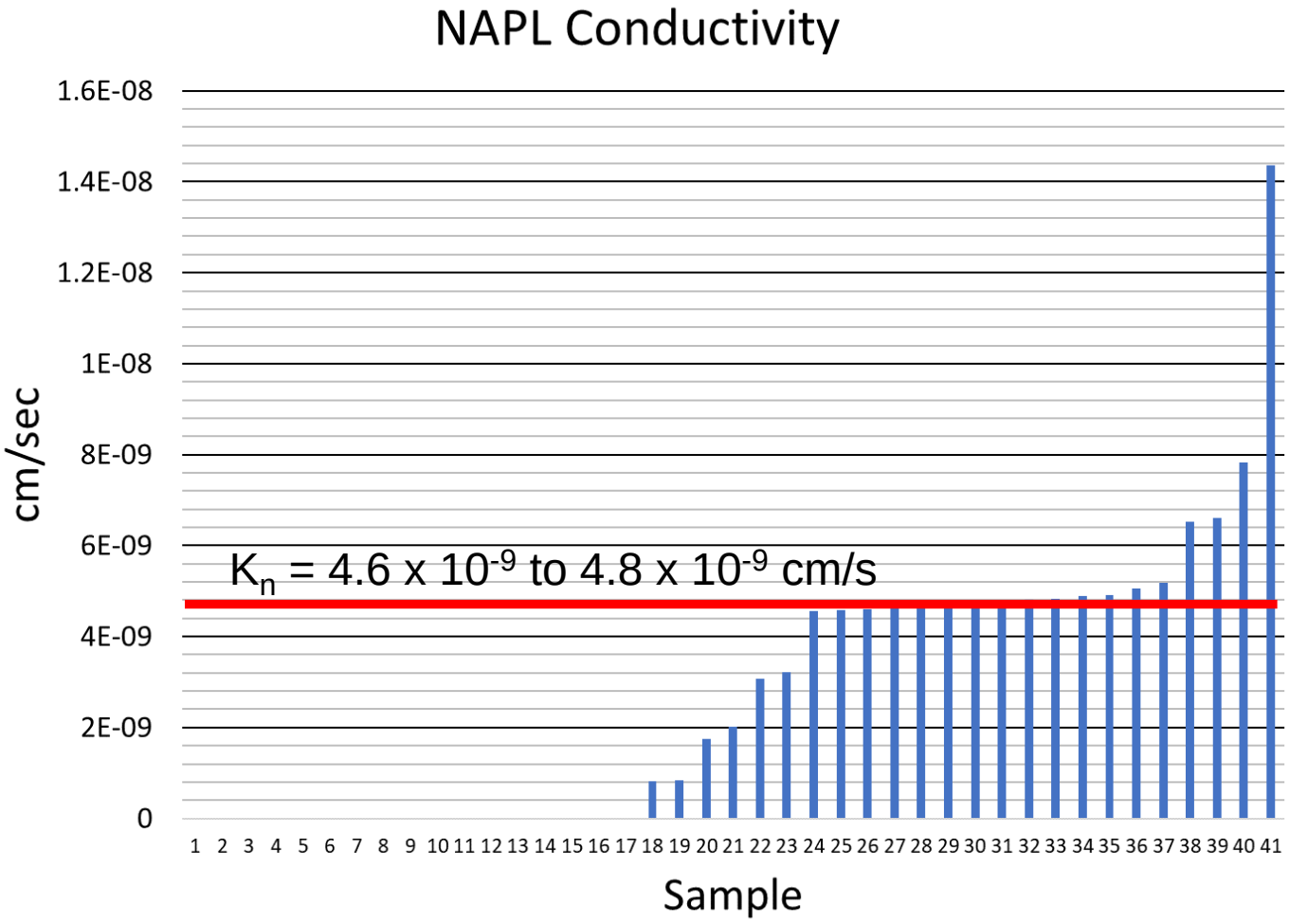
14.0%

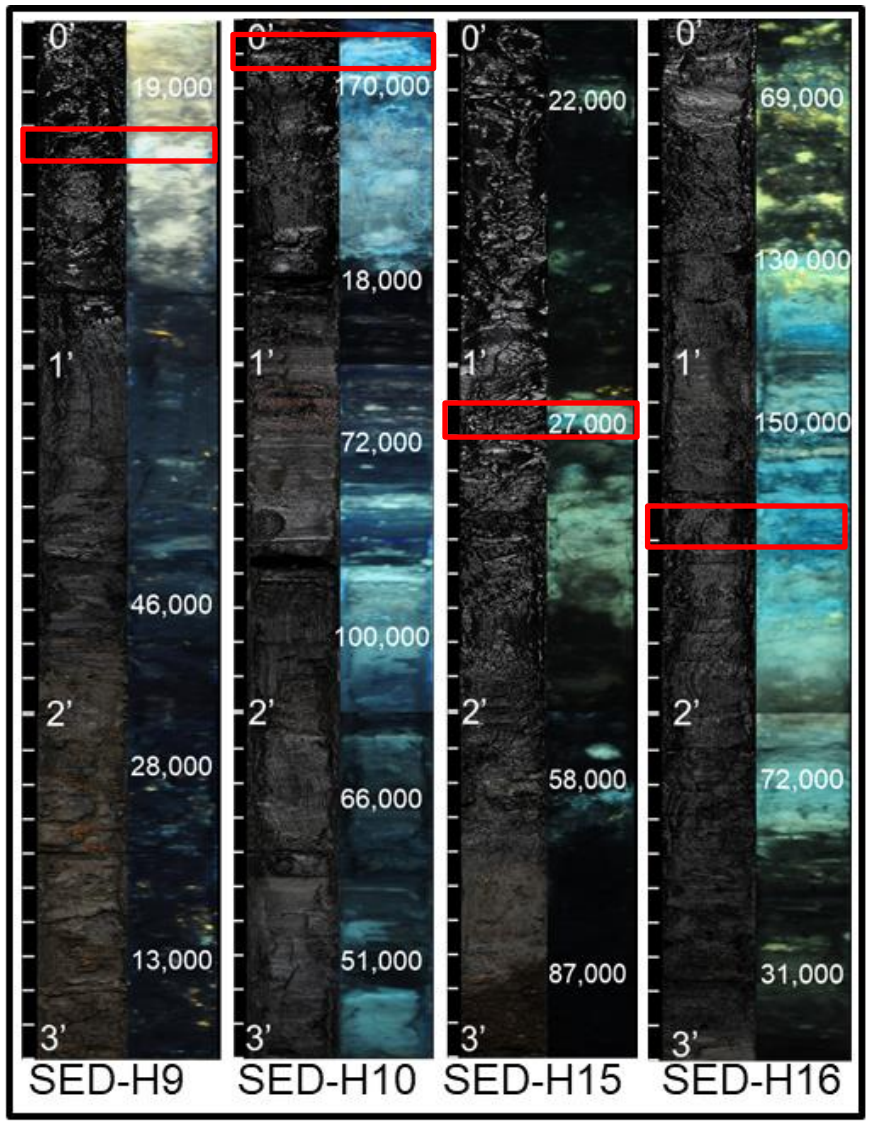
10.4%

13.5%

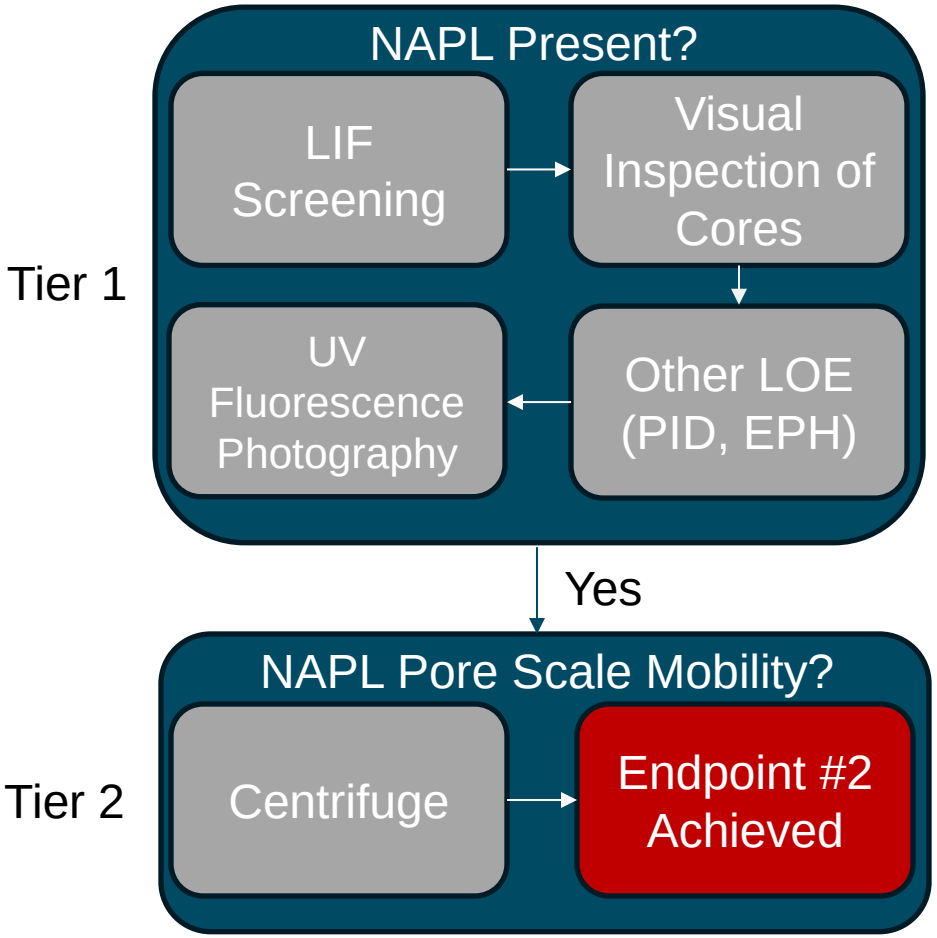


Tier 2 – Pore Scale Lab Mobility Testing
Weight of Evidence NAPL Mobility Evaluation





Outcome



- **Tier 1** – Field Testing for NAPL Presence
  - Some relatively elevated LIF responses sufficient to be NAPL
  - Limited visual observation of NAPL; partly attributable to nature of sediment (black, fine-grained)
  - Instances of elevated EPH (≤170,000 mg/kg)
  - Strong UV response in some cores; absent in others (consistent with other lines of evidence)
- **Tier 2** – Pore Scale Lab Mobility Evaluation
  - Immobile at pore scale based on weight of evidence from centrifuge testing
  - Endpoint #2 achieved

Conclusions

- ASTM methods provide a useful framework and uniform terminology for identifying NAPL in sediments and evaluating its mobility
- Improved by modifying sequence of testing and replacing shake test with other lines of evidence (e.g., chemical analysis)
- NAPL may be difficult to visually discern in fine-grained, black sediments, especially as oil-particle aggregates
- LIF provides indirect assessment with high data density of lesser certainty
- UV light photography is very useful for identifying NAPL in sediments; corroborated by EPH concentrations
- Site-specific, pore-scale NAPL immobility demonstrated in fine-grained sediments by weight of evidence

Thank You!

Emma Applegate eapplegate@kleinfelder.com

Dan Canavan, PG dcanavan@kleinfelder.com

Jeffrey Hale, PG jehale@kleinfelder.com

KLEINFELDER
Bright People. Right Solutions.