Integrated Engineering and Laboratory Services for NAPL Site Management

Presented by

Mark Bos

Mike Niemet

Laura McKinley

Morgan Bruno

The Challenge

- At sites where petroleum liquids have been released to the subsurface, the petroleum exists within the soil pores as a separate non-aqueous phase liquid (NAPL), and its fate and transport can be difficult to assess.
- The presence of NAPL in a monitoring well is not itself a reliable indicator of the potential for migration or the practicability of free-product recovery.
- How do we help our client's assess when NAPL recovery makes sense?

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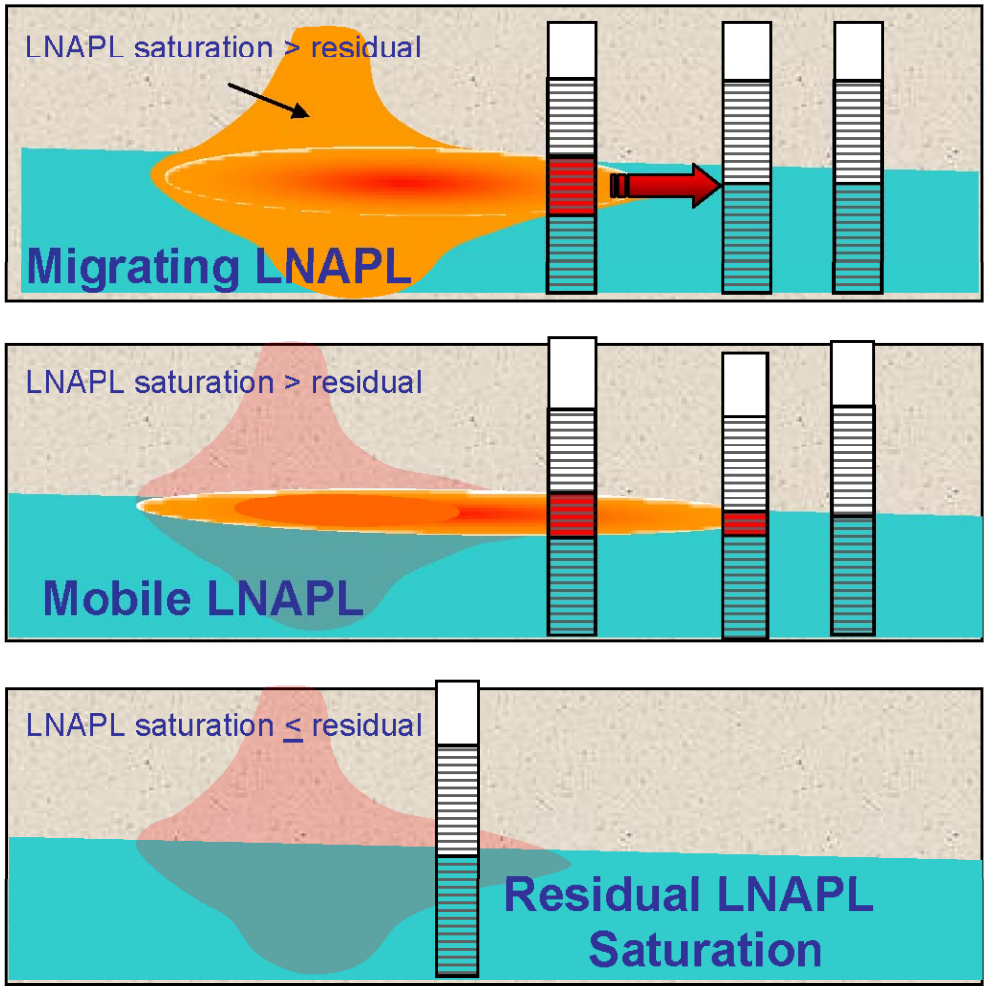
NAPL Conditions and Recoverability



Source: Evaluating LNAPL Remedial Technologies to Achieve Project Goals (ITRC 2009)

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Rethinking the Classic Approach

Classic approach tends to prescribe pumping until you get every last drop, without consideration of feasibility

NAPL mobility estimates and NAPL site conceptual models have increased the knowledge of clients, consultants, and regulators on the limits of NAPL migration and NAPL recovery.

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Considering a Different Approach

NAPL mobility assessments can be used in a number of different ways to aid in decision making processes:

- Shed light on understanding potential contaminant mobility mechanisms and mobility pathways
- Establish realistic cleanup goals
- Fluid recovery optimization and shutdown
- Risk assessments
- Justification for when monitored natural attenuation (MNA) is appropriate
- Remedial technology selection – vacuum extraction, dual-phase extraction, skimmers, etc.

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Nuts and Bolts

- Modeling data are developed from petrochemical analysis of soil cores and free product collected from NAPL impacted areas.
- Laboratory analyses can quantify the percent of the soil pore space occupied by NAPL and allows for comparison to the residual saturation after the sample is subjected to centrifugal or other forces.
  - Residual saturation is the point at which NAPL is no longer mobile.
- CH2M HILL Applied Sciences Laboratory (ASL), with support from the firm's principal NAPL mobility assessment technologists and engineers, has developed a suite of analytical methods specifically for use in NAPL mobility assessments.

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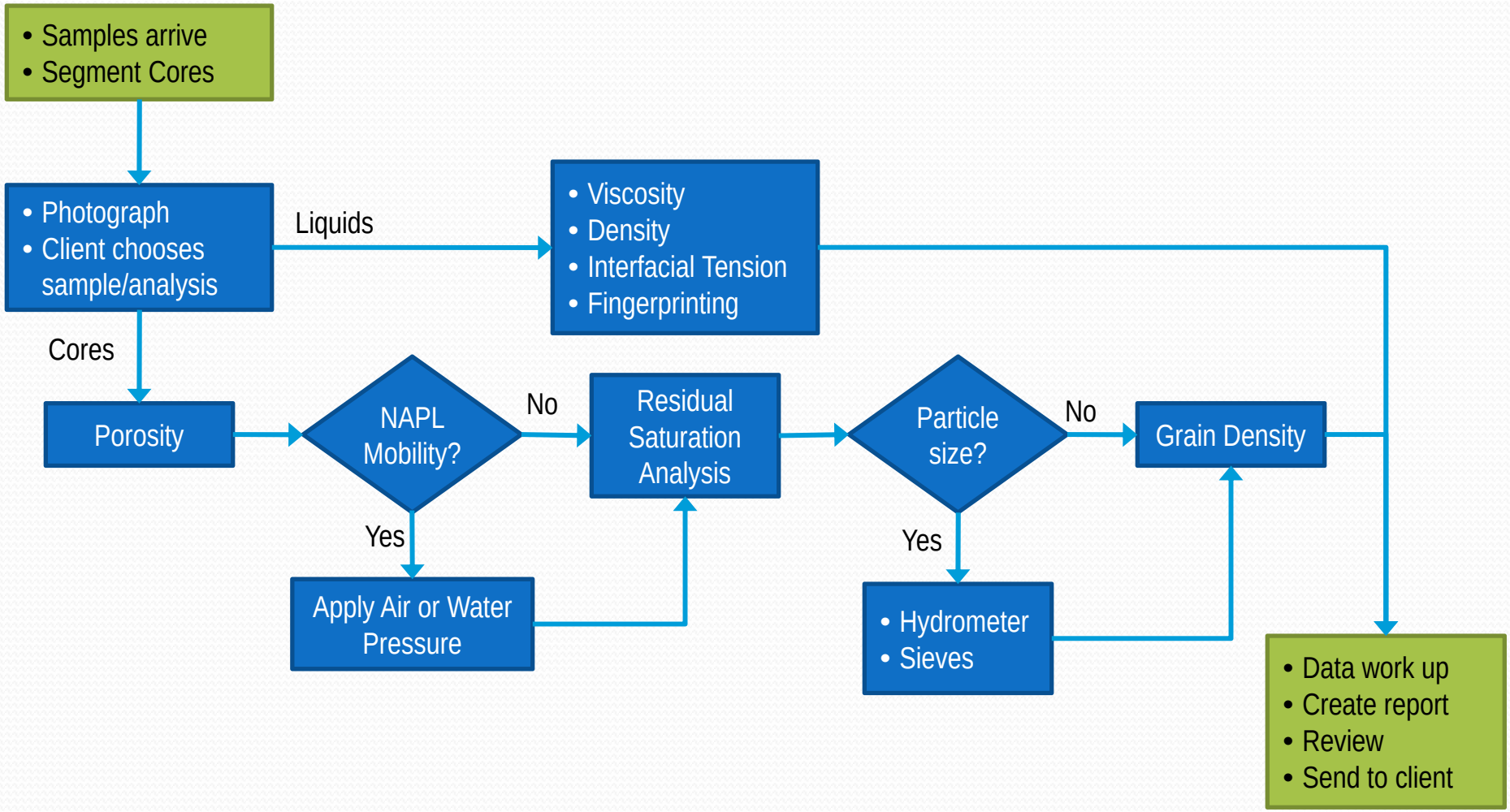
The Tool Kit

- Through the analysis of soil cores, groundwater and NAPL obtained from the site, ASL can assist in determining NAPL mobility using methods established by the American Petroleum Institute (API) and ASTM.
- API and ASTM methods are not completely prescriptive but rather provide fundamental guidance.
- Methods or approaches can be tailored to specific site conditions (e.g., different temperatures, centrifuge speeds, etc.)
- Methods require proprietary development coupled with evolutionary advancement as dictated by site conditions.
- NAPL mobility assessment support can also be provided using a mobile laboratory in the field while cores are being collected.

Analytical Roadmap



Analytical Considerations

- Destructive technique
  - Entire sample segment is processed through each analytical phase
- Individual sample segments are a unique representation
  - Care must be exercised in order to not compromise potentially important mobility information at that selected depth.
- You cannot go back, irreversible!!
  - No second chance, no duplicates
  - A favorite consideration for most analytical laboratories.

Lift-Off!

- Core Preparation and cutting using liquid nitrogen (API, 1998 Sec. 3.5.2)

Frozen core slices after cutting

Core obtained from the field before freezing

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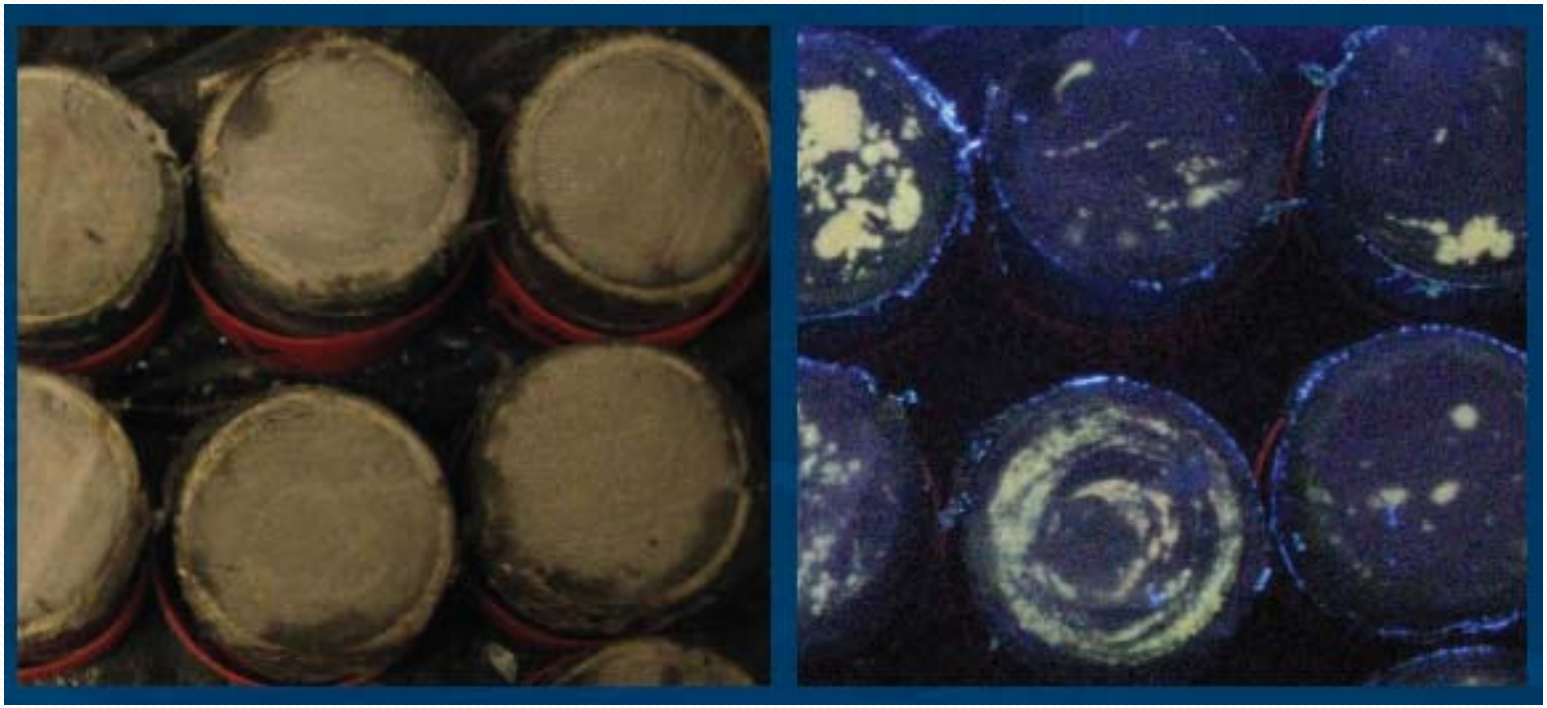
Core Selection – UV Photography

- Ultraviolet Core Photography (API, 1998 Sec. 3.4.1; ASTM 5079)



White and U/V light images of core sections

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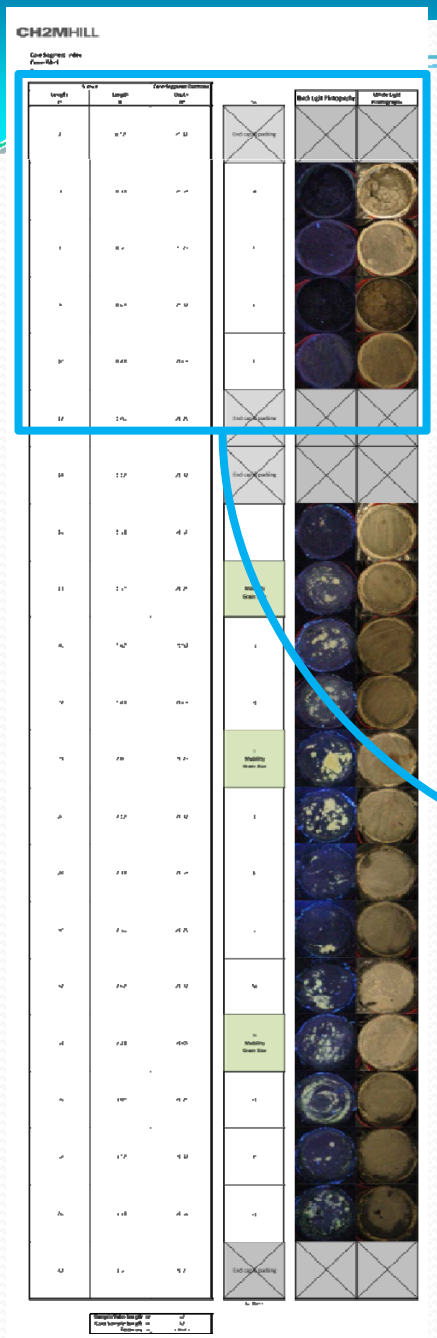
Core Indexing



Sleeve		Core Segment (bottom)			
Length in	Length ft	Depth ft	Top	Black Light Photography	White Light Photography
2	0.17	22.42	End cap & packing		
4	0.33	22.58	A		
6	0.50	22.75	B		
8	0.67	22.92	C		
10	0.83	23.08	D		
12	1.00	23.25	End cap & packing		

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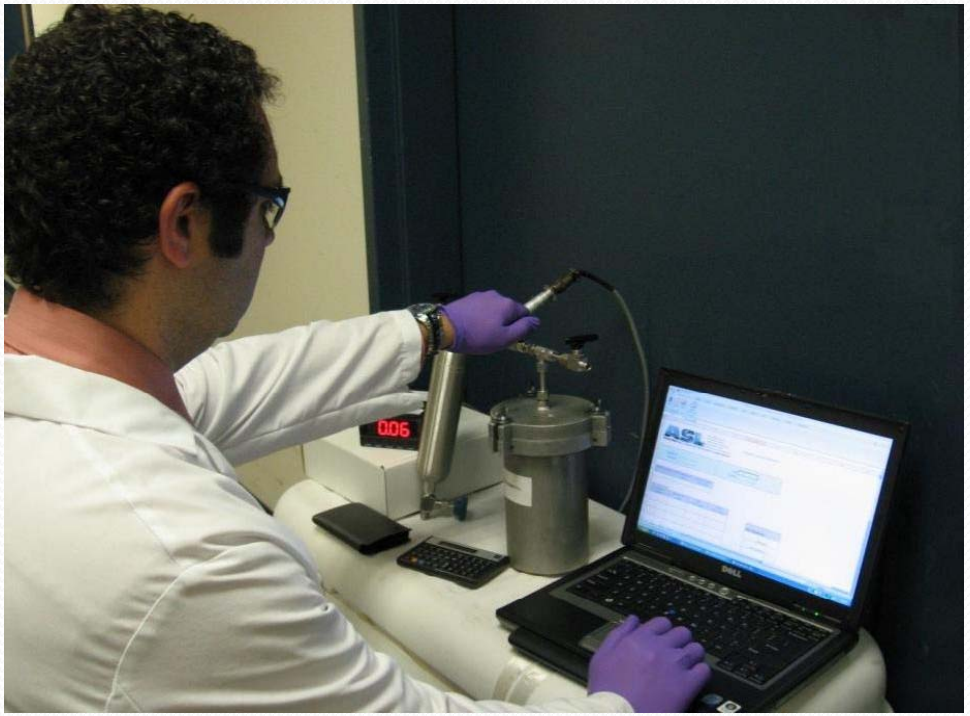
Mobility Determination Initial Phase

- Air-Filled and Total Porosity (API, 1998 Sec. 5.3.2.1.1; and Sec. 5.3.2.2.3)



Boyle's Law double-cell porosimeter

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Pressure Mobility?

- NAPL Mobility Analysis by Centrifuge with or without water flushing(ASTM D425)

Centrifuge test apparatus

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NAPL Mass Assessment

- Water and Oil Saturation (by Dean-Stark extraction, API, 1998 Sec.4.3)

Additional Requisite Soil Parameters

- Bulk and grain density (API, 1998 Sec. 5.3.1.1)
- Particle size analysis (ASTM D422)
- Saturated Hydraulic Conductivity (ASTM2434)
- Soil/Water Characteristic Curve (ASTM D6836)
- Van Genuchten and Brooks-Corey parameter estimation using particle size and/or characteristic curve analysis
- Field-Applied NAPL Mobility Analysis by Centrifuge (Adaptation of lab method)

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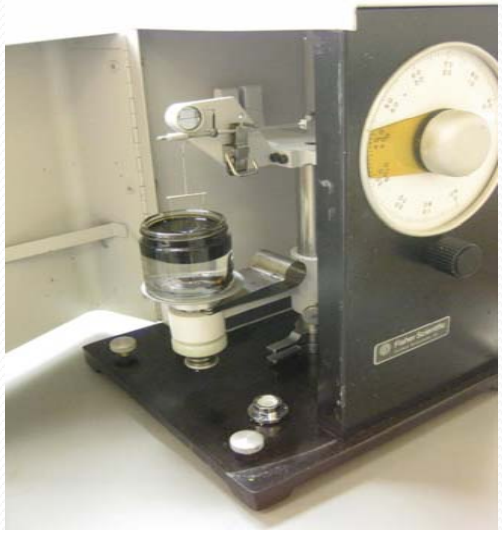
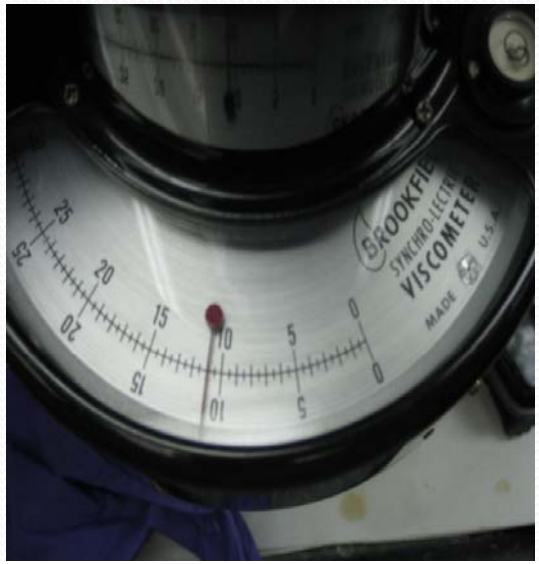
Requisite Liquid-Phase Parameters

- Groundwater/NAPL Analysis
  - Water and Oil Density (ASTM D1298)
  - Air/Water, Air/Oil, and Water/Oil Interfacial Tension (ASTM D971)
  - Water and Oil Viscosity (ASTM D445)





Modeling Parameter Summary

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Core Sample Summary

Cores BH507, BH508, BH510

Core Segment Results (as-received / pre-centrifuge)										Analyses Performed		
Sample Name	Sample Depth Range*, ft bgs	Bulk Volume, cm^3	Pore Volume (V_P), cm^3	Total Porosity, %	Grain Density, g/cm^3	Bulk Density, g/cm^3 dry	Air Saturation, % V_P	Water Saturation, % V_P	NAPL Saturation, % V_P	NAPL Mobility by Centrifuge	NAPL Mobility by Water Drive	Pore Fluid Saturation
Core BH507 - Collected 06/04/2010												**Core BH507**
BH507-F	21.14 - 21.31	231.7	115.8	50.0	2.49	1.25	62.0	37.3	0.71			x
BH507-O	22.81 - 22.99	231.7	122.4	52.8	2.38	1.12	79.0	20.1	0.86			x
BH507-V	24.14 - 24.31	231.7	110.3	47.6	2.47	1.29	47.5	52.5	0.00			x
BH507-AE	25.81 - 25.99	231.7	122.9	53.1	2.48	1.16	48.1	51.1	0.77			x
BH507-AK	26.88 - 27.05	231.7	82.4	35.6	2.54	1.64	45.5	51.3	3.20			x
BH507-AP	28.13 - 28.30	231.7	70.9	30.6	2.73	1.89	53.6	41.9	4.49	x		x
BH507-AQ	28.30 - 28.48	231.7	90.1	38.9	2.51	1.53	44.1	50.7	5.19			x
Core BH508 - Collected 06/04/2010												**Core BH508**
BH508-E	26.96 - 27.14	231.7	95.8	41.3	2.50	1.47	44.3	54.7	1.00			x
BH508-N	28.64 - 28.81	231.7	121.9	52.6	2.51	1.19	65.0	33.2	1.77			x
BH508-S	29.60 - 29.78	231.7	85.2	36.8	2.65	1.67	47.7	49.3	2.98		x	x
BH508-T	29.78 - 29.96	231.7	95.4	41.2	2.54	1.49	42.5	54.9	2.57			x
BH508-AC	31.45 - 31.63	231.7	105.6	45.6	2.48	1.35	49.9	49.6	0.48			x
BH508-AM	33.32 - 33.50	231.7	94.4	40.7	2.54	1.51	34.5	64.5	0.94			x
Core BH510 - Collected 06/04/2010												**Core BH510**
BH510-H	16.31 - 16.49	231.7	84.5	36.5	2.53	1.61	60.2	37.8	2.07			x
BH510-K	18.17 - 18.25	231.7	93.4	40.3	2.49	1.49	52.6	46.4	1.02			x
BH510-T	19.75 - 19.93	231.7	81.5	35.2	2.50	1.62	41.1	58.3	0.60			x
BH510-AF	21.96 - 22.14	231.7	112.8	48.7	2.53	1.30	80.8	17.0	2.23			x
BH510-AJ	22.75 - 22.93	231.7	86.3	37.3	2.60	1.63	58.8	32.7	8.51	x		x
BH510-AK	22.93 - 23.10	231.7	108.8	46.9	2.48	1.32	44.4	45.9	9.72			x
BH510-AL	23.10 - 22.28	231.7	107.1	46.2	2.49	1.34	47.4	47.1	5.50		x	x
BH510-AO**	23.46 - 23.64	231.7	102.5	44.2	2.45	1.37	30.3	69.7	0.00			x
BH510-AW	25.15 - 25.32	231.7	99.4	42.9	2.47	1.41	39.2	60.8	0.00			x

Mobility Assessment

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Product Mobility by ASTM D425 and API RP40 (Dean-Stark)

Cores BH507, BH508, BH510

Sample Name	Sample Depth Range*, ft bgs	USCS Description by ASTM D2487	Pressure Applied, psig	Volume, cm^3			Saturation, % V_P			NAPL Drained, %
				Air	Water	NAPL	Air	Water	NAPL	
Core BH507										
BH507-F	21.14 - 21.31	Sandy Silt/Clay	--	71.7	43.2	0.82	62.0	37.3	0.71	--
BH507-O	22.81 - 22.99	Sand with Silt/Clay Fines	--	96.7	24.6	1.05	79.0	20.1	0.86	--
BH507-V	24.14 - 24.31	Sandy Silt/Clay	--	52.4	57.9	0.00	47.5	52.5	0.00	--
BH507-AE	25.81 - 25.99	Silt/Clay with Sand	--	59.2	62.8	0.95	48.1	51.1	0.77	--
BH507-AK	26.88 - 27.05	--	--	37.5	42.3	2.64	45.5	51.3	3.20	--
BH507-AP	28.13 - 28.30	--	0	38.0	29.7	3.18	53.6	41.89	4.49	--
			1	38.3	29.4	3.18	54.0	41.47	4.49	0.00
			5	39.4	28.3	3.18	55.6	39.92	4.49	0.00
			45	41.4	26.3	3.18	58.4	37.09	4.49	0.00
BH507-AQ	28.30 - 28.48	Sand with Silt/Clay Fines	--	39.7	45.7	4.68	44.1	50.7	5.19	--
Core BH508										
BH508-E	26.96 - 27.14	Sandy Silt/Clay	--	42.4	52.4	0.96	44.3	54.7	1.00	--
BH508-N	28.64 - 28.81	Sand with Gravel and Silt/Clay Fines	--	79.3	40.5	2.16	65.0	33.2	1.77	--
BH508-S	29.60 - 29.78	--	0	40.7	42.0	2.54	47.7	49.3	2.98	--
			10	29.2	53.6	2.54	34.3	62.9	2.98	0.00
BH508-T	29.78 - 29.96	Sandy Silt/Clay	--	40.6	52.4	2.45	42.5	54.9	2.57	--
BH508-AC	31.45 - 31.63	Sandy Silt/Clay	--	52.7	52.4	0.51	49.9	49.6	0.48	--
BH508-AM	33.32 - 33.50	Sandy Silt/Clay	--	32.6	60.9	0.89	34.5	64.5	0.94	--
Core BH510										
BH510-H	16.31 - 16.49	--	--	50.8	31.9	1.75	60.2	37.8	2.07	--
BH510-K	18.17 - 18.25	--	--	49.1	43.3	0.95	52.6	46.4	1.02	--
BH510-T	19.75 - 19.93	Sand with Silt/Clay Fines	--	33.6	47.5	0.49	41.1	58.3	0.60	--
BH510-AF	21.96 - 22.14	Sand with Silt/Clay Fines	--	91.1	19.2	2.51	80.8	17.0	2.23	--
BH510-AJ	22.75 - 22.93	--	0	50.8	28.2	7.34	58.8	32.7	8.51	--
			1	69.4	10.70	6.24	80.4	12.4	7.23	15.0
			5	74.8	6.70	4.84	86.6	7.8	5.61	34.1
			45	76.7	5.30	4.34	88.8	6.1	5.03	40.9
BH510-AK	22.93 - 23.10	Poorly Graded Sand	--	48.3	49.9	10.6	44.4	45.9	9.72	--
BH510-AL	23.10 - 22.28	--	0	50.8	50.4	5.89	47.4	47.1	5.50	--
			10	50.8	50.4	5.89	47.4	47.1	5.50	0.00
BH510-AO**	23.46 - 23.64	Silt/Clay with Sand	--	31.1	71.4	0.00	30.3	69.7	0.00	--
BH510-AW	25.15 - 25.32	Sandy Silt/Clay	--	39.0	60.4	0.00	39.2	60.8	0.00	--

Groundwater/NAPL Parameters

Density and Specific Gravity by ASTM D1217 and Viscosity by ASTM D445

Sample Name	Matrix	Temperature °F	Specific Gravity	Density g/cc	Viscosity cP
RW4	Water	50	1.010	1.010	1.11
BH309	Water	50	0.998	0.998	1.09
RW1	Water	50	1.002	1.002	1.43
RW4	NAPL	50	1.005	1.005	3.40
BH309	NAPL	50	0.789	0.789	9.15
RW1	NAPL	50	0.999	0.999	1.27
Quality Control					
Millipore water	Water	70		0.9982	
			Published Value:	0.9980	
			RPD:	0.0193	

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Groundwater/NAPL Interfacial Tension Data

Interfacial Tension by ASTM D971

Phase Pair					
Phase One		Phase Two		Temperature	Interfacial Tension
Sample ID	Matrix	Sample ID	Matrix	°F	Dynes/centimeter
RW4 - Water*	Water	Air	Air	50	49.16
RW4 - Product*	NAPL	Air	Air	50	27.60
RW4 - Water*	Water	RW4 - Product*	NAPL	50	UTM_a
BH309 - Water	Water	Air	Air	50	38.80
BH309 - Product	NAPL	Air	Air	50	24.64
BH309 - Water	Water	BH309 - Product	NAPL	50	7.57
RW1 - Water*	Water	Air	Air	50	75.60
RW1 - Product*	NAPL	Air	Air	50	61.15
RW1 - Water*	Water	RW1 - Product*	NAPL	50	UTM_b
Quality Control					
DI Water	Water	Air	Air	70	68.36
				Published Value:	72.8
				RPD:	6.29

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Physical Soil Description via Particle Size

Particle Size Distribution Summary, ASTM D422

Cores BH507, BH508, BH510

Core Sample Information		USCS Description by ASTM D2487	Particle Size Distribution, weight %						
			Gravel		Sand			Approximate Fines	
Sample Name	Sample Depth Range, ft bgs		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
Core BH507									
BH507-F	21.14 - 21.31	Sandy Silt/Clay	0.00	0.00	0.00	4.24	43.8	30.4	21.5
BH507-O	22.81 - 22.99	Sand with Silt/Clay Fines	0.00	0.00	0.06	7.10	62.7	11.3	18.8
BH507-V	24.14 - 24.31	Sandy Silt/Clay	0.00	0.00	0.00	1.52	36.0	34.6	27.9
BH507-AE	25.81 - 25.99	Silt/Clay with Sand	0.00	0.00	0.00	0.00	15.1	53.1	31.8
BH507-AQ	27.86 - 27.95	Sand with Silt/Clay Fines	0.00	1.97	0.70	1.30	12.4	60.9	22.8
Core BH508									
BH508-E	26.96 - 27.14	Sandy Silt/Clay	0.00	1.78	1.51	1.12	12.9	60.8	21.8
BH508-N	28.64 - 28.81	Sand with Gravel and Silt/Clay Fines	23.7	0.18	0.80	4.89	27.9	23.6	18.9
BH508-T	29.78 - 29.96	Sandy Silt/Clay	0.00	1.88	1.53	5.63	32.6	34.5	23.8
BH508-AC	31.45 - 31.63	Sandy Silt/Clay	13.0	1.12	0.27	3.26	19.2	38.0	25.2
BH508-AM	33.32 - 33.50	Sandy Silt/Clay	0.00	0.81	1.80	4.96	37.4	33.4	21.7
Core BH510									
BH510-T	19.75 - 19.93	Sand with Silt/Clay Fines	0.00	1.47	0.80	9.36	51.5	17.7	19.2
BH510-AF	21.96 - 22.14	Sand with Silt/Clay Fines	0.00	0.25	0.63	17.4	62.4	10.0	9.34
BH510-AK	22.93 - 23.10	Poorly Graded Sand	0.00	0.00	0.00	0.00	94.7	2.59	2.67
BH510-AO	23.46 - 23.64	Silt/Clay with Sand	0.00	0.06	0.00	1.50	20.3	32.6	45.5
BH510-AW	25.15 - 25.32	Sandy Silt/Clay	0.00	0.44	0.73	2.62	44.7	33.0	18.5

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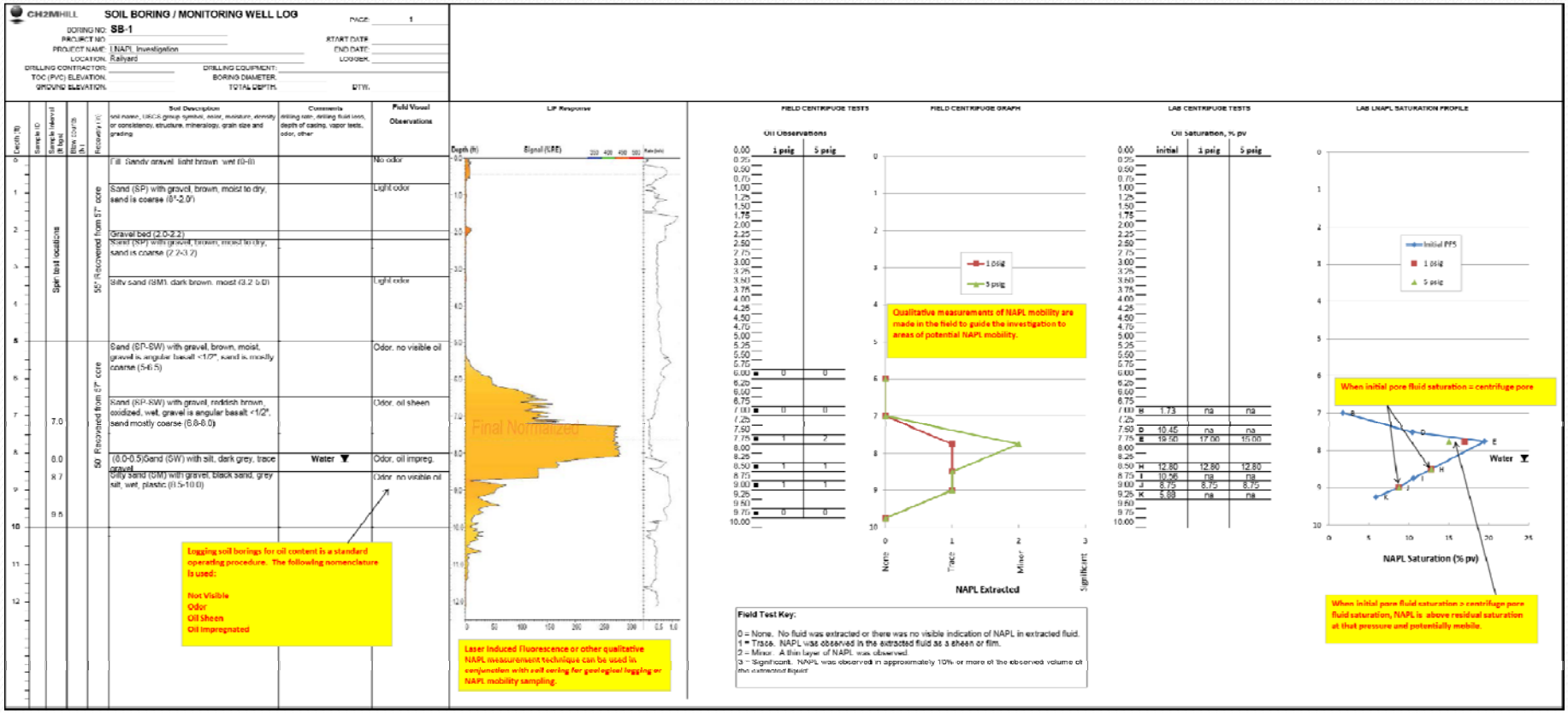
Engineering – Tying it all together



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