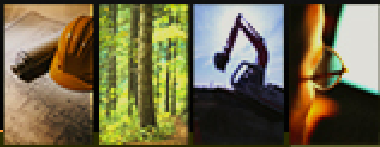

Rethinking the "Interim Measure" Strategy for LNAPL Remediation Projects

Presented by:
Conestoga-Rovers & Associates
Matthew Rousseau
David Cushman

Remediation Technologies Symposium
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Presentation Agenda

- Interim Measures defined:
  - What, where, why, and when?
- LNAPL Conceptual Site Model (LCSM)
  - Identification, characterization, delineation, mobility/recoverability evaluation, risk assessment
- Case Study
  - Existing biosparge operations
  - LIF investigation
  - LNAPL mobility evaluation
  - Future actions

Interim Measures for LNAPL

- What?
  - "Temporary" engineering or institutional controls
- Where?
  - Typically wherever free product is observed above some in-well thickness threshold (e.g., greater than 0.01' or a sheen)
- Why?
  - To be protective of human health and the environment while a final remedy is developed (i.e., temporarily mitigate risk)
- When?
  - Implemented fairly quickly, sometimes immediately

Interim Measures for LNAPL

- When interim measure for LNAPL
  - Designed and implemented properly
  - Implemented for the right reasons
  - Monitored adequately throughout the life of the measure
  - Discontinued when appropriate

- Net benefits can be significant!

Interim Measures for LNAPL

- Otherwise…Problems
  - "Perceived risk" due to the presence of LNAPL vs. "actual risk": in-well LNAPL thickness thresholds for remediation are often not consistent with a risk-based approach to LNAPL management
  - Interim measures are often viewed as permanent measures over time, despite the fact that the measures were meant to be temporary until further work completed

Interim Measures for LNAPL

- "Perceived risk" has often led to…
  - Implementation of interim measure remediation systems based upon mere presence of free product
    - Prior to delineation and thorough characterization of soil and LNAPL chemical/physical properties
    - Prior to thorough evaluation of risk issues
    - Prior to thorough evaluation of appropriate LNAPL management and/or remediation alternatives

Interim Measures for LNAPL

- Result of interim measure has often led to…
  - Costly, and often times ineffective, remediation system that only addresses a portion of the LNAPL
  - LNAPL plume that has not yet been adequately delineated (horizontally or vertically)
  - LNAPL project with no real progress or end in sight
  - Unsatisfied client and/or regulator

Interim Measures for LNAPL

- So…What Should be Done?
  - Implement interim measures if a known immediate risk exists or if inaction may constitute an imminent threat (e.g., stopping an active release source, cutting off active migration, etc.)
  - Develop a technically sound LNAPL Conceptual Site Model (LSCM)
  - Use the LSCM as a basis for appropriate corrective action decision making

LCSM

- ASTM Standard E 2531-06, *Standard Guide for Development of Conceptual Site Models and Remediation Strategies for Light Nonaqueous-Phase Liquids Released to the Subsurface*
- This Standard supplements the conceptual site model (CSM) developed in the RBCA process, and provides an in-depth description of LCSMs
- The LCSM forms the basis for LNAPL corrective action decisions
- Three tiers of LCSMs: Tier 1, Tier 2, Tier 3.

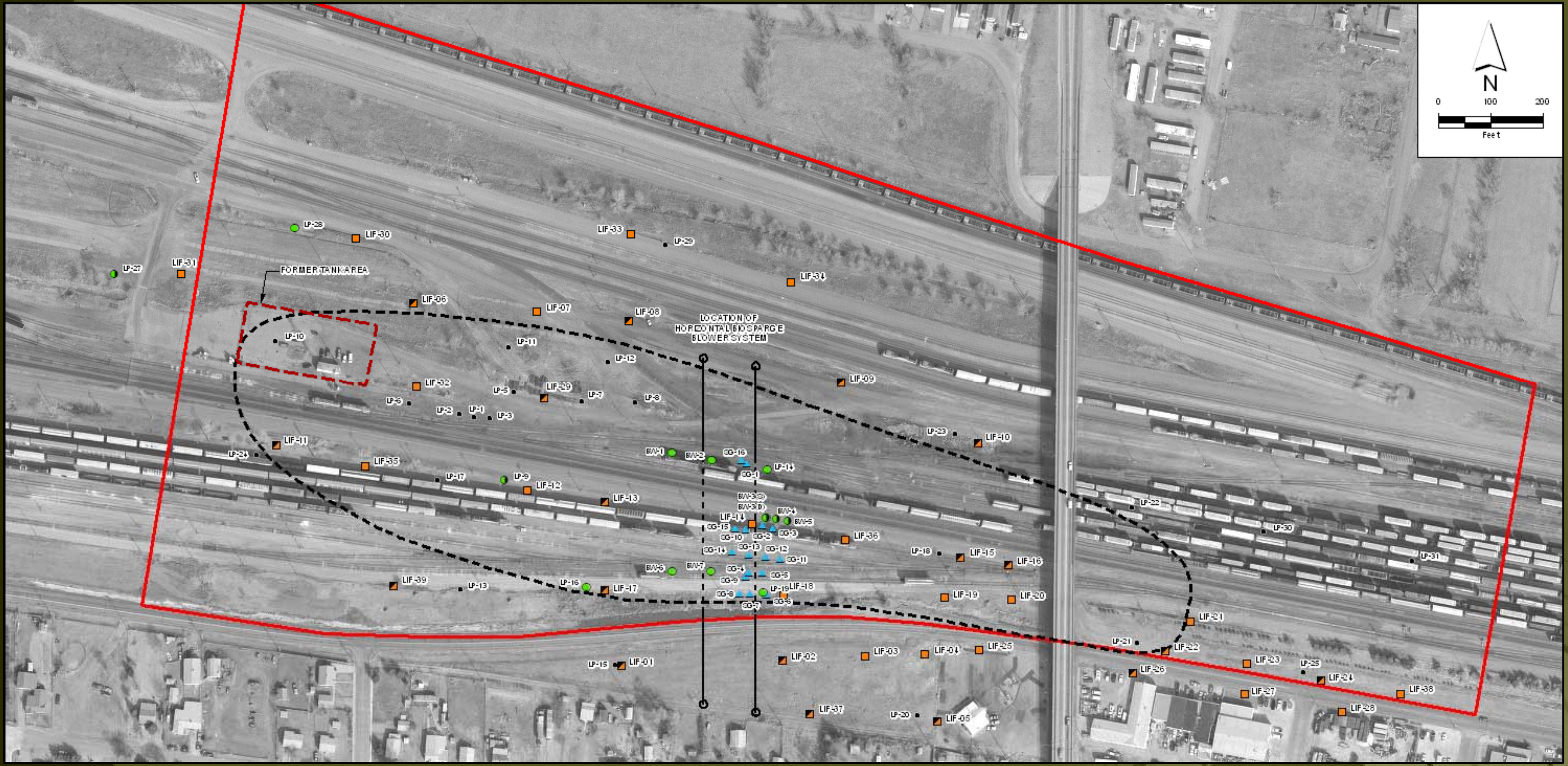
LCSM

- A thorough LCSM includes evaluating some/all of the following:
  - Vertical and horizontal delineation
  - Geology – soil type(s), soil physical properties
  - Hydrogeology – hydraulic conductivity, hydraulic gradient, LNAPL gradient
  - LNAPL physical/chemical properties
  - LNAPL mobility/recoverability
  - Potential exposures/risk

LCSM

- In addition to the scientific-technological information contained in the LCSM, additional consideration must be given to:
  - Regulatory requirements
  - Other (business, legal, stakeholder, etc.) requirements
- The LCSM and associated considerations are used to identify the true “remedial drivers” for the LNAPL

Case Study – Union Pacific Rail Yard



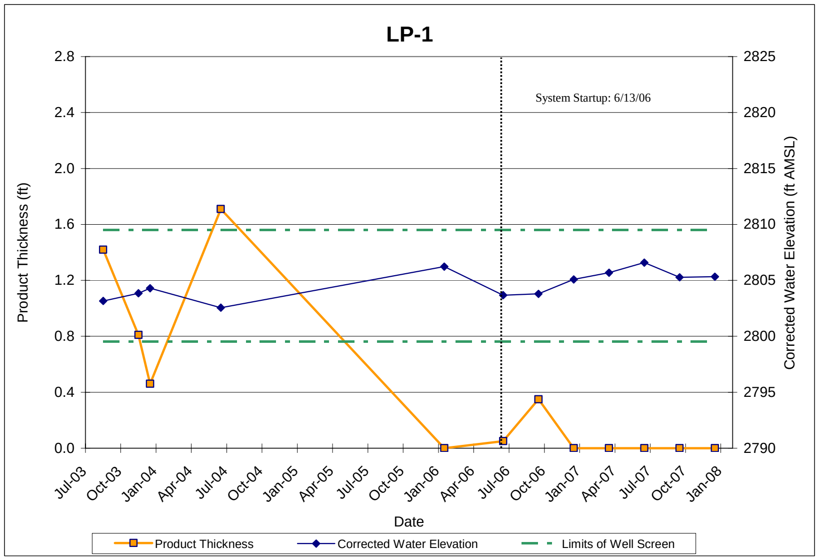
Setting

- Residential properties located 200 feet to the south and one-quarter of a mile north of the Site
- Three municipal water supply wells located within 2,000 feet of the Site (two wells upgradient, one cross-gradient)
- Groundwater table fluctuates between 6.5 and 16 feet bgs
- Hydraulic conductivity (fine to medium grained sand) estimated at approximately 48 feet/day
- Approximate hydraulic gradient is 0.001

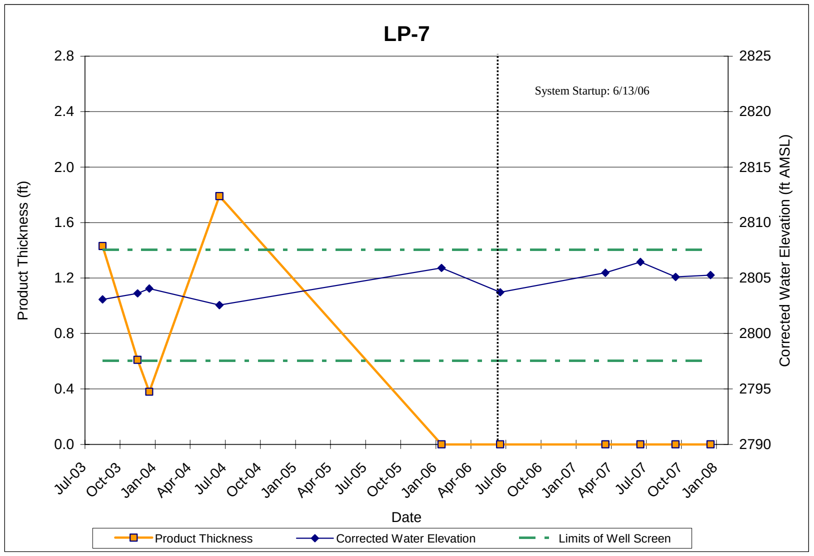
Setting

- LNAPL (characterized as a weathered diesel) identified in various on-site monitoring wells at various thicknesses, depending on the water table elevation
- Aquifer is behaving as a classic unconfined granular aquifer, with in-well LNAPL thicknesses increasing as water table elevation decreases, and vice versa
- During high water table elevations, no in-well LNAPL

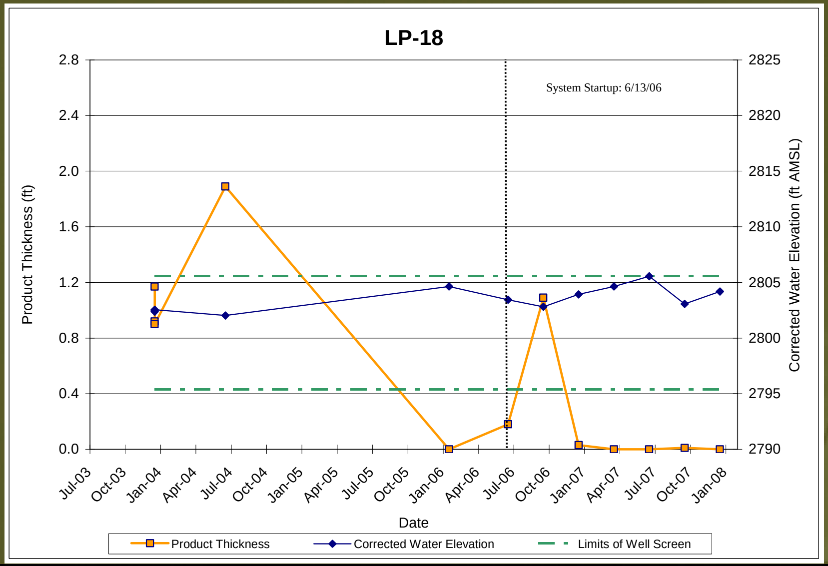
Setting



LP-1
System Startup: 6/13/06
Product Thickness (ft)
Corrected Water Elevation (ft AMSL)
Date
Product Thickness
Corrected Water Elevation
Limits of Well Screen



LP-7
System Startup: 6/13/06
Product Thickness (ft)
Corrected Water Elevation (ft AMSL)
Date
Product Thickness
Corrected Water Elevation
Limits of Well Screen



LP-18
System Startup: 6/13/06
Product Thickness (ft)
Corrected Water Elevation (ft AMSL)
Date
Product Thickness
Corrected Water Elevation
Limits of Well Screen

Site History

- Source of LNAPL attributed to group of large above-ground fuel storage tanks (ASTs) formerly located in the Site area and removed in the late 1960s
- Work plan proposed the use of horizontal biosparge technology to be implemented in a phased approach
- Phase 1 horizontal biosparge system was implemented in December 2005

Site History

- Biosparge system
  - Two horizontal sparge wells approximately 35 feet bgs placed approximately 100 feet apart
  - 300’ well screens with uniform perforations
  - 150 cfm design air flow
- System startup occurred on June 13, 2006
- Biosparge operations initiated despite completion of a thorough LCSM

Site Strategy Change

- Site strategy approach changed in 2007
- Prior to continuing with the evaluation of biosparging activities, and the potential implementation of a full-scale (numerous horizontal wells) biosparging remediation alternative, client authorized additional LNAPL delineation and characterization activities to develop technically sound LCSM
- Comprehensive LNAPL mobility evaluation was also authorized as part of the LCSM

Preliminary LNAPL Mobility Evaluation

- Conducted a preliminary Tier 1 LCSM LNAPL mobility evaluation based on the results of the LIF survey.
- Calculated LNAPL saturation profiles and associated LNAPL mobility, velocity, specific volume, and recoverable volume values for the following LNAPL formation thicknesses: 4 feet, 6 feet and 8 feet.
- All model input parameters for Tier 1 evaluation (with the exception of thickness) were based on typical literature default values for a diesel LNAPL and medium grained soil material.

Preliminary LNAPL Mobility Evaluation

This LNAPL Mobility Calculation Tool enables users to input an in-well LNAPL thickness and other relevant data to generate LNAPL saturation and relative permeability profiles and calculate corresponding LNAPL conductivity, mobility, velocity and specific volume values.
See "Instructions for Use" below.

Data Inputs and Intermediate Calculations

Maximum In-Well LNAPL Thickness

In-Well LNAPL Thickness (b_o) - (ft)	4.000

Soil Characteristics

LNAPL Residual Saturation - Vadose (S_{orv})	0.050
LNAPL Residual Saturation - Saturated (S_{ors})	0.150
Irreducible Water Saturation (S_{wr})	0.290
van Genuchten N (N)	2.700
van Genuchten α (α) - (1/ft)	4.420
Total Soil Porosity (Φ)	0.300

Fluid Characteristics

LNAPL Density (ρ_o) - (g/cm^3)	0.830
LNAPL Viscosity (μ_o) - (cp)	2.700
Air-Water Interfacial Tension (σ_{aw}) - (dynes/cm)	65.000
Oil-Water Interfacial Tension (σ_{ow}) - (dynes/cm)	50.000
Air-Oil Interfacial Tension (σ_{ao}) - (dynes/cm)	25.000

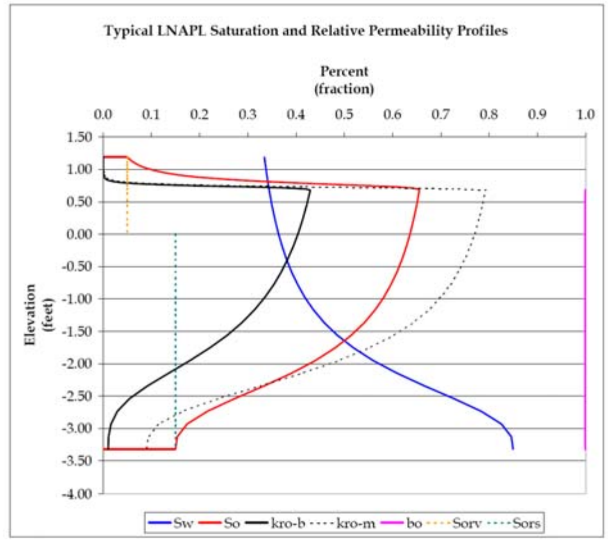
Calculated Parameters

Capillary Pressure Head Parameter - Oil/Water (α_{ow}) - (ft^{-1})	0.977
Capillary Pressure Head Parameter - Air/Oil (α_{ao}) - (ft^{-1})	9.338
Air-Oil Interface Elevation (z_{ao}) - (ft)	0.680
Oil-Water Interface Elevation (z_{ow}) - (ft)	-3.320
Maximum LNAPL Elevation (z_{max}) - (ft)	1.136
Model Parameter 1 (λ)	1.135
Model Parameter 2 (M)	0.630

Calculation of Points for Graphs

z	S_w	S_t	S_o	$k_{ro\text{-}b}$	$k_{ro\text{-}m}$	b_o	S_{orv}	S_{ors}
1.188			0					
1.188	0.335	0.385	0.050	0.0000	0.0001		0.050	
1.136	0.335	0.394	0.058	0.0000	0.0001		0.050	
1.119	0.336	0.397	0.061	0.0000	0.0001		0.050	
1.103	0.336	0.401	0.065	0.0000	0.0002		0.050	
1.086	0.336	0.405	0.069	0.0000	0.0002		0.050	
1.069	0.337	0.410	0.073	0.0000	0.0002		0.050	
1.052	0.337	0.415	0.078	0.0000	0.0003		0.050	
1.035	0.337	0.421	0.084	0.0001	0.0004		0.050	
1.018	0.337	0.428	0.090	0.0001	0.0004		0.050	
1.001	0.338	0.436	0.098	0.0001	0.0006		0.050	
0.984	0.338	0.444	0.106	0.0002	0.0007		0.050	
0.967	0.338	0.454	0.116	0.0002	0.0010		0.050	
0.950	0.339	0.466	0.127	0.0003	0.0013		0.050	
0.934	0.339	0.479	0.140	0.0005	0.0018		0.050	
0.917	0.339	0.495	0.155	0.0008	0.0026		0.050	
0.900	0.340	0.513	0.173	0.0012	0.0037		0.050	
0.883	0.340	0.535	0.195	0.0020	0.0054		0.050	
0.866	0.340	0.561	0.220	0.0033	0.0083		0.050	
0.849	0.341	0.591	0.251	0.0058	0.0129		0.050	
0.832	0.341	0.628	0.287	0.0105	0.0208		0.050	
0.815	0.341	0.671	0.330	0.0195	0.0344		0.050	
0.798	0.342	0.722	0.380	0.0364	0.0580		0.050	
0.781	0.342	0.779	0.436	0.0676	0.0990		0.050	
0.765	0.342	0.839	0.497	0.1210	0.1674		0.050	
0.748	0.343	0.898	0.555	0.2004	0.2736		0.050	
0.731	0.343	0.948	0.604	0.2950	0.4154		0.050	
0.714	0.344	0.981	0.638	0.3770	0.5824		0.050	
0.697	0.344	0.997	0.653	0.4212	0.7243		0.050	
0.680	0.344	1.000	0.656	0.4295	0.7925	1	0.050	
0.453	0.350	1.000	0.650	0.4222	0.7864	1	0.050	
0.227	0.356	1.000	0.644	0.4138	0.7790	1	0.050	
0.000	0.364	1.000	0.636	0.4039	0.7701	1	0.050	0.150
-0.195	0.372	1.000	0.628	0.3940	0.7608	1		0.150
-0.391	0.380	1.000	0.620	0.3825	0.7497	1		0.150
-0.586	0.391	1.000	0.609	0.3692	0.7363	1		0.150
-0.781	0.404	1.000	0.596	0.3536	0.7198	1		0.150
-0.976	0.419	1.000	0.581	0.3351	0.6995	1		0.150
-1.172	0.437	1.000	0.563	0.3133	0.6742	1		0.150
-1.367	0.459	1.000	0.541	0.2874	0.6424	1		0.150
-1.562	0.486	1.000	0.514	0.2568	0.6023	1		0.150
-1.758	0.519	1.000	0.481	0.2210	0.5516	1		0.150
-1.953	0.560	1.000	0.440	0.1801	0.4886	1		0.150
-2.148	0.609	1.000	0.391	0.1358	0.4125	1		0.150
-2.344	0.666	1.000	0.334	0.0921	0.3262	1		0.150
-2.539	0.727	1.000	0.273	0.0549	0.2388	1		0.150
-2.734	0.784	1.000	0.216	0.0296	0.1647	1		0.150
-2.929	0.825	1.000	0.175	0.0165	0.1160	1		0.150
-3.125	0.846	1.000	0.154	0.0116	0.0941	1		0.150
-3.320	0.850	1.000	0.150	0.0108	0.0901	1		0.150
-3.320			0.149					
-3.320			0					

Typical LNAPL Saturation and Relative Permeability Profiles



Notes:

Sw - Water saturation
So - Oil (LNAPL) saturation
kro-b - Oil relative permeability from Burdine equation (Eq. 2.26 in API Publication Number 4729)
kro-m - Oil relative permeability from Mualem equation (Eq. 2.28 in API Publication Number 4729)
bo - In-well LNAPL thickness
Sorv - LNAPL residual saturation in the vadose zone
Sors - LNAPL residual saturation in the saturated zone

Average S_o, $k_{ro\text{-}b}$ and $k_{ro\text{-}m}$ Calculations

i	z	S_w	S_t	S_o	$k_{ro\text{-}b}$	$k_{ro\text{-}m}$	S_o*n
1	1.136	0.335	0.394	0.058	0.0000	0.0001	0.022
2	0.780	0.342	0.784	0.442	0.0715	0.1039	0.168
3	0.602	0.346	1.000	0.654	0.4271	0.7905	0.248
4	0.423	0.351	1.000	0.649	0.4212	0.7855	0.247
5	0.245	0.356	1.000	0.644	0.4145	0.7797	0.245
6	0.067	0.361	1.000	0.639	0.4070	0.7729	0.243
7	-0.111	0.368	1.000	0.632	0.3984	0.7650	0.240
8	-0.290	0.376	1.000	0.624	0.3887	0.7557	0.237
9	-0.468	0.384	1.000	0.616	0.3775	0.7447	0.234
10	-0.646	0.395	1.000	0.605	0.3646	0.7315	0.230
11	-0.824	0.407	1.000	0.593	0.3497	0.7157	0.225
12	-1.003	0.421	1.000	0.579	0.3324	0.6964	0.220
13	-1.181	0.438	1.000	0.562	0.3122	0.6729	0.214
14	-1.359	0.458	1.000	0.542	0.2885	0.6438	0.206
15	-1.537	0.482	1.000	0.518	0.2610	0.6079	0.197
16	-1.716	0.511	1.000	0.489	0.2291	0.5635	0.186
17	-1.894	0.547	1.000	0.453	0.1929	0.5090	0.172
18	-2.072	0.589	1.000	0.411	0.1533	0.4436	0.156
19	-2.250	0.638	1.000	0.362	0.1125	0.3681	0.137
20	-2.429	0.693	1.000	0.307	0.0747	0.2874	0.117
21	-2.607	0.748	1.000	0.252	0.0446	0.2106	0.096
22	-2.785	0.796	1.000	0.204	0.0252	0.1492	0.077
23	-2.963	0.830	1.000	0.170	0.0152	0.1104	0.064
24	-3.142	0.847	1.000	0.153	0.0115	0.0932	0.058
25	-3.319	0.850	1.000	0.150	0.0108	0.0901	0.057
		Total:					4.297
		Average:		0.452	0.2274	0.4957	

LNAPL Conductivity, Mobility and Velocity Calculations

Relative Permeability Method	Burdine
Water Hydraulic Conductivity (cm/s)	1.00E-02
Average LNAPL Conductivity (cm/s)	6.99E-04
Average LNAPL Mobility (cm/s)	4.07E-03
Hydraulic Gradient	0.001
Average LNAPL Velocity (cm/s)	4.07E-06

Specific and Recoverable Volume of LNAPL

LNAPL Specific Volume (ft^3/ft^2):	0.77
LNAPL Recoverable Volume (ft^3/ft^2):	0.56
LNAPL Specific Volume (liters/ft^2):	21.94
LNAPL Recoverable Volume (liters/ft^2):	15.94
LNAPL Specific Volume (U.S. gallons/ft^2):	5.80
LNAPL Recoverable Volume (U.S. gallons/ft^2):	4.21

INSTRUCTIONS FOR USE:

1. Under the "Data Inputs and Intermediate Calculations" section, select default input parameters from the "Input" sheet or enter site-specific input data.

2. Under the "Calculation of Points for Graphs" section, enter different values of z in cell F13 (as an iterative process), slightly higher than the z values in the cells below, so that the resulting LNAPL Saturation calculation (S_o) in cell I13 is equal to the LNAPL residual saturation vadose zone (S_{orv}) value in cell D19.

3. Change the title block in the bottom right-hand-corner to identify the appropriate soil type, product type and in-well thickness.

4. If soil type is sand or gravel, enter "Burdine" in cell AO47; if soil type is silt or clay, enter "Mualem" in cell AO47.

Notes:

(a) - The zero value on the z-axis in the above graph represents the theoretical groundwater elevation or the "air-water" interface.
(b) - Yellow highlighted cells identify critical elevations such as: the maximum (or near maximum) elevation of LNAPL in the vadose zone; the air-oil interface elevation; the air-water interface elevation; and the oil-water interface elevation.
(c) - Brown highlighted cells identify areas where user manipulation is required or areas where calculations are set equal to an established value based on physical conditions.

Calculations based on equations presented in American Petroleum Institute (API) Publication Number 4729, *Models for Design of Free-Product Recovery Systems for Petroleum Hydrocarbon Liquids*, August 2003.

CRA LNAPL Volume and Mobility Calculation Tool, Version 3

LNAPL MOBILITY CALCULATION TOOL

SOIL TYPE:	MEDIUM SAND
PRODUCT TYPE:	DIESEL
IN-WELL THICKNESS:	4 FEET

CONESTOGA-ROVERS & ASSOCIATES

Preliminary LNAPL Mobility Evaluation

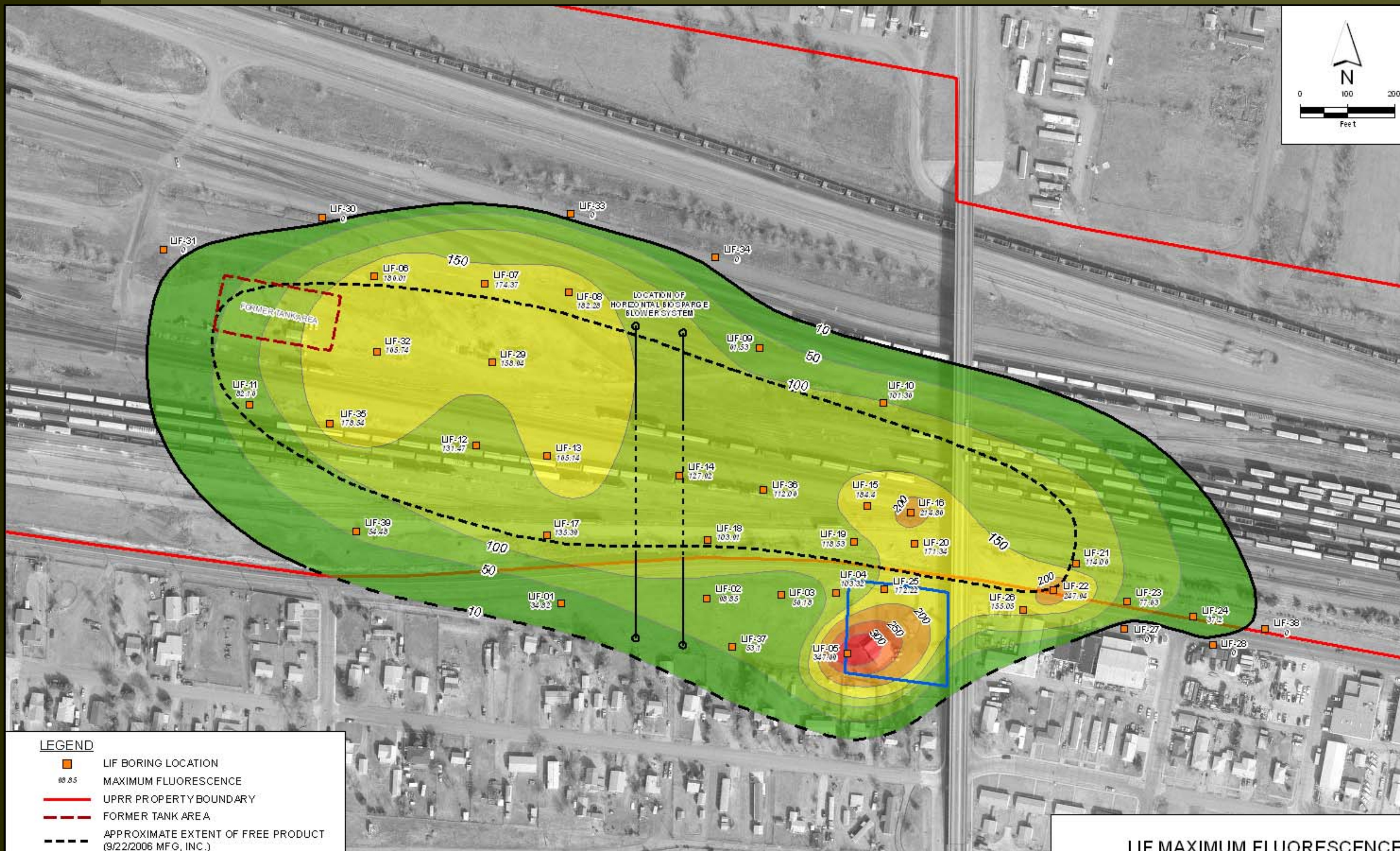
LNAPL Thickness (ft)	Average Mobility (cm/s)	Average Velocity (cm/s)	Specific Volume (gal/ft^2)	Recoverable Volume (gal/ft^2)
4	4.07×10^{-3}	4.07×10^{-6}	5.80	4.21
6	4.57×10^{-3}	4.57×10^{-6}	9.71	7.33
8	4.85×10^{-3}	4.85×10^{-6}	13.68	10.52

Note: *LNAPL velocities less than 1×10^{-6} cm/s (approximately equal to 1 foot per year) are considered to be effectively immobile (ASTM 2007).*

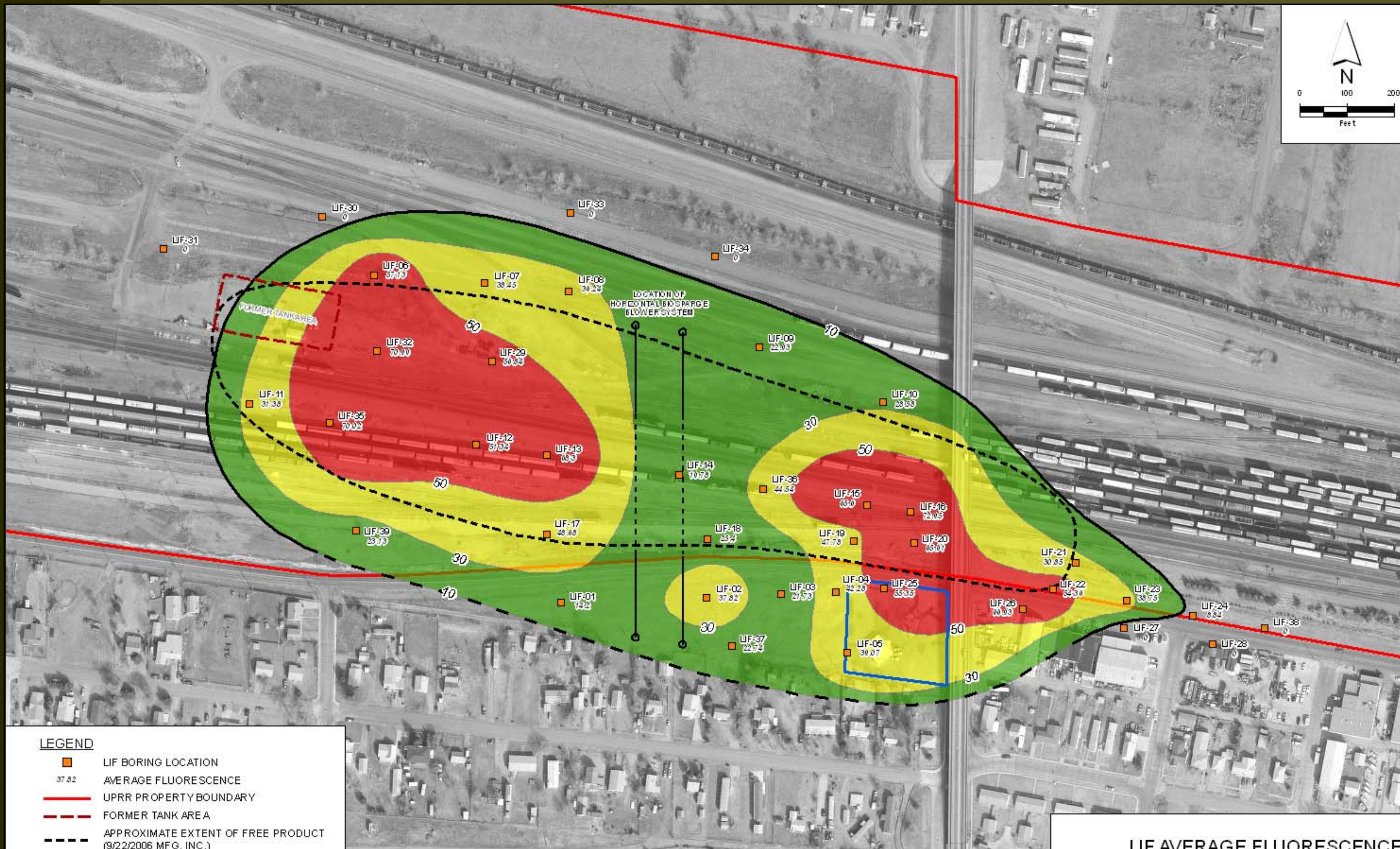
LIF Investigation

- Conducted a laser induced fluorescence (LIF) survey using ultraviolet optical screening tool (UVOST) techniques.
- Completed thirty-nine (39) LIF test locations across LNAPL-impacted areas, both on-Site and off-Site.
- Imported the LIF data into a three dimensional visualization program to interpolate LIF reflectance results.

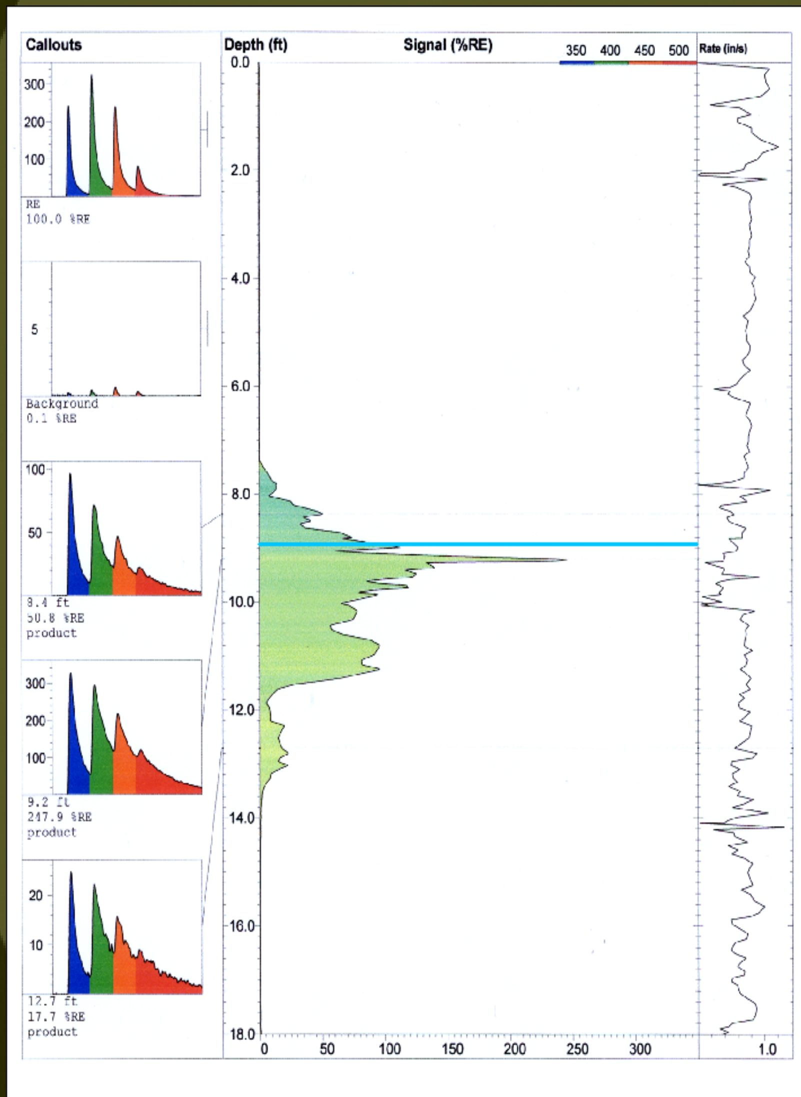
LIF Investigation

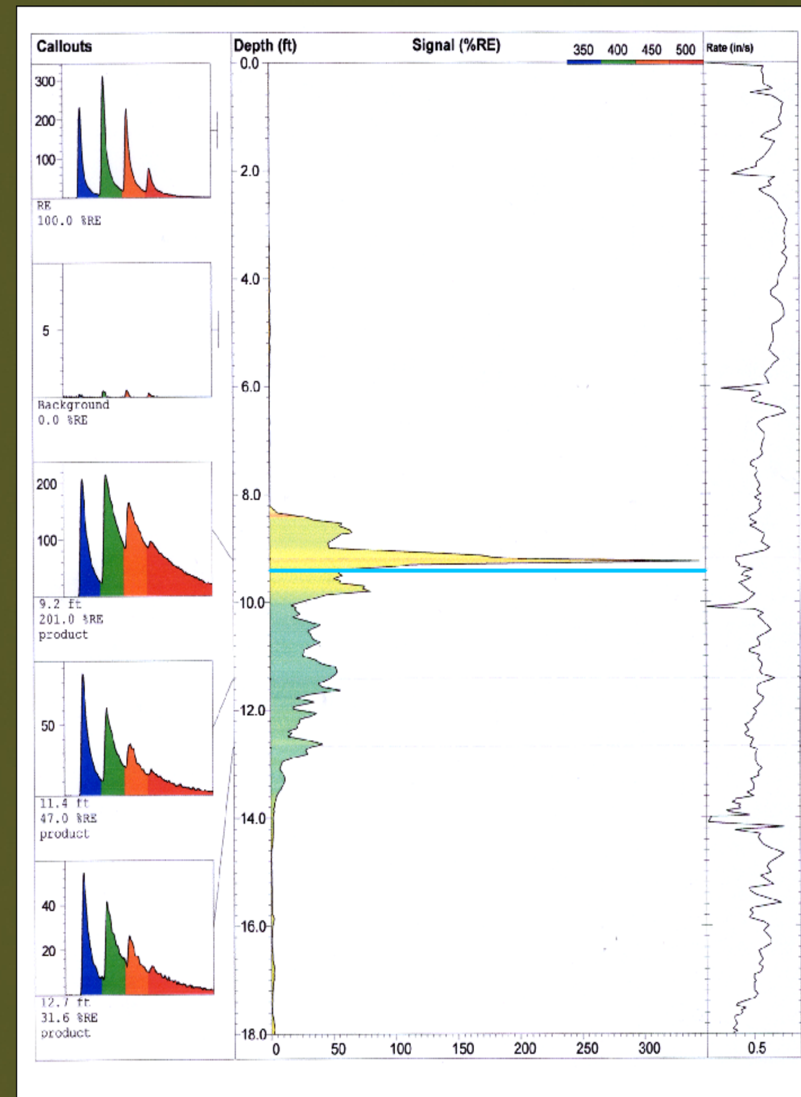


LIF Investigation

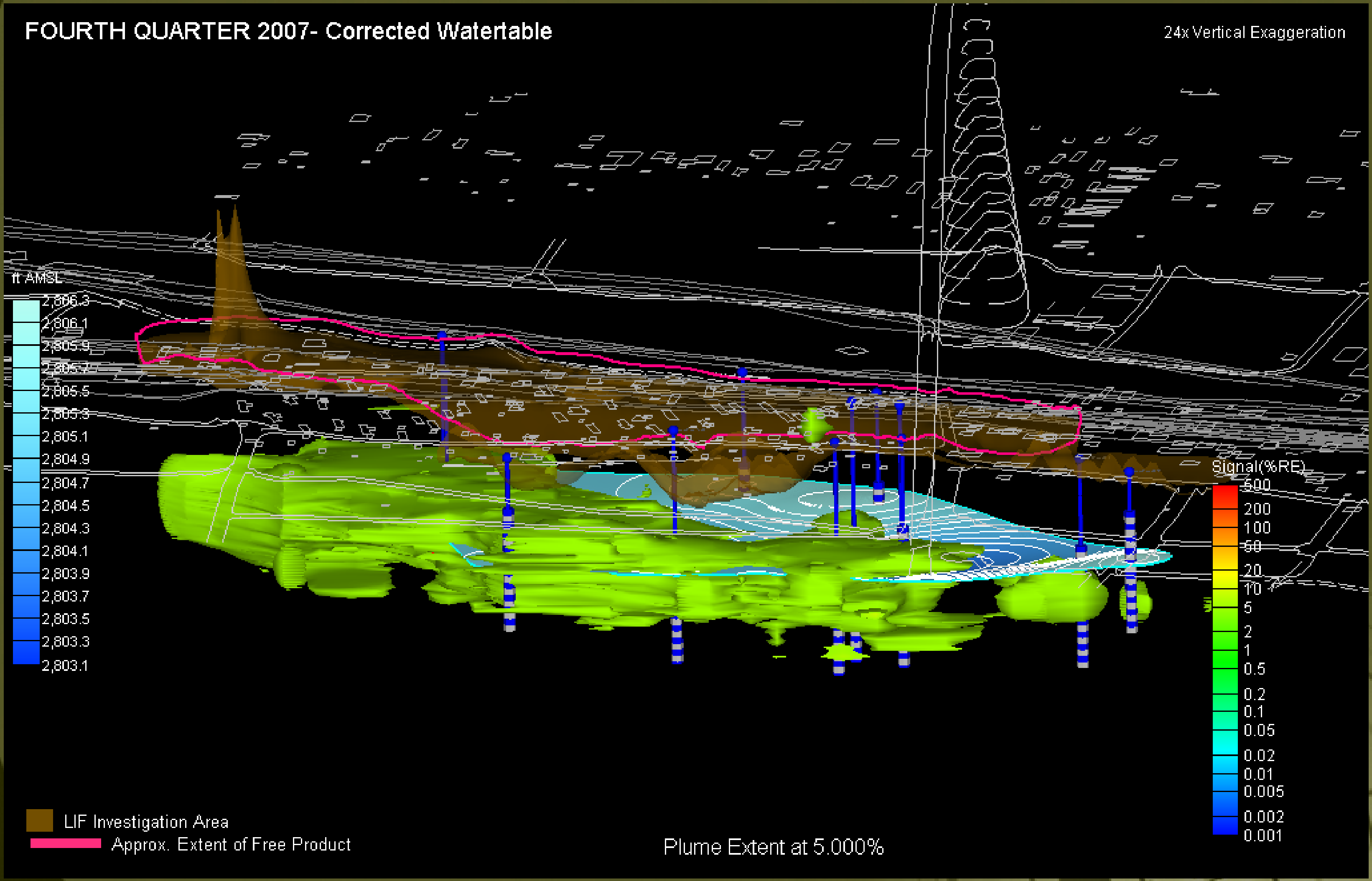


LIF Investigation

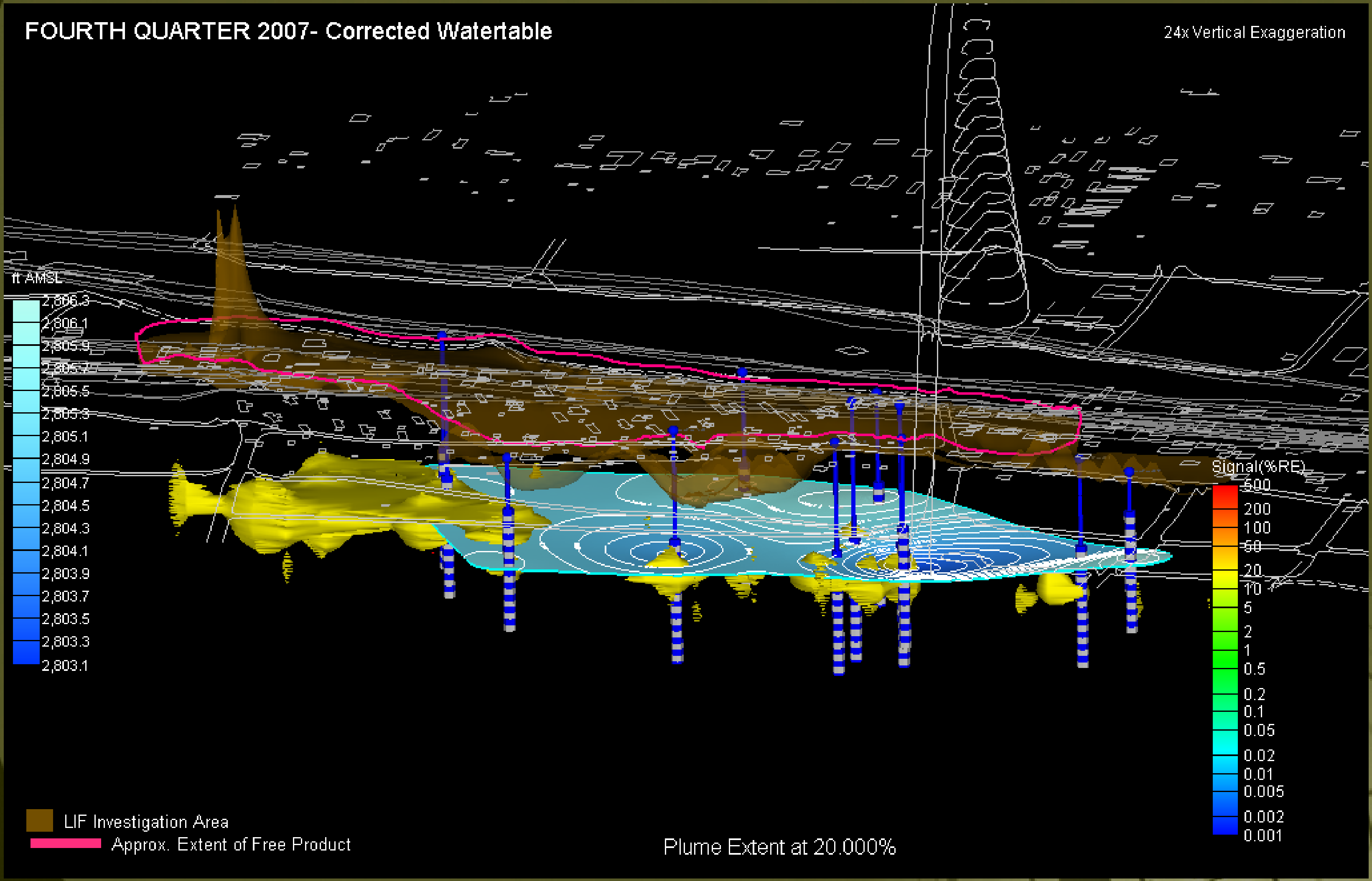




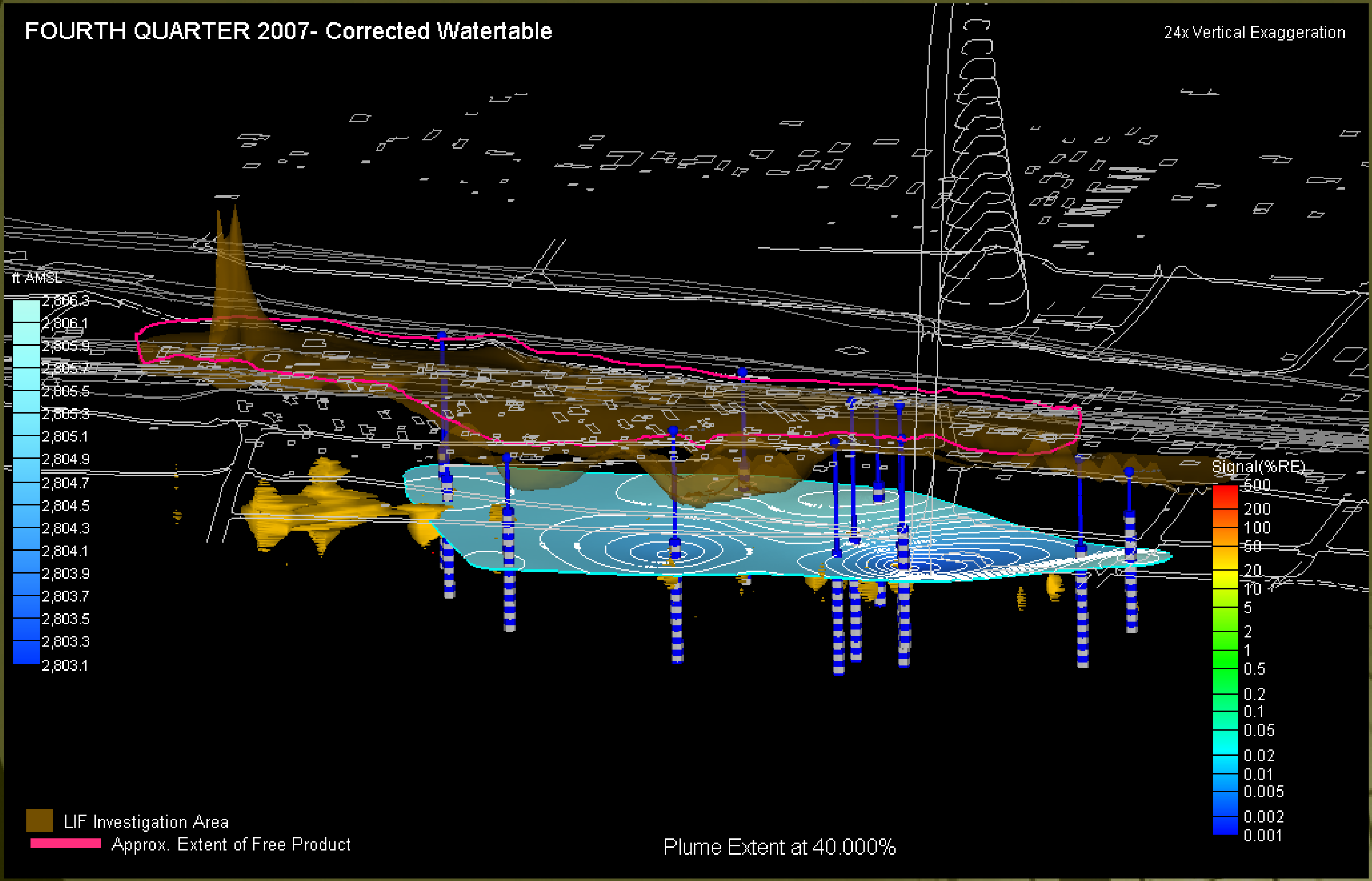
3-D LIF Visualization



3-D LIF Visualization



3-D LIF Visualization

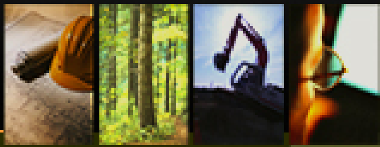


LIF Investigation

- Based on the LIF results, it was apparent that the majority of LNAPL impacts are present beneath the water table.
- The water table is currently located approximately 8 feet below bgs – the majority of LNAPL impacts are located from 9 feet to 15 feet bgs.
- No product currently in wells.

LIF Investigation

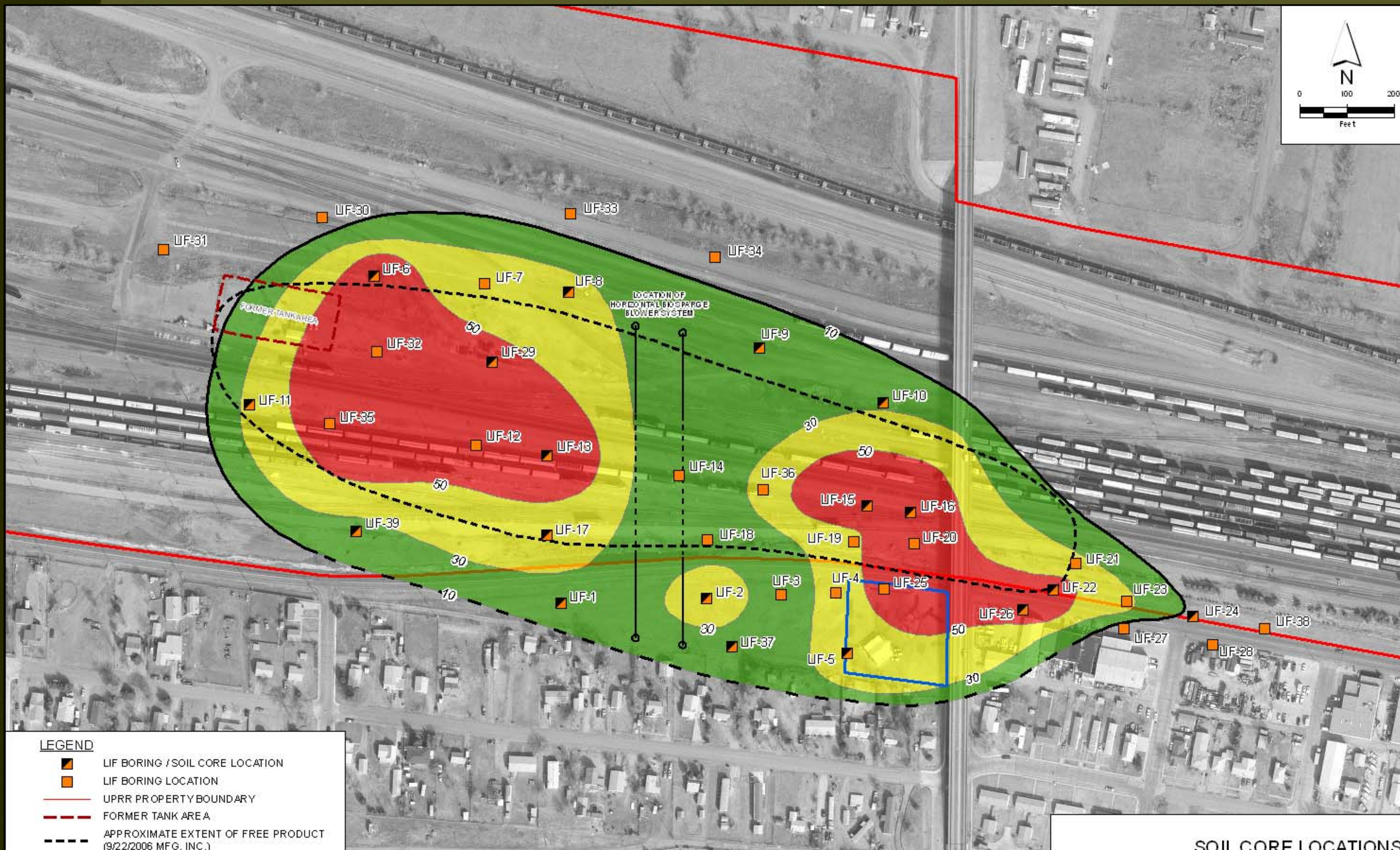
- Based on the previous LIF plots, the following issues were considered:
  - The biosparging operations may have effectively remediated/reduced LNAPL saturations within the vicinity of the two horizontal biosparge wells;
  - The biosparging operations may have pushed LNAPL to the east and west, away from the biosparge wells; and/or
  - There may be two separate sources of LNAPL.



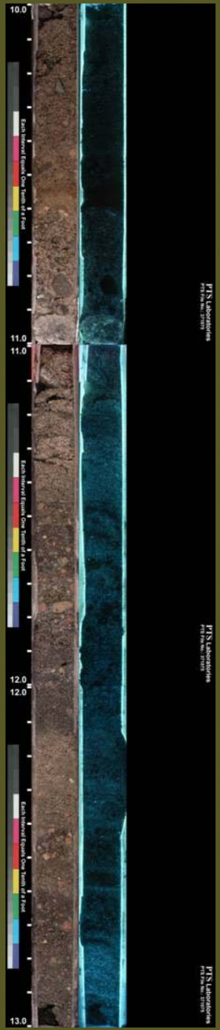
Detailed LNAPL Mobility Evaluation

- Completed a detailed LNAPL mobility evaluation.
- Collected LNAPL-impacted soil cores from eighteen (18) locations, both on-Site and off-Site.
- Submitted soil cores to PTS laboratories for core photography (white light and UV light) and determination of LNAPL mobility evaluation parameters.

Detailed LNAPL Mobility Evaluation

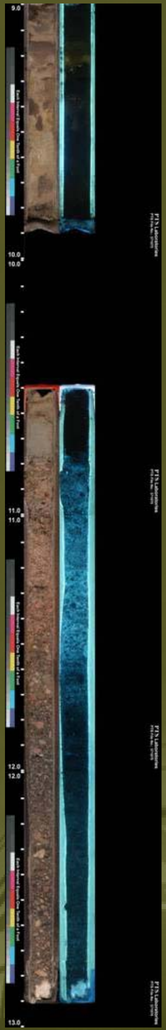


Core Photography



LIF-11
(10'-13' bgs)

LIF-13
(9'-13' bgs)



LIF-5
(9'-13' bgs)

Detailed LNAPL Mobility Evaluation

- LNAPL mobility was evaluated using the following two methods:
  - Comparing initial LNAPL saturations to residual saturations directly from laboratory test results
  - Utilizing the laboratory measured ‘maximum’ LNAPL saturations to determine corresponding LNAPL relative permeability, conductivity, mobility and velocity values using API methodology

Detailed LNAPL Mobility Evaluation

PTS Laboratories

ENDPOINT SATURATION WATER DRIVE TEST: INITIAL AND RESIDUAL SATURATIONS

		METHODS:	API RP 40		API RP 40	ASTM D425M, DEAN-STARK			
						PORE FLUID SATURATIONS, % Pv			
		SAMPLE	DENSITY		TOTAL	Initial Fluid Saturations		After Waterflood Test	
SAMPLE ID.	DEPTH, ft.	ORIENTATION (1)	BULK, g/cc	GRAIN, g/cc	POROSITY, %Vb	WATER (Swi) SATURATION	NAPL (Soi) SATURATION	WATER (Srw) SATURATION	NAPL (Sor) SATURATION
LIF-22 (11-13)	12.1	V	1.77	2.63	32.7	47.1	9.1	64.3	9.1
	NOTE:	**No visible LNAPL produced; 12.3 pore volumes of water injected. Produced water clear with faint HC odor.**							
LIF-15 (11-13)	12.4	V	1.78	2.62	32.2	45.5	8.3	70.2	8.3
	NOTE:	**No visible LNAPL produced; 12.6 pore volumes of water injected. Produced water clear with faint HC odor.**							
LIF-13 (11-13)	12.3	V	1.67	2.62	36.2	48.0	6.3	70.1	6.3
	NOTE:	**No visible LNAPL produced; 12.1 pore volumes of water injected. Produced water clear with faint HC odor.**							
LIF-11 (11-13)	12.8	V	1.79	2.63	32.0	56.8	6.6	72.7	6.6
	NOTE:	**No visible LNAPL produced; 12.1 pore volumes of water injected. Produced water clear with faint HC odor.**							
LIF-37 (9-11)	9.8	V	1.78	2.62	32.2	59.3	6.6	68.3	6.6
	NOTE:	**No visible LNAPL produced; 12.6 pore volumes of water injected. Produced water clear with faint HC odor.**							
LIF-8 (11-13)	12.4	V	1.77	2.62	32.2	46.1	9.1	64.7	9.1
	NOTE:	**No visible LNAPL produced; 12.5 pore volumes of water injected. Produced water clear with faint HC odor.**							

Detailed LNAPL Mobility Evaluation

LNAPL MOBILITY AND VELOCITY CALCULATIONS
BASED ON MAXIMUM SATURATIONS AND API METHODOLGY

	Location, Data Input and Calculations [3]										
Data Input Values	*LIF-001*	*LIF-002*	*LIF-008*	*LIF-009*	*LIF-011*	*LIF-013*	*LIF-015*	*LIF-022*	*LIF-024*	*LIF-026*	*LIF-037*
LNAPL Saturation (S_o)	0.099	0.121	0.091	0.057	0.066	0.063	0.083	0.091	0.037	0.070	0.066
Water Saturation (S_w)	0.544	0.547	0.461	0.616	0.568	0.480	0.455	0.471	0.598	0.514	0.593
Total Fluid Saturation (S_t)	0.643	0.668	0.552	0.673	0.634	0.543	0.538	0.562	0.635	0.584	0.659
Irreducible Water Saturation (S_{wr})	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057
van Genuchten N (N) (1)	3.117	3.117	3.117	3.117	3.117	3.117	3.117	3.117	3.117	3.117	3.117
LNAPL Density (ρ_o) - (g/cm^3)[(1)]	0.850	0.850	0.850	0.850	0.850	0.850	0.850	0.850	0.850	0.850	0.850
LNAPL Viscosity (μ_o) - (cp)[(1)]	3.500	3.500	3.500	3.500	3.500	3.500	3.500	3.500	3.500	3.500	3.500
Total Soil Porosity (Φ)	0.420	0.420	0.420	0.420	0.420	0.420	0.420	0.420	0.420	0.420	0.420
Hydraulic Gradient	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Hydraulic Conductivity Water (K_w) - (cm/s)	5.97E-03	5.97E-03	5.97E-03	5.97E-03	5.97E-03	5.97E-03	5.97E-03	5.97E-03	5.97E-03	5.97E-03	5.97E-03
Calculated Parameters											
Model Parameter 1 (λ)	1.354	1.354	1.354	1.354	1.354	1.354	1.354	1.354	1.354	1.354	1.354
Model Parameter 2 (M)	0.679	0.679	0.679	0.679	0.679	0.679	0.679	0.679	0.679	0.679	0.679
LNAPL Relative Permeability (k_{ro}) [(2),(4)]	1.11E-03	2.10E-03	6.63E-04	2.42E-04	3.35E-04	2.24E-04	4.87E-04	6.85E-04	6.15E-05	3.45E-04	3.58E-04
LNAPL Conductivity (K_o) - (cm/s) [(4)]	1.61E-06	3.05E-06	9.62E-07	3.51E-07	4.86E-07	3.24E-07	7.06E-07	9.94E-07	8.92E-08	5.00E-07	5.19E-07
LNAPL Mobility (M_o) - (cm/s) [(4)]	3.87E-05	6.00E-05	2.52E-05	1.46E-05	1.75E-05	1.23E-05	2.02E-05	2.60E-05	5.74E-06	1.70E-05	1.87E-05
LNAPL Velocity (V_o) - (cm/s) [(4)]	7.73E-08	1.20E-07	5.03E-08	2.93E-08	3.51E-08	2.45E-08	4.05E-08	5.20E-08	1.15E-08	3.40E-08	3.75E-08
Potentially Mobile ($V_o > 10^{-6}$ cm/s)?	No	No	No	No	No	No	No	No	No	No	No

Notes:

(1) - Values taken from American Petroleum Institute (API) Interactive LNAPL Guide (Version 2.0, Release 2.0.2, August 2004) - Assessment Tools - Parameter Tables. Values selected based for diesel fuel.

(2) - LNAPL relative permeability calculation based on Burdine Equation 2.26 and Equation 2.27 in American Petroleum Institute (API) Publication Number 4729, *Models for Design of Free-Product Recovery Systems for Petroleum Hydrocarbon Liquids*, August 2003.

(3) - Blue highlighted data input values were based on Site-specific laboratory test results and/or field measurements.

(4) - Calculations based on laboratory generated LNAPL saturation values.

Detailed LNAPL Mobility Evaluation

- Site LNAPL exhibits no potential for mobility according to two different evaluation methodologies
- Recoverability of LNAPL is expected to be low due to low LNAPL saturations and mobility potential
- The lack of comparable pre-remediation data prevents a definitive answer on whether biosparge system was effective in remediating the LNAPL

Conclusions

- The completion of a thorough LCSM enabled a much better understanding of actual LNAPL conditions and “realistic” as opposed to “perceived” risk issues
- The results of LCSM activities suggest that the LNAPL plume is effectively immobile, stable, and non-recoverable
- Although it does not appear that biosparging was adversely pushing the LNAPL away, it is unclear if there was a net benefit resulting from the biosparging (due to the absence of LNAPL mobility data pre-biosparging)

Conclusions

- Pending the evaluation of other considerations (regulatory, business, etc.), a LNAPL monitoring program may be the preferred LNAPL management approach at site, as opposed to the implementation of a full-scale biosparging alternative
- Results in a potential cost savings in excess of $5 million