Strategies for Environmental Risk Management at LNAPL Sites

RITS Spring 2009

Remediation Vocabulary Pop Quiz

What is an Environmental Risk Management Strategy?

A. A regulatory-driven document that someone spends a lot of time writing and sits invisible on a dusty shelf until the cleaning crew discards it

B. An action plan that establishes goals, specifies a remedy, and charts a clear course for long-term site management or achieving site closure

C. An outcome of a long, rambling project team brainstorming meeting where most are multi-tasking on their Blackberries

D. Duh! A statement of the obvious that the project team already knows and consistently executes

Vocabulary Pop Quiz (cont.)

- The correct answer is B
  - An action plan that establishes goals, specifies a remedy, and charts a clear course for long-term site management or achieving site closure
- It consists of the following primary elements:
  - Summary of site closure criteria
  - Description of remediation approach
  - Statement of objectives and milestones
  - Execution plan
    - Performance monitoring plan
    - Data evaluation and optimization program
    - Definition of remediation endpoints

Focus of Presentation and Objectives

- Present Remedial Project Managers (RPMs) with a process and toolbox for light non-aqueous phase liquid (LNAPL) risk management strategy development
  - With a focus on natural attenuation (NA) to control/reduce LNAPL mobility and toxicity
- Define the problem:
  - Stagnation of LNAPL site remediation, poorly defined LNAPL conceptual site models (LCSM)…undefined end points
- Specify a solution:
  - Re-evaluate remediation approaches and define sustainable long-term care (LTC) strategies
- Demonstrate the solution through case studies:
  - Naval Air Station (NAS) North Island, San Diego, California
  - SS-11, Hickam Air Force Base (AFB), Hawaii

Topic Context – Past RITS

- Estimating MNA Remedial Timeframes with Natural Attenuation Software (NAS v2) (Spring 2008)
- Long-Term Site Management (Fall 2007)
- Strategies to Enhance Risk Management (Spring 2006)
- Remediation Performance Objectives (Spring 2006)
- Conceptual Site Models (Spring 2004)

Presentation Overview

- Status of LNAPL Site Management
- Fundamentals of an LNAPL Strategy
- Steps to Develop an LNAPL Risk Management Strategy
  - Collect Key Data for the LNAPL Conceptual Site Model
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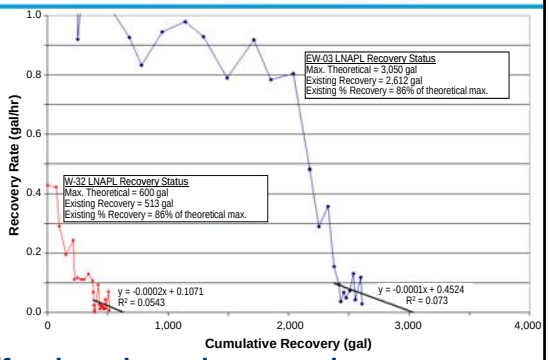
- Case Study Illustrations
- Food for Thought and Resources

General Status of LNAPL Site Management

- Stagnated
  - Treatment systems are no longer effective
    - Reached recovery plateau
  - Restrictive regulatory requirements



- Lack of up-to-date and effective site exit strategies
  - Many people would not answer B on the Pop Quiz
  - Many strategies undocumented and/or flying by the seat of their pants
  - Others think it unnecessary

Variable LNAPL Regulatory Requirements

- Requires removal "to the extent practical," but non-degradation legislation makes it difficult to leave LNAPL in-place
- Some Regional Water Boards are distinguishing between mobile and immobile LNAPL and allowing LTC strategies with monitored natural attenuation (MNA) for stable plumes

- Requires quantifying 4-phases of fuel in CSM
- LNAPL management strategy includes "removal to the extent practical" followed by MNA
- LNAPL removal to 0.01-ft is generally required for site closure
- Other LTC strategies accepted for immobile, low-risk sites

- LNAPL removal to 0.01-ft is desired, but "removal to the extent practical" is included in their risk-based corrective action (RBCA) rule
- Difficult to get No Further Action (NFA) site closure with over 0.01-ft in wells

LNAPL Site Management Concerns

- LNAPL sites remain a significant component of the US Navy portfolio
  - Often a persistent, long-term source of contamination
  - LNAPL weathering can create other environmental problems including vapor- and dissolved-phase plumes
  - The nature and extent of LNAPL plumes are unpredictable and site-specific
- Its *in situ* occurrence is commonly misunderstood
  - "Pancake" theory – RARELY TRUE!
  - In-well LNAPL = Mobile LNAPL – RARELY TRUE!
- Optimization opportunities abound
  - Many sites with ineffective active fluid recovery systems
  - Move from aggressive technologies toward MNA and LTC

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Importance of an LNAPL Strategy

- Sites require a road map to site closure or LTC
- LNAPL strategy is primary reference for remediation decision making rationale
  - Bridges the dynamic gap between the time of the Decision Document (DD) and end of remediation
  - Maintains continuity amongst changing project members
- Provides RPMs with a framework for progress
  - Prescribes process to proceed from active to passive approach
  - Seeks up-front regulatory approval for flexible treatment technology implementation and treatment train approach

Benefits of an LNAPL Strategy

- Obtains regulatory pre-approval for a site management approach that explicitly acknowledges the inherent challenge of LNAPL remediation and incorporates an adaptive remediation process
- Recognizes the ability of intrinsic processes, e.g., natural attenuation, to contain/reduce LNAPL
- Achieves a cost-effective, "green," and more sustainable remediation endpoint

Take Home Message

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Steps to Develop a Risk Management Strategy

1. COLLECT KEY DATA
2. PERFORM LNAPL NA EVALUATION
3. EVALUATE RISKS FOR SOIL, SOIL GAS, GROUNDWATER
4. DEVELOP CSM
5. DEFINE SITE AND LNAPL REMEDIATION OBJECTIVES
6. IDENTIFY RISK REDUCTION/REMEDIATION METRICS
7. DEVELOP RISK MANAGEMENT STRATEGY
8. PREPARE AN EXECUTION PLAN TO ACHIEVE CLOSURE OR LTC

Publically-Available Toolbox for RPM Use

- See HANDOUT 1 in your binders

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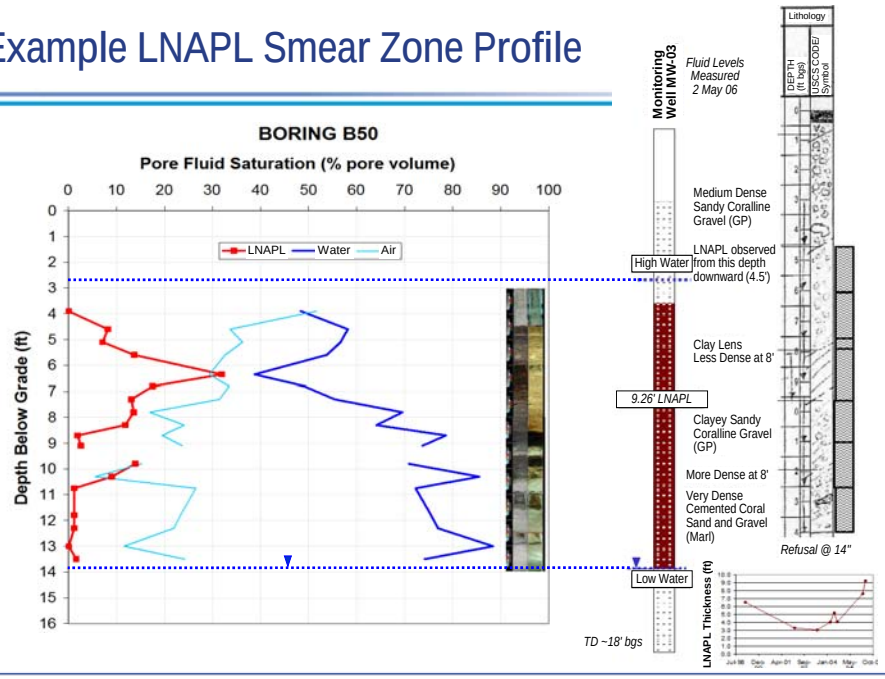
Understand the LNAPL Condition

- Continuous LNAPL
  - Connected
  - Typically seeps into monitoring wells (MWs) under convergent gradient
  - POTENTIALLY MOBILE under gradient > pore entry pressure
- Residual LNAPL
  - Disconnected ganglia/blobs
  - "Pendular" residual above water
  - "Insular" residual below water table
  - Does not accumulate in MWs
  - IMMOBILE under any gradient

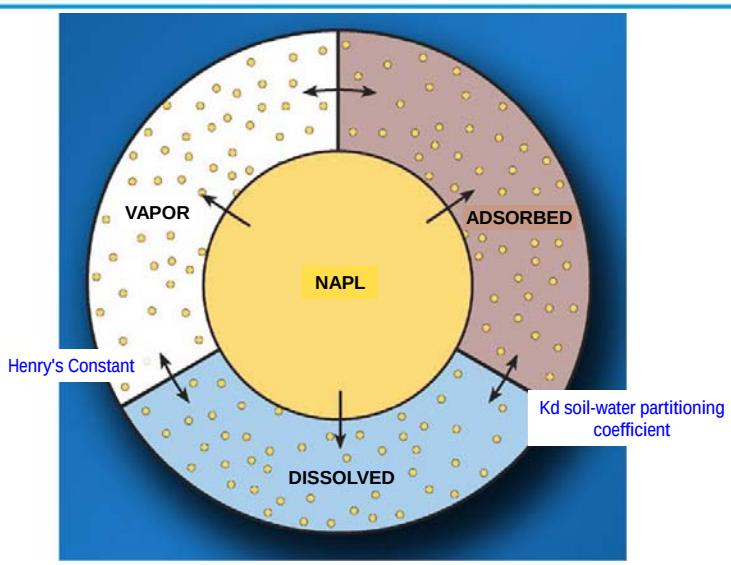
Example LNAPL Smear Zone Profile



Real-time Discrete LNAPL Characterization

- Laser-induced fluorescence (LIF)
  - Direct-push technology outfitted with a special probe point with a sapphire window protected laser and detector fiber optics
  - Laser energizes and excites PAH-containing petroleum compounds and causes them to fluoresce
  - Digital results from tuned wavelength detector are generated in the field as color-coded, scaled graphical logs
- Benefits
  - Real-time results
  - Gives relative concentration & speciation of petroleum
  - Data can be used to produce high quality 2-D and 3-D graphics

Quantify the 4-Phases of LNAPL



List of Tools that Assist CSM Development

- See HANDOUT 1 in your binders

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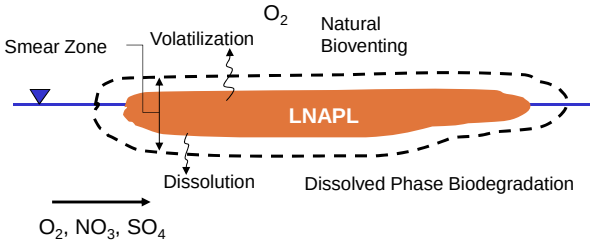
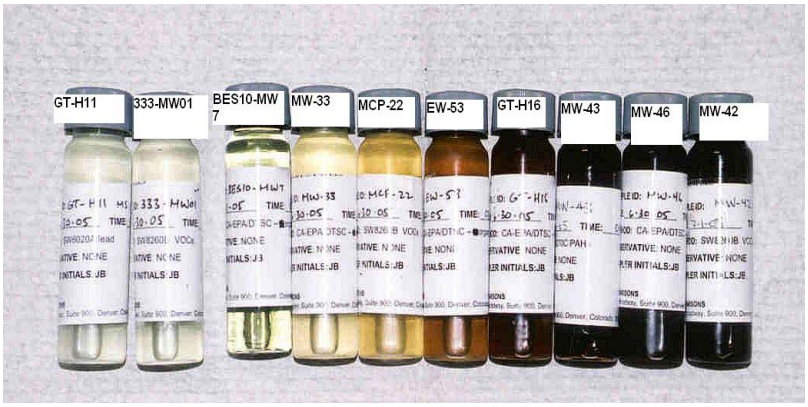
Overview of LNAPL Natural Attenuation

- LNAPL weathering processes include:
  - Dissolution
  - Volatilization
  - Biodegradation



- LNAPL weathering literature database is growing.
  - AFCEE fuel weathering study
  - See Resources slide for detailed listing

Weathered LNAPL Samples



Use Multiple Lines of Evidence Approach

1st Line of Evidence

The LNAPL is immobile and does not threaten surface water or create dissolved-phase plume expansion

2nd Line of Evidence

The LNAPL presents no risk to human or ecological receptors under current and reasonable future scenarios

3rd Line of Evidence

LNAPL recovery has been completed to the extent practical

Take Home Message

1st Line of Evidence – Mobility Evaluation

- Demonstrate that LNAPL is immobile or limited mobility and does not threaten surface water or create dissolved-phase plume expansion
  - LNAPL is no longer spreading laterally
  - Resulting dissolved plume is stable/receding
  - Surface water is not impacted
  - LNAPL thickness is decreasing
    - Ideal, but may not be a good indicator if water table fluctuations cause vertical redistribution and confound in-well thickness trend analysis

Take Home Message

LNAPL Mobility Evaluation Methods

- Intact Coring, LNAPL Analysis, and Mobility Estimate
- Laboratory LNAPL Mobility Testing
- LNAPL Dye Tracer Testing

Intact Coring, LNAPL Analysis, and Mobility Estimate

- Quantified understanding of the LNAPL condition and potential for mobility and recoverability
  - Analytics based on adaptation of established soil science and widely published by the American Petroleum Institute (API)
- Performed on select set of sample depths – location of potential mobility front (i.e., the LNAPL saturation peak)
- Methods and metrics gaining acceptance
  - Percent of pore volume saturated with LNAPL
  - LNAPL hydraulic conductivity (cm/sec)
  - LNAPL gradient (ft/ft)
  - LNAPL pore velocity estimates (ft/yr)

Laboratory LNAPL Mobility Testing

- Centrifuge or water-drive methods
  - Apply force to soil sample and measure LNAPL drainage

Sample ID	Depth (ft)	Applied Force (xG)	Applied Force (psig)	Initial LNAPL Saturation (% Pore Volume)	After Centrifuge LNAPL Saturation (% Pore Volume)	Cumulative LNAPL % Reduction
SS11-049	8.55	20	0.9	3.0	3.0	0%
		200	9.3	3.0	3.0	0%
		1000	46.2	3.0	3.0	0%
SS11-050	7.0	0	0	26.8	26.8	0%
		20	0.9	26.8	26.3	2%
		200	9.3	26.3	20.8	23%
		1000	46	20.8	15.6	42%

LNAPL Dye Tracer Testing

- New method to "resolve" LNAPL stability
  - Developed by Colorado State University
- Uses single- or multiple-well tracer dilution theory and methods
  - Equates in-well tracer loss to LNAPL velocity
- Benefits
  - Visual technique with straight forward analysis
- Precautions
  - Applied at only a handful of sites

Dissolved-Phase Plume Stability Evaluation

- Groundwater contaminant trend analysis to prove stability
  - Follow EPA guidance (1999, 2004)
- Assimilative capacity analysis to document ability of NA mechanisms to intrinsically degrade and stabilize a plume emanating from LNAPL
- Use predictive modeling as support

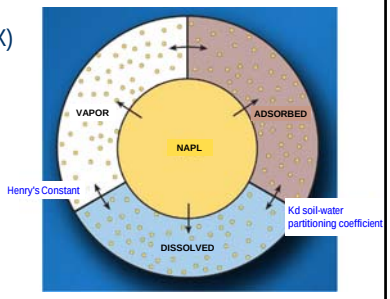
2nd Line of Evidence – LNAPL Risk Evaluation

- Demonstrate that LNAPL presents no risk to human or ecological receptors under current or reasonable future scenarios
  - Impacted groundwater is not a current risk or future risk when groundwater use restrictions are in place
  - Soil gas above the LNAPL area is not a current risk or future risk with or without engineering controls
  - LNAPL toxicity is decreasing over time based on LNAPL weathering evaluations
    - Use a 3- or 4-phase risk evaluation

Take Home Message

4-Phase Risk Evaluation Tool

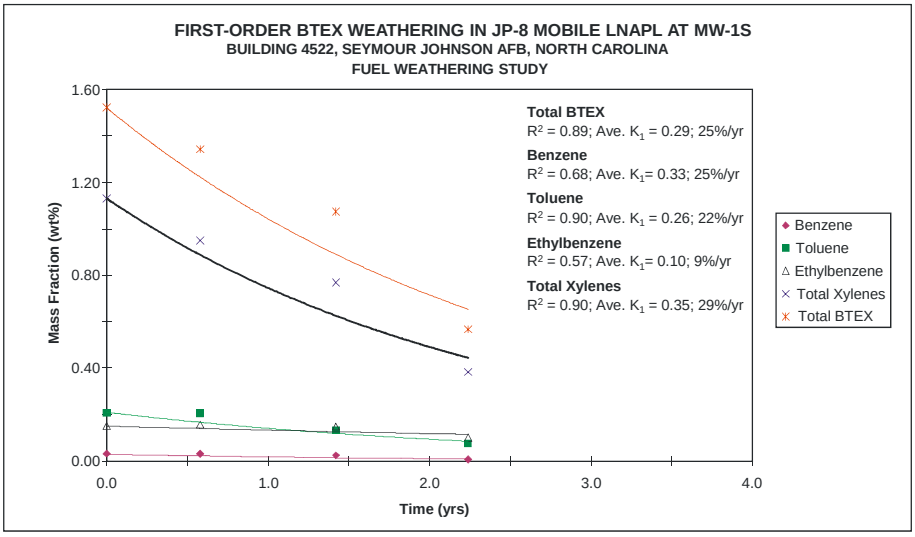
- Excel™ spreadsheet uses "solver" to calculate phase distribution
  - Follows Raoult's Law
  - Assess whether 3- or 4-phase distribution is present
- Uses actual phase distribution data and EPA soil screening transport equations to calculate risk
  - Use iteratively to estimate risk-based clean-up levels
- Compounds and fractions
  - Benzene, toluene, ethylbenzene, and xylene (BTEX)
  - Polycyclic aromatic hydrocarbons (PAHs)
  - Gasoline-range organics (GRO)
  - Diesel-range organics (DRO)
  - Residual-range organics (RRO)
  - Aromatics and aliphatics
  - Other mixed with LNAPL
    - VOCs, pesticides, PCBs



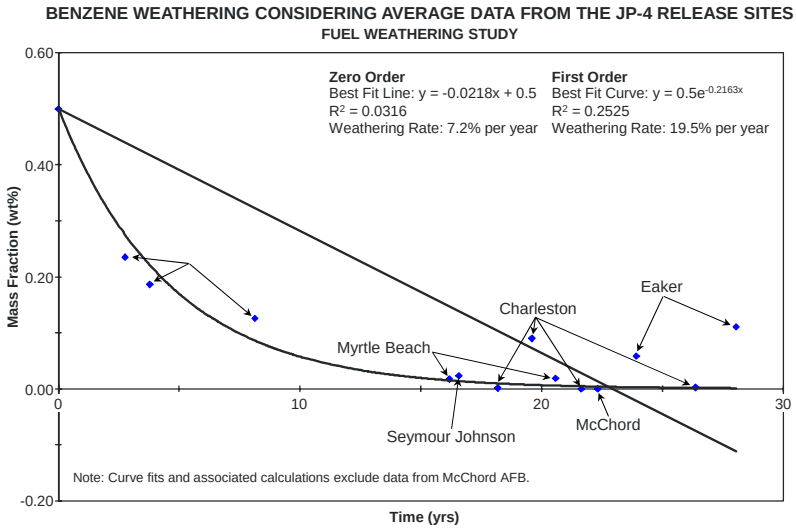
LNAPL Weathering Research

- Air Force Center for Environmental Excellence (AFCEE) LNAPL Weathering Study (AFCEE, 2003)
  - Measured BTEX and weathering in JP-4, JP-5, and JP-8 LNAPL
  - Known spill events were 10 to 30 years old
  - Included data from Cecil Field, FL and Beaufort MCAS, SC
  - Toxicity reduction focused
- Conclusions
  - BTEX weathering rates were first order
  - BTEX mass in LNAPL degraded 4% to 28% per year
    - Average degradation 13% per year in JP-4
  - Fastest degradation in sandy aquifers with higher velocities
  - Slowest degradation in clay aquifers and low velocities

JP-8 Weathering of BTEX Over 2 Year Period



LNAPL Weathering Sites – Composite Over 30 years

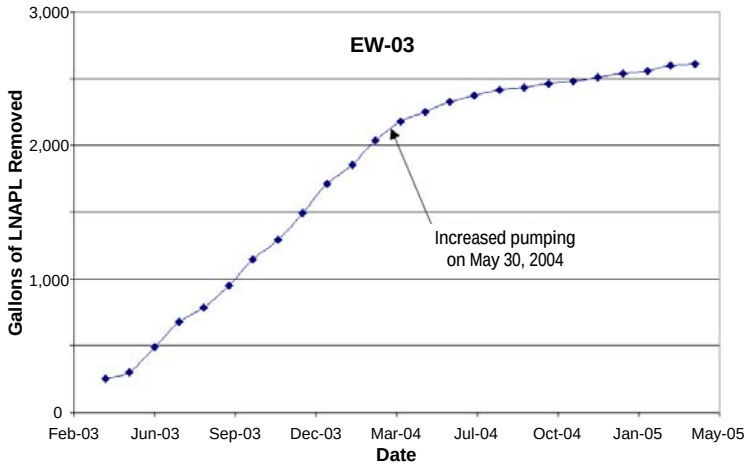


3rd Line of Evidence – Removal to Extent Practical

- Demonstrate that LNAPL recovery has been completed to the extent practical
  - Chart LNAPL recovery versus time to show asymptotic removal
  - Use simple bail down tests to determine passive recoverability
  - Provide rationale to support a logical progression from active to passive removal
  - Present sustainability arguments showing net negative environmental benefits of continued recovery
  - COMPARE NATURAL ATTENUATION RATES TO FLUID RECOVERY RATES

Take Home Message

Example of LNAPL Recovery Chart



LNAPL Attenuation Case Study in Nevada

REMEDIAL TECHNIQUE	Estimated Hydrocarbon Removed	
	Pounds	Gallons*
Mechanical Excavation	16,200	2,700
SVE (pilot + full scale)	2,500	420
Ozone Injection/Air Sparging	200	30
Direct Recovery (bail & skim)	1,200	200
Natural Biodegradation (16 yrs)	5,000	830
TOTAL MASS REMOVED	**25,000**	**4,200**

TAKE CREDIT FOR NATURAL PROCESSES

Take Home Message

Consider Sustainability Impacts of Remedial Efforts

Impact	Multi-Phase Extraction 25HP System (200 scfm)	Solar Powered Skimmers (4)
Capital Cost	$280,000	$40,000
Operating Cost	$400,000 over 4 years	$240,000 over 10 years
Electrical Use	**800,000 kWhr**	None
Natural Gas (Thermal Oxidizer)	**640,000 cubic feet**	None
GHG Produced in Operations	**120 tons**	**None**
LNAPL Recovered	2,000 gallons	1,000 gallons
Percent LNAPL Recovered Based on 5,000-Gallon Diesel Spill	40 %	20 %

List of Tools that Assist LNAPL NA Evaluation

- See HANDOUT 1 in your binders

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Develop a Risk Management Strategy

- Define realistic LNAPL remediation goals to maintain protectiveness of human health and environment
  - Eliminate LNAPL mobility potential
    - Via LNAPL saturation reduction or gradient control
  - Reduce BTEX/PAH risk to soil gas and groundwater
    - Demonstrate a stable groundwater plume
    - Demonstrate no vapor intrusion risks

Note: We do not propose using LNAPL thickness criteria although the regulatory agency may insist on it

Develop a Risk Management Strategy (cont.)

- Consider gamut of options to meet site and LNAPL remediation objectives
- Identify risk reduction/remediation metrics, for example
  - LNAPL stabilization via reduction of LNAPL gradient
  - Reduction of LNAPL mass to a level at which NA can assimilate the dissolved-phase and source zone
  - Reduction of BTEX and PAH content in LNAPL to eliminate vapor intrusion or leachability to groundwater risk
  - Reduction of aromatic and aliphatic components in LNAPL to reduce risk of direct exposure

Hierarchy of LNAPL Management Approaches

- NFA
  - For sites that satisfy all three lines of NA evidence and regulations do not require continued monitoring
- LTC via MNA, long-term monitoring, and land use controls (LUCs)
  - For sites with controlled contaminant exposure and limited mobility within boundary of controls
- Treatment to meet mobility/toxicity reduction requirements
  - Options include:
    - Aggressive total-phase treatment approaches
    - Active fluid recovery
    - Passive fluid recovery

Tools to Assist Risk Management Strategy Development

- See HANDOUT 1 in your binders

Example Risk Management Strategy Template

- See HANDOUT 2 in your binders

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Execution Plan

- Important for use as a Road Map for remedy optimization and achievement of closure or LTC
  - Includes technology phase-out goals
  - Important for regulator buy-in during design stage
- A work plan that pulls remediation goals, performance metrics, milestones, and endpoints into a flexible implementation and optimization plan
- A living, dynamic document meant to be revisited frequently

Example of Performance Standards

- Establish a performance verification process to evaluate the effectiveness of system operation

SYSTEM OBJECTIVE	METRIC	LOCATION	SAMPLING INTERVAL	EXPECTED VALUE	RED FLAG VALUE
Recover LNAPL to prevent off-site migration	LNAPL Thickness (ft)	Sumps U-216, 217, 218, 220, 221	Monthly	0.0 to 0.5 ft	>0.5 ft
	LNAPL Recovery (gal)	Sumps U-216, 217, 220	Monthly	250 gal/mo	<50 gal/mo
		Sump 218	Monthly	1 gal/mo	None

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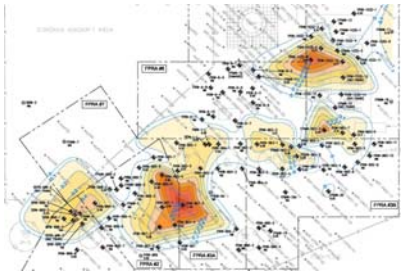
Two Case Studies of LNAPL Risk Management

- Case Study 1
  - Naval Air Station North Island, San Diego, California
- Case Study 2
  - SS-11, Hickam Air Force Base, Hawaii

CSM – NAS North Island

- Active fuel storage and distribution facility
  - AVGAS, JP5, and diesel in 26 large capacity underground and aboveground storage tanks
    - Former concrete and steel tanks were removed
    - A couple 250,000-gallon USTs were partially submerged
- Shallow, non-beneficial use brackish aquifer impacted by LNAPL
  - ~ 10 acres of LNAPL impact, in-well thickness up to 2 feet
    - Estimated original release volume 100,000 to 600,000 gals
  - Site is within 100 feet of San Diego Bay
- Site lithology consists of bay dredge fill
  - Unconfined aquifer in silty sand
  - Depth to water ~15 to 18 feet below grade
  - Flat water table, ~0.0002 to 0.001 ft/ft



Actions – NAS North Island Fuel Farm

- Water-drawdown and vapor-enhanced methods of LNAPL recovery used to remediate site
  - 40-well system built/operated, 1994 through 2/2005, for a cost of ~$9M
  - 270,500 gal of LNAPL removed via ~50 Mgal groundwater
    - Plus ~11,186 gal by vacuum-enhanced product recovery
- Argument made to classify site as RWQCB "Low-Risk"
  - Using sentry well monitoring program to support
- Currently conducting a rebound study
  - LNAPL is laterally stable
    - Water table elevation is affecting vertical distribution
  - Small and stable dissolved-phase plume halo

Site Screening Criteria
NAS North Island Fuel Farm

Analyte	Maximum Detected Site Concentrations (µg/L)	RWQCB Guidance (1996)
Benzene	20	400
Toluene	2.5	5,000
Ethylbenzene	260	430
Xylenes	15.6	10,000
Naphthalene	74.0	2,350
Total PAHs (excluding naphthalene)	63.5	300

CSM – NAS North Island Fuel Farm

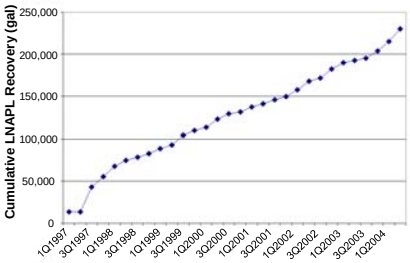
- Dissolved-phase plume is co-located with LNAPL footprint
- Natural attenuation is containing contamination
  - Groundwater transitions to aerobic along Bay frontage road
    - Within 50 feet of the LNAPL front
  - Anaerobic within LNAPL footprint
    - Methanogenesis, sulfate-, and ferric iron-reducing
- No vapor intrusion risk identified
  - No benzene detected at 3 feet below grade
- Cooperating with San Diego RWQCB

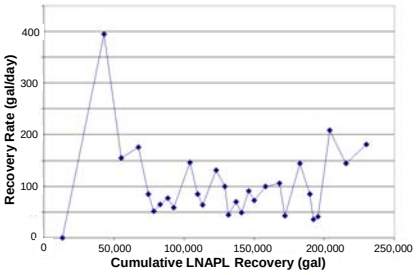
NA Multiple Lines of Evidence

- The LNAPL is immobile or limited mobility does not threaten surface water or create dissolved-phase plume expansion
  - ~4 years of data showing LNAPL and dissolved-phase plumes are stable
- The LNAPL presents no risk to human or ecological receptors under current and reasonable future scenarios
  - LNAPL is immobile and LUCs restrict access to soil/groundwater
  - Vapor intrusion pathway has been addressed via soil gas survey and no shallow VOC detections were observed
- LNAPL recovery has been completed to the extent practical
  - 281,500 gal removed, but rate was increasing at shutdown
  - System operation was continuously optimized by focusing extraction where greatest thicknesses of in-well LNAPL occurred
  - This will require multiple lines of evidence to support shutdown rationale

LNAPL Recovery History through 2Q04

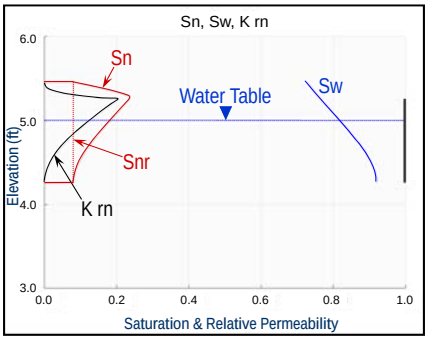
- No plateau evident
- Rate was increasing
  - Revolving operation focused on wells with largest in-well thickness
  - System showed signs of continued effectiveness
- Leads to thinking that additional recovery is feasible





Cursory Recoverability Analysis

- API's LDRM model estimates
  - Plume Core: 0.6 gal/ft^2 for 1-foot in-well LNAPL thickness (max)
    - ~45% is recoverable
  - LNAPL Footprint: 0.07 gal/ft^2 for 0.2-foot in-well LNAPL thickness (avg.)
    - Total LNAPL volume estimate ~30,000 gal (185,000 lb) for 10-acre LNAPL footprint
    - ~5% is recoverable



Cursory LNAPL Weathering Analysis

- Aromatic compounds in LNAPL are significantly degraded

TPH Fractions	Example Compounds	Mass Fraction in LNAPL	Source	Fresh Site Mixture 80/20 AVGAS/JP5	% Degraded
C5-C7 Aromatic	Benzene	0.000003	Meas.	0.000443	**99.3%**
C7-C8 Aromatic	Toluene	0.000067	Meas.	0.102844	**99.9%**
C5-C8 Aliphatics	Pentane, Hexane, Heptane, Branched Chain Alkanes (Isopentane), Cycloalkanes, Straight Chain Alkenes	0.320	Est.	0.307410	**-4.0%**
C8-C9 Aromatic	Ethylbenzene and xylenes	0.000587	Meas.	0.005784	**89.9%**
C9-C10 Aromatic	Trimethylbenzenes, Methyl-Ethylbenzenes, Propylbenzenes	0.000256	Meas.	0.000623	**58.9%**
C8-C10 Aliphatics	Octane, Nonane, Branched Chain Alkanes, Cycloalkanes	0.419	Est.	0.403137	**-4.0%**
C10-C12 Aromatic	Naphthalene, Methyl-Naphthalene, Indan	0.000631	Meas.	0.007224	**91.3%**
C10-C12 Aliphatics	Decane, Undecane, Branched Chain Alkanes	0.123687	Est.	0.061378	**-101.5%**
C12-C16 Aromatic	Acenaphthylene, Acenaphthene	0.000133	Meas.	0.015303	**99.1%**
C12-C16 Aliphatics	Dodecane, Tridecane, Tetradecane, Pentadecane, Branched Chain Alkanes	0.105773	Est.	0.079876	**-32.4%**
C16-C24 Aromatic	Fluorene, Methylfluorene	0.000000	Meas.	0.002769	**100.0%**
C16-C24 Aliphatics	Hexadecane, Heptadecane, Octadecane, Nonadecane, Branched Chain Alkanes	0.026411	Est.	0.013106	**-101.5%**
C24-C35 Aromatic	Anthracene, Phenanthrene, Pyrene, Fluoranthene, Methylphenanthrene, Methyl-anthracene	0.000056	Meas.	0.000032	**-75.8%**
C24-C35 Aliphatics	Eicosane, Heneicosane, Docosane, Tetracosane, Branched Chain Alkanes	0.000005	Est.	0.000052	**90.4%**

Potential Site Management Strategy

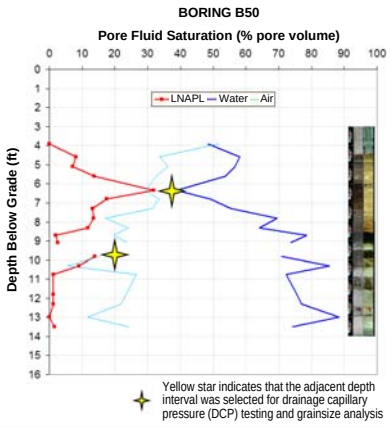
- Stability and risk are adequately addressed
- Recoverability and NA mechanisms may not meet RWQCB criteria for site closure
  - Consider tailoring remediation effort back toward a more sustainable effort
    - Limited extraction system or skimming operation in hot spots >6-inches in-well LNAPL thickness to achieve cost-effective fluid recovery
      - Design to meet 90% recoverability metric (by LDRM modeling standards)
    - Enhanced biological degradation of LNAPL zones exceeding groundwater leachability criteria
      - Consider biosparging as more effective mass removal technique
    - Perform a life-cycle analysis and include sustainability criteria to select best approach

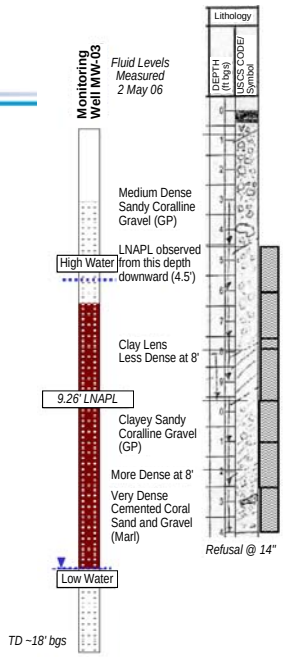
CSM – SS-11, Hickam AFB

- JP-4/8 delivery pipeline, ~10 ac LNAPL footprint
  - Wide range release estimates – 400,000 – 800,000 gallons
- Multiphase extraction (MPX) operated as an interim remedy
  - 8,500 gallons recovered over 6 years of operation (2000-2006)

CSM – SS-11, Hickam AFB (cont.)

- Sandy coralline gravel with clay lens and variable density
  - Total porosity up to 60%
  - LNAPL up to 40% of pore volume





Strategy Analysis – SS-11, Hickam AFB

- Within pre-existing Hawaii Department of Health (HDOH) regulations, recovery "to the extent practicable" achieved and risk can be controlled
- Site-Specific Factors
  - Risk Evaluation
    - Risk can be effectively controlled with land use controls (LUCs) and long-term monitoring (LTM) in active flight line
  - LNAPL Mobility Evaluation
    - Limited mobility, contained within LUC boundaries and LTM used to track LNAPL perimeter

Strategy Analysis – SS-11, Hickam AFB (cont.)

- Site-Specific Factors
  - Recoverability Evaluation
    - Additional 20% mass recovery provides minimal reduction in time for remediation to risk-based cleanup goals for regulated Total Petroleum Hydrocarbon (TPH) compounds
    - NA Evaluation – Dissolution and biodegradation modeling used to demonstrate source zone NA (albeit slow) (>1,000 years in best recovery case)
  - Technical, Logistical, and Cost Analysis
    - Submerged LNAPL trapped coralline setting, >$100/gallons recovered and increasing, and flight line limitations

Selected Site Management Strategy – Hickam AFB

- Discontinue LNAPL recovery
- Manage LNAPL in-place with LUCs and LTM
- Implement sentinel well monitoring program to track LNAPL and dissolved-phase plume regression
- Contingency plan to be enacted if mobility outside of the LUC boundaries is observed
- Performance expectations (within next 100 years)
  - LNAPL plume stability
  - Dissolved-phase plume stability and regression
  - Benzene in groundwater <Cleanup Goals in <25 years
  - TPH in soil to persist for >1,000 years

Presentation Overview

- Status of LNAPL Site Management
- Fundamentals of an LNAPL Strategy
- Steps to Develop an LNAPL Risk Management Strategy
  - Collect Key Data for the LNAPL Conceptual Site Model
  - Perform an LNAPL Natural Attenuation Evaluation
  - Develop a Risk Management Strategy
  - Establish an Execution Plan
- Case Study Illustrations
- Food for Thought and Resources

Strategy Development Challenges

- Involves detailed site understanding and multiple lines of evidence to support
- Life cycle analysis most prudent method to select best site closure or LTC approach
  - Modeling may be needed to support decisions
  - Sustainability considerations may or may not be of concern to regulators
- Requires commitment and regular update
  - A good business decision, not a hard-line regulatory requirement
  - 1- to 3-year update frequency
    - Consistent with magnitude of data collection and observed change

Food for Thought

- LNAPL naturally attenuates
  - Sandy aquifers, high groundwater velocity, and tidally influenced settings may observe large weathering rates
- Regulatory avenues exist for alternative LNAPL management approaches
  - A matter of building a technically and administratively sound argument
  - Focus on mobility control and toxicity reduction

Take Home Message

Food for Thought (cont.)

- Weight-of-evidence approaches are necessary
  - Tool box is needed because multiple lines of evidence are needed to ascertain uncertain in situ conditions
  - Weight-of-evidence makes for a convincing argument, e.g., that "the extent practicable" has been met
- Many resources are publically available

Take Home Message

Information Resources

- Documents
  - 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 (February 2007)
  - ASTM E1689-95: Standard Guide for Developing Conceptual Site Models for Contaminated Sites
  - EPA/540/S-95/500: Light Non-Aqueous Phase Liquids (July 1995)
  - EPA/542/R-04/011: A Decision-Making Framework for Cleanup of Sites Impacted with Light Non-Aqueous Phase Liquids (March 2005)
  - EPA Directive 9200.4-17P: Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites (April 1999)
  - EPA/600/R-04/027: Performance Monitoring of MNA Remedies for VOCs in Ground Water (April 2004)
  - AFCEE Light Nonaqueous-Phase Liquid Weathering at Various Fuel Release Sites, 2003 Update (August 2003)
  - MNA Protocol for Fuels, AFCEE