LNAPL Technical Overview

New Jersey Department of Environmental Protection
Site Remediation Program
LNAPL Guidance Training
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Available LNAPL Training and the ITRC

Brief Overview of Key LNAPL Concepts
- LNAPL Basics
- LNAPL Conceptual Site Model
- Recoverability
- Goals / Objectives / Endpoints

Case Study 1 – Active Recovery
Case Study 2 – Maintenance Recovery
Welcome – Thanks for joining us.
ITRC’s Internet-based Training Program

LNAPL Training
An Improved Understanding of LNAPL Behavior in the Subsurface

State of Science vs. State of Practice

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ITRC LNAPL Team Training

- Internet Based Training Part 1: Understanding LNAPL Behavior
- Internet Based Training Part 2: LNAPL Characterization and Recoverability
- 2-Day Classroom training: LNAPL Science, Management and Technology
Simplified Conceptual Model for LNAPL Release to the Subsurface and Migration

Modified from Huntley and Beckett, 2002
Common (mis) Perceptions about LNAPL

- LNAPL enters the pores just as easily as groundwater
- You can recover all LNAPL
- All the pores in an LNAPL plume are filled with LNAPL
- LNAPL floats on the water table or capillary fringe like a pancake and doesn’t penetrate below the water table
- Thickness in the well is exaggerated by a factor or 4, 10, 12, etc.
- LNAPL thickness in a well is always equal to the formation thickness
- If you see LNAPL in a well it is mobile and migrating
- LNAPL plumes spread due to groundwater flow
- LNAPL plumes continue to move over very long time scales
Pore Scale LNAPL Distribution

Modified from Huntley and Beckett, 2002

Modified from ASTM, 2006
“Resistance” to Movement of LNAPL into and Out of Water-saturated Soil Pores

- LNAPL will only move into water-wet pores when entry pressure (resistance) is overcome
  - To distribute vertically and to migrate laterally

For water wet media:

- Soil grains
- Non-wetting fluid (e.g., air or LNAPL)
- Wetting fluid (e.g., water) preferentially contacting the soil

~1mm

Flow

Flow

LNAPL Water
Vertical LNAPL Distribution

- LNAPL penetrates below water table
- LNAPL and water coexist in pores

**Pancake Model** vs. **Vertical Equilibrium Model**

- Assumes LNAPL floats on water table
- Uniform LNAPL saturation

**Pancake Model**

**Vertical Equilibrium**

- LNAPL penetrates below water table
- LNAPL and water coexist in pores
Measured and Modeled Equilibrium LNAPL Saturations

Huntley et al. (1994)

Aquiver Inc.

- Soil Type

LNAPL Saturation (%)
LNAPL Saturations Are Not Uniform

- LNAPL preferentially enters larger pores (easier to move water out of the pore)
- Maximum LNAPL saturations typically low (5-30%) in sands (can be higher at new release or constant release)
- Saturations even lower for finer-grained sediments

Fluoresced benzene in soil core

Percent fine-grains

Percent benzene saturation

Plain light

UV light

Higher LNAPL saturation in coarser-grained soil

Lower LNAPL saturation in finer-grained soil

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Saturation versus Residual Saturation

When LNAPL Saturation in the ground exceeds LNAPL Residual Saturation

**LNAPL Saturation (So)**
Fraction of pore space occupied by LNAPL

**Residual LNAPL Saturation (Sor)**
Fraction of pore space occupied by LNAPL that cannot be mobilized under an applied gradient

When $So < Sor$, non-multiphase flow fate-and-transport decision frameworks (dissolved phase or vapor phase) work well (e.g., RBCA)
Residual LNAPL Saturation – Higher in Saturated Zone than in Vadose Zone

Example ranges from Parker et al., 1989
Potentially Mobile Fraction of the LNAPL Distribution

Key Point: LNAPL potentially mobile only if the saturation exceeds residual saturation

Source: Garg
Key Point: Once the LNAPL head dissipates, it is no longer sufficient to overcome LNAPL entry pressure and LNAPL movement ceases.
The Three Basic LNAPL Site Scenarios

1. LNAPL sat > residual
   Condition: LNAPL in wells, mobile
   Driver: LNAPL saturation

2. LNAPL sat > residual
   Condition: LNAPL in wells, mobile, not migrating
   Driver: LNAPL composition, saturation

3. LNAPL sat < residual
   Condition: No LNAPL in wells
   Driver: LNAPL composition

Covered in this training
Example Seasonal LNAPL Redistribution

LNAPL Monitoring Over Time Refinery

- Measured LNAPL Depth in Monitoring Wells: 0 to 3 feet
- Seasonal Water Table Variation: 8 foot range

From API Interactive NAPL Guide, 2004
Well Thickness versus Formation Thickness

Unconfined
Water Table Rise

Perched

Confined

Fractured
Summary of LNAPL Basics

- LNAPLs are not distributed vertically in a “pancake” fashion, but are distributed according to vertical equilibrium as a multiphase (saturations vary vertically-always less than 100%)
- LNAPL saturations are not uniform, but depend on soil type, capillary pressure and soil heterogeneity
- The specific volume of LNAPL within soil will be greater in coarse than fine grained soil for a given LNAPL thickness
- As the LNAPL saturation increases, the relative permeability and potential LNAPL velocity also increases
The pressure exerted by LNAPL must exceed the displacement pore entry pressure for LNAPL to enter a water-filled pore.

Measurable LNAPL thickness in a well does not necessarily indicate mobility, LNAPL plumes generally come to stable configurations over relatively short periods of time.

Once the LNAPL release stops, LNAPL near the water table will eventually cease to spread as the resistive forces in soil balance the driving forces (LNAPL head) in the LNAPL pool.

- Smaller releases will stop migrating sooner
- Continuing releases will result in a growing plume

LNAPL plume may be stable at the LNAPL fringe, but there may be local re-distribution within the LNAPL core.
LNAPL Concerns and Drivers

**LNAPL Concerns:**
- Explosive hazards
- Dissolved-phase concentration
- Vapor-phase concentration
- Direct contact or ingestion
- Mobility (spreads and creates new or increased risk)
- Visible aesthetics

**LNAPL driver:**
- LNAPL Composition
- LNAPL Saturation

**Regulatory driver:** “recover to maximum extent practicable” – State’s interpretation?
LNAPL Understanding is an Iterative Process

LNAPL Characterization
- LNAPL composition
- LNAPL saturation
- LNAPL location

LNAPL Conceptual Site Model

LNAPL Management
- Maximum extent practicable?
- Drivers: mobility and future risk
- Remedial objectives and end points
- Remedial action selection
LNAPL Conceptual Site Model (LCSM)

- Site characterization and management link
- Description and interpretation of physical and chemical state of the LNAPL body
- Facilitates understanding of the LNAPL conditions, site risks, and how best to remediate
- Scaled to the LNAPL impacts and associated issues that require management
- Iterative process to increase the understanding of the LNAPL body and site risks
- Sufficient when additional information likely would not lead to a different decision
Hydraulic Recovery (recoverability)
Objectives, Goals and Performance Metrics

- **LNAPL Remedial Objectives** – Established to mitigate the LNAPL concerns

- **LNAPL Remediation Goals** – the Remedial Objectives stated in the context of a remedial technology

- **Performance Metrics** – measurements that demonstrate achievement or progress to achievement of the Remediation Goal

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<tr>
<th>Examples</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
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<tbody>
<tr>
<td><strong>Objective</strong></td>
<td>Stop LNAPL migration off site. (Saturation Objective)</td>
<td>Stop dissolved BTEX plume in groundwater from migrating off site. (Composition Objective)</td>
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<td><strong>Goal</strong></td>
<td>Remove LNAPL by skimming to reduce LNAPL head and stop LNAPL migration.</td>
<td>Remove BTEX components in the LNAPL using air sparging &amp; vapor extraction.</td>
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<tr>
<td><strong>Metric</strong></td>
<td>No LNAPL appearing in monitor wells on property line.</td>
<td>BTEX less than MCLs in monitor wells at downgradient property line.</td>
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Case Study #1 – Active Recovery

Objectives

- Walk through process – (although older site, generally consistent with current LNAPL Guidance)
- Provide example of LCSM
- Illustrate key points leading to final remedy decision
Site Plan
Overview of Process Steps

- Focused remedial investigation (RI)
  - 13 additional monitoring wells
  - Tidal study
  - Product sampling/fingerprint analysis
  - Soil core physical property analysis and UV photos
- Recoverability Assessment
  - Baildown testing
  - API Mobility Modeling
- Initial Recovery and IRM
- Operational Monitoring
- LNAPL Skimming and MPE Pilot Testing
- Final Remedy Selection and Design
Investigation and Characterization

**LNAPL Description**
mixture of extremely weathered middle distillate such as diesel fuel or fuel oil, a smaller amount of heavier material and perhaps a very small amount of alkylate.
Investigation and Characterization

- Fine Sand
- Fine Sand & Silt
- Sand & Gravel

- Silt & Clay
- Sand & Gravel
- Fluorescence Indicates Free Product
- Wax Sealing (Contains Hydrocarbons)
Baildown Testing Results

% Percent of Original Product Thickness Recovered

- MW-1
- MW-2
- MW-3
- MW-4
- MW-5

Time (minutes)

0.1 1 10 100 1000 10000
API Modeling Results

Apparent LNAPL Thickness (feet) vs. Recoverable Volume (feet\(^3\)/feet\(^2\))

Specific Volume (feet\(^3\)/feet\(^2\))
LNAPL Conceptual Site Model

- LNAPL plume in proximity to, but not migrating toward the river - GW flow is away from river (losing stream)
- Large LNAPL smear zone – elevations influenced by tidal fluctuations (avg. 1.5 feet)
- LNAPL is a mixture of petroleum middle distillates with varying degree of weathering
- LNAPL trapped in distinct soil zones due to heterogeneities
- Baildown tests indicate LNAPL is recoverable in central core area of plume
- API model results show variable recoverability based on LNAPL type, saturation and soil conditions
Initial Recovery and IRM Selection

- Vacuum truck extraction initially used to address areas of newly detected LNAPL
- Wells and extraction frequency selected and “prioritized”
- IRM implemented as 3 events / week
- Well head assembly utilized to achieve multi-phase vacuum extraction
Operational Monitoring Program

- Quarterly gauging events (DTW, DTP, LNAPL thickness)
- On-going evaluation of LNAPL volume recovered from each recovery point and total groundwater and LNAPL recovery volumes from IRM activities
- Ongoing system adjustments based on LNAPL recovery observations, drop tube depths and total applied vacuum measurements
Product Skimming and Multi-Phase Extraction Pilot Testing

- Assess the feasibility and performance of skimming vs MPE
- Skimming showed poor recovery affected by tidal fluctuations
- MPE showed very good results
  - 345 gpd of LNAPL
  - up to 60 foot vacuum radius of influence
Full-Scale LNAPL Recovery System Design

- MPE selected for full scale system
- Site construction and piping installation has been completed.
- Fabrication of mobile MPE system currently on-going. System startup anticipated in the 2\textsuperscript{nd} half of 2011.
- Ultimate goal is to recover free-phase LNAPL to extent practicable.
LNAPL Recovery Approach
Detailed Remedial Investigations

- September 1997 Extent of Product
- July 1996 Extent of Product
- March 1996 Extent of Product
Initial Product Recovery and Interim Remedial Measures

Cumulative Product Recovery (gallons)

Days of Operation

Ave. recovery rate = 0.3 - 0.5 gpd

Ave. recovery rate = 1.7 gpd

Free Product Recovery Method
- Bailer
- SWAP
- Piston pump
- HVE

Quarterly HVE - March 1998
Quarterly HVE - June 1998
Quarterly HVE - Sept. 1998
Supplemental Pilot Test 1
Supplemental Pilot Test 2
HVE Pilot Test

LANGAN
Cumulative Product Recovery Through Time
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