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LNAPL Site Management

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Module 1: LNAPL Site Management Handbook

Learning Objectives

By the end of this section, you will be able to:

- **Identify** the physical and chemical properties of LNAPL that influence its behavior in the subsurface.
- **Evaluate** the components and development process of an LNAPL Conceptual Site Model (LCSM).
- **Select** appropriate remedial technologies based on site-specific objectives and the multiple lines of evidence approach.

Executive Summary: Effective LNAPL site management requires a strategic, consensus-based approach that moves beyond arbitrary thickness requirements to focus on risk-based objectives. By integrating a comprehensive LNAPL Conceptual Site Model (LCSM) with multiple lines of evidence—mobility, risk, and recoverability—engineers can implement adaptive remediation plans that ensure environmental protection while avoiding the high costs and diminishing returns of stagnant remedial efforts.

Subsurface Fundamentals of LNAPL

Light Non-aqueous Phase Liquid (LNAPL) consists of hydrocarbon mixtures that exist as a separate immiscible phase in the subsurface. Because their density is less than water, these contaminants are generally buoyant.

From "Pancake" to Multiphase Conceptualization

Modern engineering practice has shifted from the "pancake-layer" model to a more accurate **multiphase conceptualization**.

- **Historical Pancake Concept:** Assumed LNAPL existed as a thin, continuous lens on top of the water table where pore spaces were completely filled with product.
- **Multiphase Concept:** Recognizes that LNAPL, water, and air coexist in the pore space.
- **Saturation Dynamics:** LNAPL saturation is variable, typically peaking near the top of the **capillary fringe**.
- **The Smear Zone:** Groundwater fluctuations create a vertical zone where LNAPL is distributed across varying elevations.

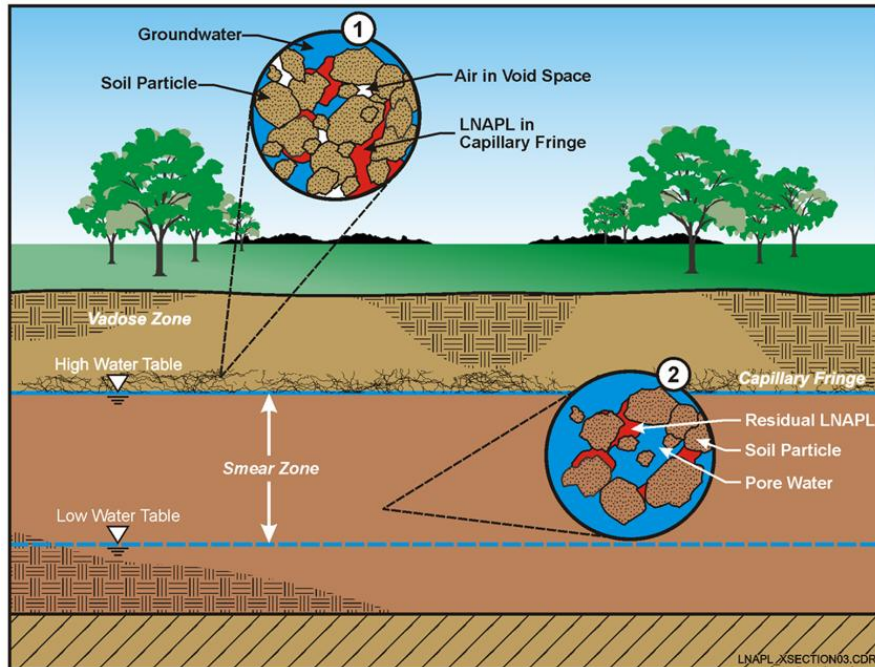


Figure 1. Conceptual Depiction of LNAPL in the Subsurface

Critical LNAPL Properties

Subsurface distribution and recovery success are directly impacted by the physical and chemical properties of the specific fuel type.

Table 1a. Common Properties of LNAPL

Fuel Type	Specific Gravity (g/mL) ⁷	Viscosity (Centipoise) ⁷	Boiling Point Range (°C)	Flash Point (°C)	Interfacial Tension (mN/m) ⁷
Gasoline ¹	0.67 to 0.8 @ 15°C	0.62 at 15°C	38 to 204	-43 to -38	52 @ 20°C
AVGAS ²	0.711 @ 16°C	2.3 @ 15°C	33 to 170	-46	37 @ 20°C
JP-4 ³	0.75 @ 15°C	1.0 @ 15°C	60 to 270	-29	50 @ 15°C
JP-5	0.82 @ 15°C	2.0 @ 15°C	176	60	-
JP-8	0.78 to 0.84 @ 15°C	2.0 @ 20°C ⁸	205 to 300	38	-
Diesel (#2) ⁴	0.87 @ 15°C	2.7 @ 15°C	150 to 370	52 to 96	50 @ 20°C
Kerosene ⁵	0.81 @ 15°C	2.3 @ 15°C	151 to 301	>38	47-49 @ 20°C
Bunker C ⁶	0.9 to 1.1 @ 15°C	45,030 @ 15°C	>177	>166	40 @ 23°C

1 ChemADVISOR, 2010a 4 ChemADVISOR, 2010d
 2 ChemADVISOR, 2010b 5 ChemADVISOR, 2009
 3 ChemADVISOR, 2010c6 ChemADVISOR, 20010e
 7 API Interactive LNAPL guide, July 2004 (accessed through www.api.org)
 8 U.S. Air Force Defense Quality and Standardization Office "TURBINE FUELS, AVIATION, KEROSENE TYPES, NATO F-34 (JP-8), NATO F-35, AND JP-8+100" MIL-DTL-83133, 1999. Wright-PattersonAFB
 9 EPA – OSWER June 2000. Accessed via http://www.clu-in.org/download/studentpapers/strbak_flushing.pdf

Table 1b. Composition of Selected Fuels

Fuel Type	Mass Fractions (%)				
	Paraffins	Isoparaffins	Aromatic	Naphtha	Olefins
Gasoline	9.1	38.1	43.4	3.8	5.6
AVGAS	3.3	74.2	22.0	0.5	0.001
JP-4	29.3	31.0	43.4	3.3	6.2
JP-5	-	-	-	-	-
JP-8 ²	79.7	-	20.3	-	-
Diesel (#2)	55.0	12.0	24.0	-	5.0
Bunker C	21	21	34	-	-

1 Morrison, Robert D. 1999. Environmental Forensics: Principles & Applications.

2 API Interactive LNAPL guide, July 2004 (accessed through www.api.org)

Table 1c. Effective Solubility of BTEX components from different LNAPL fuels

Fuel Type	BTEX component solubility (mg/L)			
	Benzene	Toluene	Ethylbenzene	Xylenes
Gasoline	42.0	25.1	3.2	15.1
JP-4	-	22.2	8.6	-
JP-8 ²	-	27.8	-	-
Diesel (#2)	4.17	7.15	0.62	1.51
Kerosene	3.56	12.2	0.79	2.3

1 API Interactive LNAPL guide, July 2004 (accessed through www.api.org)

The LNAPL Management Strategy

A successful strategy provides a framework for measuring progress and garnering regulatory pre-approval.

Strategy Development Steps

The development of a sound management strategy follows a structured sequence:

1. **Data Collection:** Focus on the geologic and geospatial distribution of LNAPL.
2. **Natural Attenuation (NA) Evaluation:** Assess the impact of weathering (dissolution, volatilization, biodegradation) on LNAPL fate and transport.
3. **Risk Evaluation:** Identify exposure routes and receptors for human health and environmental impact.
4. **LCSM Development:** Synthesize site information to characterize the problem extent.
5. **Risk Management Strategy:** Define Remedial Action Objectives (RAOs).
6. **Execution Plan:** Detail the roadmap for implementation, milestones, and endpoints.



Figure 2. Activity Sequencing for Development of an LNAPL Management Strategy

The LNAPL Conceptual Site Model (LCSM)

The LCSM is a living body of information used to identify RAOs. It must focus on the source, pathway, and receptors.

Design Tip: Regularly reevaluate the LCSM as new data from monitoring or pilot tests become available to ensure optimal remedial decisions.

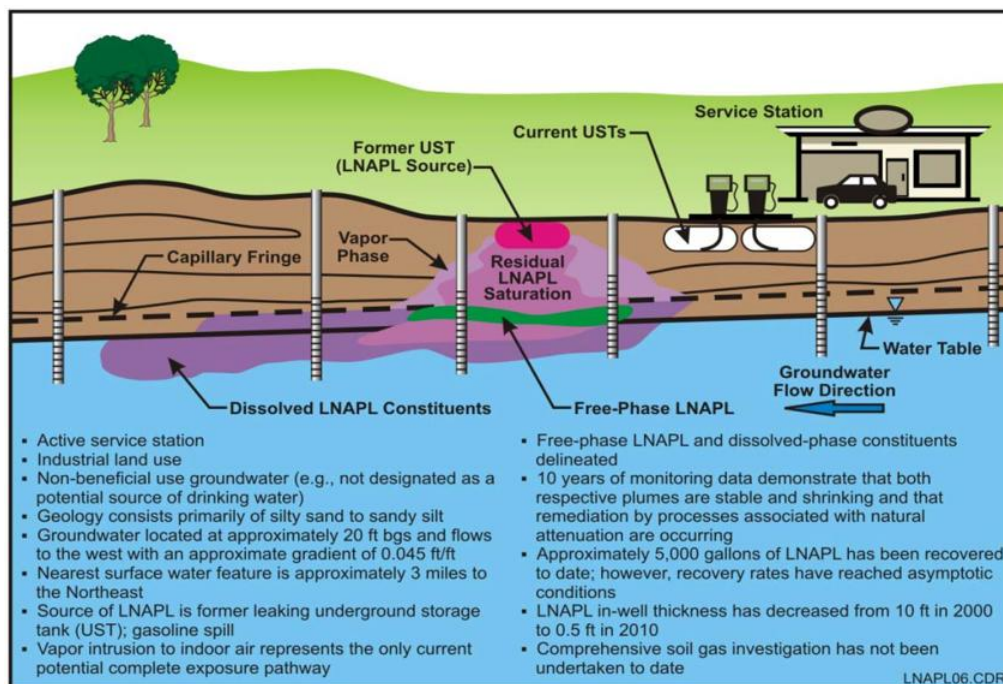


Figure 3. Example of an LNAPL Conceptual Site Model



Multiple Lines of Evidence Approach

When recommending **No Further Action (NFA)** or **Long-Term Management (LTMgt)**, engineers must present weighted evidence across three categories:

First Line: Mobility Evaluation

Demonstrate that LNAPL is stable and not migrating.

- **Mobile vs. Migrating:** LNAPL is **mobile** if it accumulates in wells; it is **migrating** only if it moves over time.
- **Stability Indicators:** Collect data showing LNAPL is at **residual saturation**, the dissolved-phase plume is stable or shrinking, and surface water is not impacted.

Second Line: Risk Evaluation

Demonstrate no current or future risk to receptors.

- Verify groundwater use restrictions are in place.
- Confirm soil gas levels do not pose a threat.
- Show that LNAPL toxicity is decreasing due to natural attenuation.

Third Line: Removal to the "Maximum Extent Practicable"

Show that active recovery has reached its limit.

- **Decline Curve Analysis:** Use cumulative recovery plots to show **asymptotic removal**.
- **Transmissivity:** Use bail-down tests to prove low recoverability.
- **Sustainability:** Demonstrate that continued recovery provides a **net negative environmental benefit**.

⚠ Safety Constraint: Federal and state regulations often require recovery to the "extent practicable" (40 CFR §280.64). Avoid relying on arbitrary thickness metrics; instead, define "practicable" using site-specific parameters in conjunction with regulators.

Remedial Objectives and Technology Selection

Engineers must distinguish between site-wide **RAOs** and remedy-specific **Remedial Goals (RGs)**.

- **RAOs:** Describe protection (e.g., "Prevent exposure to VOCs in indoor air").
- **RGs:** Define endpoints (e.g., "Achieve asymptotic recovery").



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