LNAPL Site Management

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Introduction

This *Light Non-Aqueous Phase Liquid (LNAPL) Site Management Course* provides an overview of effective strategies for managing LNAPL-contaminated sites to ensure protectiveness of human health and the environment, while simultaneously avoiding unnecessary and prolonged remedial efforts. Concepts presented in this document can be applied throughout the life-cycle of an LNAPL remediation project; therefore, the information provided in this course can be useful regardless of the stage of the project.

LNAPL-contaminated sites can be very challenging to assess, remediate, and ultimately close out due to both technical and regulatory issues. Therefore, if possible, it is essential to develop a strategic action plan early in the process to establish goals, specify a remedy, and chart a clear course to achieve site closure. It should be noted that even if a strategic action plan was not developed early on, this exercise is still recommended even in the latter stages of a project. LNAPL can be technically challenging to recover from the subsurface due to high residual saturation, low mobility/recoverability, and continuous changes in the LNAPL saturation profile with water table fluctuations. In addition, LNAPL weathering can create other environmental problems including vapor and dissolved-phase contaminant plumes. Furthermore, other than the common “recover LNAPL to the maximum extent practicable” requirement, most state or federal regulatory programs address saturation concerns on a site-specific basis, with few specifics provided. This course presents two case studies (Appendices A and B) to highlight different approaches for managing sites impacted with LNAPL.

The information provided in this course is based on the Navy Remediation Innovative Technology Seminar (RITS) presentation given in Spring 2009 (CH2M Hill, 2009), the Interstate Technology Regulatory Council (ITRC) guidance documents for *Evaluating LNAPL Remedial Technologies for Achieving Project Goals* (ITRC, 2009a) and *Evaluating Natural Source Zone Depletion at Sites with LNAPL* (ITRC, 2009b), and *A Decision-Making Framework for Cleanup of Sites Impacted with Light Non-Aqueous Phase Liquid* (U.S. Environmental Protection Agency [EPA], 2004).

What is LNAPL and where is it found?

LNAPL is a mixture of hydrocarbons existing as a separate immiscible phase occurring within the unsaturated (vadose) and saturated (groundwater) zones of the subsurface. The density of LNAPL is less than that of water, making it generally buoyant in water-saturated media and readily observed in monitoring wells as a discrete layer residing above groundwater.

LNAPL is one of the most common groups of contaminants found in the environment. The majority of LNAPL consists of petroleum hydrocarbons that have been released to the environment from aboveground storage tanks (ASTs), underground storage tanks (USTs), pipelines, and associated handling and transfer equipment. Some examples of LNAPL include jet fuel (JP-4, JP-5, and JP-8), bunker fuel, diesel fuel, kerosene, and gasoline.

In the past, LNAPL was conceptualized as existing as a thin, continuous lens of hydrocarbons residing on top of the water table. This is referred to as the “pancake-layer” concept. It assumed that the pore space in the formation immediately above the water table was completely filled with LNAPL. Based on this concept, the volumes of LNAPL present at sites were estimated and the recoverable portion and ease of recovery were predicted. More recently, LNAPL has been conceptualized to coexist with other fluids (water and air) in the subsurface. This “multiphase” conceptualization assumes that LNAPL saturation is variable with a saturation peak near the top of the capillary fringe. As shown in Figure 1 (Highlight 1), in the capillary fringe located immediately above the groundwater table, small volumes of LNAPL coexist with groundwater and air in the pore space. At the air-water interface, LNAPL that accumulates will gradually push out a portion of the water (and air) and occupy a greater fraction of the pore space. Changes in LNAPL pressure head and natural groundwater fluctuations result in a mixture of LNAPL and water that will occupy the pore space across a vertical LNAPL smear zone, as shown in Figure 1 (Highlight 2). The amount of interconnected LNAPL and its associated pressure head available to displace the groundwater decreases with increasing depth beneath the water table. As such, the LNAPL saturation decreases and the pore space becomes predominantly saturated with water. The degree of saturation at any depth is dependent on many site-specific factors; including the volume of LNAPL released, soil lithology, the age of the release, the magnitude of water table fluctuation, and fluid properties.

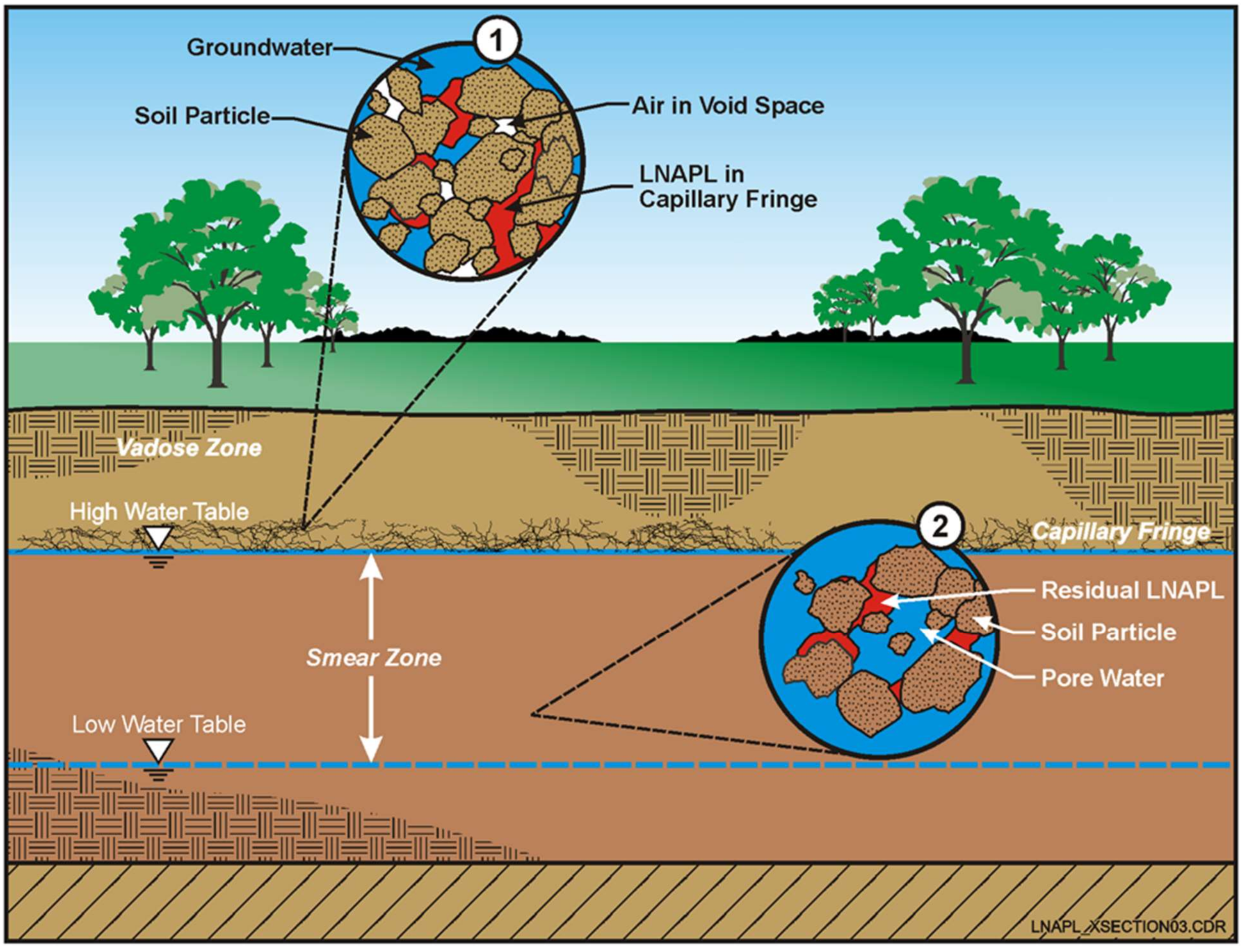

Figure 1. Conceptual Depiction of LNAPL in the Subsurface

The properties of LNAPL affect its distribution in the subsurface and impact the selection and success of a technology to recover or degrade it. Critical properties include density, viscosity, interfacial tension, and chemical composition. These values vary considerably depending on LNAPL type (see Tables 1a through 1c). It should be noted that weathering, which includes processes such as dissolution, biodegradation, volatilization, and retardation, will change the characteristics of LNAPL (principally the chemical composition) and these key properties.

Table 1a. Common Properties of LNAPL

Fuel Type	Specific Gravity (g/mL)[7]	Viscosity (Centipoise)[7]	Boiling Point Range (ºC)	Flash Point (ºC)	Interfacial Tension (mN/m)[7]
Gasoline[1]	0.67 to 0.8 @ 15ºC	0.62 at 15°C	38 to 204	-43 to -38	52 @ 20°C
AVGAS[2]	0.711 @ 16ºC	2.3 @ 15°C	33 to 170	-46	37 @ 20°C
JP-4[3]	0.75 @ 15ºC	1.0 @ 15°C	60 to 270	-29	50 @ 15°C
JP-5	0.82 @ 15ºC	2.0 @ 15°C	176	60	-
JP-8	0.78 to 0.84 @ 15ºC	2.0 @ 20°C[8]	205 to 300	38	-
Diesel (#2)[4]	0.87 @ 15ºC	2.7 @ 15°C	150 to 370	52 to 96	50 @ 20°C
Kerosene[5]	0.81 @ 15ºC	2.3@ 15°C	151 to 301	>38	47-49 @ 20°C
Bunker C[6]	0.9 to 1.1 @ 15ºC	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-Patterson AFB
9 EPA – OSWER June 2000. Accessed via http://www.clu-in.org/download/studentpapers/strbak_flushing.pdf

Table 1b. Composition of Selected Fuels[1]

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[1]

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)

What is an LNAPL Management Strategy?

An LNAPL management strategy is the primary toolkit for decision-making at an environmental remediation site where LNAPL is present. Having such a strategy in place provides the Navy Remedial Project Manager (RPM) with a framework to measure progress throughout the life of the project. Benefits of implementing an LNAPL management strategy include: (1) garnering regulatory pre-approval for a site management approach that explicitly acknowledges the inherent challenge of LNAPL remediation and incorporates an adaptive remediation process; (2) recognizing the ability of intrinsic processes (e.g., natural attenuation) to contain or reduce LNAPL; and (3) helping to achieve a cost-effective and more environmentally-sustainable remediation program.

What steps are taken to develop an LNAPL Management Strategy?

The first step involved in developing a sound LNAPL management strategy is collecting key data to develop an understanding of the nature (i.e., geologic and geospatial distribution of LNAPL saturation) and extent of the LNAPL problem. The next step is to perform an LNAPL natural attenuation (NA) evaluation to determine the effects of natural weathering (e.g., dissolution, volatilization, and biodegradation) on the fate and transport (e.g., concentration, mobility, and stability) of the LNAPL. The term LNAPL NA is analogous with what is often referred to as source zone natural attenuation (SZNA) or natural source zone depletion (NSZD). However, for this course, it will be referred to as LNAPL NA. An evaluation of risk to human health and the environment should also be performed for the media and exposure routes of concern. At this point, an LNAPL conceptual site model (LCSM) can be developed. The LCSM provides the basis for understanding the LNAPL condition and characterizes the extent of the problem. Once all of the relevant information has been gathered and incorporated into an LCSM, the overall risk management strategy should be developed to define realistic LNAPL remedial action objectives (RAOs) that maintain protectiveness of human health and the environment and comply with regulatory requirements. The final step taken during development of an LNAPL management strategy is to establish an execution plan that details RAOs, performance metrics, milestones, and endpoints. This plan serves as a road map for remedy implementation and optimization. It should be flexible, dynamic, and chart a clear course for achieving site closure, which may include long-term management (LTMgt). Figure 2 illustrates the sequence of activities recommended when developing a comprehensive LNAPL management strategy.

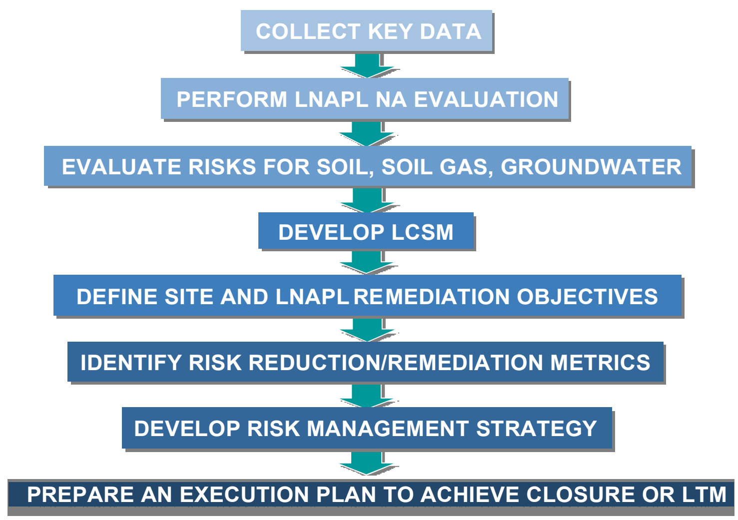

Figure 2. Activity Sequencing for Development of an LNAPL Management Strategy

What is an LCSM and how is it prepared?

The LCSM is the body of information describing multiple facets of the LNAPL and site setting that is necessary for use as a basis to identify the LNAPL RAOs (ITRC, 2009a). A simplified example is shown in Figure 3. The LCSM is a conceptual site model, which includes the source, pathway, and receptors, with a focus on the source component (e.g., the LNAPL). Overall, the level of detail required for an LCSM is site-specific and influenced by a number of factors such as the RAOs of the LNAPL site management strategy, site complexity, and regulatory framework. The LCSM can comprise some or all of the following scientific and technological inputs (ITRC, 2009a):

- Site setting (historical and current) – includes land use, groundwater classification, presence and proximity of receptors, exposure pathways, etc.
- Geological and hydrogeological information/setting
- LNAPL properties (specific gravity, viscosity, boiling and flash points, interfacial tensions)
- LNAPL chemical properties (concentration, constituent solubilities, fractionation/speciation of mole fractions of TPH constituents, and half-lives)
- LNAPL spatial distribution (vertical and horizontal delineation)
- LNAPL mobility and body stability information
- LNAPL recoverability information
- Associated dissolved-phase and vapor-phase plume information
- LNAPL natural attenuation processes

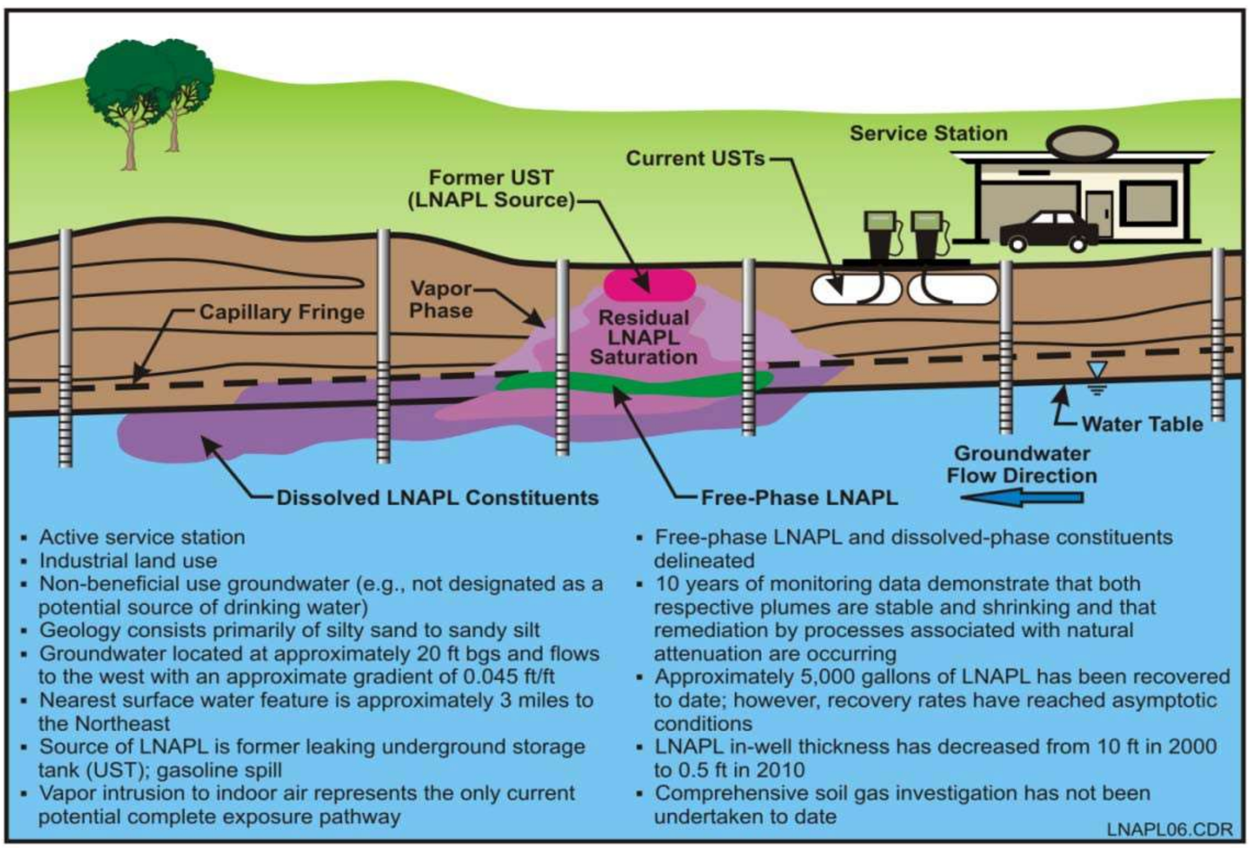

Figure 3. Example of an LNAPL Conceptual Site Model

Purchase this course to see the remainder of the technical materials.