

“The Basics”
Understanding the Behavior of Light Non-Aqueous Phase Liquids (LNAPLs)
in the Subsurface
Final Draft, September 2004

Glossary and References

Slide #:	
1A	Non-Aqueous Phase Liquid (NAPL) Cleanup Alliance —A public-private partnership, established in 2001, dedicated to pursuing aggressive technologies for removing large-scale non-aqueous phase liquid (NAPL) contamination. The Alliance is one of the six Action Teams under the Remediation Technologies Development Forum (RTDF), created by the U.S. Environmental Protection Agency (EPA) to foster collaboration between the public and private sectors in developing innovative solutions to mutual hazardous waste problems. The Alliance includes representatives from the petroleum industry, and federal and state government. For more information, visit http://www.rtdf.org/public/napl/ .
1B	Light Non-aqueous Phase Liquids (LNAPLs) —Contaminants, such as gasoline, diesel, motor oils, and similar petroleum hydrocarbons, that are immiscible (remain undiluted) in water, have a very low solubility in water, and are less dense (lighter) than water.
1C	American Petroleum Institute (API) —The U.S. oil and natural gas industry’s primary trade association. API works to influence public policy in support of a strong, viable U.S. industry and provides the opportunity for standards development, technical cooperation, and other activities to improve the industry’s competitiveness through sponsorship of self-supporting programs. For more information, visit http://www.api.org .
2A	Vadose Zone —The zone between land surface and the water table within which the moisture content is less than saturation (except in the capillary fringe) and pressure is less than atmospheric pressure.
2B	Water Table —Underground surface in an unconfined aquifer below which the ground is wholly saturated with water.
2C	Capillary Fringe —The zone just above the water table within which porous media are saturated by water under less than atmospheric pressure. The capillary fringe is in the vadose zone.
2D	Saturated Zone —The area in an unconfined aquifer that is below the water table and where all open spaces are filled with water under pressure equal to or greater than atmospheric pressure.

3A	Aquifer —An underground geological formation, or group of formations, containing water. Aquifers are sources of groundwater for wells and springs.
3B	Porosity —Degree to which soil, gravel, sediment, or rock is permeated with pores or cavities through which water or air can move. The ratio of the volume of void space to the total volume of the media.
3C	Saturation —The ratio of the volume of a fluid phase in the pore space to the pore volume, expressed as a percent. The sum of the saturations of each fluid phase in a pore volume is 100 percent.
3D	Capillary Pressure —The pressure in the non-wetting phase minus the pressure in the wetting phase. Capillary pressure causes porous media to draw in the wetting fluid and repel the non-wetting fluid due to the dominant adhesive force between the wetting fluid and the solid surfaces of the media. (Often referred to as “capillary suction pressure,” because the wetting phase is “sucked” up the tube. The terms are interchangeable.) For a water-LNAPL system, where water is the wetting fluid, capillary pressure equals the LNAPL pressure minus the water pressure.
3E	Viscosity —The internal friction derived from internal cohesion within a fluid that causes it to resist flowing, expressed in centipoise. The fluid property that characterizes its “thickness.”
3F	Density —The mass per unit volume of a substance. The higher the density, the higher its mass per volume.
3G	Interfacial Tension —The strength of the film separating two immiscible fluids (for example, oil and water), measured in dynes (force) per centimeter or millidynes per centimeter.
3H	Surface Tension —The interfacial tension between a liquid and its own vapor, typically measured in dynes per centimeter.
3I	Distribution — The spatial property of being scattered within a particular area or volume.
3J	Hydraulic Conductivity —A coefficient of proportionality describing the rate at which a fluid can move through the interconnected pore spaces in a porous medium. The density and viscosity of the fluid must be considered in determining conductivity.
3K	Migration —Movement of a fluid in the subsurface. LNAPL migration is affected by volume released; area of infiltration, duration of release, the properties of the LNAPL, properties of the porous media, and subsurface flow conditions.
3L	Hydraulic Recovery —The extraction of LNAPL from the subsurface using conventional hydraulic methods (pumping, skimming, etc.) at a technically and economically feasible rate.

4A	Non-aqueous Phase Liquids (NAPLs) —Contaminants, for example, halogenated compounds and petroleum hydrocarbons, that are immiscible (remain undiluted as the original bulk liquid) in the subsurface.
4B	Dense non-aqueous phase liquids (DNAPLs) —Contaminants, for example, chlorinated solvents, that are immiscible (remain undiluted as the original bulk liquid) in the subsurface and are heavier (denser) than water.
7A	Farr, A.M., Houghtilan, R.J., and McWhorter, D.B. 1990. "Volume Estimation of Light Non-Aqueous Phase Liquids In Porous Media." <i>Ground Water</i> , 28(1).
7B	Lenhard, R.J. and Parker, J.C., 1990. "Estimation of Free Hydrocarbon Volume from Fluid Levels in Monitoring Wells," <i>Ground Water</i> , 28(1):57-67 .
8A	Lithology —The characteristics, including grain size, of the strata of the subsurface media.
8B	Charbeneau, R.J., 2003. <i>Models for Design of Free-Product Recovery Systems for Petroleum Hydrocarbon Liquids, Spreadsheets, User's Guide and Model Documentation</i> , API Publication 4729, available at www.api.org/LNAPL .
19A	Displacement Entry Pressure —The pressure exerted in the drainage process to overcome capillary pressure and drive the non-wetting phase into the porous medium, increasing its saturation.
19B	Mercer, J. W., and R. M. Cohen, 1990. "A Review of Immiscible Fluids in the Subsurface: Properties, Models, Characterization and Remediation, <i>Journal of Contaminant Hydrology</i> , 6:107-163.
20A	Drainage —The process during which the saturation of the wetting phase (water) is decreasing and the saturation of the non-wetting phase (LNAPL) is increasing in a porous medium. Determining drainage is the first step in developing the capillary pressure curves that describe "the complete wetting history."
20B	Imbibition —The process during which the saturation of the non-wetting phase (LNAPL) is decreasing and the saturation of the wetting phase (water) is increasing in a porous medium. Determining imbibition is the second step in developing the capillary pressure curves that describe "the complete wetting history."

21A	American Petroleum Institute. 2003. <i>Answers to Frequently Asked Questions About Managing Risk at LNAPL Sites.</i> API Soil and Groundwater Research Bulletin No. 18, available at http://api-ep.api.org/filelibrary/ACFE0.pdf .
24A	Beckett, G.D. and S. Joy. 2003. <i>Light Non-Aqueous Phase Liquid (LNAPL) Parameters Database.</i> American Petroleum Institute. API Publication 4731, available at www.api.org/LNAPL .
26A	Specific Volume —The volume of a substance divided by its mass, expressed in cubic feet per square feet (feet ³ /feet ²).
28A	API Gravity —A term used by the petroleum industry to express the relative density of liquid petroleum products, which varies for different grades of fuel. API gravity values were developed by the API (American Petroleum Institute). API gravity is measured by a hydrometer instrument having a scale calibrated in terms of degrees API.
28B	Carsel, R. F. and R. S. Parrish. 1988. "Developing Joint Probability Distributions of Soil Water Retention Characteristics," <i>Water Resources Research</i> , 24:755-769.
30A	Vertical Equilibrium —The lack of up or down movement in the water table.
37A	Beckett, G.D., and Lundegard, P., 1997. "Practically Impractical - The Limits of LNAPL Recovery and Relationship to Risk," <i>Proceedings of the Petroleum Hydrocarbons and Organic Chemicals in Ground Water, NGWA, Houston Texas.</i>
37B	Relative Permeability —The ability of a porous medium to allow flow of a fluid when other fluid phases are present, relative to its ability to allow flow of that fluid when no other fluid phases are present.
40A	Burdine, N. T., 1953. "Relative Permeability Calculations from Pore Size Distribution Data," <i>Trans. AIME</i> , 198:71.
40B	Mualem, Y., 1976. "A New Method for Predicting the Hydraulic Conductivity of Unsaturated Porous Media," <i>Water Resources Research</i> , 12:513–522.

43A	Centipoise (cP, cPs, or cPo) – A common metric unit of dynamic viscosity equal to 0.01 poise or 1 millipascal second (mPa·s). The dynamic viscosity of water at 20 °C (68 °F) is about 1 centipoise.
44A	Baildown Test —A method for collecting data about LNAPL conductivity in the subsurface. The test can be performed in monitoring wells in the field by quickly extracting or withdrawing a volume of LNAPL from a well and monitoring both the water-LNAPL and LNAPL-air interfaces versus time. The rate at which the LNAPL flows back into the well is then used to calculate its conductivity.
44B	Lundy, D.A., Zimmerman, et al, 1993. “Estimation of Soil Properties and Free Product Volume from Baildown Tests,” National Ground Water Association, <i>Proceedings of the Petroleum Hydrocarbons and Organic Chemicals in Ground Water, NGWA, Houston Texas, 273-284.</i>
44C	Huntley, D., 2000. “Analytic Determination of Hydrocarbon Transmissivity From Baildown Tests,” <i>Ground Water</i> , 38(1):46-52.
45A	Bouwer, H. and Rice, R. C. 1976. "A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers with Completely or Partially Penetrating Wells," <i>Water Resources Research</i> , 12(3), 423-428.
47A	Darcy’s Law —The mathematical relationship that governs the rate of flow of groundwater or other fluids, such as LNAPLs, through porous media. A) Generalization for three dimensions: The rate of viscous flow of water in isotropic porous media is proportional to, and in the direction of, the hydraulic gradient. B) Generalization for other fluids: The rate of viscous flow of homogeneous fluids through isotropic porous media is proportional to, and in the direction of, the driving force. While it was established under saturated flow conditions, Darcy’s Law may be adjusted to account for unsaturated and multiphase flow.
52A	Areal Multiphase Organic Simulator (ARMOS) —A numerical model to simulate the flow of water and/or hydrocarbon in an unconfined aquifer.
52B	Multiphase Areal Remediation Simulator (MARS) —A two-dimensional multiphase areal remediation simulator to model coupled areal flow of water and LNAPL.

52C	Hydrocarbon Spill Screening Model (HSSM) —A model that simulates the impacts of water-immiscible contaminants (LNAPLs) on water-table aquifers. The HSSM model is based on approximate treatments of flow through the vadose zone, LNAPL spreading along the water table, and miscible transport of a single chemical constituent of the LNAPL through a water-table aquifer to various receptor points.
63A	Thiem Approximation —Describes steady-state flow to a confined aquifer with no leakage.
63B	Magnas Simulation —Simulates the flow of water, non-aqueous phase liquid (NAPL), and vapor phases through porous media in two dimensions or 3 dimensions.
64A	Charbeneau, R.J., 2003. <i>Models for Design of Free-Product Recovery Systems for Petroleum Hydrocarbon Liquids, Spreadsheets, User's Guide and Model Documentation</i> , API Publication 4729, available at www.api.org/LNAPL..
68A	Laser-Induced Fluorescence (LIF) — LIF method provides data on the <i>in situ</i> distribution of petroleum hydrocarbons based on the fluorescence response induced in the polycyclic aromatic hydrocarbon (PAH) compounds that are components of petroleum hydrocarbons. PAHs in petroleum products are induced to fluoresce by excitation with UV light. The method provides a "detect/non-detect" field screening capability relative to a detection limit derived for a specific fuel product on a site-specific soil matrix.
68B	ASTM International (ASTM) —Formerly known as the American Society for Testing and Materials, ASTM International is one of the largest organizations in the world devoted to developing voluntary consensus standards, related technical information, and services. ASTM standards address a wide range of topic areas, including analytical chemistry, environmental assessment, risk management, and toxicology; geotechnical engineering; petroleum; and waste management. For more information, visit www.astm.org .
69A	Cone Penetrometer Technology (CPT) —CPT is a standard civil engineering device that can distinguish lithology by various pressure and strain measurements as it is pushed into the ground. The CPT typically consists of an enclosed 20-40 ton truck equipped with vertical hydraulic rams that are used to force a sensor probe into the ground; a data acquisition, processing, and data storage computer system; and electronic signal processing equipment.

69B	Photoionization Detector (PID) —PID uses ultraviolet light as a means of ionizing an analytes (specifically, aromatic hydrocarbons or organo-heteroatom species) exiting from a GC column. The ions produced by this process are collected by electrodes, and the current generated provides a measure of the analyte concentration.
69C	Flame Ionization Detector (FID) —FID consists of a hydrogen/air flame and a collector plate. The effluent from the GC column passes through the flame, which breaks down organic molecules and produces ions. The ions are collected on a biased electrode and produce an electrical signal.
71A	Dean-Stark Extraction —A method for the measurement of fluid saturations in a core sample by distillation extraction.
71B	American Petroleum Institute, 2001. “Methods for Determining Inputs to Environmental Petroleum Hydrocarbon Mobility and Recovery Models,” API Publication 4711, available at www.api.org/LNAPL .
72A	Atterberg Limits (ASTM D4318) —The moisture contents which define a soil's liquid limit, plastic limit, and sticky limit. These are used to determine if the finer fraction of the soil (passing 200 sieve performed on particles passing a #40 sieve) are classified as clay or silt and whether they have low or high plasticity.
72B	Light Non-Aqueous Phase Liquid (LNAPL) Parameters Database —This is a collection of information about samples that have had their capillary parameters determined, as well as other physical parameters measured. The primary purpose of this database is to provide information to users who are trying to characterize the movement and distribution of LNAPL within a site that has a limited set of direct observations of the capillary properties of the site. Download information for the database is available at http://groundwater.api.org/lnapl/database/ .
81A	Huntley, D., Hawk, R.N., and Corley, H.P., 1994. “Non-aqueous Phase Hydrocarbon in a Fine-grained Sandstone, (1) Comparison Between Measured and Predicted Saturations and Mobility,” <i>Journal of Ground Water</i> , v. 32, n4. (2) “Effect of Local Sediment Variability on the Estimation of Hydrocarbon Volumes,” <i>Journal of Ground Water</i> , 32(5).
81B	Brubaker, G.R., Myers, J., and Fantone, K., 2003. “The Use of Chemical and Mobility Analysis to Design a NAPL Recovery Program at a Former Petroleum Refinery, 2003 <i>Petroleum Hydrocarbons and Organic Chemicals in Ground Water®: Prevention, Detection, and Remediation, 20th Conference and Exposition, Costa Mesa, CA.</i>

87A	van Genuchten, M., Leij, J. and Yates, R.,1991. “The RETC Code for Quantifying the Hydraulic Functions of Unsaturated Soils Version 1.0,” U. S. Environmental Protection Agency, Ada, OK, EPA Report 600/2-91/065, 9-17.
97A	Rapid Optical Screening Tool (ROST) —ROST is a type of LIF. It consists of a sensor, which uses a wavelength tunable ultraviolet laser source coupled with an optical detector, to measure fluorescence. The measurement is made through a sapphire window on a probe that is pushed into the ground with a truck-mounted CPT.
Other Related Documents	
U.S. EPA, 1995. <i>Ground Water Issue: Light Nonaqueous Phase Liquids</i> , EPA/540/S-95/500, U.S. EPA Technology Innovation Office, Washington, DC.	
U.S. EPA, 1996. <i>How to Effectively Recover Free Product at Leaking Underground Storage Tank Sites: A Guide for State Regulators</i> , EPA/510/R-96/001, U.S. EPA National Risk Management Research Laboratory, Cincinnati, OH.	
Michigan Department of Environmental Quality, 2001. <i>Revised Operational Memorandum No. 7, Identification, Reporting, and Recovery of Free Product at LUST Sites</i> , available at http://www.deq.state.mi.us/documents/deq-std-Opmemo7.pdf .	