Montana Light Non-Aqueous Phase Liquid (LNAPL) Recovery and Monitoring Guidance

Montana Department of Environmental Quality

Remediation Division

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Executive Summary

The Montana Department of Environmental Quality Remediation Division (DEQ) prepared this guidance to assist responsible parties, environmental professionals, and DEQ technical contacts in the investigation and recovery of Light Non-Aqueous Phase Liquid (LNAPL) where LNAPL has been released to the environment and is found in the subsurface. It is the intent of this guidance to provide general assistance on how to:

- Develop a conceptual site model describing an LNAPL release;
- Delineate the extent of LNAPL in the subsurface, laterally and vertically;
- Evaluate potential receptors exposed to LNAPL;
- Perform LNAPL monitoring and recovery; and
- Report the results of LNAPL recovery and monitoring efforts to DEQ.

Acute health effects, direct exposure, and fire hazards from high concentrations of petroleum vapors are beyond the scope of this guidance. Immediately refer situations involving fire, explosion, or serious acute health affects to local fire or emergency response teams.

The primary objectives of LNAPL recovery and monitoring efforts are to: 1) prevent LNAPL migration; and 2) reduce the LNAPL contaminant mass in the subsurface. In general, responsible parties are expected to take action to monitor and recover LNAPL wherever LNAPL is equal to or exceeds 0.01 feet in thickness. However, final LNAPL recovery requirements may be greater or less than 0.01 feet in thickness depending on site-specific characteristics. DEQ determines these requirements on a site-by-site basis according to the regulations that govern a particular site.

ARM 17.56.602(1)(c) requires that after a release from an underground storage tank system is identified in any manner, responsible parties must investigate to determine the possible presence of free product, begin free product removal as soon as practicable, conduct free product removal in a manner that minimizes the spread of contamination into previously uncontaminated zones by using recovery and disposal techniques appropriate to the hydrogeologic conditions at the site, and that properly treats, discharges or disposes of recovery byproducts in compliance with applicable local, state and federal regulations. This regulation also provides that abatement of free product migration is a minimum objective for the design of the free product removal system and provides that any flammable products must be handled in a safe and competent manner to prevent fires or explosions. In addition, ARM 17.56.607 requires LNAPL recovery to the "maximum extent practicable" (MEP), which is a site-specific determination based on numerous factors including, but not limited to: site-specific geology, depth to groundwater, LNAPL composition, existing surface or underground structures, and measured LNAPL thicknesses.

Receptor exposure to LNAPL through vapor intrusion is **not** addressed in this guidance. The presence of LNAPL in the subsurface presents a potential source of vapors that may migrate to indoor air of nearby or overlying structures. As a result, it is important to evaluate the vapor intrusion pathway in situations where LNAPL is present within 100 feet laterally from a structure (and potentially at distances greater than 100 feet laterally if preferential pathways are present). Please refer to the most current version of DEQ's Vapor Intrusion Guide (http://deq.mt.gov/StateSuperfund/viguide.mcpx) for assistance on investigation of the vapor intrusion pathway.

It is not the intent of this guidance to provide a thorough description of the science of LNAPL fate and transport. Therefore, for purposes of this guidance, it is assumed that the reader is familiar with the science underlying the fate and transport of LNAPL released to the subsurface. Please refer to the references listed in Section 8.0 for more information on the science of LNAPL fate and transport in the subsurface.

This guidance is organized into the following sections:

Section 1: Introduction: This section explains LNAPL recovery and the purpose of the guidance.

Section 2: Regulatory Time Frames: This section discusses LNAPL discovery notification and LNAPL delineation and recovery efforts.

Section 3: LNAPL Fate and Transport in the Subsurface: This section presents a brief summary of the science behind LNAPL migration in the subsurface following a surface or subsurface LNAPL release.

Section 4: LNAPL Delineation Methods: This section presents some common field methods to delineate the horizontal and vertical extent of LNAPL in the subsurface.

Section 5: Conceptual Site Model: This section discusses the development of a Conceptual Site Model describing a LNAPL release.

Section 6: LNAPL Recovery and Monitoring: This section discusses some methods to record LNAPL thicknesses and recover LNAPL from the subsurface.

Section 7: Reporting: This section discusses the typical contents of an LNAPL monitoring and recovery report.

Section 8: References: This section provides references to citations in the guidance.

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Definitions and Acronyms

Acronyms
ARM – Administrative Rules of Montana
AST – Aboveground Storage Tank
ASTM – American Society for Testing and Materials
CECRA – Comprehensive Environmental Cleanup and Responsibility Act
COC – Contaminants of Concern
CPT – Cone Penetrometer Technology
CSM – Conceptual Site Model
DNAPL – Dense Non-Aqueous Phase Liquid
DEQ – Montana Department of Environmental Quality Remediation Division
DEQ-7 – Circular DEQ-7, Montana Numeric Water Quality Standards
ITRC – Interstate Technology Regulatory Council
LBS – LUST Brownfields Section
LIF – Laser Induced Fluorescence
LNAPL – Light Non-Aqueous Phase Liquid
LUST – Leaking Underground Storage Tank
MCA – Montana Code Annotated
MEP – Maximum Extent Practicable
MIP – Membrane Interface Probe
NJDEP – New Jersey Department of Environmental Protection
NRC – National Response Center
PST – Petroleum Storage Tank
PTS – Petroleum Technical Section
RBCA – Risk Based Corrective Action
RBSL – Risk Based Screening Level
SRS – Site Response Section
USEPA - United States Environmental Protection Agency
UST – Underground Storage Tank
WQA – Water Quality Act

Definitions used in Guidance:

Active LNAPL Recovery - The use of equipment (such as a belt skimmer or well bailer) to induce LNAPL migration to a LNAPL collection point and subsequent removal of LNAPL

DEQ Technical Contact – DEQ Remediation Division Project Officer

DNAPL – Dense non-aqueous phase liquid; an immiscible liquid that is denser than water

Free Product – Non-aqueous (immiscible) phase liquids; including those that are lighter than water (LNAPL) and those denser than water (DNAPL)

Globules – Small spherical LNAPL masses

LNAPL – Light non-aqueous phase liquid; an immiscible liquid that has a lower density than water

LNAPL Body – All LNAPL present in the subsurface, both above and below the water table

LNAPL Collection Point – Any location where LNAPL can be measured or otherwise observed. Collection points include, but are not limited to, test pits, excavations, piezometers, monitoring wells, surface water, test pits, trenches, sumps, utility vaults, etc.

LNAPL Recharge Rate – The amount of time it takes LNAPL to recover to pre-removal thickness immediately following a measure of the LNAPL removal rate

LNAPL Recovery Test – A test designed to estimate the rate at which LNAPL can be collected at a collection point. The recovery rates can be estimated from the results of specialized pumping tests, projection of initial recovery rates, and the use of theoretical models (EPA, 1996)

LNAPL Removal Rate – The length of time required to reduce the level of LNAPL at a LNAPL collection point to a thickness as close as practicable to non-detectable

Migrating LNAPL - An LNAPL body that is observed to spread or expand laterally or vertically or otherwise result in an increased volume of the LNAPL extent, usually indicated by time-series data. Migrating LNAPL does not include LNAPL that appears in a well due to a dropping water table (ITRC, 2009b)

Mobile LNAPL – LNAPL that exceeds residual saturation; it includes migrating LNAPL, but not all mobile LNAPL is migrating LNAPL (ITRC, 2009b)

Passive LNAPL Recovery - The collection of LNAPL as it migrates into a LNAPL collection point, typically through placement of LNAPL absorbent material or equipment (such as absorbent "socks" or free product recovery canisters) at the top of the water table

Petroleum Storage Tank – An above ground or below ground permanent vessel in which petroleum is or has been stored, and associated pipes with some limited exceptions

Residual LNAPL Saturation – The range of LNAPL saturation greater than zero LNAPL saturation up to the LNAPL saturation, at which LNAPL capillary pressure equals pore entry pressure. It includes the maximum LNAPL saturation, below which LNAPL is discontinuous and immobile under the applied gradient (ITRC, 2009b)

Smear Zone – The area of soil immediately above the water able that may be below the water table during high groundwater or above the water table during low groundwater

Vadose Zone – The unsaturated zone between the ground surface and the top of the groundwater table

1.0 Introduction

The Montana Department of Environmental Quality Remediation Division (DEQ) prepared this guidance to assist responsible parties, environmental professionals, and DEQ technical contacts in the investigation and recovery of LNAPL where LNAPL has been released to the environment and is found in the subsurface. DEQ has developed this guidance using its scientific and technical expertise as well as other technical documents (referenced in sections 1.3 and 8.0).

Work plans and corrective action plans (collectively referred to as "plans") that follow this guidance are likely to contain the information necessary for DEQ to approve the plans. DEQ encourages parties to contact DEQ with any additional or clarifying questions about this guidance.

1.1 Applicability

Acute health effects, direct exposure, and fire hazards from high concentrations of petroleum vapors are beyond the scope of this guidance. Immediately refer situations involving fire, explosion, or serious acute health affects to local fire or emergency response teams.

This guidance is only for use on sites being overseen by the Remediation Division and may not be used for active petroleum refineries. This guidance only addresses LNAPL (immiscible liquids less dense than water) and not DNAPL (immiscible liquids denser than water).

This guidance does not address the potential vapor intrusion pathway to indoor air that the presence of LNAPL in the subsurface may create. It is important to evaluate the vapor intrusion pathway in situations where LNAPL is present within 100 feet laterally from a structure (and potentially at distances greater than 100 feet laterally if preferential pathways are present). Please refer to the most current version of DEQ's Vapor Intrusion Guide (http://deq.mt.gov/statesuperfund/viguide.mcpx) for assistance on the investigation of vapor intrusion.

This document contains guidance, not regulation. Adherence to the requirements outlined in the statutes and regulations that apply to a particular site is mandatory; however, adherence to this guidance is not. This guidance does not create any requirements or obligations on the regulated community. Instead, the sources of authority and requirements for addressing LNAPL are the relevant statutes and regulations, including but not limited to, the Comprehensive Environmental Cleanup and Responsibility Act (CECRA) contained in §§ 75-10-701 through 757, MCA, Petroleum Storage Tank Cleanup Act, contained in §§ 75-11-301 through 321, MCA, and the Montana Underground Storage Tank Act, contained in §§ 75-11-501 through 526, MCA. This guidance does not supersede any statutory or regulatory requirements, is subject to change, and is not independently binding on DEQ. Additionally, if a conflict exists between this guidance and the statutory or regulatory requirements applied to a particular site, the conflict will be resolved in favor of the statute or regulation.

ARM 17.56.602(1)(c) requires that after a release from an underground storage tank system is identified in any manner, responsible parties must investigate to determine the possible presence of free product, begin free product removal as soon as practicable, conduct free product removal in a manner that minimizes the spread of contamination into previously uncontaminated zones by using recovery and disposal techniques appropriate to the hydrogeologic conditions at the site, and that properly treats, discharges or disposes of recovery byproducts in compliance with applicable local, state and federal regulations. This regulation also provides that abatement of free product migration is a minimum objective for the design of the free product removal system and provides that any flammable products must be handled in a safe and competent manner to prevent fires or explosions. In addition, ARM 17.56.607 requires LNAPL recovery to the "maximum extent practicable" (MEP), which is a site-specific determination based on numerous factors including, but not limited to: site-specific geology, depth to groundwater, LNAPL composition, existing surface or underground structures, and measured LNAPL thicknesses.

The primary objectives of LNAPL recovery and monitoring efforts are to: 1) prevent LNAPL migration; and 2) reduce the LNAPL contaminant mass in the subsurface. In general, responsible parties are expected to take action to monitor and recover LNAPL wherever LNAPL is equal to or exceeds 0.01 feet in thickness. However, final LNAPL recovery requirements may be greater or less than 0.01 feet in thickness depending on site-specific characteristics and DEQ determines these requirements on a site-by-site basis according to the regulations that govern a particular site.

1.2 LNAPL Investigation and Recovery

In general:

- The responsible party reports the discovery of LNAPL to DEQ as soon as possible (see Section 2.0 for initial notice requirements);
- Efforts to delineate and recover LNAPL are undertaken and reported to DEQ according to a regular schedule, as further detailed in Sections 2.3 and 7.0. There may also be reporting requirements depending on the regulations that apply to the site and it is the responsible party's obligation to be aware of reporting requirements and ensure compliance with them;
- An evaluation of any receptors potentially exposed to LNAPL (such as LNAPL in a groundwater surface seep), dissolved phase concentrations of LNAPL contaminants, or LNAPL vapors (through vapor intrusion or direct exposure, such as a construction worker scenario) is typically conducted immediately following the discovery of LNAPL at a site, in communication with the appropriate DEQ technical contact;
- LNAPL plumes are laterally and vertically delineated with appropriate means, such as soil borings or permanent groundwater monitoring wells (as further described in Section 4.0);
- Attempts to recover LNAPL are made at all locations where LNAPL is equal to or greater than 1/8 of an inch or 0.01 feet in thickness according to a routine schedule which may be determined on a site specific basis. Depending on site-specific circumstances, alternative recovery goals (approved by the DEQ technical contact) may be appropriate;
- LNAPL is recovered to the MEP, where MEP is determined based on the specifics of each site (including but not limited to factors such as depth to the groundwater table, observed thickness of LNAPL in monitoring wells, recharge rate of LNAPL in monitoring wells, the type of LNAPL present, etc.);
- Recovered LNAPL is appropriately stored and disposed of, as described in Section 6.5.

1.3 Documents for Further Guidance

This guidance presents a summary of LNAPL investigation, delineation, and recovery. It is assumed that users of this guidance document are familiar and experienced in the underlying science of LNAPL fate and transport in the subsurface. The following documents provide more detailed discussion of investigation, recovery, and fate and transport of LNAPL in the subsurface:

ITRC, 2009. Evaluating LNAPL Remedial Technologies for Achieving Project Goals. Prepared by Interstate Technology and Regulatory Council.

USEPA, 1995. Light Non-Aqueous Phase Liquids. U.S. Environmental Protection Agency. EPA 540-S-95-500. July, 1995.

USEPA, 1996. How to Effectively Recover Free Product at Leaking Underground Storage Tank Sites: A Guide for State Regulators. EPA 510-R-96-001, September 1996.

USEPA, 2005. A Decision-Making Framework for Cleanup of Sites Impacted with Light Non-Aqueous Phase Liquids (LNAPL). U.S. Environmental Protection Agency. EPA 542-R-04-011, March 2005.

2.0 Regulatory Timeframes

This section provides detail regarding timeframes for reporting releases or discovery of LNAPL, initiating efforts to delineate and recover LNAPL, and reporting of LNAPL monitoring and recovery. It is critical that all releases or spills of hazardous or deleterious substances or other wastes, regardless of size, are properly and expeditiously managed, contained, and removed to protect public health, safety, and welfare and the environment.

Regulations specific to LNAPL related to Petroleum Storage Tank (PST) releases are contained within ARM Title 17, Chapter 56: Underground Storage Tanks, subchapters 5 and 6. These regulations may be found at: http://deq.mt.gov/dir/legal/Chapters/Ch56-toc.mcpx.

Additional information regarding reporting initial petroleum releases or discovery may be found at: http://deq.mt.gov/LUST/default.mcpx and http://deq.mt.gov/enf/spillpol.mcpx.

2.1 Initial Notice – Releases from a PST

ARM 17.56.505 requires that owners or operators of a PST report any release of LNAPL in excess of 25 gallons to DEQ within 24-hours of discovery. Petroleum releases less than 25 gallons in volume must be contained and cleaned up within 24-hours. If cleanup cannot be completed within 24-hours, owners and operators must immediately report the release to DEQ.

ARM 17.56.502 and 17.56.506 require that suspected or confirmed LNAPL releases from a PST be reported to an appropriate DEQ technical contact and identify who is required to make the report. Suspected or confirmed releases must be reported to one of the following:

- DEQ release reporting hotline (normal business hours): 800-457-0568;
- Disaster and Emergency Services (outside of normal business hours): 406-324-4777.

Releases or suspected releases must be directly reported to a DEQ technical contact at one of the above phone numbers. A voicemail, email, facsimile, or letter does not constitute an appropriate report.

DEQ's suspected release notification form for PST releases may be found at: http://deq.mt.gov/LUST/downloadables/UOCtitlepage.mcpx.

2.2 Initial Notice – Releases from a non-PST Source

Confirmed or suspected releases of petroleum in any quantity from any other source (pipeline, railcar, tanker truck, etc.) should be reported to DEQ within 24-hours of discovery.

In addition, notification may be required by permits issued by state, federal, or local government agencies or other statutes or regulations. Notification to the National Response Center (NRC) may also be required. NRC can be reached at 800-424-8802. DEQ is not responsible for notifying the NRC. It is the responsible party's obligation to be aware of reporting requirements and ensure compliance with them.

2.3 LNAPL Delineation and Recovery

In general, the responsible party should submit a work plan defining methods for delineation of all newly discovered occurrences of LNAPL in the subsurface, regardless of LNAPL source, within 30-days of LNAPL discovery. Recovery of LNAPL should begin immediately upon discovery or as soon as practicable following LNAPL discovery. Please consult with the DEQ technical contact regarding the requirements for the work plan and LNAPL recovery; requirements are determined on a site-specific basis.

Methods for delineation and recovery of LNAPL are presented within Sections 4.0 and 6.0 respectively. Storage of recovered LNAPL on-site and off-site disposal is presented in Section 6.5.

2.4 Reporting LNAPL Monitoring and Recovery

LNAPL monitoring and recovery are described in a work plan and subsequent LNAPL monitoring and recovery reports specific to the site. Please consult with the DEQ technical contact for work plan requirements, which are determined on a site-specific basis.

ARM 17.56.602 requires that a report summarizing the initial PST released LNAPL response and abatement efforts be submitted to the appropriate DEQ technical contact within 30-days of the confirmed release.

All efforts conducted to delineate, monitor, and recover LNAPL from the subsurface are reported to the appropriate DEQ technical contact according to a schedule determined on a site-specific basis.

Please confer with the appropriate DEQ technical contact regarding a reporting schedule and requirements for individual sites with LNAPL present. Section 7.0 provides a general description of the types of information that may be required in LNAPL monitoring and recovery reports.

3.0 LNAPL Fate and Transport in the Subsurface

This section presents a brief and general summary of factors related to LNAPL fate and transport in the subsurface. This section does not address the fate and transport of LNAPL that may be present in fractured bedrock. LNAPL in fractured bedrock will likely behave very differently than LNAPL present in the vadose zone, capillary fringe, and non-bedrock aquifer. The following subsections assume a relatively homogenous geology and an unconfined, minimally fluctuating water table.

3.1 Initial LNAPL Release

LNAPL released at or near the ground surface will migrate downward under the force of gravity through the vadose (unsaturated) zone of soil. As LNAPL migrates downward through the vadose zone, some LNAPL will be left behind, sorbed, trapped, and immobilized in soil pore spaces by capillary forces and geologic heterogeneities (NJDEP, 2012). If a sufficient volume of LNAPL is released, the LNAPL will reach the saturated zone (capillary fringe and water table), where it will accumulate and begin to migrate horizontally due to its lower density and relative immiscibility with respect to water. LNAPL will continue to migrate vertically and horizontally until equilibrium is reached, displacing soil vapor from pore spaces in the vadose zone and water from pores in the saturated zone (NJDEP, 2012). As it takes less force for LNAPL to displace soil vapor than water, LNAPL will preferentially enter unsaturated soil pore spaces (MN, 2010).

Though LNAPL is less dense than water, LNAPL may still be driven vertically downward into the saturated zone if a sufficient vertical gravitational head of LNAPL is present in the subsurface. Vertical migration of LNAPL will continue until vertical equilibrium is reached. Vertical LNAPL equilibrium will usually occur before horizontal equilibrium is reached, and LNAPL will continue to migrate laterally until horizontal equilibrium is reached. The vertical and horizontal migration of LNAPL is limited by buoyancy and capillary forces, respectively, that counteract the force of the LNAPL gradient. Since LNAPL is immiscible in water, it will persist in a separate phase in the pores within the saturated zone after the LNAPL body is spatially stable. All LNAPL present in the subsurface, both above and below the water table, is considered to be part of the LNAPL body (MN, 2010).

3.2 LNAPL Composition

While any non-aqueous fluid with a lower specific gravity than water may be defined as LNAPL, the type of LNAPL released will also influence the LNAPL's ability to migrate in the subsurface. Other factors that influence LNAPL transport in the subsurface include the LNAPL's density and viscosity, as well as the interfacial tension and wettability between the LNAPL and groundwater (EPA, 1995).

3.3 LNAPL Mobility and Migration

There are two general stages in the development of a LNAPL body at the saturated zone, the initial expansion stage when LNAPL is actively migrating under a sufficient LNAPL gradient (as described in Section 3.1) and the longer duration stable stage when migration is minimal or nonexistent after the hydraulic forces driving LNAPL migration have diminished relative to counteracting forces (MN, 2010). Geologic heterogeneity, pore geometry, the presence of groundwater in pores, as well as perched, hydraulically confined, and fractured conditions affect LNAPL migration. This section assumes relatively homogenous geology and an unconfined, minimally fluctuating water table.

LNAPL body behavior can be characterized based partly on the LNAPL saturation, or the percentage of total pore volume occupied by LNAPL (Interstate Technology Regulatory Council (ITRC, 2009b)). In the vadose zone, soil vapor and soil moisture occupy the balance of the pore volume, while the saturated zone pore volume is occupied by water. Under vertical equilibrium in the saturated zone, the relative amount of LNAPL in the pores varies with depth, and higher LNAPL saturations are usually observed near the top of the LNAPL body due to capillary pressure forces. Over time and as the water table fluctuates, some of the LNAPL may be vertically and locally redistributed. Some of the LNAPL will eventually become hydraulically disconnected leaving independent globules of LNAPL in some pores. Residual LNAPL saturation is the LNAPL saturation where the LNAPL is immobile under the applied gradient (ITRC, 2009b). LNAPL exceeding residual saturation is mobile, potentially migrating, and potentially recoverable (MN, 2010).

The presence of mobile LNAPL (above residual saturation) in a monitoring well does not necessarily mean that the LNAPL body is migrating. In order for the LNAPL body to migrate at the lateral edge of the LNAPL body, the forces that drive lateral LNAPL migration must overcome counteracting forces, such as capillary forces, which inhibit LNAPL displacement of water (and thus migration) from pores. Eventually, the leading edges of the LNAPL body will no longer be able to overcome counteracting forces (in the absence of a stronger LNAPL gradient caused by a continued release) and will become spatially stable (i.e, reach equilibrium), though LNAPL exceeding residual saturation may still occur in the center of the LNAPL body (MN, 2010).

Detectable LNAPL in a monitoring well indicates that some of the LNAPL in the immediate vicinity of the well exceeds residual saturation. The lack of LNAPL present in a well does not necessarily indicate that no LNAPL is present in the vicinity of the well. LNAPL still may occur in the well vicinity below residual saturation or may occur exceeding residual saturation, but entrapped within the saturated zone due to the stronger force needed to displace water from pores and mobilize LNAPL (MN, 2010). Therefore, LNAPL may accumulate in greater volumes in monitoring wells during low groundwater table conditions. Accordingly, water table fluctuations must be accounted for when evaluating LNAPL saturations and the potential for LNAPL migration (MN, 2010). Changing site conditions over time (i.e., lowered water table) may mobilize LNAPL and necessitate additional LNAPL recovery activities at sites where LNAPL was formerly present below residual saturation.

3.4 Preferential Pathways

LNAPL may deviate from its anticipated migration route if preferential pathways (natural or anthropogenic subsurface features of higher permeability or soil vapor filled porosity than the surrounding matrix) are present in the area of LNAPL release. Typical preferential pathways include subsurface utility lines and corridors, dry wells, backfill material, higher permeability lithologic layers or zones, etc. If LNAPL enters a preferential pathway, it may migrate in an unexpected direction, much further than may be anticipated, or accumulate in greater volumes in localized areas.

4.0 LNAPL Delineation Methods

This section describes typical field methods to delineate LNAPL in the subsurface. This section assumes the reader has prior knowledge of each method described. Delineation of LNAPL should be conducted in a manner such that the LNAPL body is delineated efficiently and the thickness of the LNAPL may be easily measured. Consideration should also be given to the need for long term LNAPL monitoring and recovery when selecting delineation methods. DEQ will determine the requirements for LNAPL delineation on a site-specific basis. Some methodologies (such as test pits) may provide for a quick delineation of the LNAPL body extent, but lack the ability to conduct long term LNAPL monitoring and recovery that a permanent monitoring well provides. Please consult the DEQ technical contact for specific questions regarding appropriate delineation strategies for a particular site. Much of the text in this section was adapted from Appendix D, NJDEP, 2012.

4.1 Test Pits

Test pits are soil excavations, typically completed by heavy machinery such as a backhoe or excavator. Test pits are most effective in situations where LNAPL is expected to occur at shallow depths and in unconsolidated soils. Test pits offer the advantages of rapid delineation, visual observation of shallow soils, and ease of collecting soil samples. Disadvantages of test pits include depth limitations, disturbance to the ground surface and subsurface, and lack of permanent LNAPL monitoring points.

When selecting test pits as a LNAPL delineation method, consideration should be given to disposal costs associated with excavating contaminated soils and the future needs of the site in terms of LNAPL monitoring or recovery points.

4.2 Soil Borings and Temporary Wells

Soil borings and temporary wells are typically installed with rotary or direct push drilling technology. Soil borings allow for direct visual observation, sampling, and field screening of soils. Temporary monitoring wells installed in soil borings allow for the short-term monitoring of LNAPL thickness and sampling of groundwater.

Soil borings and temporary wells provide relatively rapid delineation of LNAPL occurrence, allow for discrete soil sampling, allow groundwater sampling and LNAPL thickness gauging, may be advanced to greater depths than test pits, and offer some ability to recover LNAPL. Temporary wells and soil borings provide a good guide to direct the location of permanent monitoring wells or permanent LNAPL recovery structures.

Based on construction, temporary wells may not be as effective in recovering or monitoring LNAPL. Temporary wells typically do not offer the same security as permanent wells and may be damaged over time. Consideration should be given to installing temporary wells in a manner so that they may be converted to permanent wells if necessary.

4.3 Direct Push Technologies

The same direct push drilling technologies that may be used to complete soil borings and temporary or permanent wells also offer an additional LNAPL delineation method through the use of specialized direct push technologies such as Membrane Interface Probe (MIP), Laser Induced Fluorescence (LIF), and Cone Penetrometer Technology (CPT). These technologies offer the advantages of rapid LNAPL delineation and the detection of LNAPL in-situ through the advancement of the MIP, LIF, and CPT sensors. Direct push technologies may be used in combination with a temporary or permanent monitoring well installation program in order to provide for long term LNAPL monitoring and recovery.

4.4 Permanent Wells

Permanent wells are often necessary in any long-term LNAPL investigation and the need for permanent wells is made on a site-specific basis. Permanent wells allow for documentation of groundwater flow direction, measurement of water table fluctuations, groundwater sampling, LNAPL thickness monitoring, and are often necessary for LNAPL recovery. Permanent wells also allow for discrete soil sampling during well installation and long term monitoring of LNAPL thickness. Permanent wells should be located in the center and periphery of the LNAPL body in order to monitor the thickness of the LNAPL body over time and monitor any potential LNAPL migration.

Permanent wells may be used for both monitoring and recovering LNAPL. Wells must be constructed in compliance with the requirements of ARM 36.21.601, et seq., by a licensed well driller. Wells are screened to bridge the water table and allow for LNAPL to migrate into the well through a sand filter pack (coarser than the surrounding soils).

Although LNAPL can be recovered from standard 2-inch monitoring wells, larger diameter wells may provide increased efficiency and broader equipment options for recovery. If LNAPL is expected to accumulate in a monitoring well, consideration should be given to installing larger diameter wells to allow for greater volume of LNAPL to accumulate in the well in order to enhance LNAPL recovery. Requirements for well diameter are made on a site-specific basis.

5.0 Conceptual Site Model

Following vertical and lateral LNAPL delineation at a site, a Conceptual Site Model (CSM) is developed in order to describe the occurrence and extent of LNAPL. The CSM is a written and graphical representation of the physical, chemical, and biological processes that control the transport, migration, and interaction of Contaminants of Concern (COCs) and LNAPL, through environmental media associated with the site (NJDEP, 2012). The CSM clearly identifies the LNAPL release mechanism, the fate and transport of LNAPL in the subsurface, and the current extent of LNAPL and COCs associated with the LNAPL in groundwater, soil, sediment, surface water, and air at a site.

A CSM can be as simple or complex as necessary to depict LNAPL fate and transport and is a "living" document that gains refinement as more data are collected. Necessary data to include in a CSM will vary based on site-specific details, but the following provide a summary of typical data that is in a CSM:

- The source of the LNAPL release and the known or estimated volume of LNAPL released;
- The type and composition of LNAPL released;
- Site specific geology, hydrogeology, and any natural or anthropogenic subsurface features that may influence LNAPL distribution or recoverability;
- The extent and distribution of LNAPL laterally and vertically, with the LNAPL body delineated in all directions;
- Groundwater flow direction and hydraulic conductivity;
- Potential receptors that could be exposed to LNAPL through direct contact, exposure to dissolved phase contaminants in groundwater, or exposure to LNAPL vapors, including the vapor intrusion pathway;
- LNAPL saturation, mobility, and recoverability; and
- Groundwater, surface water and sediment (if necessary), surface soil, subsurface soil, and soil vapor (or indoor air if a vapor intrusion investigation is necessary) concentrations of LNAPL related contaminants.

6.0 LNAPL Recovery and Monitoring

This section describes various methods to monitor the extent and thickness of an LNAPL body and to recover LNAPL from the subsurface. This section presents some typical methods of conducting LNAPL monitoring and recovery. Other monitoring or recovery methods may also be effective and appropriate. Please consult with the DEQ technical contact if a different monitoring or recovery method is proposed for a site; requirements are established on a site-specific basis. Appendix A presents a summary of LNAPL remediation technologies from ITRC, 2009b.

6.1 LNAPL Recharge Rates in LNAPL Collection Points

LNAPL removal and recharge rates may be used to determine an appropriate method and frequency of LNAPL recovery, specific to a LNAPL collection point. LNAPL removal rate is the length of time required to remove a measurable level of LNAPL from a LNAPL collection point to the smallest practicable thickness, or until no further continuous recovery is possible. LNAPL recharge rate is the amount of time it takes LNAPL to recover to pre-removal thickness immediately following a measure of the LNAPL removal rate. LNAPL removal and recharge rates are determined through a LNAPL recovery test. Additional information regarding LNAPL recovery tests may be found in the USEPA, 1996 reference (see Section 8.0).

An LNAPL recovery test is typically conducted as follows:

1. Depth to LNAPL and groundwater are measured using an interface probe in order to calculate the volume of LNAPL present;
2. LNAPL is removed as quickly as possible while minimizing the removal of groundwater. Volumes of recovered LNAPL and groundwater, and the length of time it took for removal to occur are recorded;
3. Depth to LNAPL and groundwater are measured immediately after LNAPL removal is completed and over time until LNAPL thickness reaches (or comes very close to reaching) pre-removal thickness. Thickness measurements should be recorded more frequently during initial recovery stages (i.e., every minute), and less frequently as LNAPL recovery rate slows (i.e., every 10 minutes). Both recovery rate and total recovery time are important to record;
4. The test should be repeated within 24-hours in order to verify the test results and assess LNAPL recharge from the formation (MN, 2010).

6.2 LNAPL Monitoring Methods and Frequency

The LNAPL body should be monitored for LNAPL thickness near the release area, or center of the LNAPL body, to provide data regarding the LNAPL source over time. Additionally, sufficient monitoring points should be installed within the LNAPL body to allow for LNAPL recovery from the areas of the LNAPL body with the greatest LNAPL thicknesses.

LNAPL releases should be delineated laterally and vertically. Therefore, appropriate LNAPL monitoring points should be used to demonstrate that the LNAPL body is stable and not migrating or to identify future LNAPL body migration. For example, permanent monitoring wells should be installed at the periphery of the LNAPL body, outside of the extent of LNAPL exceeding residual saturation, and in a downgradient direction to demonstrate that the LNAPL body is stable and not migrating. The requirements for monitoring will be established on a site-specific basis.

Monitoring of LNAPL thickness and presence/absence within permanent monitoring wells is typically conducted using field instruments, such as oil/water interface meters. Oil/water interface meters utilize infra-red beam and detector technology to differentiate between water and LNAPL and can accurately measure LNAPL thicknesses to 0.01 feet in thickness. The use of oil/water interface meters to measure LNAPL thicknesses may also be supplemented with direct visual confirmation of LNAPL thickness by lowering a submersible bailer to the top of the water table and gently allowing the bailer to fill from the top of the water column present in the monitoring well. The bailer may be recovered and LNAPL thickness in the bailer directly observed. However, LNAPL thickness measurements should be recorded with an oil/water interface probe due to potential accuracy issues associated with measuring the thickness of LNAPL observed in a bailer.

LNAPL extent and thickness monitoring may be conducted on a monthly frequency. For sites with recent LNAPL releases, more frequent monitoring may be necessary. For older releases and stable LNAPL bodies of minimal thicknesses, a less frequent schedule may be appropriate. Please consult with the DEQ technical contact regarding LNAPL monitoring schedules, which are established on a site-specific basis.

6.3 Active LNAPL Recovery

Active LNAPL recovery refers to the use of equipment (such as a skimmer or well bailer) to induce migration to a LNAPL collection point and subsequent removal of LNAPL. There are a variety of effective and appropriate means of LNAPL recovery. Appendix A presents an overview of LNAPL remedial technologies (reproduced from ITRC, 2009b). The selection of the most effective LNAPL recovery method is site specific. Numerous active LNAPL recovery methods may be considered and evaluated prior to the selection of an active recovery technology for a site. Please consult with the DEQ technical contact regarding proposed active LNAPL recovery technologies, which will be established on a site-specific basis.

Active LNAPL recovery often occurs where LNAPL exceeds 0.5 feet in thickness. However, site specific characteristics (such as LNAPL accumulation rates in LNAPL collection points and mobility) may justify the use of active recovery in instances where LNAPL is present at thicknesses less than 0.5 feet.

Active LNAPL recovery generally occurs on a monthly basis at a minimum. However, sites with recent LNAPL releases, receptors present, or significant LNAPL thicknesses may require more frequent active LNAPL recovery. Please confer with the DEQ technical contact regarding an active LNAPL recovery schedule, which is established on a site-specific basis.

6.4 Passive LNAPL Recovery

Passive LNAPL Recovery refers to the collection of LNAPL as it naturally migrates into a LNAPL collection point, typically through placement of LNAPL absorbent material or equipment (such as absorbent “socks” or product recovery canisters) at the top of the water table. Passive LNAPL recovery methods still need regular monitoring to remove recovered LNAPL from the absorbent material and to monitor the thickness of LNAPL in the well. Passive recovery is typically only conducted when it has been demonstrated to DEQ’s satisfaction and approval that active recovery methods are of limited effectiveness at a monitoring location. This determination is made on a site-specific basis.

Passive LNAPL recovery may be appropriate where thicknesses of LNAPL are observed between 0.01 and 0.5 feet and active recovery methods have been demonstrated to have limited effectiveness (as approved by DEQ). However, site specific characteristics (such as LNAPL accumulation rates in

LNAPL collection points and mobility) may justify the use of passive recovery in instances where LNAPL is present at thicknesses greater than 0.5 feet.

Passive LNAPL recovery occurs continuously once passive LNAPL recovery materials are placed within the LNAPL body and these recovery systems are monitored on a regular basis. Please consult with the DEQ technical contact regarding an appropriate site specific monitoring schedule.

6.5 Recovered LNAPL On-Site Storage and Off-Site Disposal

If recovered LNAPL is stored on-site, it is important that the storage location be secure, locked, and protected from accidental discharge through the use of secondary containment. For sites producing small quantities of recovered LNAPL, this may be as simple as a 55 gallon drum placed on top of a secondary containment platform in a locked shed. For sites recovering greater volumes of LNAPL, larger storage vessels and secondary containment units are necessary. Please consult with the DEQ technical contact to verify the adequacy of LNAPL storage and secondary containment, which is a site-specific determination.

Off-site disposal of LNAPL may be accomplished through a used oil collector or a hazardous waste transportation service provider. Lists of used oil collectors and hazardous waste transportation service providers available to perform LNAPL disposal may be found here: http://deq.mt.gov/hazwaste/default.mcpx.

7.0 Reporting

When reporting LNAPL monitoring and recovery efforts to DEQ, reporting requirements are determined on a site-specific basis and may include:

- An introduction describing the site name and location, site operational history, site ownership and history, and a legal description and map;
- A CSM, as detailed in section 5.0;
- A thorough evaluation of receptors potentially exposed to LNAPL directly, by exposure to dissolved phase contaminants in groundwater, or by exposure to LNAPL vapors, including the vapor intrusion pathway;
- Laboratory analytical data from groundwater or soil samples collected at the site;
- Figures and tables summarizing the locations and results of sampling;
- The volume of LNAPL recovered from the subsurface;
- The volume of LNAPL disposed of off-site (supported with appropriate disposal documentation) or currently stored on-site;
- Volume and details (including analytical results) regarding groundwater treated or disposed of off-site (if applicable);
- Depth to groundwater and LNAPL thickness measurements;
- Maps drawn to scale showing LNAPL plume extent in three dimensions and extent of dissolved phase contaminants exceeding their respective Circular DEQ-7 Montana Numeric Water Quality Standard or RBCA screening level; and
- Conclusions and recommendations for further LNAPL delineation, characterization, or recovery.

8.0 References

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Appendix A: LNAPL Recovery Technologies

Table 1-1. Overview of LNAPL remedial technologies (ITRC 2009)

LNAPL technology	Description of technology
1. Excavation	LNAPL body is physically removed and properly treated or disposed (LNAPL mass recovery).
2. Physical or hydraulic containment (barrier wall, French drain, slurry wall, wells, trenches)	Subsurface barrier is constructed to prevent or impede LNAPL migration (LNAPL mass control).
3. In situ soil mixing (stabilization)	LNAPL body is physically/chemically bound within a stabilized mass to reduce mobility (LNAPL mass control).
4. Natural source zone depletion (NSZD)	LNAPL constituents are naturally depleted from the LNAPL body over time by volatilization, dissolution, absorption, and degradation (LNAPL phase-change remediation).
5. Air sparging/soil vapor extraction (AS/SVE)	AS injects air into LNAPL body to volatilize LNAPL constituents, and vapors are vacuum extracted. AS or SVE can also be used individually if conditions are appropriate (LNAPL phase-change remediation).
6. LNAPL skimming	LNAPL is hydraulically recovered from the top of the groundwater column within a well (LNAPL mass recovery).
7. Bioslurping/enhanced fluid recovery (EFR)	LNAPL is remediated via a combination of vacuum-enhanced recovery and bioventing processes (LNAPL phase-change remediation).
8. Dual-pump liquid extraction (DPLE)	LNAPL is hydraulically recovered by using two pumps simultaneously to remove LNAPL and groundwater (LNAPL mass recovery).
9. Multiphase extraction (MPE)(dual pump)	LNAPL and groundwater are removed through the use of two dedicated pumps. Vacuum enhancement is typically added to increase LNAPL hydraulic recovery rates (LNAPL mass recovery).
10. Multiphase extraction (MPE) (single pump)	LNAPL is recovered by applying a vacuum to simultaneously remove LNAPL, vapors, and groundwater (LNAPL mass recovery).
11. Water flooding (including hot water flooding)	Water is injected to enhance the hydraulic LNAPL gradient toward recovery wells. Hot water may be injected to reduce interfacial tension and viscosity of the LNAPL and further enhance LNAPL removal by hydraulic recovery (LNAPL mass recovery).
12. In situ chemical oxidation (ISCO)	LNAPL is depleted by accelerating LNAPL solubilization by the addition of a chemical oxidant into the LNAPL zone (LNAPL phase-change remediation).
13. Surfactant-enhanced subsurface remediation (SESR)	A surfactant is injected that increases LNAPL solubilization and LNAPL mobility. The dissolved phase and LNAPL are then recovered via hydraulic recovery (LNAPL phase-change remediation and LNAPL mass recovery).
14. Cosolvent flushing	A solvent is injected that increases LNAPL solubilization and LNAPL mobility. The dissolved phase and LNAPL are then recovered via hydraulic recovery (LNAPL phase-change remediation and LNAPL mass recovery).
15. Steam/hot-air injection	LNAPL is removed by forcing steam into the aquifer to vaporize, solubilize, and induce LNAPL flow. Vapors, dissolved phase, and LNAPL are recovered via vapor extraction and hydraulic recovery (LNAPL phase-change remediation, and LNAPL mass recovery).

LNAPL technology	Description of technology
16. Radio-frequency heating (RFH)	Electromagnetic energy is used to heat soil and groundwater to reduce the viscosity and interfacial tension of LNAPL for enhanced hydraulic recovery. Vapors and dissolved phase may also be recovered via vapor extraction and recovery.
17. Three- and six-phase electrical resistance heating	Electrical energy is used to heat soil and groundwater to vaporize volatile LNAPL constituents and reduce the viscosity and interfacial tension of LNAPL for enhanced hydraulic recovery. Vapors and dissolved phase may also be recovered via vapor extraction and hydraulic recovery (LNAPL phase-change remediation and LNAPL mass recovery).

Table 1-2. Summary information for remediation technologies (ITRC 2009)

LNAPL technology	Advantages	Disadvantages[a]	geology (fine, coarse)[b]	unsaturated zone, saturated zone[c]	Applicable type of LNAPL[d]	objective type (saturation, composition)[e]	Potential time frame[f]
Excavation	100% removal, time frame	Accessibility, depth limitations, cost, waste disposal	F, C	U + S	LV, LS, HV, HS	Sat + Comp	V. short
Physical or hydraulic containment (barrier wall, French drain, slurry wall)	Source control, mitigation of downgradient risk	Hydraulic control required, site management, cost, depth and geologic limitations	F, C	S	LV, LS, HV, HS	Sat + Comp	V. long
In situ soil mixing (stabilization)	Time frame, source control	Accessibility, required homogeneity, depth limitations, cost, long-term residual management	F, C	U + S	LV, LS, HV, HS	Sat + Comp	V. short to short
Natural source zone depletion	No disruption, implementable, low carbon footprint	Time frame, containment	F, C	U + S	HV, HS	Sat + Comp	V. long
Air sparging/soil vapor extraction	Proven, implementable, vapor control	Does not treat heavy-end LNAPLs/low-permeability soils, off-gas vapor management	C	U + S	HV, HS	Sat + Comp	Short to medium
LNAPL skimming	Proven, implementable	Time frame, limited to mobile LNAPL, ROI[g]	F, C	S	LV, LS, HV, HS	Sat	Long to v. long
Bioslurping/ enhanced fluid recovery	Proven, implementable, vapor control	Time frame, limited to mobile LNAPL, ROI	F, C	U + S	LV, LS, HV, HS	Sat + Comp	Long to v. long
Dual-pump liquid extraction	Proven, implementable, hydraulic control	Time frame, limited to mobile LNAPL, ROI	C	S	LV, LS, HV, HS, > residual	Sat	Long to v. long

LNAPL technology	Advantages	Disadvantages[a]	geology (fine, coarse)[b]	unsaturated zone, saturated zone[c]	Applicable type of LNAPL[d]	objective type (saturation, composition)[e]	Potential time frame[f]
Multiphase extraction (dual pump)	Proven, implementable, hydraulic control	Generated fluids treatment	C	S	LV, LS, HV, HS, > residual	Sat + Comp	Medium
Multiphase extraction (single pump)	Proven, implementable, hydraulic control, vapor control	Generated fluids treatment	C	U + S	LV, LS, HV, HS, > residual	Sat + Comp	Medium
Water flooding (including hot water flooding)	Proven, implementable	Capital equipment, hydraulic control required, homogeneity, flood sweep efficiency[h]	C	S	LV, LS, HV, HS, > residual	Sat	Short
In situ chemical oxidation	Time frame, source removal	Rate-limited hydraulic control required, by-products, cost, vapor generation, rebound, accessibility/spacing homogeneity, MNO2 crusting	C	U (ozone oxidant) + S	HV, HS	Comp	V. short to short
Surfactant-enhanced subsurface remediation	Time frame, source removal	Hydraulic control required, by-products, cost, dissolved COCs[i] treatment, required homogeneity, water treatment, access	C	S	LV, LS, HV, HS	Sat + Comp	V. short to short
Cosolvent flushing	Time frame, source removal	Hydraulic control required, by-products, cost, vapor generation, access, sweep efficiency	C	S	LV, LS, HV, HS	Sat + Comp	V. short to short
Steam/hot-air injection	Time frame, source removal, proven, implementable	Hydraulic control required, capital equipment, cost, required homogeneity, vapor generation, access, sweep efficiency	C	U + S	LV, LS, HV, HS	Sat + Comp	V. short
Radio-frequency heating	Time frame, source removal, proven, implementable	Hydraulic control required, by-products, cost, vapor generation, access	F	U + S	LV, LS, HV, HS	Sat + Comp	V. short

LNAPL technology	Advantages	Disadvantages[a]	geology (fine, coarse)[b]	unsaturated zone, saturated zone[c]	Applicable type of LNAPL[d]	objective type (saturation, composition)[e]	Potential time frame[f]
Three- and six-phase electrical resistance heating	Low-permeability soils, time frame, source removal	Hydraulic control required, by-products, cost, energy required, vapors, spacing, access	F	U + S	LV, LS, HV, HS	Sat + Comp	V. short

[a] Any of these technologies may have particular state-specific permitting requirements. Check with your state regulatory agency.
[b] Applicable geology: F = clay to silt, C = sand to gravel.
[c] Applicable zone: U = unsaturated zone, S = saturated zone.
[d] LNAPL type: LV, LS = low volatility, low solubility, medium or heavy LNAPL (e.g., weathered gasoline, diesel, jet fuel, fuel oil, crude oil);
HV, HS = high volatility, high solubility, light LNAPL with significant percentage of volatile or soluble constituents (e.g., gasoline, benzene);
> residual = only for LNAPL saturation greater than residual.
[e] Primary mechanism is in bold.
[f] V. short = <1 year, Short = 1-3 years, Medium = 2-5 years, Long = 5-10 years, V. long = >10 years.
[g] ROI = radius of influence.
[h] Sweep efficiency is analogous to ROI, but injection technology refers to effectiveness of injectate dispersal (sweep).
[i] COC = constituent of concern. (ITRC 2009)