New Jersey Department of Environmental Protection
Site Remediation Program
Light Non-aqueous Phase Liquid (LNAPL) Initial Recovery and Interim Remedial Measures Technical Guidance

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APPENDICES

LIGHT NONAQUEOUS PHASE LIQUID INITIAL RECOVERY AND INTERIM REMEDIAL MEASURES GUIDANCE

I. INTENDED USE OF GUIDANCE DOCUMENT

This guidance is designed to help the person responsible for conducting remediation to comply with the New Jersey Department of Environmental Protection (Department) requirements established by the Technical Requirements for Site Remediation (Technical Rules), N.J.A.C. 7:26E. This guidance will be used by many different people involved in the remediation of a contaminated site; such as Licensed Site Remediation Professionals (LSRP), Non-LSRP environmental consultants and other environmental professionals. Therefore, the generic term "investigator" will be used to refer to any person that uses this guidance to remediate a contaminated site on behalf of the person responsible for conducting the remediation, including the person responsible for conducting the remediation itself.

The procedures for a person to vary from the technical requirements in regulation are outlined in the Technical Rules at N.J.A.C. 7:26E-1.7. Variances from a technical requirement or deviation from guidance must be documented and adequately supported with data or other information. In applying technical guidance, the Department recognizes that professional judgment may result in a range of interpretations on the application of the guidance to site conditions.

This guidance supersedes previous Department guidance issued on this topic in N.J.S.A. 26:10C-16.

This guidance was prepared with stakeholder input. The following people were on the committee who prepared this document:

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II. PURPOSE

The Site Remediation Reform Act (SRRA) N.J.S.A. 58:10C, which was enacted in May 2009, requires the Department to develop new regulations and guidance that provide direction on a number of issues involving the remediation of contaminated sites. In particular, N.J.S.A 58:10C-28 requires the Department to establish mandatory timeframes for "control of ongoing sources" and "establishment of interim remedial measures" (IRM). This Guidance has been developed to provide general direction to investigators responsible for conducting the investigation of Light Nonaqueous Phase Liquid (LNAPL) and implementing the IRM. As a result, the overall objectives of the IRM are to prevent LNAPL migration and reduce contaminant mass. This guidance addresses the following activities when responding to the presence of measurable LNAPL (measured, or otherwise observed, to have a thickness of greater than 0.01 feet):

- Conduct Initial LNAPL recovery efforts.
- Implement LNAPL specific Remedial Investigation (RI) activities.
- Develop a Conceptual Site Model (CSM) to assist investigative and remedial decision making.
- Initiate LNAPL IRM.

This guidance should be used in concert with other Department guidance documents, the Regulations Implementing the Underground Storage of Hazardous Substances Act (N.J.A.C. 7:14B) and Industrial Site Recovery Act (N.J.A.C. 7:26B), the Technical Requirements for Site Remediation (N.J.A.C. 7:26E) and other relevant and applicable statutes and regulations. Understanding the nature and extent of the LNAPL will help define the scope of the IRM and aid in monitoring the effectiveness of the action. Implementation of both initial recovery efforts and IRM can be an effective means to reduce both the costs and the length of the remediation.

III. OVERVIEW AND LIMITATIONS

This document provides guidance on the steps that should be taken when measurable LNAPL is identified in a monitoring well or other collection points. The presence of LNAPL sheen does not trigger the LNAPL regulatory or mandatory timeframes, nor does an LNAPL that is 0.01 feet thick. It should be recognized that at any site where LNAPL has been discharged, the contamination associated with that LNAPL can exist in multiple phases simultaneously in the subsurface. A comprehensive remedial investigation and remedial action addresses the separate, residual, vapor and dissolved phases of contamination that result from a LNAPL discharge. Addressing residual, vapor and dissolved phases of contamination associated with LNAPL is required under N.J.A.C. 7:26E, but not within the scope of this guidance, nor do these activities fall within the LNAPL regulatory and mandatory timeframes. If the investigator determines that it is more effective to address the LNAPL as part of a comprehensive remedial approach that addresses multiple contaminant phases simultaneously, this guidance provides flexibility for the implementation of a comprehensive remedial strategy.

The context of this document focuses on LNAPL recovery and activities to define the extent of the LNAPL plume to comply with LNAPL timeframes. It is assumed that the investigator, as the first priority, is identifying and stopping the source of any ongoing LNAPL discharge.

For the purpose of this document, “initial” recovery efforts are the first responses to LNAPL recovery (when practicable), and are usually initiated upon identification of the presence of measurable LNAPL, but before a LNAPL specific remedial investigation is complete. The LNAPL IRM should be initiated following completion of the LNAPL specific remedial investigation.

When developing the IRM for LNAPL at a site, keep in mind that requirements for a final remedy per N.J.A.C. 7:26E-5.1(e), provides that free and/or residual product determined to be present at a site shall be treated or removed when practicable, or contained when treatment or removal are not practicable. Although it is recommended that this requirement for final remedies be considered when designing an appropriate LNAPL IRM, this Guidance is limited to compliance with the LNAPL regulatory and mandatory timeframes. As such, it is not intended to direct measures that may be necessary as part of a final remedy for the treatment or removal of free and/or residual product as defined in N.J.A.C. 7:26E. It should be noted that during the course of the RI and IRM, data and/or information may become available to determine that LNAPL recovery/treatment may not be practicable. Alternatively, the remedial actions implemented during the IRM may be a substantial component of a final remedial action.

The documents referenced within this Guidance are considered essential, prerequisite reading material that supports the efforts to address LNAPL activities within the regulatory and mandatory timeframes. It is assumed that the investigator implementing actions for LNAPL and using this Guidance is familiar with and experienced in the underlying science. The inclusion of specific reference documents within this Guidance are not intended to modify or otherwise alter compliance with N.J.A.C. 7:26E.

This guidance outlines the regulatory and mandatory timeframes established in the Technical Requirements for Site Remediation at N.J.A.C. 7:26E-1.10 and Administrative Requirements for the Remediation of Contaminated Sites at N.J.A.C. 7:26C-3.3(a)4; respectively.

A. Regulatory timeframes for LNAPL

The regulatory timeframes for LNAPL are as follows:

- 60 days from LNAPL discovery

    1. Report the presence of LNAPL on the required LNAPL Reporting Form (see N.J.A.C. 7:26E-1.10(b)1);
    2. Conduct initial LNAPL recovery, when practicable, and report the status of the actions taken within this timeframe using the required LNAPL Reporting Form (see N.J.A.C. 7:26E-1.10(b)2).

- 1 year from LNAPL discovery

    1. Complete the delineation of the LNAPL (see N.J.A.C 7:26E-1.10(c)1);
    2. Initiate a LNAPL IRM to prevent migration and reduce contaminant mass to the extent practicable and initiate operational monitoring. The IRM should consider all known human and ecological exposure risks (see N.J.A.C. 7:26E-1.10(c)2);
    3. Document the delineation of the LNAPL, the LNAPL recovery efforts conducted to date, and implementation of the LNAPL IRM through submittal of an LNAPL interim remedial measures report with an updated LNAPL Reporting Form (see N.J.A.C. 7:26E-1.10(c)3).

Unregulated Heating Oil Tank Sites are not subject to mandatory timeframes pursuant to N.J.S.A. 58:10C-30 d.(1); however, the regulatory timeframes for responding to the presence of LNAPL remain applicable and use of this guidance is encouraged.

B. Mandatory timeframe for initiating LNAPL IRM

The Mandatory Timeframe for initiating LNAPL IRM is two years from the date of discovery. This includes the completion of the remedial investigation of the LNAPL, the initiation of operational monitoring of the IRM and submission of a LNAPL interim remedial measures report with the form available from the Department (see N.J.A.C. 7:26C-3.3).

The guidance provided herein addresses conditions that are encountered at the majority of the sites where measurable LNAPL is present. However, the Department recognizes that LNAPL conditions and behavior at different sites vary significantly, as do the appropriate response actions. Not all LNAPL sites pose the same concerns and risks, and therefore, may not warrant the same level of response. For example, large facilities may have areas of LNAPL that cannot be addressed in the standard established timeframes. For large or complex LNAPL sites, the Department suggests that the investigator meet with the Department to define a strategy to meet the LNAPL regulatory and mandatory timeframes. If in the professional opinion of the investigator, deferring the action required will not compromise the stated objectives, the person responsible for conducting the remediation shall document the site specific basis for such a determination in an extension request in accordance with N.J.A.C. 7:26C-3.2 and 3.5 and request additional time to comply with these requirements.

IV. SUMMARY OF LNAPL BEHAVIOR IN THE SUBSURFACE

This section provides an overview of the basic concepts of LNAPL behavior in the subsurface. Some wording of this summary is borrowed from concepts provided in the references from Minnesota 2010, USEPA 2005, ITRC 2009 and Alaska 2006. While direct citations are noted, these documents should be consulted for the exact language attributed to these publications. Additional information on LNAPL behavior can be obtained from a variety of publications, including those listed in the attached reference section. These publications should be referenced for more detailed information regarding LNAPL behavior and other important LNAPL concepts that are not discussed in this section.

The presence of LNAPL and the characterization of LNAPL in the subsurface is often determined primarily by the measurement\observation of LNAPL in monitoring wells. It is noted, however, that the relative measure of apparent thickness of LNAPL in a well, while indicative of LNAPL presence, has been shown to be a poor indicator of the magnitude, mobility or recoverability of LNAPL in the vicinity of the well. Therefore, the investigator is cautioned on the use and reliance on in-well LNAPL thickness only, and is encouraged to develop a thorough understanding of the LNAPL conditions.

Some of the many site-specific factors that may significantly affect LNAPL migration and recoverability are as follows:

- soil/rock texture, pore size and geometry;
- hydrogeologic factors such as pore water content, hydraulic conductivity, water table fluctuations, and aquifer type (e.g., confined, unconfined, perched, fractured bedrock, etc.);
- fluid properties such as fluid density, viscosity and interfacial tension;
- soil-fluid interaction properties such as capillary pressure and relative permeability; and site-specific variability of these properties (e.g., heterogeneities).

The following discussion assumes relatively homogeneous geology and an unconfined water table, but the basic physical concepts can be applied to all geologic conditions. When petroleum LNAPL is discharged onto or into the ground, it migrates downward under the force of gravity through the unsaturated (vadose) zone. As the LNAPL migrates through the vadose zone, some of it will be left behind, sorbed, trapped and immobilized in the pores by capillary forces and geologic heterogeneities. If a sufficient volume of petroleum is released, LNAPL can reach the saturated zone (capillary fringe and water table), where it will begin to accumulate and spread laterally because of its lower density and immiscibility with respect to water. Under sufficient head pressure, the LNAPL body may infiltrate the capillary fringe and effectively depress the water table. LNAPL will continue to migrate vertically and horizontally until equilibrium is reached, displacing air from pore spaces within the vadose zone and some of the water from the larger pores in the saturated zone.

After the release has stopped, the spread of the LNAPL body is spatially limited by forces that counteract the force of the LNAPL gradient including LNAPL buoyancy and capillary forces. There are two general stages in the development of the LNAPL body at the saturated zone after a subsurface petroleum release: 1) the initial, shorter duration expansion stage when the LNAPL is actively migrating under a sufficient LNAPL gradient; and 2) a much longer duration stable stage when migration is minimal to nonexistent after the hydraulic forces driving LNAPL migration have diminished relative to counteracting forces (Minnesota 2010). However, if there are changes in these forces, such as water table elevation or gradient changes, LNAPL plume stability can change both horizontally and vertically. Because petroleum 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.

LNAPL body behavior can be characterized based partly on the LNAPL saturation. LNAPL saturation is defined as the percentage of total pore volume occupied by LNAPL (ITRC 2009). In the vadose zone, LNAPL shares pore space with both air and water (present as soil moisture). In the saturated zone, LNAPL shares pore space only with water. Under vertical equilibrium, higher LNAPL saturations are usually observed near the top of the LNAPL body and the saturated zone, and the relative amount of LNAPL in the pores generally decreases with depth below the capillary fringe and/or water table. The change in LNAPL saturation with depth is referred to as the saturation profile. The saturation profile can be irregular and can vary spatially due to stratification and other soil heterogeneities. The saturation profile also changes over time as the LNAPL is re-distributed by water table fluctuations. Vertical redistribution of LNAPL due to water table fluctuations often results in a LNAPL 'smear zone' of a thickness that is equal to or greater than the historical range of water table fluctuations. Water table fluctuations may control the appearance and disappearance of LNAPL in a well, and may significantly impact migration potential, recharge rates and recoverability.

Some of the LNAPL will eventually become hydraulically isolated leaving independent globules of LNAPL differentially trapped in pores and/or geologic irregularities. Residual LNAPL saturation is defined as the LNAPL saturation under which the LNAPL is "immobile under the applied gradient" (ITRC 2009). This terminology is synonymous with the term residual phase product defined under the Technical Requirements for Site Remediation. LNAPL below residual saturation is neither mobile nor hydraulically recoverable; although a technology that changes the LNAPL physically or chemically may be capable of increasing contaminant mass recovery. LNAPL exceeding residual saturation is referred to as mobile LNAPL (ITRC 2009). As indicated by ITRC, if mobile LNAPL is observed to spread or expand such as based upon time series data, it is referred to as migrating LNAPL. Mobile LNAPL may or may not be migrating, but it is potentially recoverable in the liquid phase. Mobile LNAPL is considered to be free product as defined by the Technical Requirements for Site Remediation.

The presence of measurable LNAPL in a given collection point indicates potential mobility in the vicinity of the collection point, but does not necessarily mean that the LNAPL body is migrating. For migration to occur at the edges of the LNAPL body, the forces that drive lateral LNAPL migration, such as the LNAPL gradient (head), must overcome the pore entry pressure. At some point at the leading edges of the LNAPL body, counteracting forces prohibit further LNAPL migration in the absence of a stronger LNAPL gradient or continuing LNAPL source. As a result, LNAPL bodies will eventually become spatially stable under prevailing conditions even though LNAPL exceeding residual saturation may remain in the core of the LNAPL body (Minnesota 2010). LNAPL bodies typically stabilize after the release stops and the driving force (head) dissipates.

In general, if LNAPL does not collect in properly constructed and properly located monitoring wells during periods of low water table conditions, mobile LNAPL is likely not present at the spill site, and any LNAPL present should be considered immobile residual product. If LNAPL does collect in a monitoring well, LNAPL is potentially mobile in the soil near the monitoring well, but the LNAPL plume or plume body may or may not be mobile or migrating at a site scale. Temporal gauging of monitoring wells with screened intervals bridging the water table within the LNAPL body and at the plume fringes is one of the most useful tools for determining whether mobile LNAPL is present at a site and if the LNAPL body is migrating on a site scale (Alaska 2006).

The LNAPL that is observed in collection points is the result of LNAPL draining from pores in the immediate vicinity of the collection point. LNAPL can drain into a collection point either naturally or due to engineered controls such as pumping, to the extent that it remains mobile in the area of the collection point. Once the residual saturation is reached, further hydraulic recovery, in the liquid phase without altering the chemical or physical properties of the residual LNAPL, will not be possible. The residual saturation is a theoretical endpoint for pumping-based recovery systems that will not likely be achieved on a field-scale. At residual saturation, the LNAPL cannot move unless the chemical or physical properties of the LNAPL are altered by other LNAPL remediation technologies (USEPA 2005). Examples of chemical or physical changes that can affect the residual saturation include induced pressure gradients from a soil vapor-extraction system, changes in interfacial tension through the use of surfactants, or reduction in viscosity through the addition of heat (Charbeneau, R 2000).

In the absence of an ongoing release or a migrating LNAPL body, and accounting for water table fluctuations, LNAPL recharge rates at a given collection point will decline over time as mobile LNAPL is depleted in the formation around the collection point. However, hydraulic recovery of LNAPL will not result in elimination of all LNAPL in the formation outside the collection point. Significant LNAPL mass will still be present at or below residual saturation after mobile LNAPL has been recovered. Depending on the type and composition of the LNAPL, the residual LNAPL body may continue to be a source of contaminants of concern (COCs) in the dissolved and vapor phases, even after a LNAPL body stabilizes and/or LNAPL saturation has been reduced to residual levels (Minnesota 2010).

V. CONCEPTUAL SITE MODEL

The CSM is a written and graphical representation of the physical, chemical and biological processes that control the transport, migration and interaction of COCs through environmental media associated with an Area of Concern (AOC) or an entire remediation site (site).

An understanding of LNAPL behavior and specific pathway information should be incorporated into the development of an overall CSM for the site and/or AOC, as described in the Department CSM Guidance (http://www.nj.gov/dep/srp/guidance/#csm). The Department CSM Guidance provides a description of the basic components that should be included in the development of a CSM for a site or AOC. The following information for LNAPL should be collected to support the development of a complete CSM. Important data to include in a LNAPL CSM may include the following:

- understanding LNAPL sources
- chemical composition and physical characteristics of the LNAPL
- site specific geology, hydrogeology and related stratigraphic and structural controls that may be influencing LNAPL distribution and recoverability
- extent and distribution of LNAPL body in three dimensions
- groundwater flow including correction factors for LNAPL
- location of potential receptors, including potential preferential migration pathways
- LNAPL saturation, mobility and recoverability
- known concentrations of compounds in dissolved and vapor phase

As the limits of the LNAPL in the subsurface are defined, updating the conceptual site model is appropriate. The information gained through the site and remedial investigations is used to characterize the physical, biological, and chemical systems existing at a site. The type of contaminant discharge, contaminant migration, and environmental receptor exposure to contaminants are described and integrated in the CSM. The CSM is used to integrate all site information, identify data gaps and determine whether additional information needs to be collected at the site. The model is further used to facilitate the selection of remedial alternatives and to evaluate the effectiveness of remedial actions in reducing the exposure of environmental receptors to contaminants (ASTM E1689 - 95(2008)). The CSM should be considered iterative and dynamic and should be modified and expanded upon as site specific data and information is collected and evaluated. The scope and complexity of the CSM should be scaled to match the level of risk, complexity of the site, and remedial goals.

Many articles have been written on conceptual site models, but ASTM 2007, USEPA 2005 and ITRC 2009 may be particularly useful.

When reporting to the Department, the investigator should be able to describe the CSM developed for the site. Based upon the CSM, the investigator should be able to depict the extent of measurable LNAPL, depict groundwater flow direction, and document the evaluation of preferential pathways, both natural and manmade, for potential LNAPL migration. Decisions regarding the scope of the LNAPL Initial Recovery efforts and IRM should be supported by the CSM.

VI. INITIAL LNAPL RECOVERY

When selecting an initial LNAPL recovery method, human and ecological receptor issues should be considered, as guided by the CSM. It should be noted that all receptor risks and requirements for evaluating receptors may not be known or completed at the time of initial LNAPL discovery. Professional judgment should be used to select the initial method of recovery recognizing that this initial approach may change as more site information becomes available. Use of a more aggressive IRM may be warranted depending on the estimated volume of LNAPL discharged (if known), the mobility, toxicity and solubility of the LNAPL being addressed, potential migration pathways and the proximity of receptors to the LNAPL. It should also be recognized that the application of an expeditious approach during the initial response (i.e., for removal of LNAPL from tank field wells following a catastrophic release or removal of product from the water table during excavation activities, etc.) may reduce long term remediation and monitoring costs and allow for the use of less intensive remedial techniques over the long term for overall site cleanup. Initial LNAPL recovery efforts should be conducted concurrently with LNAPL delineation activities and initial recovery efforts should be expanded, as necessary, as the extent of LNAPL is defined. Appendix A contains “Table 1-1. Overview of LNAPL remedial technologies” and “Table 1-2. Summary information for remediation technologies” (ITRC 2009) that provide examples of LNAPL remediation technologies that can be considered, except as noted below, for initial recovery efforts.

While natural processes such as dissolution, volatilization and biodegradation can contribute to LNAPL mass reduction, natural source zone depletion alone does not meet this Guidance or the LNAPL removal requirements under the Technical Requirements for Site Remediation.

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VII. DELINEATION OF LNAPL

The data gathered during delineation should be added to the CSM. The CSM should:

- account for LNAPL behavior as described in Section IV;
- be used as a guide when determining the horizontal and vertical distribution of the LNAPL in the subsurface, and;
- be used as a tool for choosing the appropriate delineation methods and sampling locations.

Delineation should include an evaluation of the presence of LNAPL within the saturated zone.

Appendix B provides a brief description of typical methods used to delineate LNAPL. Additional guidance can be found in the Field Sampling Procedures Manual located at http://www.nj.gov/dep/srp/guidance/fspm/ and in the Ground Water SI/RI/RA Technical Guidance located at http://www.nj.gov/dep/srp/guidance/#pa_si_ri_gw, as well as in the guidance documents cited in Section IV.

Following initial delineation, the presence and extent of measurable LNAPL should be confirmed through additional monitoring events and/or the completion of additional wells, borings or trenches. It should be noted that the presence of a sheen in a newly installed well may or may not be indicative of measurable LNAPL. Regular gauging of wells with a sheen should be conducted in order to evaluate whether measurable LNAPL appears with changing water level elevations. Useful information concerning key LNAPL concepts related to its presence, distribution and mobility in the subsurface can be found in the references.

VIII. INTERIM REMEDIAL MEASURE (IRM) FOR LNAPL

The person responsible for conducting the remediation is required to implement an IRM and initiate operational monitoring within 1 year of the initial discovery of the LNAPL. Based on the results of the LNAPL delineation and characterization, the investigator should have a better understanding of site information to select an appropriate IRM, which, if appropriate, could be a continuation of the initial recovery effort. The CSM should be refined using information collected during the initial recovery efforts and remedial investigation to help guide IRM selection.

The IRM should be selected, designed and implemented to meet the following remedial objectives:

- Prevent migration and any further spreading of the LNAPL body.
- Reduce LNAPL contaminant mass, when practicable.
- Consider and address any known receptor risks associated with the LNAPL.

Appendix A contains Table 1-1. “Overview of LNAPL remedial technologies” and Table 1-2 “Summary information for Remediation Technologies” (ITRC 2009) that provide examples of LNAPL remediation technologies that can be considered, except as noted in Section VI above, for LNAPL IRMs.

Information collected as part of the CSM should be screened against available LNAPL remedial technologies. Remedial measures that use liquid product recovery and/or phase change methodologies to influence LNAPL mobility/recoverability should be considered. Using Appendix A and/or other screening tools, such as API 2004, can assist the investigator in initially narrowing the range of practicable LNAPL IRMs.

In the selection/development of some IRMs, completion of pilot tests may be necessary to evaluate the feasibility and/or applicability of the proposed technology and to support final design or the conclusion that recovery is not practicable. USEPA 2005 and API 2004 can provide additional insights on LNAPL recoverability, Depending on the IRM being evaluated, pilot tests and the IRM itself may require permits or other approvals from regulatory agencies which may result in the need for additional time to complete the process. In this situation, the initial LNAPL recovery should continue and an extension to the LNAPL timeframe should be requested, as warranted, until the IRM is implemented.

Depending upon the complexity of the site, and the practical and technological limitations of the selected IRM approach, the investigator should identify specific IRM goals and performance metrics or endpoints to meet the stated overall IRM objectives. The specific IRM goals and performance metrics should be clearly identified to allow for measuring the progress of the IRM.

IX. OPERATIONAL MONITORING

Once an IRM is implemented, monitoring is required pursuant to N.J.A.C. 7:26E-1.10(c)2 to assess the protectiveness and effectiveness of the chosen IRM. The type and frequency of monitoring should be based on the CSM developed for the site which identifies the LNAPL type, source and distribution, site specific receptor issues, hydrogeologic influences on LNAPL behavior and other factors affecting LNAPL migration and recoverability. The operational monitoring should validate the assumptions developed for the site and document that the selected IRM is effective in preventing migration, reducing mass, when practicable, and is protective of known human and ecological receptors.

The operational monitoring plan for the site should be designed to gather sufficient data to verify that the IRM specific goals, performance metrics and endpoints of the IRM, as defined by the investigator, have been or are being met. The operational monitoring plan should be modified, as necessary, to adapt to changing site conditions which may occur during IRM implementation. An effective operational monitoring plan could also be designed to generate additional data for site characterization and completion of RI activities which may be needed to design the final remedy for the site.

A . Types of Monitoring

1. Monitoring the LNAPL Body

Since a remedial investigation should have resulted in a detailed understanding of the source(s) and distribution of the LNAPL at the site, it is anticipated that an appropriate monitoring well network was installed during the RI phase. This monitoring well network should include wells located within the LNAPL body and an appropriate array of wells around the perimeter of the LNAPL body. The spacing of these wells should reflect and account for site specific subsurface characteristics as well as the characteristics of the LNAPL being monitored. A sufficient number of monitoring points shall be located within the LNAPL body to establish and document LNAPL distribution, to predict behavior and migration and to assess recoverability. Perimeter wells should be located just beyond the LNAPL body, but close enough to verify that LNAPL is not migrating.

Monitoring should be conducted on a regular basis at all LNAPL sites during the IRM phase. Operational monitoring should include gauging events that collect depth to water, depth to LNAPL and LNAPL thickness measurements using appropriate field instruments. Adjustments in monitoring may be needed based on performance monitoring data and changing site conditions.

2. Receptor Monitoring

Receptor monitoring, if applicable, should be conducted to assess that the IRM is protective of known risks. The frequency will be based on the professional judgment of the investigator and should consider the CSM developed for the site. Receptor monitoring should be conducted in accordance with other relevant Guidance Documents and Regulations.

3. Interim Remedial Measure Monitoring

The specifics of remedial system monitoring will vary with the type of IRM selected for a site. All IRMs should include a means to monitor the response of the LNAPL body to remedial efforts and should include the collection of sufficient system data to allow an assessment of IRM effectiveness.

a. An IRM monitoring protocol should include the following:

i. Hydraulic gauging which includes depth to water/depth to LNAPL/LNAPL thickness measurements in pertinent monitoring wells and recovery points both within and along the perimeter of the LNAPL body;
ii. Determination regarding the amount of LNAPL recovered at each recovery point during the reporting period;
iii. System-specific monitoring; and
iv. NJPDES Permit parameters, if applicable.

As previously discussed, the monitoring protocol chosen for the site should be designed to gather sufficient data to verify that the objectives of the IRM have been, or are being, met. Examples are included below. This list is not comprehensive, but is intended only to provide examples of types of technologies and associated types of monitoring which may be considered.

b. For IRMs which include groundwater extraction as a component of remedial system design, system monitoring should include:

i. Regular hydraulic gauging of both pumping and non-pumping wells;

ii. Verification of depths of pump intakes in all dewatering points;
iii. The pumping rate established at each dewatering point during the reporting period; and
iv. The degree of drawdown established in both active pumping wells and nearby monitoring points.

c. For IRMs which utilize total fluids extraction using a drop tube technology, system monitoring should include:

i. The depth to which the drop tube is placed in each extraction point;
ii. Measurements of total applied system vacuum during system operation;
iii. The casing vacuum as determined in each extraction point during system operation;
iv. Photo-ionization detector (PID) readings of the extracted vapor phase mass (if applicable) at each extraction point;
v. Hydraulic gauging and vacuum gauging at nearby monitoring points; and
vi. The amount of groundwater and LNAPL recovered from each extraction point during the reporting period.

d. For IRMs which include the injection of surfactants to increase the mobility of LNAPL in order to enhance recovery rates in the liquid phase, system monitoring should include:

i. pre-injection groundwater sampling for both the compounds of concern and compounds/by-products associated with the injected material;
ii. details regarding the volume, rate, duration, and depth of introduction of the injected material at each injection point;
iii. details regarding the recovery phase of the IRM including depth of pump intake(s), pumping rate at each extraction point and duration of the recovery phase;
iv. hydraulic gauging during the recovery phase at both the recovery points and nearby monitoring wells to determine pumping zone of influence;
v. post-injection groundwater sampling for both the compounds of concern and the compounds/by-products associated with the injected material; and
vi. NJPDES DGW permit parameters.

X. REPORTING REQUIREMENTS

A. Immediate Reporting Requirement

The identification of LNAPL at a site can trigger the requirement to make immediate telephone notification to the Department Hotline at 1-877-WARNDEP (1-877-927-6337). The call to the Department Hotline is required if the LNAPL identified is not related to a previously reported discharge or if the discharge is first discovered as a result of the LNAPL discovery (see N.J.A.C 7:1E-5). The 60-day reporting form does not take the place of the call to the Department's Hotline reporting the discharge. The investigator should evaluate the need to call the Department's Hotline.

B. Initial Reporting Form Requirement

As per the regulatory timeframes established in N.J.A.C. 7:26E, the person responsible for conducting the remediation at a site where measurable LNAPL is identified is required to submit the LNAPL Reporting Form, available on the Department's website, within 60 days of the LNAPL being identified. (Note: For cases that existed with LNAPL prior to November 4, 2009, the reporting form was due April 29, 2010.)

C. LNAPL Interim Remedial Measures Report

As per the regulatory timeframes established in N.J.A.C. 7:26E, the person responsible for conducting the remediation at a site where LNAPL is identified is required to submit an updated LNAPL reporting form, available on the Department's website, within one year of the identification of LNAPL at the site. An LNAPL interim remedial measures report is required to be included with the updated LNAPL Reporting Form submission. A suggested format of the report is listed in Appendix C.

The purpose of the IRM Report is to document the investigative and remedial work conducted at the site in response to the discovery of the LNAPL. This report should provide information as follows:

- LNAPL source and extent;
- description and justification for the selected IRM;
- discussion of the specific remedial goals and the performance metrics by which the goals will be determined to have been met;
- results of the operational monitoring which has been conducted during the IRM phase; and
- detailed assessment, to date, regarding the effectiveness of the chosen initial recovery effort, and IRM, if implemented.

When reporting to the Department, the investigator should be able to describe the conceptual site model developed for the site and document that the chosen IRM is supported by the CSM. Based upon the conceptual site model, the investigator should be able to depict the extent of LNAPL on a site map, depict groundwater flow direction, and document the evaluation of preferential pathways for LNAPL migration.

1. The LNAPL interim remedial measures report due at the end of the 1-year regulatory timeframe should include one of the following as applicable:

a. if measureable LNAPL remains in wells and IRM specific goals have not yet been met, the IRM Report should include a detailed plan to continue or implement LNAPL IRM activities until the IRM specific goals and endpoints are achieved or until the final remedy is implemented;

b. if LNAPL removal is considered complete, the IRM Report should present a detailed discussion supporting this finding, and include a monitoring plan to, at a minimum, continue hydraulic gauging to verify that measurable LNAPL does not reappear under the full range of water table conditions at the site, or until the final remedy is implemented; or

c. if LNAPL remains in monitoring wells and continued removal or treatment is not practicable, the LNAPL IRM Report should clearly document the technical rationale supporting this conclusion, and include a summary of all work done to assess LNAPL recoverability and demonstrate that LNAPL has been recovered to the maximum extent practicable. The LNAPL IRM Report should include a monitoring plan designed to document that the conditions limiting LNAPL recoverability and migration have not changed until a final remedy is implemented.

2. Compliance with the LNAPL Regulatory Timeframe

The overall intent of the LNAPL timeframes is to require the investigator to proactively characterize the LNAPL body identified and to implement an appropriate response. Completing the requirements of N.J.A.C. 7:26E-1.10 will result in compliance with LNAPL regulatory and mandatory timeframes; however, there may be circumstances where the collection of data and implementation of the IRM cannot be completed within the regulatory and mandatory timeframes. The investigator should then complete and submit to the Department a [Remediation Timeframe Extension Request Form](#).

There may be situations where the selection and implementation of an IRM cannot be completed within the regulatory and mandatory timeframe. In this case, the extension request should be documented in a report which contains the applicable components outlined for inclusion in the LNAPL interim remedial measures report along with justification for the reasons for the extension and detailed schedule for additional RI activities and IRM, as appropriate.

In cases where the investigator believes the specific site conditions justify the deferment of IRM implementation, an extension request should be submitted with that justification and a detailed schedule. Generally, in these cases, the LNAPL body will be well understood and the selected IRM will be implemented within a reasonable timeframe and is either incorporated within a planned final remedy for the LNAPL or the LNAPL IRM is a component of a more comprehensive multiphase remedy. The Request for Extension should be supported and justified by the key provisions outlined for inclusion in a LNAPL interim remedial measures report and includes the proposal for implementation of the remedy. An example of this situation could involve #4 or #6 fuel oil (limited dissolved phase contamination with no LNAPL migration and shallow groundwater) at a site with planned redevelopment and demolition/excavation work. Rather than implement a remedy that is hindered by on-site buildings that will be demolished as part of redevelopment within one year, the implementation of the IRM using excavation could be deferred for one year until demolition is complete.

The redesign of an IRM that is not achieving the objective or goals established for the IRM at the site does not restart the regulatory or mandatory timeframe clock. In this situation, subsequent key document submissions (i.e., completion of the remedial investigation and submission of a remedial action work plan) would be sufficient to report the information regarding any updates/changes implemented since the prior LNAPL reporting.

The IRM, or aspects of the IRM, may be discontinued prior to implementation of the final remedy if it is documented that the IRM has met its overall objectives, and any specific IRM goals and performance endpoints established by the investigator. This includes situations where LNAPL removal or treatment has resulted in reducing LNAPL thickness to 0.01 feet or less in monitoring wells; where further recovery or treatment is determined to be impracticable; or where other specific IRM goals and performance endpoints are met. If LNAPL remains at cessation of the IRM, then the selected final remedy for the site should address the remaining LNAPL.

Professional judgment should be used to determine the minimum ongoing maintenance approach for removal of available LNAPL from monitoring wells pending implementation of a final remedy. This may include the use of active or passive LNAPL collection techniques. It should be noted that for some LNAPL plumes or portions of LNAPL plumes, such as high viscosity, low solubility or highly weathered situations where the LNAPL is immobile and does not contribute to a dissolved or vapor phase plume or present other risk to receptors, a monitoring only approach may be appropriate as an IRM until the final remedy is implemented. In this case, the IRM Report should provide a detailed discussion supporting the approach, the steps taken to evaluate both the LNAPL and any potential receptor risks and schedule for the anticipated final remedy and management approach that will address the remaining LNAPL.

If at any time during implementation of a monitoring plan LNAPL reappears and is related to the original LNAPL reporting/response, the investigator should continue with LNAPL management consistent with the objectives of the IRM. If the LNAPL reoccurrence is from a new discharge, a new discharge shall be reported to the Department Hotline at 1-888-WARN DEP and new LNAPL response initiated pursuant to N.J.A.C. 7:26E-1.10 with a new " timeframe clock" being initiated.

XI. REFERENCES

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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.

APPENDIX A

LNAPL RECOVERY TECHNIQUES

LNAPL RECOVERY TECHNIQUES

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)

APPENDIX B

LNAPL DELINEATION METHODS

LNAPL DELINEATION METHODS

The delineation of contamination is contingent on a number of factors. With regulatory and mandatory timeframes to implement an IRM for LNAPL, it is important for investigators to understand the extent of LNAPL in a timely manner. Conducting this activity should include upfront planning for, and obtaining access to, locations to gather the data necessary to comply

Compliance with the LNAPL regulatory time frame is, to an extent, also reliant on an effective and efficient approach to delineation. In deploying a delineation strategy, consideration of the circumstances of the initial LNAPL identification and the resources already available at the site may dictate the methods selected for delineation. If LNAPL is identified during conductance of excavation activities on the site, utilizing that available equipment to advance test pits for delineation may provide an ideal means to collect a large amount of data in a short period of time. Similarly, if LNAPL is identified during an SI event where direct push borings are being advanced, continuing with that technology may provide the best choice for the near term delineation need and provide the best cost benefits.

Traditional methods, including the methods listed below, will often yield both an adequate and cost effective means to complete the delineation. As the need to address LNAPL is becoming more widely understood and accepted, more complex proprietary delineation tools are becoming available. For larger or more complex LNAPL bodies, use of these technologies may provide significant benefit in completing the necessary delineation within a timeframe which supports timely installation of an IRM.

Delineation methods should also be selected such that the physical extent of the LNAPL body can be delineated efficiently and the distribution (thicknesses) is easily measured. Also, the selected method should be supportive in providing monitoring points which can be utilized after the IRM is installed to verify stabilization and mass reduction.

The NJDEP Field Sampling Procedures Manual, the NJDEP Alternate Ground Water Sampling Guide and N.J.A.C. 7:9D – Well Construction and Maintenance; Sealing of Abandoned Wells should be consulted for information on drilling methods, well construction and permitting requirements for borings and wells.

1. Test Pits

Test Pits can be used in situations where LNAPL occurs at shallow depths in unconsolidated deposits.

Advantages:
- rapid delineation possible
- direct visual observation of shallow stratigraphy
- direct measurement of LNAPL in soils and groundwater
- test pits may be converted into recovery trenches

Disadvantages:
- practical depth limitations at sites with a deep water table, non-cohesive subsurface materials, or shallow bedrock
- difficult to collect undisturbed soil samples for laboratory analysis and for LNAPL screening as the depth of the test pit increases
- physical access constraints at small and/or heavily developed sites including utilities
- permanent groundwater monitoring points are still necessary to document groundwater flow direction and LNAPL plume behavior over time

Factors to consider:

- disposal costs associated with the excavated contaminated material
- costs associated with clean backfill
- site safety and security

2. Soil Borings and Temporary Well Points

Soil borings and temporary well points are essentially synonymous, except that in a temporary well point a groundwater sample may be collected. Borings/temporary well points are typically conducted with a rotary drill rig or direct push technology. Unlike test pits, soil borings/temporary well points are not constrained by depth limitations. With the use of split spoons, which are advanced ahead of the auger, they allow for direct visual observation and screening of soils using methods.

Advantages:

- rapid delineation possible
- allows the collection of discrete soil samples for laboratory analysis
- direct visual observation of stratigraphy is possible with the use of split spoons or macro-cores
- ability to go significantly deeper than test pits

Disadvantages:

- not practicable or able to be used in competent bedrock
- permanent groundwater monitoring points are still necessary to document groundwater flow direction and LNAPL plume behavior over time

3. Direct Push Technology

Delineation using a direct push technology is similar to delineation with soil borings/temporary well points performed with rotary drill rigs, except that in direct push, the drill rod is pushed using a hydraulic press, percussion hammer, or a vibratory head. In an unconsolidated setting, absent of abundant cobbles or gravel, this technology allows for rapid site characterization relative to conventional borings.

Additionally, some specialized direct push technologies have the ability to detect LNAPL without obtaining a physical soil core such as Membrane Interface Probe (MIP), Laser Induced Fluorescence (LIF) and Cone Penetrometer Technology (CPT).

Advantages:

- rapid delineation is possible
- ability to advance tools that can detect LNAPL in-situ

Disadvantages:

- driving a point is problematic in tight and/or stony formations
- cannot distinguish between free phase and residual phase product in-situ
- permanent wells are still necessary to monitor groundwater and to document groundwater flow direction

4. Permanent Wells

Permanent wells are necessary to be installed in any LNAPL investigation. They are necessary to document groundwater flow direction, seasonal and/or anthropogenic water table fluctuations, to monitor apparent LNAPL thicknesses, and are frequently used as part of the initial and interim LNAPL recovery methods.

Permanent wells should be placed within the plume to monitor the effectiveness of LNAPL recovery and down-gradient immediately outside the LNAPL plume boundary to act as a sentinel point for potential LNAPL migration. To document groundwater flow direction, a minimum of three wells is required. When documenting groundwater elevation, it is necessary for the depth to groundwater to be corrected to account for any measurable LNAPL.

When installing permanent wells, continuous spoons/macro-cores should be collected for detailed logging of stratigraphy. The wells are to be completed such that the well screen bridges the water table and constructed so that any LNAPL is able to migrate into the well. For example, the filter pack should be coarser than the surrounding aquifer material. If wells installed as part of the LNAPL investigation/remediation have a water table elevation greater than the top of the well screen, the well will need to be replaced with a monitoring well that is properly screened to account for variations in the water table.

After the wells have been installed and developed, they should be monitored for LNAPL on a regular basis. In order to accurately assess the correlation between water table fluctuations and LNAPL accumulation fluctuations in site monitoring well, monthly hydraulic gauging should be conducted during the investigative phase. To assist in the evaluation of the effect water table fluctuations have on LNAPL accumulation in a well, depth to LNAPL and LNAPL thicknesses should be determined during each gauging event. Following the collection of depth to water/depth to LNAPL readings with the appropriate field instruments, the LNAPL thickness should be verified via a clear bailer as noted in the Field Sampling Procedures Manual.

Special Note for LNAPL in Bedrock

Mud-based drilling techniques should be avoided when installing monitoring wells for investigative purposes. An acceptable drilling technique (such as air rotary) will allow cuttings to be evaluated and water and product bearing zones to be identified during boring advancement. When contamination is detected in bedrock, it is frequently necessary to conduct coring and/or a detailed down hole geophysical investigation to evaluate bedrock structure and to gain a general understanding of fracture patterns that may be controlling LNAPL distribution and migration pathways. The following may be helpful references for evaluating LNAPL in bedrock.

- Hardisty, P.E., J. Roher and J. Dottridge, 2004, LNAPL Behavior in Fractured Rock: Implications for Characterization and Remediation, U.S. EPA/NGWAFractured Rock Conference: State of the Science and Measuring Success in Remediation.
- Mercer, J.W. and R. Cohen, 1990, A Review of Immiscible Fluids in the Subsurface: Properties, Models, Characterization and Remediation, Journal of Contaminant Hydrology, 6 (1990) p. 107-163, Elsevier Science Publishers B.V., Amsterdam

Evaluating contamination in bedrock can be very complex. Many articles have been written on bedrock characterization, but the following articles may be particularly useful when conducting investigations within the Newark Basin:

- Herman, G.C., 2001, Hydrogeological framework of bedrock aquifers in the Newark Basin, New Jersey, in LaCombe, P.J. and Herman, G.C., eds., Geology in Service to Public Health, Eighteenth Annual Meeting of the Geological Association of New Jersey, p. 6-45.

- Michalski, A.M., 2001, A practical approach to bedrock aquifer characterization in the Newark Basin, in LaCombe, P.J. and Herman, G.C., eds., Geology in Service to Public Health, Eighteenth Annual Meeting of the Geological Association of New Jersey, p. 46-59.

- Michalski, A. and R. Britton, 1997. The role of bedding fractures in the hydrogeology of sedimentary bedrock – evidence from the Newark Basin, New Jersey. Ground Water, v. 35, No. 2, pp. 318-327.

The following paper provides an example of a bedrock investigation within crystalline bedrock:

- Herman, G.C., 2006, Hydrogeological framework of Middle Proterozoic granite and gneiss from borehole geophysical surveys at two ground-water pollution sites, Morris County, New Jersey, in Macaoay, Suzanne, and Montgomery, William., eds., Environmental Geology of the Highlands, 23rd Annual Meeting of the Geological Association of New Jersey, p. 26-45.

Additionally, the Ground Water SI/RI/RA Technical Guidance document located at http://www.nj.gov/dep/srp/guidance/#pa_si_ri_gw provides additional discussion regarding bedrock investigations in New Jersey.

APPENDIX C

CONTENTS OF A TYPICAL LNAPL INTERIM REMEDIAL MEASURES REPORT

CONTENTS OF A TYPICAL LNAPL INTERIM REMEDIAL MEASURES REPORT

A typical report should include the following elements:

I. General Information

A. Site name
B. Case identifiers, such as the PI number
C. Site location
D. Investigator name

II. Physical Setting

A. Topography
B. Site soils, geology, hydrogeology, and groundwater flow direction
C. Location and description of any nearby surface water bodies or wetlands

III. Components of the receptor evaluation, known at the time of the initial LNAPL investigation

A. Location of wells and other collection points near the LNAPL body
B. Land use near the LNAPL body
C. Location and details regarding potential preferential pathways for LNAPL migration
D. Identification of real or suspected vapor concerns associated with the LNAPL body
E. Location of any real or potential ecologic receptors affected by LNAPL

IV. Technical Overview

A. Summary of the LNAPL discharge
B. Summary of activities conducted to delineate the LNAPL
C. Summary of recovery efforts to date, including technologies utilized
D. Discussion of the reliability of the analytical data
E. Discussion of any problems or difficulties encountered while conducting the investigation

V. Investigative Findings

A. Physical characteristics and chemical composition of the LNAPL
B. Horizontal and vertical extent of the measurable LNAPL
C. Migratory path of LNAPL from the discharge point to its current distribution
D. Changes in product thickness with water table fluctuation
E. Stratigraphic and/or structural controls that may be influencing product distribution
F. Stability of the LNAPL body
G. Results of any aquifer tests
H. Results of any LNAPL mobility, recoverability, or treatability tests
I. Results of any tests necessary for the development of any permits

VI. Conclusions and IRM Selection

A. Description of chosen IRM
B. Methodologies and data used to support the chosen IRM
C. Monitoring plan associated with the LNAPL plume
D. Metrics that have or will be used to evaluate the effectiveness of the IRM
E. Metrics to be used to document future stability of the LNAPL body
F. Discussion of possible changes to the IRM based on metrics

VII. Maps and diagrams, scaled to be clear and legible:

A. Portion of a 7.5 minute topographic map locating the site
B. Map depicting relevant components of a receptor evaluation, if appropriate
C. Site map depicting all well, boring, and/or test pit locations
D. Map depicting the extent of measurable LNAPL and the suspected discharge location
E. Groundwater contour map
F. Top of bedrock map or lower permeability horizons, if present;
G. Cross-sections through the LNAPL body which should depict
    1. Stratigraphy
    2. Depth to water
    3. Observed LNAPL thicknesses in wells and borings
    4. Interpreted location of mobile product

VIII. Additional information

A. Summary table of well construction
    1. Well identification, well permit number, date of installation
    2. Top of casing elevation, ground surface elevation
    3. Well depth, depth to the top and bottom of the open-hole/screened interval
    4. State plane coordinates; Latitude and longitude
B. Copies of all well and boring logs used in the LNAPL investigation
C. Summary table of product thickness measurements and water table elevations
D. Summary table of volume of product recovered, with date and method of recovery
E. Summary tables of any analytical results associated with the LNAPL investigation
F. Sampling results summary tables for all relevant analyses, including location and depth
G. Results of all studies or tests used to delineate the LNAPL and to select the IRM
H. Summary table of analytical methods
I. Relevant laboratory QA/QC data
J. Groundwater field sampling summary sheets, if appropriate
K. Groundwater contour map reporting forms
L. Any other data that was collected related to the measurable LNAPL investigation

(Note: A report may be in the form of or include a CSM that incorporates all data gathered and results of testing to support the LNAPL delineation and the IRM selected.)

APPENDIX D

GLOSSARY

GLOSSARY

The following are the definitions of terms used in this guidance document.

Capillary Pressure: The pressure difference between the nonwetting phase (e.g., LNAPL) and the wetting phase (e.g., groundwater) in a multiphase system such as in a LNAPL-groundwater system (ITRC 2009).

Collection Point: Any location where LNAPL can be measured or otherwise observed on the water surface. Collection points include, but are not limited to, test pits, excavations, piezometers, monitoring wells, surface water, test pits, trench, sumps, utility vaults, etc. The term collection point is to be interpreted broadly.

Free Product: Defined in N.J.A.C. 7:26E-1.8 as separate phase material, present in concentrations greater than a contaminant's residual saturation point. This definition applies to solids, liquids, and semi-solids. The presence of free product shall be determined pursuant to the methodologies described in N.J.A.C. 7:26E-2.1(a) 14.
(Note: For the purpose of this guidance, LNAPL does not include solids or semi-solids).

***Light Nonaqueous Phase Liquid* (LNAPL):** Defined in N.J.A.C. 7:26E-1.8 as a separate and immiscible phase liquid when in contact with water and/or air, can exist as a continuous phase (mobile) and /or discontinuous mass (immobile) and is less dense than water at ambient temperature.

***LNAPL Interim Remedial Measure* (IRM*)*:** A remedial action taken to remove, control and stabilize LNAPL, as applicable, to prevent LNAPL migration, reduce contaminant mass and address known exposure to receptors until final remedial action can be implemented.

Measurable LNAPL: LNAPL measured to, or observed to be, greater than 0.01 feet in thickness.

***Pore Entry Pressure*:** The capillary pressure that must be exceeded before a nonwetting fluid (e.g., LNAPL) can invade pore space saturated with a wetting fluid (e.g., water) (ITRC 2009).

***Residual Phase Product* (**residual product)**:** Defined in N.J.A.C. 7:26E-1.8 as a separate phase material present in concentrations below a contaminant's residual saturation point, retained in soil or geologic matrix pore spaces or fractures by capillary forces. This definition applies to solids, liquids, and semi-solids. The presence of residual product shall be determined pursuant to N.J.A.C. 7:26E-2.1(a) 14.

Residual Saturation Point: Defined in N.J.A.C. 7:26E-1.8 as the saturation point below which nonaqueous phase liquid becomes discontinuous and is immobilized by capillary forces, and fluid drainage will not occur.

APPENDIX E

ACRONYMS

ACRONYMS

AOC	area of concern
AS/SVE	Air Sparging/Soil Vapor Extraction
ASTM	American Society of Testing and Materials
COC	chemicals of concern
CPT	Cone Penetrometer Technology
CSM	conceptual site model
DGW	Discharge to Ground Water
IRM	interim remedial measure
ITRC	Interstate Technology and Regulatory Council
LIF	Laser Induced Flourescence
LNAPL	light nonaqueous phase liquid
LSRP	Licensed Site Remediation Professional
MIP	Membrane Interface Probe
NJAC	New Jersey Administrative Code
NJDEP	New Jersey Department of Environmental Protection
NJSA	New Jersey Statutes Annotated
NSZD	Natural Source Zone Depletion
PID	photo-ionization detector
RI	Remedial Investigation
SI	Site Investigation
USEPA	United States Environmental Protection Agency