**New Jersey Department of Environmental Protection**
**Site Remediation Program**

# Guidance for Light Non-aqueous Phase Liquid (LNAPL) Free Product Initial Recovery and Interim Remedial Measures

**(DRAFT)**

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## I. PURPOSE

The Site Remediation Reform Act (SRRA) N.J.S.A. 58:10C, which was enacted in May 2009, required the Department of Environmental Protection (Department) to develop new regulations and guidance that provide direction on a number of issues involving the investigation and remediation of contaminated sites for those persons responsible for conducting such activities. In particular, N.J.S.A 58:10C-28 required the Department to establish mandatory timeframes for "control of ongoing sources" and "establishment of interim remedial measures". As a result, this guidance is intended to focus attention on:

- Initial LNAPL free product recovery efforts;
- LNAPL free product Remedial Investigation (RI) activities;
- Conceptual Site Model as a tool to assist decisions making; and
- LNAPL free product interim remedial measures.

This LNAPL Guidance has been developed to provide general direction to consultants, Licensed Site Remediation Professionals (LSRPs), and those persons responsible for conducting the investigation and remediation of sites at which LNAPL free product has been identified. This guidance should be used in concert with other Department guidance documents, the Regulations Implementing the Underground Storage of Hazardous Substances Act, the Technical Requirements for Site Remediation (N.J.A.C. 7:26E) and other regulations.

## II. OVERVIEW AND LIMITATIONS

This document provides guidance on the steps that should be taken when measurable LNAPL free product (measured to a thickness of 0.01 feet) is identified in the subsurface at a site. Although this document will focus on investigating and mitigating measurable LNAPL free product that has migrated to, and collected in a well or other collection point, it should be recognized that at any site where LNAPL product has been discharged, the contamination associated with that LNAPL product can exist in multiple phases simultaneously in the subsurface. For the purpose of this document, a LNAPL sheen by itself does not trigger the need to apply this guidance, but does not preclude the person responsible for conducting the remediation and their consultant from considering its application as part of the overall remedial process. A comprehensive remedial investigation and remedial action will take into account and address the separate, residual, vapor and dissolved phases of contamination that can be associated with a LNAPL discharge. Addressing residual, vapor and dissolved phases of contamination associated with LNAPL and sheens is required but not within the scope of this guidance for LNAPL free product IRMs. Regular gauging of wells with a sheen should be considered in order to evaluate whether measurable product appears with changing water level elevations. When approaching the remediation of LNAPL free product at a site, it should be kept in mind that as per N.J.A.C. 7:26E-6.1(d), 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.

When a discharge has occurred and measureable LNAPL free product associated with such a discharge is identified, certain actions are required to be taken by the person responsible for investigating and remediating the identified contamination. This document provides general guidance in regard to the reporting requirements, delineation requirements, and the initial and interim remediation requirements associated with measurable LNAPL free product identified at a site. For the purpose of this document, the initial recovery efforts are considered an “interim remedial measure”. “Initial” recovery efforts are the first responses to LNAPL free product recovery, and are usually initiated before a focused remedial investigation is complete This guidance also includes references to the mandatory and regulatory timeframes established in the Administrative Requirements for the Remediation of Contaminated Sites at N.J.A.C. 7:26C-3.3(a)3 and Technical Requirements for Site Remediation at N.J.A.C. 7:26E-1.12, respectively.

**A. <u>The regulatory and mandatory timeframes related to LNAPL are as follows</u>**:

**Regulatory timeframe for LNAPL free product defined in N.J.A.C. 7:26E-1.12**:

♦ 60 days from LNAPL discovery:

1. Report the presence of LNAPL free product on the required reporting form.
2. Conduct initial LNAPL free product recovery efforts and to report on the status of the actions taken within this timeframe on the required reporting form.

♦ 270 days from LNAPL discovery:

1. Complete a focused remedial investigation (RI) for the delineation of the LNAPL free product and submit focused RI report.
2. Complete installation of a LNAPL free product recovery system to remove, control or stabilize the LNAPL free product to prevent migration and exposure to receptors and initiate operational monitoring.
3. Submit the “Free Product Interim Remedial Measures Report” for the IRM including the form available from the Department.

**The Mandatory timeframe for Initiating LNAPL free product removal is 1 year from discovery to complete the installation of a LNAPL recovery system, initiate operational monitoring and submit a “Free Product Interim Remedial Measures Report” (for IRM) to the Department. Include form available from the Department.**

B. **Timeframe Extensions**

This guidance and timeframes address conditions that are encountered at the majority of the sites where LNAPL is discovered. However, the Department recognizes that LNAPL free product at sites can vary significantly and the response actions can vary as well. For example, LNAPL free product may be found in monitoring wells that can range in thickness from a sheen to many measurable feet with the later example prompting a more aggressive response. Large petroleum handling or manufacturing facilities may also have large areas of LNAPL that can not be addressed in the standard established timeframes. Given this and other variables associated with LNAPL free product, the fundamental goals are to foster the initiation of a comprehensive plan to removal of LNAPL free product early-on, in a cost effective and efficient manner that helps to reduce site risk, prevents contaminant migration, reduces contaminant mass loading to the aquifer and reduces the lifespan of the cleanup. If the professional opinion of the LSRP, or other consultant for existing cases, determines that deferring the action required early-on will not compromise these goals, 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.

## III. DEFINITIONS

*Light Non-Aqueous Phase Liquid:* (LNAPL) (per N.J.A.C 7:26E-1.7) means hydrocarbons that exist 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.

*Free Phase Product*: (free product) (per N.J.A.C. 7:26E-1.7) means a 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.

*Residual Phase Product*: (residual product) (per N.J.A.C 7:26E-1.7) means 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 the methodologies described in N.J.A.C. 7:26E-2.1(a) 14.

*Residual Saturation*: (per N.J.A.C 7:26E-1.7) means the saturation point below which non-aqueous phase liquid becomes discontinuous and is immobilized by capillary forces, and fluid drainage will not occur.

## IV. CONCEPTUAL SITE MODEL

Upon discovery of LNAPL free product in the subsurface, preparation of a general conceptual model of the site is recommended. The purpose of the conceptual site model is to integrate what is already known at the site and to more effectively plan how best to proceed with the necessary investigative and remedial activities to delineate the extent of LNAPL free product and to implement effective recovery measures. This model is considered dynamic and should be modified and expanded upon as site specific data and information is collected and evaluated. The following parameters should be evaluated as part of a Conceptual Site Model when investigating and remediating LNAPL free product:

- the source of the LNAPL
  --to determine if the LNAPL is part of a historic or an on-going discharge;

- the physical properties and chemical composition of the LNAPL
  --to aid in determination of recoverability as it relates to viscosity, mobility, etc.;
  --to aid in determination of threats to nearby receptors such as:
    - inhalation threats based on the volatility of the LNAPL;
    - ingestion threats based on the solubility of the LNAPL;
    - general exposure threats based on the toxicity of the LNAPL;
  --to aid in determining the most useful delineation methods;
  --to determine the correction factor for determining the depth to water for accurate ground water contour maps;
  --to aid in determination of the most effective remedial approach;

- the hydrogeologic framework for the site being investigated
  --evaluate the stratigraphic and/or structural controls that may be influencing LNAPL free product distribution;
  --evaluate correlation between water table fluctuation and free product thickness;
  --evaluate presence of any high yield pumping wells past and present that may have enhanced the horizontal and/or vertical distribution of LNAPL free product at the site;

- site specific aquifer properties
  --as relative to LNAPL free product distribution and remediation such as hydraulic conductivity;
  --evaluate LNAPL free product recovery rates for each product bearing well, trench, excavation, etc, such as with the use of bail down tests and/or constant rate pumping tests to optimize design and selection of the IRM;

- subsurface utilities
  --determine location, type, depth, dimensions, and orientation of subsurface utilities that may act as a migration pathway for LNAPL free product.

- the type and location of receptors that may be threatened or affected by the measurable LNAPL free product as stipulated by N.J.A.C. 7:26E-1.15.

Many articles have been written on conceptual site models, but the following documents may be particularly useful:

ASTM, 2007. Standard Guide for Development of Conceptual Site Models and Remediation Strategies for Light Nonaqueous-Phase Liquids Released to the Subsurface,. Publication E2531-06e1. American Society for Testing and Materials, West Conshohocken, PA.

U.S. EPA. 2003. Using Dynamic Field Activities for On-Site Decision-Making: A Guide for Project Managers. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. OSWER No. 5200.1-40, EPA/540/R-03/002, May 2003.

U.S. EPA. 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.

When reporting to the Department, the person conducting the remediation should be able to describe the conceptual site model and based upon the conceptual site model, the person responsible for remediating the site should be able depict the extent of measurable LNAPL free product on a site map, depict groundwater flow direction, and document the evaluation of preferential pathways for measurable LNAPL free product migration. Decisions regarding implementation of initial and Interim Remedial Measures should be supported by the conceptual site model.

## V. INITIAL LNAPL FREE PRODUCT RECOVERY

As stipulated in N.J.A.C. 7:26E-1.12, initial LNAPL free product recovery efforts should be initiated within thirty (60) days of discovery. Initial LNAPL free product recovery efforts should be conducted concurrently with the required delineation activities and should be expanded, as necessary, during the delineation phase.

When selecting an initial LNAPL free product recovery method (examples listed in Appendix A), receptor issues should be considered, as guided by the Conceptual Site Model. Professional judgment must be used to select the initial method of recovery recognizing that this initial approach may change as more site information becomes available. Use of more aggressive initial remedial measures as described in Appendix A below, or others not listed, may be warranted depending on the estimated volume of LNAPL discharged (if known), the mobility, toxicity and solubility of the product being addressed and the proximity of receptors to the LNAPL free product and associated dissolved phase plume. Professional judgment in selecting a method must also consider the ability of the selected method to reduce the overall receptor risks. It should also be recognized that the application of a more aggressive approach during the initial response may reduce long term monitoring costs, may allow for the use of less intensive interim remedial techniques over the long term for LNAPL free product recovery and overall site cleanup and ultimately a shortened timeframe to the issuance of a final remediation document.

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If the responsible party is not able to remove all LNAPL free product during the initial recovery efforts, a more aggressive free product recovery method may be required (see Section VII) to be installed within 270 days of discovery. In these situations, the initial product recovery phase coupled with the focused LNAPL free product remedial investigation is an opportunity to expand on the Conceptual Site Model to determine which remedial method(s) will be the most effective.

## VI. DELINEATION OF LNAPL FREE PRODUCT

For the purpose of this document, delineation of the measurable LNAPL free product is required to be completed within 270 days of its discovery to be in compliance with the regulatory timeframe established at N.J.A.C. 7:26E-1.12. The Conceptual Site Model can be extremely useful as a guide to predict the distribution of the free product in the subsurface and as a tool for choosing the appropriate delineation methods and sampling locations. As data is added to the Conceptual Site Model, the model should be reviewed for data gaps, and additional sampling should be conducted to fill the data gaps as necessary.

Various methods exist for the delineation of LNAPL free product. Appendix B. provides a brief description of typical methods used to delineate LNAPL free product. Additional sampling guidance can be found in the Field Sampling Procedures Manual found at http://www.nj.gov/dep/srp/guidance/fspm/

## VII. INTERIM REMEDIAL MEASURE (IRM) FOR LNAPL FREE PRODUCT

If the initial product recovery method was not successful in removing all of the LNAPL free product known to exist at a site, an additional IRM is required. As stipulated in N.J.A.C.7:26E-1.12 the person responsible for conducting the remediation shall install a LNAPL recovery system and initiate operational monitoring within 270 days of the initial discovery of the free product following completion of a focused remedial investigation. Since the IRM is required following completion of the focused remedial investigation, the person conducting the investigation should have a better understanding of site information to select an appropriate IRM. The Conceptual Site Model must be updated using information collected during the initial recovery efforts and remedial investigation to help guide IRM selection. The LSRP or consultant must decide, using professional judgment, whether continuing with initial recovery effort(s) is supported by the site information, or whether an alternative approach is required to effectively remove, stabilize or control the extent of LNAPL free product to prevent migration and exposure to receptors. For the purpose of this requirement "installation of a system" as specified at N.J.A.C. 7:26E-1.12 will be considered complete based upon the determination, by the LSRP or consultant, that the selected IRM is designed to effectively remove, stabilize or control the extent of LNAPL free product to prevent migration and exposure to receptors.

The need for more aggressive IRMs are implemented to address:

- receptor concerns;
- the volume of free product;
- the extent of LNAPL free product;
- challenging hydrogeologic conditions; or
- a combination of all these factors.

A fully engineered free product recovery system may be necessary to address these and other challenges. IRMs that are considered engineered systems, include but are not limited to the technologies listed in Appendix C .

. To be considered an acceptable IRM, the remedial approach system should accomplish the following objectives:

► the selected approach should be able to either remove product at a sufficient rate such that the measurable LNAPL free product ceases to migrate and reduces contaminant mass loading to the aquifer, or, if removal is not practicable, effectively contain product such that the product plume ceases to migrate, and

► any receptor risks associated with the LNAPL free product should be adequately mitigated with the chosen remedial approach.

**A. System Selection**

The Conceptual Site Model shall be used to aid in the selection of an appropriate remedial technology for each site and situation. At a minimum, the selected product recovery system should consider site specific aquifer properties, the chemical properties of the product being recovered, as well as the size and distribution of the free product plume.

## VIII. OPERATIONAL MONITORING (Reserved)

## IX REPORTING REQUIREMENTS

As per the regulatory time frames established in N.J.A.C. 7:26E, initial reporting is required within 60 days after LNAPL free product is discovered at a site. This initial reporting consists of the submittal of the LNAPL Free Product Reporting Form. A Source Control Reporting Form is also required to be submitted if an IEC condition associated with the LNAPL discharge has been determined. The initial reporting shall document when and where LNAPL free product was first observed; the type and characteristics of the product; the apparent product thickness in site monitoring wells; the known extent of the free product plume; the source of the free product, if known; and if the source is known, whether there is an on-going release. The initial reporting should also document what recovery efforts are being undertaken, as well as documenting the volume of LNAPL free product that has been removed, to date.

As per the established regulatory timeframes, delineation of the LNAPL free product plume is required to be completed within 270 days after the initial discovery of LNAPL free product. The completion of LNAPL free product delineation should be documented with the submission of a focused Remedial Investigation Report (RIR), as described in N.J.A.C. 7:26E-4 and the Free Product Interim Remedial Measures Report and form. The "Free Product Interim Remedial Measures Report" shall document all LNAPL free product recovery activities employed, the volume of free product removed since the discovery of LNAPL, a full description and justification of the of selected method of LNAPL free product recovery and operational monitoring activities. A detailed assessment regarding the effectiveness of the initial measures employed in regard to the LNAPL free product removal should also be included. The most recent Conceptual Site Model developed for the site is recommended to be included as part of the RIR. The Conceptual Site Model should include all relevant data gathered since the free product was discovered.

The RIR shall also document whether all LNAPL free product has been removed during the 270 day time frame, or whether additional remediation is required. A valid evaluation of successful LNAPL free product removal shall consider the Conceptual Site Model developed for the site and shall include, but not be limited to, hydraulic gauging data that verifies that free product does not reappear under the full range of water table conditions known to occur at the site. A valid evaluation should also include an assessment as to whether LNAPL free product remains between individual recovery points. If it is concluded that LNAPL free product recovery is not complete, a determination should be made as to whether continued use of the interim remedial measure is satisfactory, or whether a more aggressive technology should be employed to address the remaining LNAPL free product.

## Appendix A

## Examples of Initial LNAPL Free Product Recovery Techniques

Below are examples of typical types of initial LNAPL free product recovery techniques. This listing is not comprehensive and is included here only to provide examples of the more commonly used technologies.

**1.** **Passive devices** (bailers, sorbent material, etc.)

*Advantages*: Rapid deployment; passive collection devices limit the amount of ground water generated during product collection.

*Disadvantages*: Passive devices cannot manipulate water level conditions to enhance LNAPL free product recovery rates; some passive devices have a limited ability to accommodate fluctuating water / product levels within a well; may require frequent monitoring / maintenance to accommodate rapid or fluctuating product recharge rates to a given collection point; limited effectiveness due to small zone of influence.

*Items to Consider*: For passive collection systems, need to consider the storage capacity of the collection device and the frequency of monitoring/maintenance of the chosen device.

- ♦ consider the role of fluctuations in the water table as relates to LNAPL free product accumulation in a given well. The chosen device (and/or the maintenance schedule) should be able to accommodate the range and frequency of these fluctuations.
- ♦ passive collection systems are most useful in situations where the product recovery rates are low and there are no receptor risks.
- ♦ must determine when, based on site specific product recovery rates, a passive collection option is not feasible (i.e. when an automated or more aggressive product recovery system is necessary for the initial phase).

2. **Automated devices** (skimmers; single pump technologies)

*Advantages*: skimmers can be used in open excavations and trenches; automated devices may allow less frequent monitoring and maintenance than a passive collection system; limits the amount of ground water generated during product recovery activities.

*Disadvantages*: skimmers and product only pumps cannot artificially create and sustain the optimal water level conditions within a well which would enhance LNAPL free product recovery rates; the limited zone of influence as compared to systems which include total phase extraction or dual pump capabilities necessitates denser spacing of recovery points.

*Items to Consider:* For product skimming systems, need to consider the correlation between depth to water and product accumulation rates when setting the pump intakes. Large water table fluctuations may require frequent adjustments to ensure proper placement of the product recovery device in the well(s).

3. **Periodic application of vacuum enhanced / total fluid extraction recovery techniques**

*Advantages*: Mobile units can be deployed relatively quickly; can enhance short term LNAPL free product recovery rates by manipulating ground water elevations in the vicinity of the extraction point(s); can address residual product as well as free product by enabling venting of the soil column and that portion of the aquifer matrix exposed with dewatering; can remove contaminant mass in all phases (free phase, residual phase, vapor phase and dissolved phase) during each extraction event.

*Disadvantages*: Depth limitations for lifting liquid with a vacuum may limit dewatering capabilities and the associated product recovery rates at sites where depths to product and depths to water are greater than 25 feet below grade; is limited in dewatering capabilities in situations with highly transmissive water bearing zones due to the short duration of each extraction event; can generate up to 2000 + gallons of contaminated water during each event conducted at a site.

*Items to Consider:* Need to be cognizant of the depth to which dewatering must be accomplished to enhance LNAPL free product recovery as relates to:

- ♦ the duration of each extraction event.
- ♦ the frequency at which the extraction events are conducted.
- ♦ details regarding how the events are conducted in regard to:
  - ▪method of dewatering used (submersible pump or drop tube)
  - ▪depth of drop tube for total phase extraction systems.
  - ▪whether extraction events are conducted on individual points or points that are manifolded together.

Modifications to how the extraction event is conducted can often enhance LNAPL free product recovery / mass removal rates. Need to evaluate the data generated during each extraction event to assess the effectiveness of the chosen

## Appendix B

## LNAPL Free Product Delineation Methods

### 1. Test Pits

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

*Advantages:*

- Rapid delineation possible;
- Direct visual observation of shallow stratigraphy;
- Direct measurement of product 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 free product screening as the depth of the test pit increases;
- Physical access constraints at small and/or heavily developed sites including utilities.

*Factors to consider:*

- Disposal costs associated with the excavated contaminated material;
- Cost 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. 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 listed in N.J.A.C. 7:26E-2.1(a)14.

*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 ground water flow direction and product 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 convention borings.

Additionally, some specialized direct push technologies have the ability to detect product without obtaining a physical soil core.

*Advantages:*

- Rapid delineation is possible;
- Ability to advance tools that can detect separate phase product 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 ground water and to document groundwater flow direction.

## 4. Permanent Wells

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

Permanent wells should be placed within the plume to monitor the effectiveness of product recovery and down-gradient immediately outside the free product plume boundary to act as a sentinel point for product 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 free product.

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 free product 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 free product 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 free product on a regular basis. In order to accurately assess the correlation between water table fluctuations and product 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 product accumulation in a well, depth to product and product thicknesses must be determined during each gauging event. Following the collection of depth to water / depth to product readings with the appropriate field instruments, the product thickness should be verified via a clear bailer as stipulated in the Field Sampling Procedures Manual.

***Special Note for Free Product 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 product distribution and migration pathways.

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 I 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.

## Appendix C

**Examples of Typical Interim LNAPL Free Product Remedial Measures**

Below are examples of typical free product remedial technologies. This listing is not comprehensive and is included here only to provide examples of the more commonly used technologies.

### 1. Excavation

With this remedial technique, the product contaminated materials are physically removed from the surface and subsurface via excavation.

*Advantages:* Rapid removal of product saturated material is possible. Can reduce or eliminate long term monitoring costs associated with the LNAPL discharge at a site by removing the source.

*Disadvantages:* Use is limited to unconsolidated mediums. Effective removal of product contaminated material within the saturated zone is difficult with excavation alone. There may be depth limitations at sites with a high water table and/or non-cohesive subsurface. There are disposal costs associated with the excavated material as well as with the clean fill which is required to backfill the excavated area(s). These costs can be significant at sites where the extent of product contaminated material requiring removal is large. Excavation may not be a viable remedial approach due to physical access constraints at small or heavily developed sites.

*Factors to Consider:* Effective use of this technology necessitates an understanding of both the horizontal and vertical distribution of the product contaminated material which exists at a site. Understanding the vertical distribution of this source material is especially important as product contaminated material within the saturated zone is difficult to address with excavation alone.

At sites where there is a high water table, aggressive dewatering is usually necessary to effectively excavate the full extent of product contamination in the subsurface. There are costs associated with the treatment and disposal of any ground water generated in these situations. At sites where the subsurface is non-cohesive, shoring during excavation activities is often necessary.

### 2. Dewatering and Product Collection via Recovery Wells

With this technology, ground water extraction is conducted in order to create a cone of depression that induces free product to flow into the extraction point(s) along an increased hydraulic gradient. There are several variations of this technology that can be implemented. Dual pump systems involve the use of separate pumps for ground water extraction and product recovery per extraction point. Single pump systems employ a pump capable of total fluids recovery.

*Advantages:* Can enhance free product recovery rates by manipulating and controlling ground water elevations in the vicinity of the extraction points; can establish some measure of hydraulic containment of the dissolved phase plume associated with the free and residual product mass. This type of system can be augmented for use with surfactant injections to increase product mobility and recovery rates or with a venting system which will address the residual component of the LNAPL discharge.

*Disadvantages:* As a stand-alone technology, does not address the residual contamination associated with any LNAPL discharge; effectiveness is reduced at sites where product recovery is necessary from zones with low hydraulic conductivity values.

*Factors to Consider:* This approach is most effective when recovering product from zones with higher hydraulic conductivity values. For effective use of this technology, the correlation between depth to water vs. depth to product must be determined.

- appropriate pump tests must be conducted to design an effective recovery system.
- must determine the amount of water table depression necessary to optimize free product recovery without artificially increasing the smear zone. This is less of a concern if dewatering will be accompanied with soil vapor extraction.

**3. <u>Vacuum Enhanced Fluid Recovery Using Drop Tube Technique</u>**

With this technology, ground water and free product are recovered simultaneously by applying a vacuum via a drop tube inserted into each extraction point. A variation of this technique uses a separate submersible pump for ground water extraction and conducts product recovery via a vacuum applied to a drop tube.

*Advantages:* Can enhance free product recovery rates in zones of lower conductivity values by increasing the vacuum applied to the extraction point. Can address residual product as well as free product by enabling venting of the soil column and that portion of the aquifer matrix exposed with dewatering. Mobile systems are available which can allow periodic application of this technology at sites where the free product plume is: shallow, encompasses a small area, is not migrating, and where there are no ongoing receptor risks associated with the LNAPL discharge.

*Disadvantages:* There are depth limitations when lifting liquids with a vacuum which may limit dewatering capabilities and the associated product recovery rates at sites where depths to product and depths to water are greater than 25 feet below grade. Use of periodic application of this technology via a mobile system can result in incomplete product removal across the source area due to the short term duration of the each mobile event.

*Items to Consider:* Consider the depth to which dewatering must be accomplished to enhance both free product recovery and to enable venting of the residual product contaminated zones.

- there are depth limitations when lifting liquid with a vacuum that may limit the effectiveness of this technology when depth to water/depth to product is 25 feet or greater.
- in highly transmissive situations, dewatering is often better accomplished with a submersible pump with the vacuum applied via drop tube solely for product recovery / venting purposes.
- For drop tube/vacuum enhanced total fluid systems, drop tube placement is important.
    - to enable venting of the zones associated with residual product contamination, the drop tube should be placed below the zone of free and residual product saturation in order to expose the pertinent zones to venting.

## 4. Total Fluids Extraction Using A Vacuum Applied at the Well Head

With this technology, dedicated pumps are utilized to recover ground water and free product while a vacuum is applied to the well head to enhance fluid flow to the extraction point**.**

*Advantages:* Can enhance product collection in those situations where there is sufficient free product to drain in response to a depressed water table. Dedicated product recovery pump limits emulsion of the recovered product during removal which simplifies treatment trains and may reduce costs. May establish some measure of hydraulic containment of the dissolved phase plume associated with the free and residual product mass.

*Disadvantages:* Does not address the residual mass associated with the free product plume.

*Considerations:* This approach is most effective when recovering product from zones with higher hydraulic conductivity values but can increase recovery rates in zone of lower conductivity values as a result of vacuum enhancement. For effective use of this technology, the correlation between depth to water vs. depth to product must be determined.

- Conduct the appropriate pump tests to design an effective recovery system.
- Determine the amount of water table depression necessary to optimize free product recovery without artificially increasing the smear zone.