

**LNAPL and
The Massachusetts Contingency Plan**

Part I

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LSP Association Technical Practices Committee

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TABLE OF CONTENTS

1.0	INTRODUCTION.....	1
2.0	MCP REGULATIONS SPECIFIC TO LNAPL	3
3.0	DISCUSSION OF ISSUES	5
4.0	MCP PERFORMANCE STANDARDS FOR LNAPL RELEASES	10
5.0	SUMMARY AND CONCLUSIONS.....	12
6.0	REFERENCES.....	14

LIST OF TABLES

Table 1 – Comparison of Seven Alternative Methods For Correlation of Product Thickness Measured in a Monitor Well to Actual Thickness in the Soil

LIST OF FIGURES

Figure 1 - Temporal Changes in LNAPL Thickness and Piezometric Elevation
Figure 2 - Tank and Pancake Conceptual Model
Figure 3 - TPH Spatial Distribution
Figure 4 - Comparison of Vertical Profiles
Figure 5 - Potential LNAPL Migration Pathways and Exposure Points

1.0 INTRODUCTION

The assessment and regulation of petroleum releases that result in the presence of non-aqueous phase liquids (NAPL) in the environment are among the more complex issues facing practitioners and regulators. Current Massachusetts regulations and waste site cleanup practice focus primarily on the measurement of NAPL thickness in groundwater monitoring wells for compliance with reporting obligations and cleanup standards.

The LSP Association (LSPA) Technical Practice Committee (TPC) has identified the assessment and regulation of NAPL as a practice area warranting review, potential regulatory update, and practice standard improvement. In early 2004, the TPC established a subcommittee to review the current practice standards for a class of NAPL that is less dense than water, termed light non-aqueous phased liquids or LNAPL.

The Massachusetts Department of Environmental Protection (DEP) has expressed concerns about the amount of site characterization data available for LNAPL sites (DEP, 2001). Data quantity is often limited spatially and temporally. Temporal data, when available, often present interpretive difficulties. Based on the DEP studies and published audit findings, the methods to evaluate LNAPL thickness used by Licensed Site Professionals (LSPs) appear inconsistent and sometimes inappropriate.

In the environmental community, nationwide, there is debate about the appropriateness of relying solely on LNAPL thickness data from groundwater monitoring wells for site characterization, risk assessment and cleanup (DNREC, 2004; API, 2003). This concern stems primarily from a new appreciation that the historic “Tank and Pancake” LNAPL conceptual model is overly simplistic. No apparent correlation exists between the amount of NAPL present in a monitoring well and risk (DNREC, 2004).

The Massachusetts Contingency Plan (MCP) (DEP, 1993) has based regulation of LNAPL presence and behavior in the environment on this outdated model. More appropriate models and methods are now available to provide a basis for regulating these materials. Other agencies and states have transferred the knowledge and experience gained from the petroleum production and distribution industry to bear on understanding and evaluating the impacts of releases of petroleum to the ground and groundwater. This cumulative gain in knowledge, along with current research and a more specific understanding of multi-phase fluid transport in porous media, has resulted in the development of new conceptual models upon which to base regulation and cleanup of LNAPL. (API, 2003; NCA, 2004; DNREC, 2004).

The TPC LNAPL subcommittee studies are being presented in two white papers. Part I presents the principal issues currently influencing the evaluation and regulation of releases of LNAPL to the ground and groundwater in Massachusetts. The LNAPL conceptual model used to establish the current regulations is described, and its effectiveness for site characterization and risk assessment is discussed. Part I also provides a review and discussion of current MCP regulations specific to LNAPL characterization and risk

assessment. Part II will present specific technical background data and will recommend changes, as appropriate, to the current investigation and regulatory approach. Work on Part II is ongoing, and the TPC encourages interested parties to participate and to comment during the process.

2.0 MCP REGULATIONS SPECIFIC TO LNAPL

The Massachusetts Contingency Plan in 310 CMR 40.0006 defines NAPL as “*..oil and/or hazardous material that is present in the environment as a continuous separate phase as measured in a groundwater monitoring well or otherwise observed in the environment.*” The MCP does not distinguish NAPL from LNAPL. LNAPL is included in the MCP’s requirements for NAPL. The DEP has developed various policies and undertaken studies to evaluate light petroleum products.

MCP release reporting and risk assessment requirements for NAPL, and thus LNAPL, are summarized below.

2.1 Release Reporting Standards

Two specific LNAPL-related conditions trigger reporting requirements in the MCP. The first requires notification of the DEP not more than 72 hours after obtaining knowledge of “*a release to the environment indicated by the presence of a subsurface Non-Aqueous Phase Liquid (NAPL) having a measured thickness equal to or greater than 1/2-inch.*” (310 CMR 40.0313). An Immediate Response Action must be performed upon 72-hour notification to assess and/or abate the observed LNAPL condition.

The second condition requires notifying the DEP within 120-days of obtaining knowledge of “*a release to the environment indicated by the presence of a subsurface Non-Aqueous Phase Liquid (NAPL) having a measured thickness equal to or greater than 1/8-inch and less than 1/2-inch.*” (310 CMR 40.0315(4)).

While not specifically stated as being only applicable to measurements in groundwater monitoring wells, in practice as observed for the last 10 years and in policy (DEP, 2002), these reporting conditions are most likely observed from measurements made in various shapes and sizes of groundwater monitoring wells.

2.2 Imminent Hazards and Critical Exposure Pathways

NAPL presence could represent an Imminent Hazard condition as described in 310 CMR 40.0321 as(a) *a release to the environment which results in the presence of oil and/or hazardous material vapors within buildings, structures, or underground utility conduits at a concentration equal to or greater than 10% of the Lower Explosive Limit;*

An Immediate Response Action may also be required to eliminate or mitigate a Critical Exposure Pathway as required by 310 CMR 40.0414(3). A Critical Exposure Pathway is defined in 310 CMR 40.0006 as *...those routes by which oil and/or hazardous material(s) released at a disposal site are transported, or are likely to be transported, to human receptors via: (a) vapor-phase emissions of measurable concentrations of oil and/or hazardous materials into the living or working space of a pre-school, daycare, school or occupied residential dwelling; or (b) ingestion, dermal absorption or inhalation of*

measurable concentrations of oil and/or hazardous materials from drinking water supply wells located at and servicing a pre-school, daycare, school or occupied residential dwelling.

2.3 Risk Assessment Standards

MCP risk assessment standards related to NAPL include concentration-based human health standards (Method 1 Standards) for various petroleum constituents in soil and groundwater, and standards related to risk of harm to public welfare and the environment referred to as Upper Concentration Limits (UCLs). The concentration-based human health standards are compound specific, or, as is the case for petroleum hydrocarbons, specific to carbon ranges or Total Petroleum Hydrocarbons. On the other hand, according to DEP policy, the UCL for NAPL is based on concerns for bulk fluid migration; the potential for the discharge of product to underground structures, utilities and surface water bodies; and having the NAPL represent a potential continuing source of contamination. (DEP, 2002). UCL criteria are compared to average site values.

In practice today, NAPL is considered in MCP Risk Assessments principally in terms of UCLs. The following citation from 310 CMR 40.0996(1) states... *“Upper Concentration Limits in soil and groundwater are concentrations of oil and/or hazardous material which, if exceeded, indicate the potential for significant risk of harm to public welfare and the environment under future conditions”.*

The UCL specific to LNAPL is defined at 310 CMR 40.0996(6) as follows *“The presence of non-aqueous phase liquids (NAPL) having a thickness equal to or greater than 1/2-inch in any environmental medium shall be considered a level which exceeds Upper Concentration Limits.”* Spatial averaging within the contiguous area of an LNAPL plume is allowed for comparison of site conditions to the UCL.

2.4 Response Action Outcome Requirements

Non-aqueous phase liquids (NAPL) are considered by the DEP to be a possible source of intermedia transfer of oil and/or hazardous material (310 CMR 40.1003(5)(a)4). As required by 310 CMR 40.1003(5) ... *A Class A or Class B Response Action Outcome shall not be achieved unless and until each source of oil and/or hazardous material which is resulting or is likely to result in an increase in concentrations of oil and/or hazardous material in an environmental medium, either as a consequence of a direct discharge or through intermedia transfer of oil and/or hazardous material, is eliminated or controlled.* LSP practice experience sometimes interprets this to mean that NAPL must be eliminated or controlled sufficiently to not allow an increase in the level of contamination present in soil vapor, soil or groundwater. However, a great range in interpretation of how this “source” evaluation applies to LNAPL sites presently exists across the practice.

3.0 DISCUSSION OF ISSUES

Section 3.0 reviews the current state of the practice associated with investigation and response to releases of LNAPL under the MCP. This section also presents concerns raised by the DEP about the state of the practice. The current Massachusetts approach to LNAPL sites is also compared to those proposed by other groups and emerging in states that have taken a more scientifically-based approach.

3.1 Inconsistencies in Evaluation of LNAPL Thickness

Currently LSPs utilize various methods for determining the existence and quantity of LNAPL in the subsurface. The most commonly used method to estimate the quantity of LNAPL is to measure its thickness on the groundwater surface in a groundwater monitoring well. Most practitioners employ an electronic oil-water interface probe to collect these measurements. Oil-water interface probes typically contain an optical probe to indicate the presence of LNAPL, and an electrically conductive probe to indicate the presence of water. Other methods available to measure LNAPL thickness in wells include the use of clear plastic bailers, hydrophilic pastes and tapes. Non-monitoring well methods include direct observation on surface waters, and in test pits or other excavations.

None of the methods produce results that are consistent with those of alternate methods. Researchers have documented that the amount of LNAPL present in a monitoring well in a given situation is influenced by the manner in which the well was installed, the well installation and screen size design, well construction materials and well diameter (USEPA,1996). Practice experience shows it is very common for a two-inch diameter monitoring well to have LNAPL present and an immediately adjacent, four-inch diameter monitoring well to have none. Some investigators utilize only monitoring wells that are at least four inches in diameter to investigate sites where there is a potential for LNAPL to exist.

3.2 Poor Correlation between LNAPL Thickness Measured in Wells and *In-Situ* Mass

Historically, considerable research effort has been directed toward understanding the relationship between the thickness of LNAPL in a groundwater monitoring well and the thickness of a theoretical LNAPL layer floating above the water table. Tank experiments were used to demonstrate that the measured thickness in groundwater monitoring wells (referred to as the “apparent” thickness) and the theoretical “actual thickness” of the petroleum saturated “floating layer” (the “true” thickness) are not similar.

The MCP, in 310 CMR 40.0996(6), indicates that UCL exceedance compliance measurements for NAPL are determined “in any environmental medium.” This is interpreted in DEP policy (DEP, 2002) as making a distinction between measurements in a monitoring well and the theoretical “true” measure in the environment; however, little guidance is provided on how to measure “true” thickness in an environmental medium or how to correlate well measurements with the “true” thickness.

Numerous researchers have developed various methods for deriving the “true” thickness from the measured or “apparent” thickness. These methods include various equations and charts suggested for “correcting” the apparent thickness. Table 1 provides a summary of the results of applying various correction methods (USEPA, 1996). The data shows a six-fold variation in the calculated value, depending on the method used. The effect of formation soil grain size on the calculated measure of “true” thickness was summarized for different soil types in a recent LSPA News article (LSPA, 2003).

The Environmental Protection Agency (EPA) recognized that these methods can provide significantly different estimates for “true” thickness. The EPA concluded that “...*the predictability of these methods indicates an order of magnitude accuracy of the predicted versus the measured free product thickness among the methods,*” and that “*In spite of the intense attention that has been focused on developing a correlation between free product thickness measured in wells and volume of free product in the soil, none of the available methods has been particularly reliable when tested either in the field or even in the laboratory.*” (USEPA, 1996).

3.3 Temporal Variations in Piezometric Conditions

The EPA states “*Fluctuations in the water table can result in large differences in measured hydrocarbon thickness even though the in situ volumes are not significantly changed. Increases in hydrocarbon thickness are commonly observed with declining water tables.*” (USEPA, 1996).

Figure 1 illustrates monthly LNAPL in-well thickness and piezometric elevation measurements at a petroleum storage terminal site in Massachusetts. The inverse correlation of piezometric elevation and LNAPL in-well thickness is clearly exhibited. Of particular interest in this case is that LNAPL was not observed in the groundwater monitoring well approximately half of the time. These “non-detect” readings could be considered as “false-negatives,” since the LNAPL reappears in the monitoring well when piezometric elevations decline.

Consequently, LNAPL measurements from groundwater monitoring wells can be non-conservative in nature depending upon the level of the groundwater table, the frequency of measurements performed and the formation and well construction details.

3.4 Lack of Temporal Data

In 2000, the DEP reviewed RAOs filed by LSPs for disposal sites where the presence of LNAPL had been documented. The results of this study have been posted on their web site (DEP, 2001). The DEP found that, in their opinion, many LNAPL sites had been closed without sufficient data. DEP looked at 41 sites and found that 30 were closed with only one monitoring point used to evaluate that presence of LNAPL. Fourteen of the sites obtained data over only a three-month period, not considered indicative of seasonal or other piezometric variation. Only five sites had data collected in at least one monitoring well for

each season of the year. The DEP questioned the appropriateness of the documented level of effort at these sites for rendering RAO opinions. As will be discussed further in Part II, other data in lieu of temporally spaced in-well measurements can be collected to characterize LNAPL sites. The scope of what evaluations may be appropriate is rooted in the conceptual model of how LNAPL acts in environmental media.

3.5 Current Conceptual Model Not Representative of LNAPL Behavior

The current conceptual model used for characterizing the nature and extent of LNAPL contamination in the MCP is no longer considered. This model is sometimes referred to as the “Tank and Pancake” model (Ballesterio et al., 1994). In the Tank and Pancake model, LNAPL in the environment is assumed to behave like oil added to a soil-filled tank that is partially full of water. Near-surface LNAPL releases are assumed to migrate vertically in unsaturated soils under gravitational force until the groundwater table is reached, at which time the LNAPL spreads horizontally as a continuous single-phase fluid (Figure 2). The LNAPL is assumed to “float” as a separate layer on the water table (or capillary fringe) in the shape of a “pancake” and remain in one connected mass.

Certain assumptions are implicit in the Tank and Pancake model. Most importantly, the model is essentially static and assumes that LNAPL “floats” and does not penetrate the water-saturated soils below the groundwater table. In addition, it is assumed that the soil is homogeneous and the variability of porosity is not an influencing factor. Therefore, changes in LNAPL measurements in a groundwater monitoring well would be assumed to reflect changes in the thickness of the “floating layer.” The model also treats LNAPL as a single continuous fluid phase. Consequently, it is implicitly assumed that the pore spaces of soils within the floating layer are completely filled with LNAPL or “pore saturated,” and the pores do not also contain air or water. The volume of LNAPL in the floating layer is therefore proportional to the layer thickness, “pancake” area and the soil porosity. This model is no longer considered by technical associations in the oil industry and national technical consensus standard setting associations to be the best or even an appropriate conceptual model to describe and understand the presence and movement of LNAPL released to the environment (API, 2003; DNREC, 2004).

Figure 3 illustrates total petroleum hydrocarbon (TPH) concentrations in soil at a petroleum release site in Massachusetts. The cross-section shows that the bulk of the LNAPL contaminated soils are found below the piezometric surface. While the highest TPH concentrations in soil are found close to the water table, the thickness of the mass of petroleum defining the “impacted zone” or “smear zone” extends down as much as six feet below the groundwater table. This might be partially explained by vertical rise and fall of the water table, but there must be other forces driving LNAPL into the water table and holding it there because the LNAPL does not float back up to the water surface as suggested in the tank and pancake model.

Figure 4 shows the vertical distribution of TPH in soil samples collected from three representative soil borings at the same site. In each case the peak soil TPH concentration occurs near the piezometric surface. As a percentage of pore saturation, these peak TPH

concentrations represent approximately 10 to 40 percent, which again does not compare favorably with the implicit assumption in the Tank and Pancake model assumption of full pore saturation.

3.6 New “Multi-phase Flow” Conceptual Model

According to the American Petroleum Institute (API), *“LNAPL does not float above groundwater as suggested by the analogy of oil floating on water in a tank. Instead, LNAPL rests like an iceberg in the sea, largely submerged. Movement of LNAPL is constrained by the pressures needed to displace water from the pores at the margins of the LNAPL.”*(API, 2003)

The new conceptual model, referred to as the “multiphase flow” model, is documented by API and is being used by ASTM to develop an LNAPL site evaluation protocol. Certain states, including Delaware, Wyoming, New Jersey, Pennsylvania and Texas, are also beginning to use this model to determine the direction they will move their investigation and remediation programs for LNAPL releases (APT, 2003; DNREC, 2004; NCA, 2004a).

The model focuses on the spatial distribution of LNAPL, and does not address temporal behavior. It is based on the principles of multi-phase fluid flow within a porous media. In the environment, soil exists as individual soil grains and pore spaces. These pore spaces may contain air and water above the groundwater zone. Below the water table the pore spaces will typically be filled with water that is in contact with all of the soil.

In order to understand multi-phase fluid flow it is necessary to understand the distinction between the “wetting fluid” and the “non-wetting fluid.” In a porous medium, such as soil, the denser fluid will coat the soil particles. Therefore, below the water table water is the wetting fluid, and LNAPL is the non-wetting fluid. Above the water table LNAPL can be the wetting fluid, if little to no water is present, and air becomes the non-wetting fluid. In order for LNAPL to flow through the pore spaces in the groundwater zone, it must displace water. However, it cannot displace all of the water (the wetting fluid), and therefore the LNAPL and water must coexist in a multiphase fluid mass.

When LNAPL is released into the environment above the groundwater zone it flows downward under gravity. As LNAPL flows through the soil, it competes for a portion of the available pore space with air and water. If little to no groundwater is present, LNAPL will wet the unwetted soil column leaving a residual LNAPL liquid film on the soil grains as gravity forces the bulk liquid phase down through the porous soil structure. However, based on the properties of water and most soils, water is the preferred fluid to wet the soil grains. Capillary forces and other dynamics will cause the water to remain in the smaller void spaces and channels between the soil grains. Where the soil is saturated with water, as it is in the groundwater zone, there must be a dynamic pressure to push the LNAPL in, displace the water and overcome surface tension and enter smaller pores. This pressure can be from a vertical column of interconnected LNAPL. Additionally, pores may restrict the buoyant rise of LNAPL and LNAPL may be injected by the head of LNAPL and water above the water

table to points deeper in the soil column until the buoyant forces increase and limit further downward flow.

The LNAPL will flow first into the larger pores, where there is less resistance, and may break into small droplets or globules with surface tension holding LNAPL in the pore space even as water passes through. When the continued discharge of LNAPL is terminated, and the LNAPL reaches the groundwater zone, the LNAPL will reach equilibrium with the water in the soil pores. As a lack of connection develops between the LNAPL in all of the pores, water in the pores, the preferred wetting fluid, will begin to flow around the larger pores containing LNAPL, effectively isolating the LNAPL from continued movement and trapping it in the soil formation. This process is dynamic, changing continuously as the groundwater level rises and falls and atmospheric pressure and capillary force changes occur.

The percentage of the soil pore volume occupied by LNAPL is termed the degree of oil saturation. This percentage, combined with knowledge of the soil properties, can be utilized to estimate the mass of LNAPL in soil. The percentage of LNAPL at which the LNAPL is no longer mobile is termed residual NAPL saturation or residual saturation (Adamski et al., 2003). A more traditional way to discuss this same condition is to describe it in terms of LNAPL concentration, typically in units of milligrams of LNAPL per kilogram of soil. The concentration-based equivalent to residual saturation is termed residual NAPL concentration or residual concentration (API/GRI, 2000). Immobile LNAPL (at concentrations below the residual concentration) in the groundwater zone should be considered a possible source of inter-media transfer of mass to groundwater and soil vapor.

API has prepared an excellent reference document (the “API Interactive LNAPL Guide”) introducing the concepts discussed above. It also provides numerous tools to evaluate the movement and recovery of LNAPL using the multiphase flow model as a basis for its assumptions (API, 2004).

4.0 MCP PERFORMANCE STANDARDS FOR LNAPL RELEASES

This section provides a general discussion of the behavior of LNAPL in the environment and the effects that potentially become the subject of investigations under the MCP. In addition, it identifies those provisions of the MCP to be addressed by an alternative regulatory approach for LNAPL.

LNAPL can migrate significant distances if the release source is not eliminated. Migrating LNAPL has the potential to impact soil, groundwater, surface water bodies, and water supply wells, and it can appear in underground utilities that intercept the release. It can also act as a source for vapor migration to ambient or indoor air and pose an odor nuisance and an explosion hazard if encountered unexpectedly during excavation activities. Contact with heavily contaminated soil and groundwater can also provide a source of dermal and inhalation risk. These potential migration pathways, and thus the potential risks to human and environmental receptors from an LNAPL release, are illustrated on Figure 5.

Groundwater within the smear zone coming in direct contact with LNAPL will itself become contaminated with the constituents of the LNAPL, be it gasoline, fuel oil, or specific distillates. This occurs in a predictable manner based on groundwater and LNAPL chemistry. Dissolved phase migration away from the area impacted with LNAPL can also occur, regardless of whether or not the LNAPL mass itself is moving. Dissolved phase groundwater contamination has the potential to act as a source of contamination to surface water bodies and water supply wells, and may act as a source of soil vapor migration to indoor air.

The MCP currently requires the assessment and evaluation of risks associated with these various pathways and contaminated media. Performance standards are specified for site characterization, including determining the nature and extent of contamination, and routes of exposure. The need for temporal data to evaluate groundwater contamination migration potential for these releases is now understood by LSPs. Risk characterization requirements and guidance documents provide characterization methods and approaches for evaluating the regulatory impacts of contaminated soil gas, soil and groundwater. Concentration-based UCLs are provided for petroleum contamination fractions and compounds of concerns in soil and groundwater.

Assuming vapor and groundwater related risks are addressed within the current structure of the MCP, the evaluation of temporal data and the comparison of site data to soil and groundwater UCLs provides most of the assessment methodology needed to investigate response action requirements for LNAPL releases. Demonstrating that LNAPL is not a continuing source of contamination as a consequence of intermedia transfer, as required under 310 CMR 40.1003(5), remains the final requirement for filing a Class A or B RAO. Potential LNAPL mobility should be addressed under this requirement. However, UCLs for petroleum contamination in soil were not derived based on a direct assessment of LNAPL mobility and are not appropriate for this purpose.

Any alternative characterization and evaluation approach that might be undertaken for LNAPL should provide data sufficient to address the overall Performance Standards and various specific requirements of the MCP. While there may not be specific criteria for LNAPL in the MCP other than the current notification and UCL criteria, the MCP does require that certain conditions must be satisfied before a permanent solution can be obtained for an LNAPL or any other type of release.

Under the MCP, the following issues associated with LNAPL need to be evaluated or provided for:

- Notification
- Imminent Hazard or Critical Exposure Pathway Condition
- Identification of the Presence of LNAPL
- Site and Release Characterization Level of Effort
- Soil Contamination
- Vapor Migration
- Dissolved Phase Migration
- LNAPL Mobility
 - Surface Water Discharge
 - Preferential Pathway Migration
 - Discharge to Subsurface Utilities
- Existence as a Source of Continuing Contamination
- Welfare-Odor
- Safety-Explosion

5.0 SUMMARY AND CONCLUSIONS

The key issues identified in this paper are summarized below:

- Measured LNAPL thickness in groundwater monitoring wells is a highly variable parameter that can not be relied upon from site to site due to variations in methods used to obtain measurements, variation in well construction details, influences of formation characteristics, etc and is therefore an unreliable parameter.
- Measured and “actual” LNAPL thicknesses do not correlate in the field or the laboratory.
- LNAPL does not form a discrete continuous single-phase layer floating on or above the groundwater table. The Tank and Pancake model of LNAPL behavior is not an accurate or reliable conceptual model for the existence of LNAPL or to predict LNAPL behavior in the environment.
- Temporal piezometric changes create challenges when applying currently used tools and approaches to determining LNAPL presence and the evaluation of risk.
- Various agencies and states are using a multiphase flow conceptual model that is more representative of conditions in the environment than the Tank and Pancake model used by Massachusetts to derive NAPL Upper Concentration Limits.
- The multiphase flow model is more effective in predicting LNAPL occurrence and behavior in the environment. An understanding of wetting and non-wetting fluid, along with the concepts of pore saturation and residual concentration can be used as a framework to understand observed phenomena.
- In the multiphase flow model, LNAPL contamination is characterized on either a percent pore saturation basis, or on a soil concentration basis. In either case, LNAPL is being treated as a soil contaminant, as opposed to being considered a “separate” phase contaminant.

Based on the information summarized in this white paper, the LSPA Technical Practices Committee concludes the following:

1. The use of the Tank and Pancake conceptual model to evaluate and predict movement and risks associated with LNAPL by the MCP should be reviewed and updated based on the current state of science and technologies characterizing the conditions of multi-phase fluid flow in porous soil media.
2. The Tank and Pancake model used to develop the UCL standard in the MCP does not adequately or accurately represent actual field conditions and does not reliably predict the spatial or temporal behavior of LNAPL.

3. LNAPL thickness as measured in monitoring wells or determined to be present in the environment is not an accurate indicator of risks to harm that are required to be addressed by the MCP.
4. The regulatory provisions in the MCP that are based on the Tank and Pancake conceptual model should be reviewed to determine if more appropriate measures should be substituted. The multiphase flow model should be used as the basis for these changes, along with the recognition that LNAPL is best characterized as a soil contaminant.
5. The MCP currently has the mechanisms for addressing the remediation requirements for LNAPL releases without relying on a thickness based UCL. Any revision in the manner in which LNAPL is treated under the MCP needs to encompass the following MCP requirements of specific concern to LNAPL:
 - Notification
 - Possible Imminent Hazard or Critical Exposure Pathway Conditions
 - Identification of the Presence of LNAPL
 - Level of Effort for Site and Release Characterization
 - Soil Contamination Levels
 - Vapor Migration
 - Dissolved Phase Migration
 - LNAPL Mobility
 - Surface Water Discharge
 - Preferential Pathway Migration
 - Discharge to Subsurface Structures and Utilities
 - Existence as a Source of Continuing Contamination
 - Risk of Harm to Welfare-Odor
 - Risk of Harm to Safety-Explosion
6. A systematic evaluation should be undertaken of the manner in which NAPL (primarily LNAPL) releases are addressed under the MCP. The following should be evaluated:
 - NAPL Site Characterization Requirements
 - Data Needs
 - Traditional and Emerging Site Characterization Methods
 - Applicable and Alternative Analytical Methods
 - Data Assessment Methods
 - Special Risk Evaluation Requirements
 - Recommended Regulatory and Policy Updates/Changes

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**Table 1 - Comparison Of Seven Alternative Methods For
Correlation Of Product Thickness Measured In A Monitor
Well To Actual Thickness In The Soil**

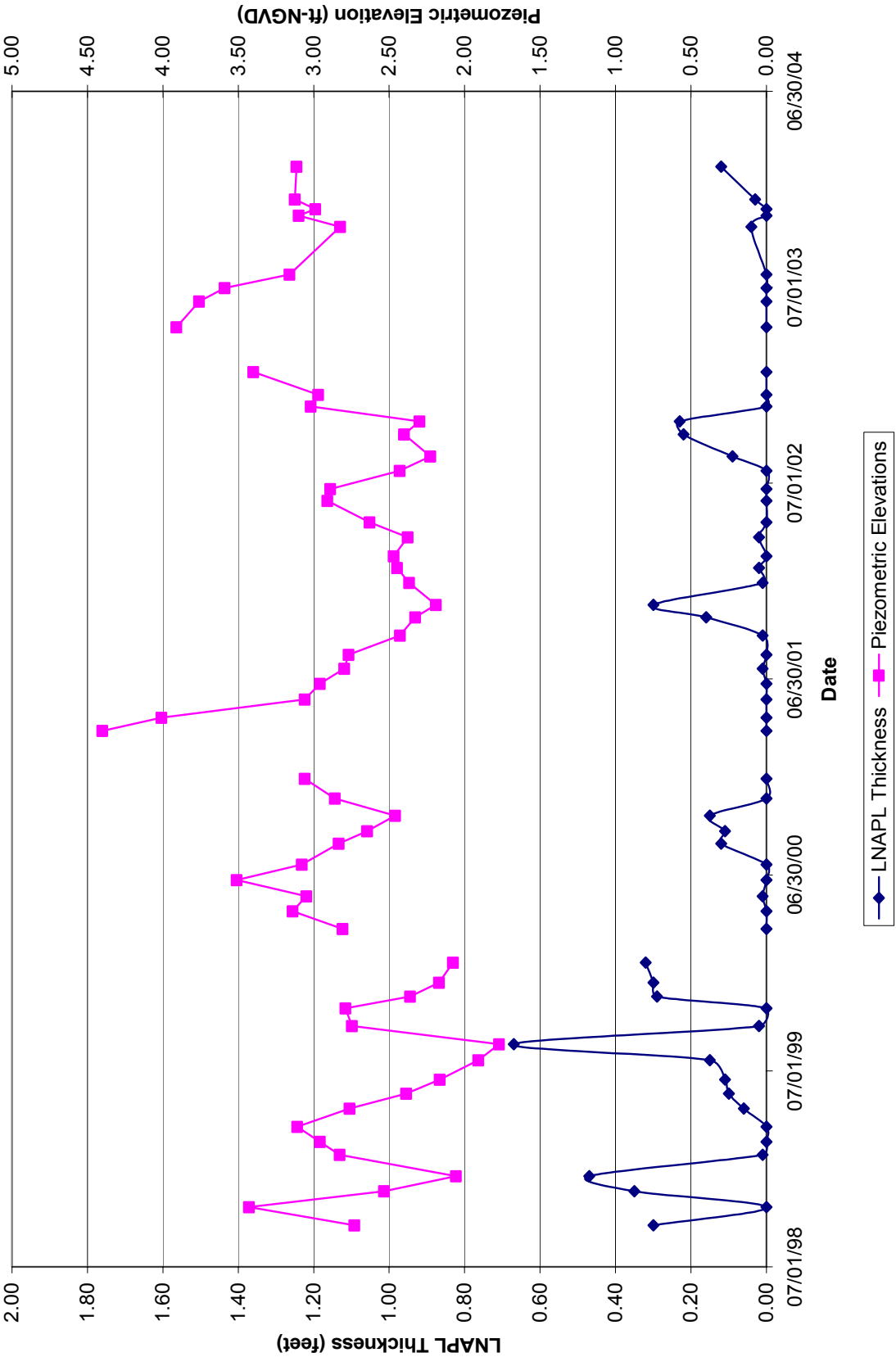
Calculated Results (Hydrocarbon Thickness in Soil)

Measured hydrocarbon thickness in the soil (cm)	de Pastrovich et al. (1979)	Hall et al. (1988)	Blake and Hall (1984)	Ballestero et al. (1994)	Schiegg (1985)	Farr et al. (1990)	Lenhard and Parker (1990)
---	1.1	-6.5	-16	-16	-28	2.3	7.1
1	12	50.5	1.1	1.1	29	24.3	74.3
3	13	55.5	4.4	4.4	34	26.2	80.2
7	13.9	60.5	9.7	9.7	39	28.1	86.1
13	16	71.5	13.4	13.4	50	32.4	99.1

Note: All values in centimeters except those for Farr et al. (1990) which are volume in cm³/cm².

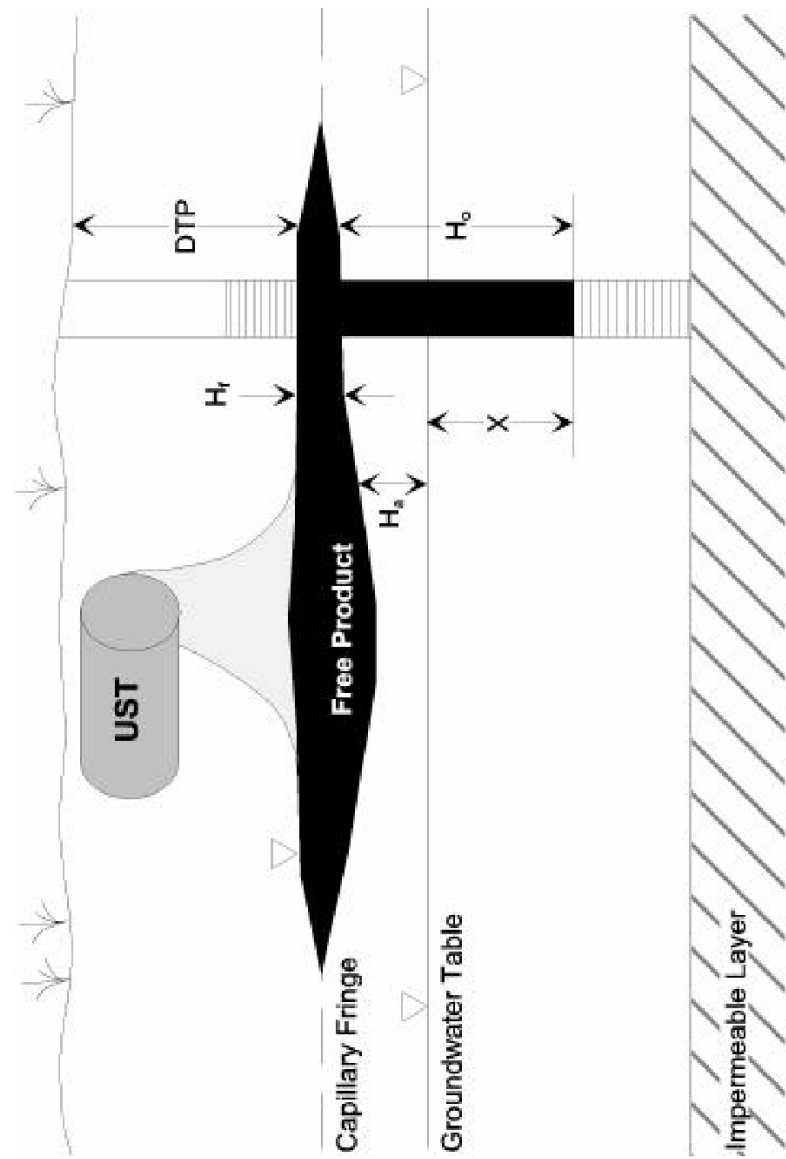
This comparison is based on a study published by Ballestero et al. (1994) using data published in Abdul et al. (1989). Additional data required for the methods of Lenhard and Parker (1990) and Farr et al. (1990) were obtained from their respective papers. Note that the results presented above are only applicable for the data specified in this example. The use of different data may alter the relative performance of the methods. Refer to the Appendix for a more complete presentation of the individual equations used in this comparison.

Figure 1 – Temporal Changes in LNAPL Thickness and Piezometric Elevation



Courtesy, Ambient Engineering, Inc.

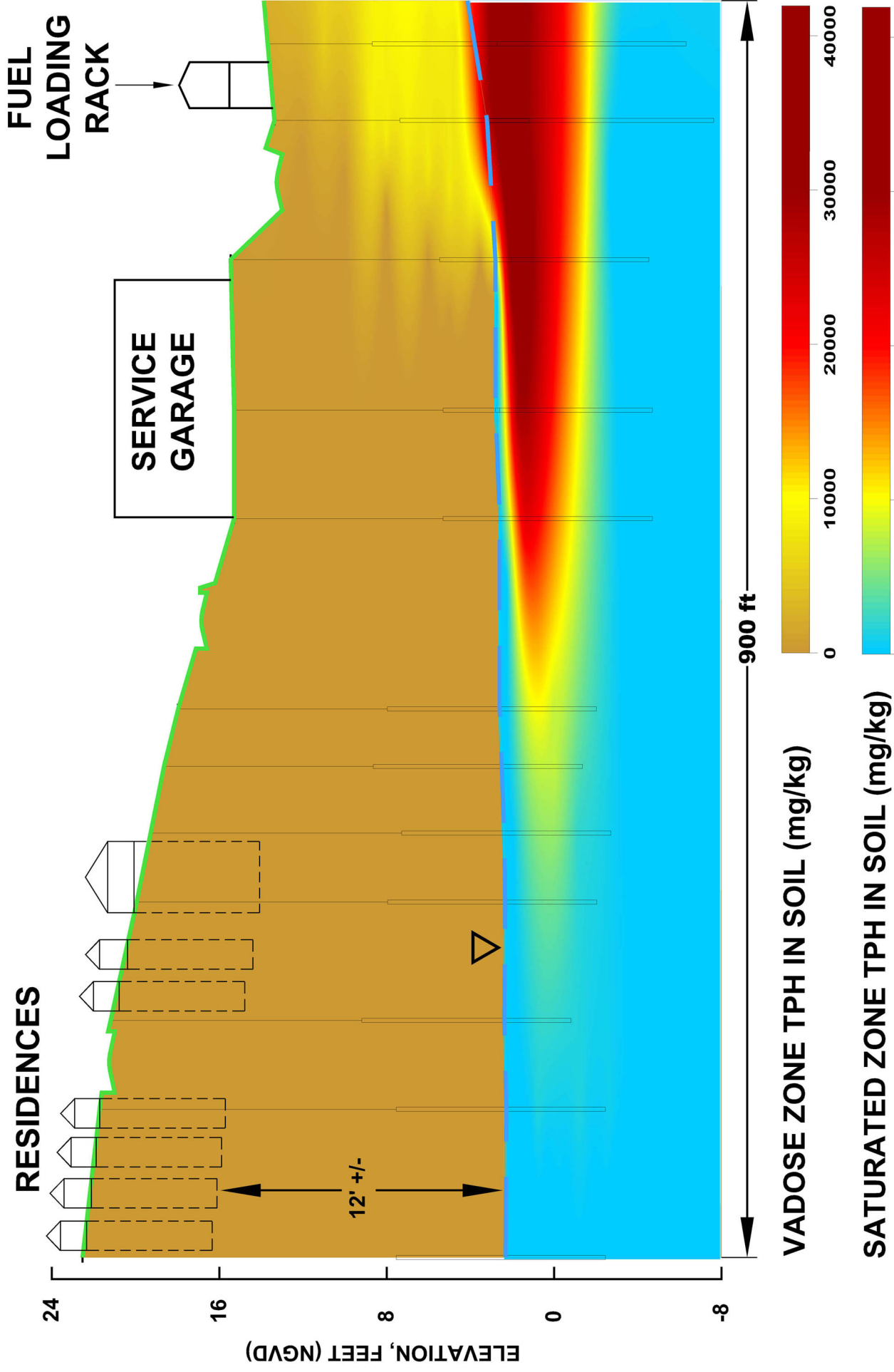
Figure 2 – Tank and Pancake Conceptual Model



Legend

- H_o = apparent (wellbore) product thickness
- H_r = actual formation free product thickness
- DTP = depth to wellbore product level from ground surface
- H_s = free product distance to groundwater table, within formation
- X = interface distance below groundwater table, within well

FIGURE 3 - TPH SPATIAL DISTRIBUTION



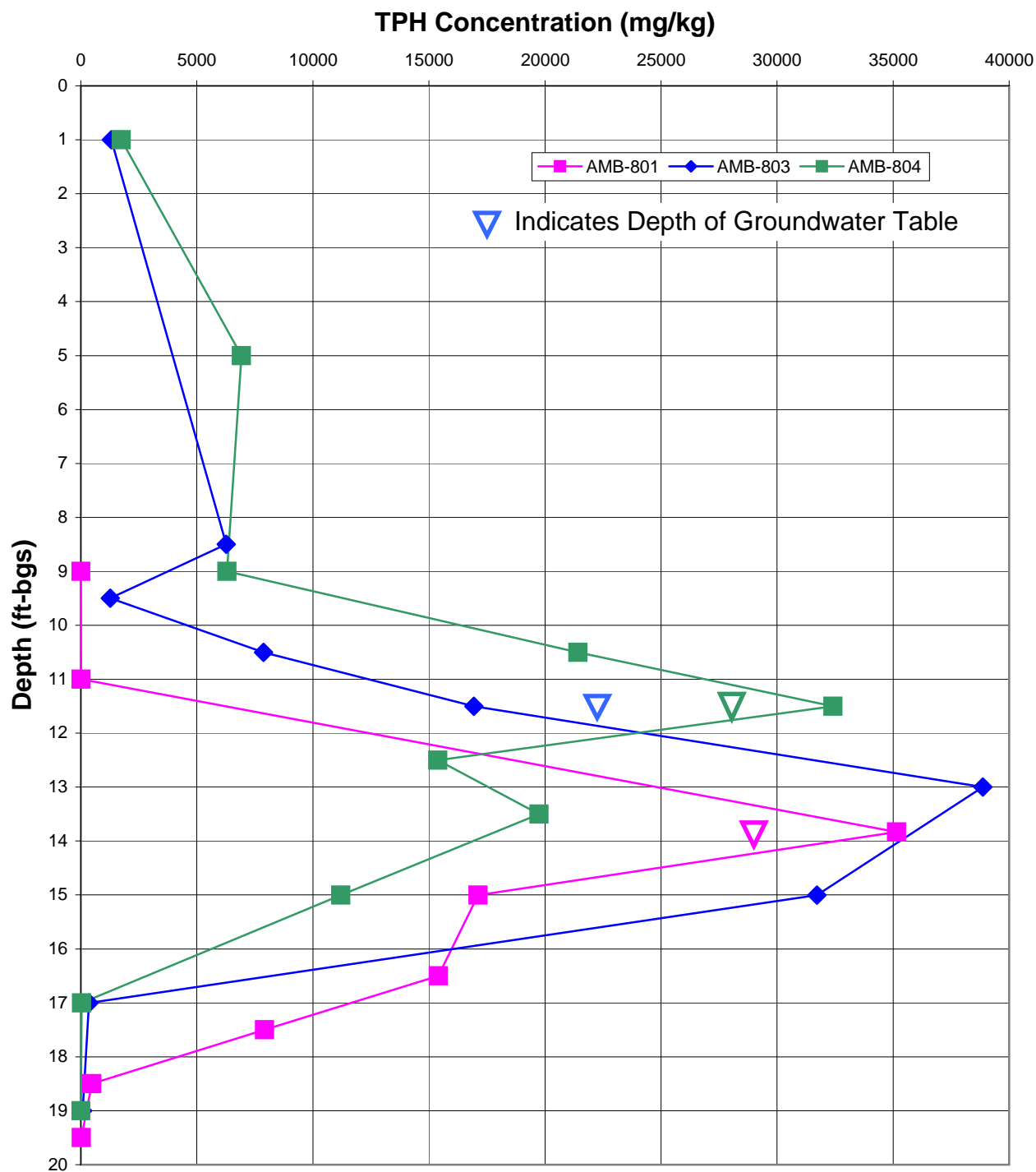


FIGURE 4 - COMPARISON OF VERTICAL PROFILES

Courtesy of Ambient Engineering, Inc.

FIGURE 5 - POTENTIAL LNAPL MIGRATION PATHWAYS AND EXPOSURE POINTS

