Outline for LNAPL Training

Module 1

The Basics

Approximate time: 2 hours

This section presents the physics of multi-phase fluid flow in porous media.

I. What is NAPL?

  a. LNAPL (mix of hydrocarbons)
  b. DNAPL (define but don't deal with in this training)
  c. General misconceptions about LNAPL and LNAPL movement

    1. LNAPL floats on the water table (False)
    2. LNAPL forms a pancake like lens with uniform (high) saturation on the water table (False)
    3. If you see product in a well it is mobile and migrating (False)
    4. Geology is uniform (False)
    5. LNAPL cannot penetrate below the water table (False)
    6. Generally, LNAPL plumes are mobile under natural conditions (False)
    7. The environmental LNAPL problem is completely analogous to the that of petroleum engineering (false)

II. What happens when LNAPL is released?

a. Source
b. Displacement entry pressure
c. Pore sizes
d. Sharing pore space with water (Water is the wetting fluid in shallow aquifer soil. LNAPL is the non-wetting phase and, therefore, occupies a fraction of the larger pores in the soil matrix)
e. LNAPL spreads laterally until it reaches steady state, but does not form a “lens” on the water table (Lenhard and Parker, 1990). No pancake – rather dispersed pores partially saturated with LNAPL.
f. Iceberg effect (if there is sufficient head on the LNAPL as it contacts the water table, it will partially displace the water in those larger pores and create this effect)
g. LNAPL exists as a discontinuous, or residual phase in the vadose zone and below the LNAPL-water interface if there has been a fluctuation of the groundwater elevation
    i. LNAPL does not form a layer, but coexists with air and water in the soil pore matrix. The LNAPL saturation profile changes with height above the LNAPL/water interface.
    ii. LNAPL is very loosely constrained by the water table
h. Soil-fluid interaction properties
    i. Porosity
    ii. Capillary pressure (The distribution of LNAPL saturation between the LNAPL/water interface and the air/LNAPL interface is a function of water-LNAPL capillary pressure. The distribution of LNAPL saturation above the air/LNAPL interface is a function of LNAPL-air capillary pressure. The complete LNAPL saturation profile can be obtained by

        having both the water-LNAPL and LNAPL-air capillary pressure curves.)

    iii. Drainage and imbibition capillary pressure. Capillary pressure vs. saturation relationships change depending on the wetting history of the soil. Therefore, it is important to understand how capillary pressure changes and which curve (drainage or imbibition) controls the various portions of the LNAPL saturation vs. height profile. In addition, other useful soil/fluid interaction properties can be obtained from the capillary pressure curves.
    iv. Relative permeability. There is a direct and measurable function between LNAPL saturation and LNAPL permeability. Therefore, the LNAPL saturation obtained from capillary pressure data can be used to calculate LNAPL mobility (or lack of) if the relative permeability relationship is known. Water-LNAPL relative permeability can be measured in the laboratory, or can be approximated using several algorithms.
        1. Because LNAPL saturation is typically low the LNAPL conductivity will also be low.
        2. Laboratory-measured relative permeability
        3. Relative permeability models
            a. Mualem
            b. Burdine
    v. Maximum LNAPL saturation in soil tends to be surprisingly low (2-30%) depending on the soil. The finer the soil, generally the lower the LNAPL saturation.

i. Effect of product type
j. Effect of aging

III. LNAPL recovery

a. How above factors influence thickness of product in a well. The amount of LNAPL thickness in a well is a function of the water and LNAPL pressure gradients in the adjacent aquifer. The pressure difference between LNAPL and water at any given depth is the capillary pressure.

b. Water table fluctuation effect on LNAPL levels in monitoring wells. The change in measured LNAPL thickness in monitoring wells with changes in groundwater elevation can be explained using capillary pressure curves.

c. LNAPL volume in place. Improved estimates of the LNAPL volume in place can be made by knowing both the LNAPL saturation and the aerial distribution of LNAPL saturation.

    i. In fine grained soils, maximum LNAPL saturations are typically 2-5% and volume in place is low

    ii. In coarser grained soils, maximum LNAPL saturations are typically 10-30% and volumes in place are much lower than traditionally believed

d. LNAPL conductivity

    i. How to measure (LNAPL baildown tests vs. calculated LNAPL conductivity from capillary pressure and relative permeability).

    ii. It’s effect on LNAPL recovery (How does saturation and distribution of LNAPL in soil affect its ability to flow?)

Module 2

The Management Module

Approximate time: 2 hours

I. Purpose statement for the LNAPL training: There is a need for a good LNAPL conceptual model starting from release, to how LNAPL spreads in soil, to free phase recovery, to free phase impact on dissolved phase, to mass issues, to potential risk and when/why we should try to recover LNAPL (videos).

II. Realities of LNAPL Management:

1. Hydraulic recovery can be used for containment, but does little or nothing to change risk magnitude and little impact on longevity
2. Many plumes, without other treatment, will be very long lived
3. Coverage/safety issues at operating facilities generally precludes cleanup to groundwater standards (with some exceptions)
4. Any cleanup that misses the source zone will fail to meet all typical cleanup standards
5. Common misconceptualizations of the smear zone causes misapplication and optimistic expectations regarding the efficacy of cleanups
6. Ephemeral occurrence of free product in wells generally has little or nothing to do with the

plume state factors that control risk and groundwater impacts

7. All risk evaluations inherently depend on correct NAPL zone conceptualization
8. All cleanup technologies have an application and a limit; an appropriate CSM is needed to describe what those will be ahead of attempted application
9. As the ambient risk magnitude diminishes, the worth on a cost per pound basis of engineered cleanup also diminishes
10. If the desired end is water use, MCLs are meaningless for most plumes as taste, odor, nuisance will be present long after most common chemicals of concern are depleted from the source zone

III. NAPL management discussion and product recovery versus risk

A. Current decision-making process. The current decision making process is typically based on undefined or unquantifiable goals, and an incomplete or lack of understanding of the magnitude and characteristics of the LNAPL plume. This often results in the installation of ineffective remediation systems with no performance metrics. In addition, these systems may be installed without any clearly defined endpoints.

B. Improvements to current process. The RTDF NAPL Cleanup Alliance is developing a decision-making framework for use in guiding NAPL remediation projects. The decision-making framework follows a clear and logical progression that has been proven effective on several large sites. This NAPL management process starts by establishing a practical and quantifiable cleanup goal. The NAPL plume is then investigated using sound science to quantify the magnitude and the behavior of the NAPL plume. Once the problem is better understood, appropriate technologies can be evaluated which are designed to achieve the specified goal. Investigation results allow the design engineer to make performance predictions for each technology and to recommend endpoints for the remediation system. The performance predictions and endpoints provide benchmarks to assess future system performance and success (or failure) relative to the goal. At each step in this process the previous steps are re-evaluated based on the current level of understanding (e.g., based on the investigation results and technology selection, the previously assigned goal may not be achievable).

IV. Development of practical endpoints

A. LNAPL mobility and implications

i. Plume wide versus interior migration. LNAPL plumes will expand until the source of the release is discontinued and until the LNAPL reaches a condition of steady state with the soil and hydrogeologic conditions. At that point, the separate-phase LNAPL will stop migrating (although the dissolved-phase can continue to migrate). The interior portion of the LNAPL plume may contain LNAPL at sufficient saturation to have mobility (i.e., a continuous phase with a relative permeability greater than zero) (under induced drive – not natural conditions). A well completed in this interior area may produce LNAPL. However, the overall plume is not migrating.

ii. Well thickness as an indicator (good or bad indicator – needs to be considered with other data). Measured LNAPL thickness in a well may provide an approximation of the thickness of the LNAPL interval in the adjacent soil (i.e., the interval between the LNAPL/water interface and the air/LNAPL interface). However, LNAPL thickness in a well is not by itself an indication of LNAPL mobility or LNAPL productivity. In fact, a well may contain some amount of LNAPL although the LNAPL in the adjacent soil is immobile in the natural state.

B. Implications of dissolved phase plume studies. It is quite common that NAPL plumes may be static yet dissolved phase impacts may continue to migrate for a long time or distance after the NAPL plume stabilizes. Recent research (Tom Sale) has demonstrated that a significant fraction of NAPL mass must be removed to have any appreciable effect on long-term site management. Combined technologies (i.e., robust boundary control combined with decreased emphasis on upgradient NAPL recovery), or phased technologies (i.e., active NAPL mass removal to the point where natural attenuation will remediate the remaining mass within 100 years) may be appropriate remediation strategies where dissolved-phase impacts are an issue.

C. Lack of written guidance. Endpoints are highly site and project-specific. The RTDF NAPL Cleanup Alliance decision-making framework discusses the recommended procedures for establishing endpoints. Endpoints cannot be established without first defining the cleanup goal, having a complete understanding of the problem and knowing what technology will be used. Endpoints not only quantify the point at which active systems can be shut down, but they also define whether or not an active system even needs to be installed (e.g., If the endpoint is a specified LNAPL mobility value, system operations will be discontinued once that value has been achieved. Likewise, if the LNAPL mobility in an area of the site is already below the endpoint value then installation of an active system in that area is not necessary). Furthermore, endpoints can be phase or tiered (e.g., an "endpoint" value of some number of pounds per day of LNAPL mass removal can be used to shut off an active system. However, a "closure" value such as an MCL at a certain monitoring well can be used following active system operations to know when the site has achieved the cleanup goal and can be closed).

V. Remediation of LNAPL—why there are limits to recovery

A. NAPL is the source and, although it may be more concentrated, it may not exist at a saturation sufficient to have mobility. Even if it has sufficient saturation to be mobile, the process of recovering the LNAPL decreases its saturation thereby making it progressively less mobile.

B. Many decisions made on "gut reactions" of project managers. Many active systems are installed without adequately understanding the extent, distribution and behavior of the LNAPL. For this reason, active systems may be located in the wrong place or may not even be the right technology for the job. Even if the systems are properly selected and installed, no attempt may have been made to accurately predict system performance. The lower than expected recovery may simply be because of low LNAPL plume mobility.

C. Soil and fluid characteristics. LNAPL mobility and recovery is a direct function of soil and fluid characteristics. These characteristics are some of the essential data that are collected and evaluated during the investigation step in the decision-making framework.

D. Longevity issues (high viscosity fluid, more long-lived)

VI. High-end technologies. The technology selected for any site needs to be the right tool for the job (e.g., if the goal is to reduce LNAPL mobility then selecting a high-end technology such as surfactant or steam flooding is unnecessary. These high-end technologies are designed to recover LNAPL below residual saturation and are, therefore, mass reduction technologies).

A. Scale up issues

B. Comparison of costs (life cycle)

C. Which sites deserve high-end technology consideration

VII. Performance monitoring. Performance Monitoring is performed during active system operation to track system performance compared to the initial performance predictions. The Performance Monitoring program is used to optimize system performance and to know when the system has reached the shutoff endpoint.

A. Without knowing the complex science behind LNAPL, realize the concept of practical endpoints, monitoring networks

B. Case studies

Module 3

Intermediate topics

Approximate time: 3 hours

This section presents the modeling tools and calculation methods used to estimate LNAPL distribution and recovery.

I. Data acquisition

Data required. Because LNAPL distribution and behavior are highly site-specific, site-specific data are required to more accurately estimate the volume and recovery of LNAPL.

  i. What to get (Fluid samples and “undisturbed” soil samples for laboratory analysis, fluid level measurements, LNAPL baildown tests, laser-induced fluorescence (LIF) logs)
  ii. How to get (Drilling, sampling and sample preservation techniques)

II. Estimating LNAPL saturation and distribution

a. API / Charbeneau LNAPL Distribution Model
  i. Van Genuchten algorithm
  ii. Brooks and Corey algorithm
  iii. Displacement pressure head difference and resulting effect
  iv. Model input parameters (Discussion of data sources and calculation methods to obtain porosity, pore size distribution index and displacement pressure head (RETC model), residual saturations, interfacial and surface tensions and specific gravity)

b. Calibrating the API model to site-specific data

        i. Matching the model output to the LNAPL saturation profile calculated from the capillary pressure data
        ii. Using the measured LNAPL saturation data and the API model to correlate LIF data to LNAPL saturation
    c. Mapping
        i. Validating estimated LNAPL saturations using LNAPL baildown tests
        ii. Constructing an LNAPL-in-place map
        iii. Constructing an LNAPL mobility map

III. Estimating LNAPL recovery
    a. API / Charbeneau LNAPL Recovery Model
        i. Model input parameters (Discussion of data sources and calculation methods to obtain minimum monitoring well thickness (alpha) and LNAPL layer specific yield (beta).
        ii. Relative permeability (Discussion of empirical {Mualem and Burdine} vs. laboratory-measured methods)
    b. Volumetric method
        i. Calculating recoverable LNAPL-in-place.
        ii. Recovery efficiency

IV. Case studies
    a. Coarse grained site
        i. Models applied
        ii. Model predictions
            1. LNAPL distribution
            2. LNAPL recovery
        iii. Field observations
            1. LNAPL distribution
            2. LNAPL recovery

b. Fine grained soils
    i. Models applied
    ii. Model prediction
        1. LNAPL distribution
        2. LNAPL recovery
    iii. Field observations
        1. LNAPL distribution
        2. LNAPL recovery

Module 4

Advanced topics—train the modeler

Approximate time: 8 hours

This module would provide hands-on experience in applying the principles and tools that were presented in the earlier modules. Walk folks through the details on how to form the conceptual models, analyze the data, and decide which equations are best suited (Van Genuchten, Brooks—Corey, Mualem, Burdine, baildown, Laboratory relative-permeability data, etc).

I. Preparing the data
   a. Collecting and reviewing laboratory data
   c. Obtaining moisture drainage curve data (RETC)

II. Running the API / Charbeneau LNAPL Distribution Model
   a. Model input parameters.
   b. Calibrating the API model to site-specific data.

III. Analyzing baildown tests
   a. The Bower-Rice method
   b. The Cooper-Jacobs methods.
      i. 1/Q vs. time method
      ii. s/Q vs. time method
      iii. Sum of squared residual method