Remediation and Redevelopment Program

Issues & Trends 2016

June 1, 2016
12:00 p.m. – 1:00 p.m.

Dial: 1-855-947-8255
Passcode: 6612 745#
LNAPL Transmissivity
Testing/Analysis

(Assessing LNAPL Recoverability)

David Swimm, PG
David.Swimm@wisconsin.gov
608-264-8766
NAPL Data

- Well gauging and dissolved GW contaminant results
- Soil boring contaminant results
- Laboratory LANPL fluid analyses
- **LNAPL Transmissivity (well testing or remedial production evaluation)**
- NAPL saturation concepts/core evaluation
- Computer modeling (e.g., LDRM)
- Laser Induced Fluorescence (LIF) Surveys
- Natural Source Zone Depletion (NSZD)
Resources and References:

ASTM Standard Guide— E2856 (May 2013):
Estimation of LNAPL Transmissivity

API User Guide (September 2012) for the:
LNAPL Transmissivity Workbook: A Tool for Baildown Test Analysis

ITRC Guidance (December 2009):
Evaluating LNAPL Remedial Technologies for Achieving Project Goals

Note: ITRC guidance is currently in the process of being updated (yours truly on team) to reflect changes in industry practices/emphasis since 2009.
Other References:


Simply stated, \textbf{transmissivity} \((T_n)\) is a hydraulic measure (ft\(^2\)/d) of how quickly LNAPL moves from the aquifer to wells:

- Controlled by dual phase flow (i.e., relative perm. to LNAPL), so directly explains why so much GW is typically produced
- Reflects horizontal flow to a well (radial flow assumed)
- Related to the mobile LNAPL partition saturation, soil type, porosity architecture, and fluid properties
- Changes over time, so is not an \textit{intrinsic} property of the aquifer (ASTM 2013)
- Increasingly cited as a remedial metric that is far better than the well-based thickness, which have been used for decades.
Regarding remedial endpoints......

**LNAPL T<sub>n</sub>** is only one of several factors used to judge “maximum extent practicable” (MEP); other factors include:

- Risk factors (e.g., PVI, surface discharge, potable wells),
- Dissolved plume dynamics,
- Natural source zone depletion (usually contextual),
- Remedial technology evaluated/employed,
- Green sustainability, etc.
LNAPL Hydraulic Terminology:

- LNAPL Mobility/Migration
- LNAPL Recoverability
- LNAPL Transmissivity

defined for this presentation only
LNAPL Mobility or Migration Potential:

- Relative ability to migrate into water saturated porous media not previously occupied by LNAPL under the natural range of hydraulic gradients present
- Typically associated with the margin of the LNAPL plume
- Usually conceptualized as potential for lateral migration
- Is limited (stabilizes) over short-term due to cessation of release (i.e., diminishing LNAPL head conditions)
- After lateral “stabilization”, mobile LNAPL partition saturations typically still are present within the LNAPL plume

$T_n$ can be a metric for LNAPL mobility, but it is usually not framed in that manner
LNAPL Recoverability:

• Relative ability to migrate into a well within the LNAPL plume under artificially induced hydraulic gradients

• Typical measured to assess future hydraulic remedial potential (prospective) or historical remedial efficiency (retrospective)

• Progressively diminishes over time by virtue of remedial removal

• Mobile LNAPL partition saturations can be reduced to MEP within the zone of influence

\( T_n \) is a metric for recoverability that could be used as on measure of MEP.
Declines in modeled hydraulic recovery (and associated $T_n$) as one reduces initial formation/LNAPL conditions from ideal.

LDRM model results - see Appendix E, Assessment Guidance For Sites With Residual Weathered Product (RR-787)
Model Result - Skimmer Production Well

$T_n$ reduces as Ideal Sand$^1$ is produced

$^1$Ideal Sand reflects parameters listed at “origin” of graph on previous slide
Basis was range whereby some states were closing sites retrospectively (i.e., lagging metric) with the following characteristics:

• Consensus on comprehensive LCSM
• Active hydraulic recovery performed and showed diminishing returns (i.e., becomes asymptotic)
• Reportedly did not rely on well-based thicknesses

ITRC 2009 Guidance: provided “acceptable” range of $T_n$ values ($0.1$ to $0.8$ ft$^2$/d) below which hydraulic recovery is not practical

(Kirkman, 2014)
ITRC Guidance Update:

Will further qualify the meaning of the LNAPL $T_n$ range:

- Assess/refine range using updated API database
- Expand discussion and move from *Concepts* Section of document to *LCSM* Section

Considerations:

- $T_n$ is both a leading and lagging metric (Kirkman 2014), so current range may be problematic as a prospective (leading) recoverability metric
- Adoptions of single “bright-line” values may be problematic
Questions?

Next: Test Methods and Analyses
Field Test Methods

**Baildown Testing**
- Induced LNAPL head differential & gauged recovery
- $\geq 6$-inch thickness

**Manual Skimming Testing**
- Removal at a sustained rate - maintain drawdown

**Existing Recovery System Analysis (Retrospective)**
- Assumes steady state conditions
- Needs frequent operational parameters/measures

**Tracer Testing**
- Uses hydrophobic fluorescence tracers
- Relatively new method

(ASTM, 2013)
Baildown Method:

Pre-test:
- LNAPL removal <2 years ago
- Confirm equilibrium fluid levels
- Estimate filter pack specific yield
- Essential to know details of well construction

Test:
- "Instantaneous" LNAPL removal while minimizing GW removal
- 10-15 minute removal OK, if test to be measured over a day
- Not all LNAPL needs to be removed from the well
- Essential to accurately measure removed volumes
- Essential to accurately measure interfaces over time

Note: ASTM Standard does not specify removal method (ASTM 2013)
Baildown Suggestions:

1. Start early/plan on long recoveries – may have to return next day, or for high viscosity (>2 cp) may be several days. [so, plan other work]

2. Assess data in the field and be willing to truncate problematic tests – poor results are obvious/easy to criticize

3. Consider using a transducer to measure LNAPL/GW interface

4. Use consistent changes in LNAPL thickness to assess frequency of measurements
   • lesser of 5-10% of equilibrium or 0.05 ft.
   • plot semi-log

(ASM 2013)
Manual Skimming Method:

**Test:**
- Removal of LNAPL on a repeated basis – allowing no more than 25% recovery
- Remove to the extent possible; minimizing GW removal
- Continue test until 3 consecutive removals show discharge rates within 25% of each other (i.e., consistent responses)
- Essential to record start/stop times
- Essential to accurately measure removed volume
- Essential to know details of well construction
- Essential to accurately measure interfaces over time

(ASTM 2013)
Retrospective LNAPL Remedial Production Analysis:

Skimmer System Data Needed:
- Skimmer drawdown & estimated radius of influence
- Quantity of LNAPL produced (must exclude any GW produced) over a period of consistent operation

Total Fluids System Data Needed:
- LNAPL density & aquifer transmissivity
- Quantity of LNAPL & GW produced (separately) over period of consistent operation (or use skimmer/GW drawdown ratio, if operational consistency a problem)

Other system analyses possible:
- Vacuum enhanced skimmer
- Dual phase extraction

(ASTM 2013)
### Well Construction and LNAPL Parameters

**Initial Casing LNAPL Vol. (gal.):** 0.26
**Initial Filter LNAPL Vol. (gal.):** 0.70

#### LNAPL Q_n

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>DTP (ft btoc)</th>
<th>DTW (ft btoc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>33.76</td>
<td>35.39</td>
</tr>
</tbody>
</table>

**Enter Test Data:**

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>DTP (ft btoc)</th>
<th>DTW (ft btoc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7</td>
<td>34.22</td>
<td>35.02</td>
</tr>
<tr>
<td>1.0</td>
<td>34.11</td>
<td>35.01</td>
</tr>
<tr>
<td>2.0</td>
<td>34.03</td>
<td>34.99</td>
</tr>
<tr>
<td>3.7</td>
<td>33.96</td>
<td>34.99</td>
</tr>
<tr>
<td>4.1</td>
<td>33.92</td>
<td>35.01</td>
</tr>
<tr>
<td>5.3</td>
<td>33.87</td>
<td>35.01</td>
</tr>
<tr>
<td>6.2</td>
<td>33.86</td>
<td>35.03</td>
</tr>
<tr>
<td>7.0</td>
<td>33.84</td>
<td>35.04</td>
</tr>
</tbody>
</table>

#### Recoveries

**Ground Surface Elev (ft msl):** 0.0
**Top of Casing Elev (ft msl):** 0.0
**Well Casing Radius, r_c (ft):** 0.083
**Well Radius, r_w (ft):** 0.333
**LNAPL Specific Yield, S_y:** 0.175
**LNAPL Density Ratio, ρ_r:** 0.780
**Top of Screen (ft bgs):** 0.0
**Bottom of Screen (ft bgs):** 0.0
**LNAPL Baildown Vol. (gal.):** 0.39

**Effective Radius, re3 (ft):** 0.158
**Effective Radius, re2 (ft):** 0.148

**Initial Fluid Levels:**

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>DTP (ft btoc)</th>
<th>DTW (ft btoc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>33.76</td>
<td>35.39</td>
</tr>
</tbody>
</table>

**Enter These Data**

**API (2012)**
API Workbook – Figures Worksheet:
Iterative value selection (yellow cells) for Figures 3, 4, and 10

1. Time/Depth Plots
2. LNAPL Discharge/Depth Measure Plots
3. LNAPL Thickness/Time and Discharge/Time Plots
4. Total LNAPL Well Inflow/Time Plot
Problematic raw data - “jittery” measurements
API Workbook/Figures Worksheet - Figure 3 (API example)

Unconfined LNAPL – Drawdown/Discharge Relationship – Data Before Adjustment

Diagnostic: assessing drawdown for non-equilibrium concerns

<table>
<thead>
<tr>
<th>(Q_n (\text{ft}^3/\text{d}))</th>
<th>(s_n (\text{ft}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.08</td>
</tr>
<tr>
<td>4</td>
<td>0.45</td>
</tr>
</tbody>
</table>

Drawdown Adjust.

<table>
<thead>
<tr>
<th>(\Delta s_n (\text{ft}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

late adjustment (0.08 ft)

early sand pack drainage effect

(API 2012)
API Workbook/Figures Worksheet - Figure 3 (API example)

Unconfined LNAPL – Drawdown/Discharge Relationship – Data After Adjustment

<table>
<thead>
<tr>
<th>$Q_n$ ($ft^3/d$)</th>
<th>$s_n$ (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Data now extrapolates to origin

(API 2012)
Unconfined LNAPL – Drawdown/LNAPL Thickness Relationship

<table>
<thead>
<tr>
<th>b_n</th>
<th>s_n</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.71</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0.52</td>
</tr>
</tbody>
</table>

J-ratio -0.192

*Essential* calculated parameter that is directly used in later worksheets that estimate $T_n$ (API 2012)
Unconfined LNAPL – Drawdown/LNAPL Thickness Relationship

<table>
<thead>
<tr>
<th>(b_n)</th>
<th>(s_n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0.5</td>
</tr>
</tbody>
</table>

J-ratio \(-0.250\)

<table>
<thead>
<tr>
<th>(b_n)</th>
<th>(s_n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>2.9</td>
</tr>
</tbody>
</table>

J-ratio \(-1.381\)
Unconfined LNAPL - Time Cut-off Estimate

Cut-off time (20 min.)

Figure 10

Data to be analyzed further > 20 min.

(API 2012)
API Workbook – Bouwer and Rice (B&R) Worksheet (API example)
Unconfined LNAPL - Transmissivity Solution

Enter early time cut-off for least-squares model fit

| Timecut | 20 | <- Enter or change value here |

Model Results: $T_n$ (ft$^2$/d) = 2.81 +/- 0.07 ft$^2$/d

$$T_n = \frac{r_e^2 \ln(\frac{R}{r_e}) \ln(\frac{s_n(t_1)}{s_n(t)})}{2(-J)(t-t_1)}$$
API Workbook – B&R Worksheet (API example)

Unconfined LNAPL - type curves using normalized drawdown/time relationship

B&R Type Curves:  Casing Rad. (ft) = 0.17 ;  Borehole Rad. (ft) = 0.5

Normalized Drawdown ($s/s_{initial}$) (ft/ft) vs Time (min)

(API 2012)
API Workbook – Cooper and Jacob (C&J) Worksheet (API example)
Unconfined LNAPL – Transmissivity Solution

Enter early time cut-off for least-squares model fit

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{cut}$ (min)</td>
<td>20</td>
</tr>
<tr>
<td>Time Adjustment (min)</td>
<td>13</td>
</tr>
<tr>
<td>Trial $S_n$</td>
<td>$d$</td>
</tr>
<tr>
<td>Root-Mean-Square Error</td>
<td>0.117</td>
</tr>
<tr>
<td>Trial $T_n$ (ft$^2$/d)</td>
<td>3.660</td>
</tr>
<tr>
<td>Model Result: $T_n$ (ft$^2$/d)</td>
<td>3.66</td>
</tr>
</tbody>
</table>

Add constraint $T_n > 0.00001$
API Workbook – Site Example
Unconfined LNAPL – Transmissivity Solution

$T_n$ results (B&R only):
Consultant = 1.75 ft²/d
Revised (just for well measures) = 0.64 ft²/d
Revised to a 20 min cutoff = 0.54 ft²/d
API Workbook – Confined Worksheet (API example)
Confined LNAPL – Transmissivity Solution

\[ T_n = \frac{Q_n \ln\left(\frac{R}{r_w}\right)}{2\pi(1-\rho_r)(b_{nR} - b_{nW})} \]

Depth to base of confining bed (ft bgs) [from boring log]: 7
Constant LNAPL discharge to well (ft³/d): 40
Depth to top of screen (ft bgs): 7.0
Corrected water table elevation (ft bgs): 17.7
Limiting effective LNAPL thickness in well, \(b_{nW}\) (ft): -12.2
Limiting effective LNAPL drawdown, \(s_{nW}\) (ft): 2.46
Initial LNAPL thickness, \(b_{nR}\) (ft): 7.9
Radius of influence ratio (from Bouwer and Rice), \(R/r_w\): 13.4

LNAPL Transmissivity, \(T_n\) (ft²/d): 6.72

Note drawdown is many feet

(API 2012)
API Workbook – Confined Worksheet (another API example)
Confined LNAPL – Discharge Profile (“Figure 4”)

Figure from Appendix F

Confining Bed (dark grey)

Seepage Face Discharge

LNAPL Drawdown - Discharge Relation

(API 2012)
API Workbook – Confined (site example)
NAPL; note drawdown is many feet

Consultant only considered data over first 60 min

Tn results:
Consultant = 1.42 – 4.26 ft²/d
Revised = 0.05 - 0.14 ft²/d

Note drawdown is many feet
Questions?

David.Swimm@wisconsin.gov

608-264-8766
Issues & Trends 2016

August 3, 2016
12:00 p.m.

Calculating Background Levels for Common Soil Contaminants

Audio and information from today’s presentation and future Issues & Trends Series events can be found on the RR Program Training Webpage at:  
Http://dnr.wi.gov/topic/Brownfields/Training.html

Questions/Comments/Suggestions regarding the Issues & Trends Series can be submitted to:  
DNRRRComments@wisconsin.gov