LNAPL Transmissivity End Points Why, How and When

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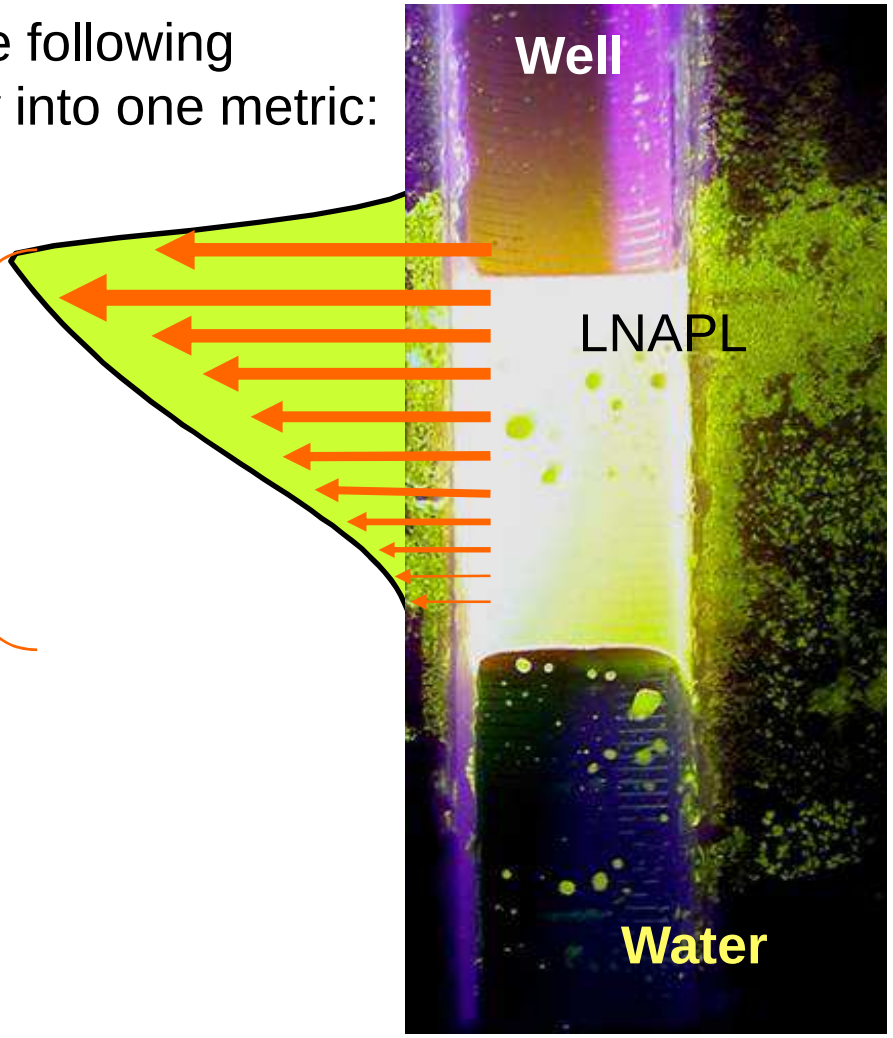
LNAPL Transmissivity (Tn)

- LNAPL Transmissivity summarizes the following key considerations in LNAPL recovery into one metric:
  - LNAPL Density
  - LNAPL Viscosity
  - Soil permeability
  - Magnitude of LNAPL saturation in soil (i.e., LNAPL concentration)
  - Thickness that LNAPL flows over

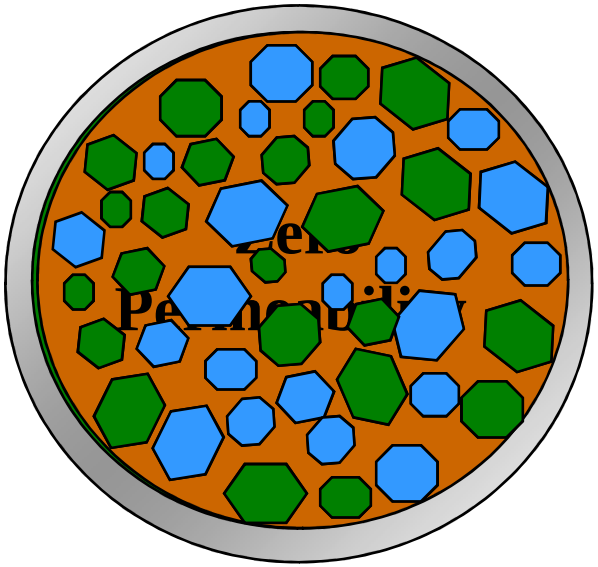
$$T_n = \sum K_n \Delta b_n$$



$$K_n = \frac{\rho_n \cdot g \cdot k \cdot k_{rn}}{\mu_n}$$

How Transmissivity Relates to Reduction of Mobile LNAPL

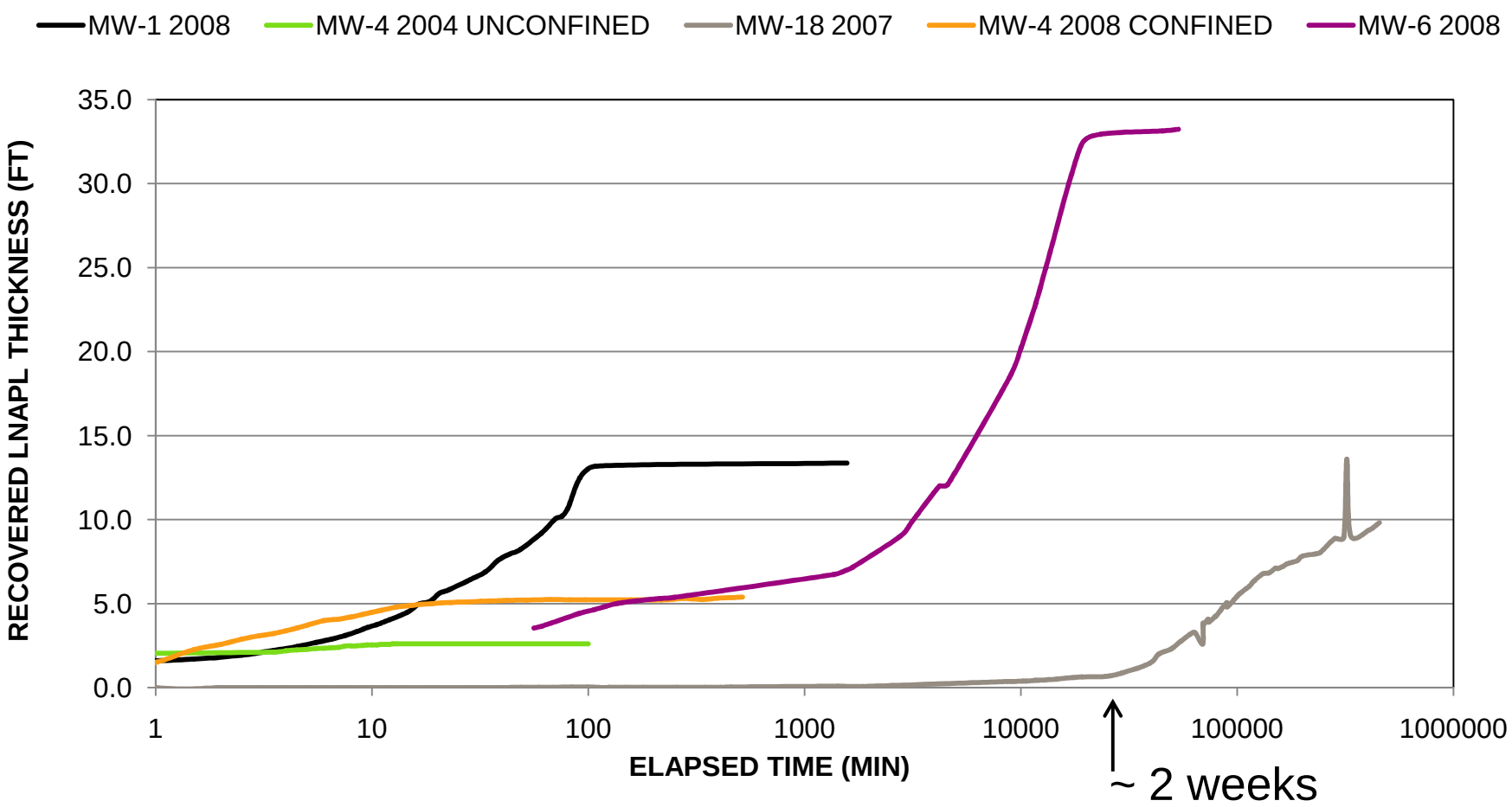
$K_2 < K_1$



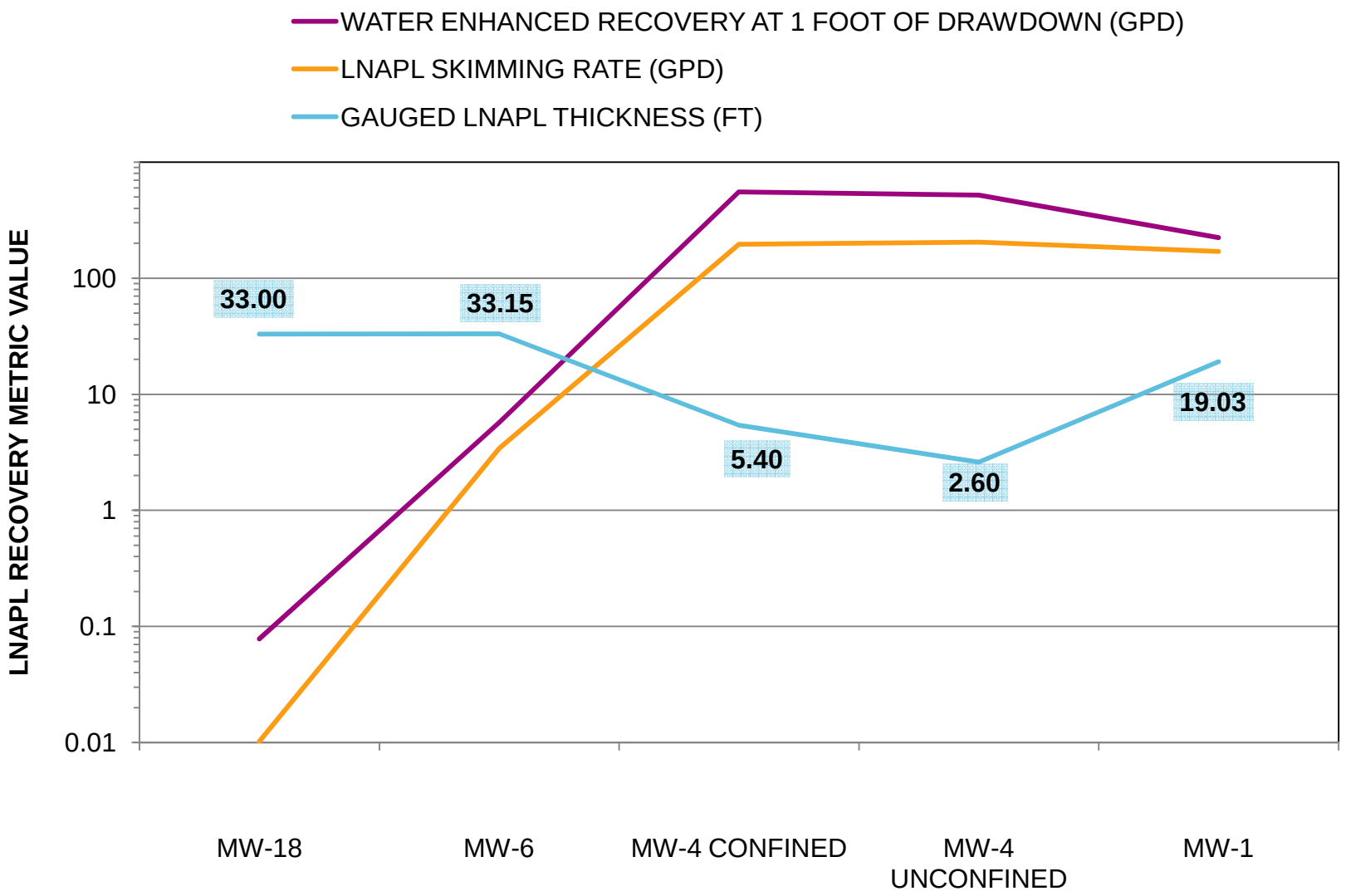
As LNAPL is recovered the number of pores occupied by LNAPL decreases, which in turn decreases its relative permeability. This is reflected in a decrease in LNAPL Transmissivity

Gauged Thickness – Poor Metric for Recoverability

- MW-4 Confined recovers to 5 feet thickness fast than wells with 33 feet of starting thickness
- MW-18 expected to take 3 years to recover to ~35 ft of thickness

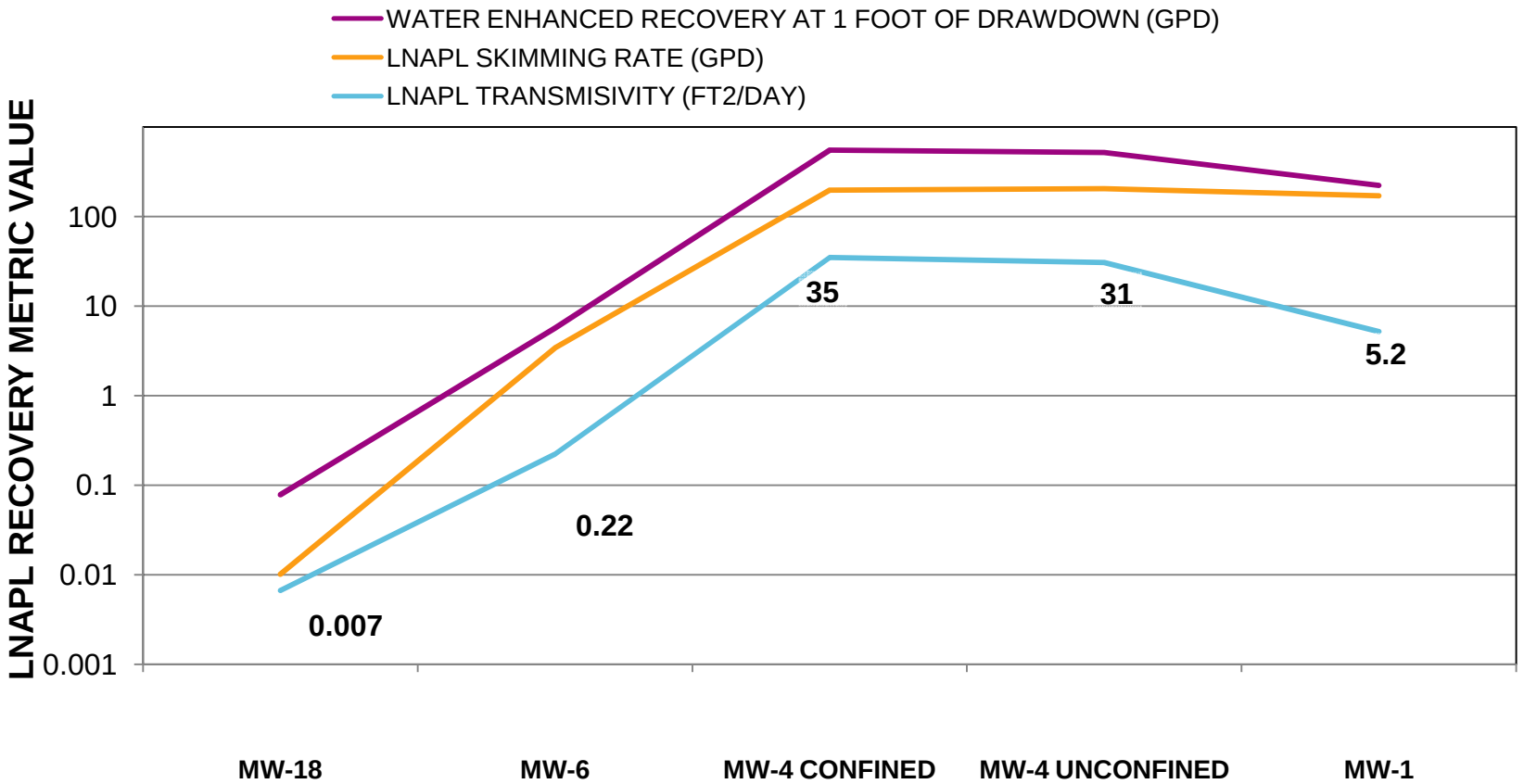


Gauged LNAPL Thickness Versus Recovery - Poor Correlation



LNAPL Transmissivity Versus Recovery
Good Correlation

- LNAPL Transmissivity exhibits improved correlation
- LNAPL Recovery Rate is a Function of both drawdown induced and LNAPL transmissivity
- Skimming drawdown is controlled by equilibrium fluid levels and soil profile



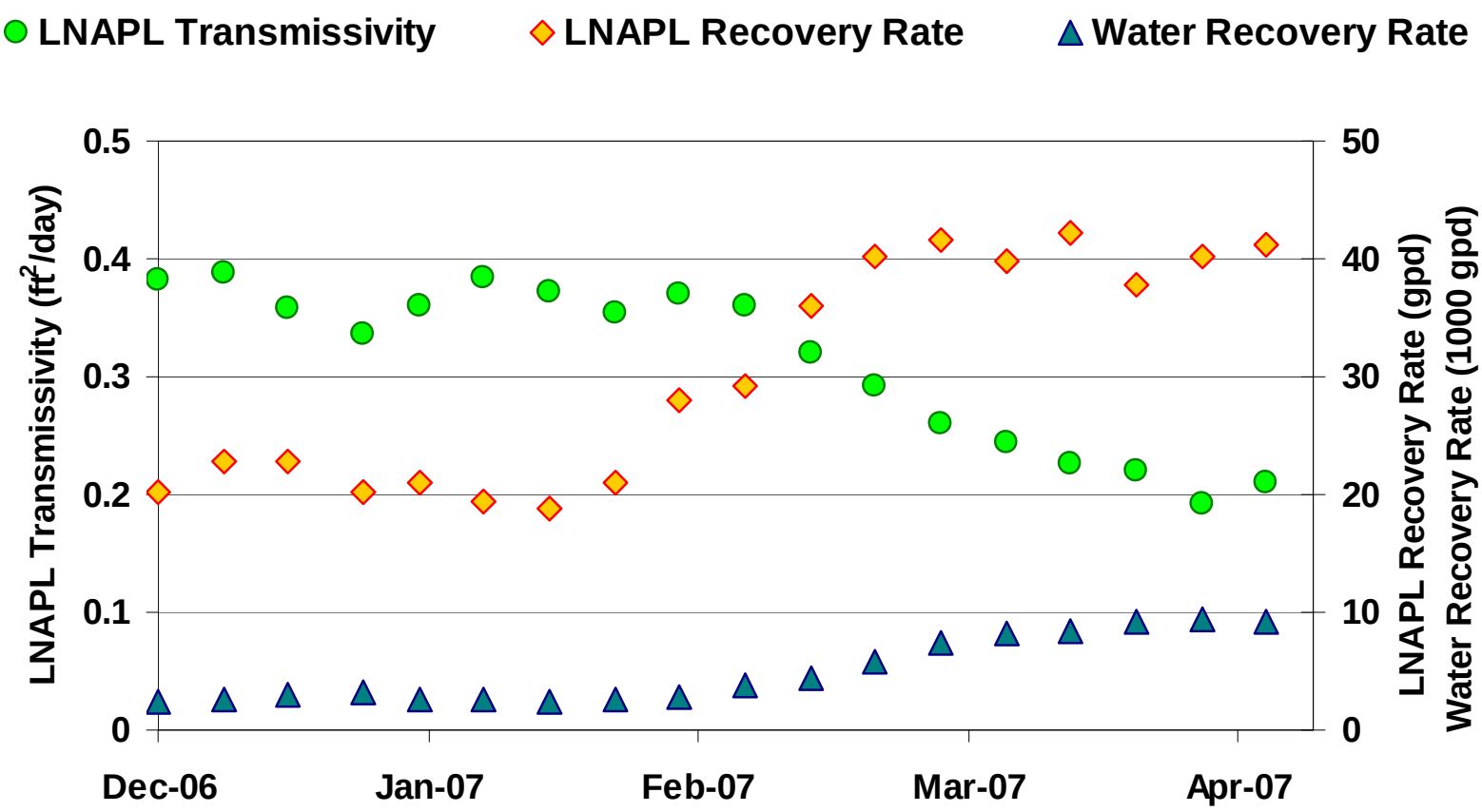
Why use LNAPL transmissivity?

- LNAPL Thickness
  - Inconsistent between hydraulic scenarios (perched, confined, unconfined)
  - Inconsistent between soil types
  - Poor indicator of LNAPL recovery
- LNAPL Recovery Rate More Robust Metric than LNAPL Thickness
  - Need recovery system or pilot test data
  - Operational variability and technology differences make it difficult to use across technologies and/or sites
- Transmissivity
  - Estimated with recovery data or field testing on monitoring wells
  - Consistent across soil types
  - Consistent across confined, unconfined or perched conditions

In well LNAPL thickness is a poor metric

- ITRC (2010) - recover LNAPL from areas with the largest equilibrium in well thicknesses BUT
  - Poor metric: correlates unfavorably with LNAPL recoverability
  - Does not account for soil and LNAPL properties, soil heterogeneity, and LNAPL aquifer conditions (unconfined/perched/confined)
- ASTM (2005) –
  - LNAPL regulatory policies that define remediation metrics by small LNAPL thickness in wells are…often inconsistent with risk-based screening levels and with current technical knowledge regarding LNAPL mobility and recoverability ¶ 5.14.

Short Term Recovery Evaluation



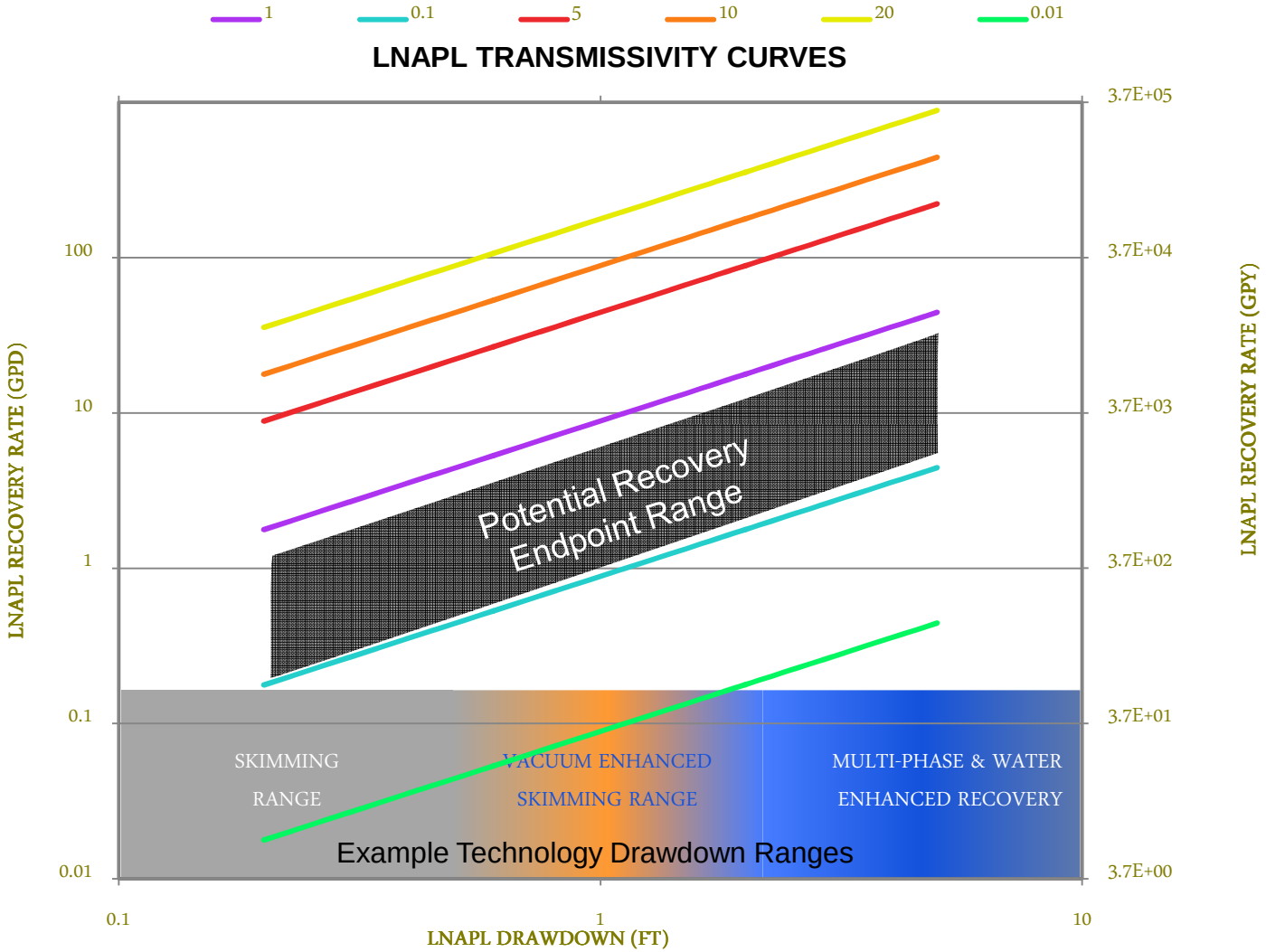
$$T_o = T_w \rho_r \, Q_o / Q_w$$

So What Transmissivity Value Means there's a Bunch of LNAPL There

- New Catastrophic release scenario's have resulted in observed values of 80 ft2/day
  - ~1% of other sites exhibit Tn values this high several /decades after the release period
- Consider the Theim Equation
  - 80 ft2/day with 1 ft of drawdown results in 816
  - Or 80% recovery of a 700k release in 2 years with 6 skimming wells
- LNAPL Tn of 0.1 ft2/day with 0.1 ft of drawdown results in <0.2 gpd
  - How does this rate compare with the remaining LNAPL mass?, mobile mass?, residual mass?
  - Does it matter if migration is documented

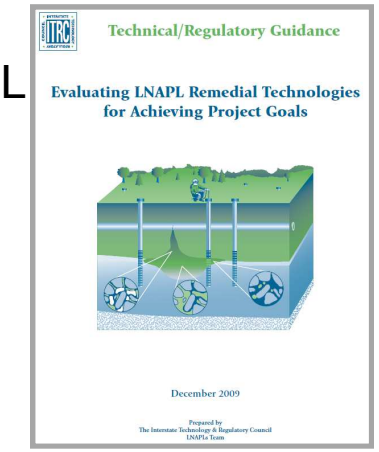
LNAPL Transmissivity in Practice

- Skimming LNAPL at 0.1 ft2/day results in less than 400 GPY skimming
- Skimming LNAPL at 5 ft2/day results in 7300 GPY skimming



Ongoing support for LNAPL Transmissivity

- 2006 ASTM Guide of LNAPL Conceptual Site Models (E2531-06)
- 2009 ITRC Guide for LNAPL technology selection – includes LNAPL transmissivity range 0.1 to 0.8 ft2/day that corresponds to closed sites in various states
- 2011 ASTM Guide for Estimation of LNAPL Transmissivity (E2856-13)
- API LNAPL Transmissivity work book
  - search for LNAPL Baildown Test on API.org
  - API multiple tools and documents – most pertinent here LNAPL baildown test spreadsheet and guide document
- Applied NAPL Science Review (www.napl-ansr.com)
  - Online publication related to advancing LNAPL understanding within the remediation industry

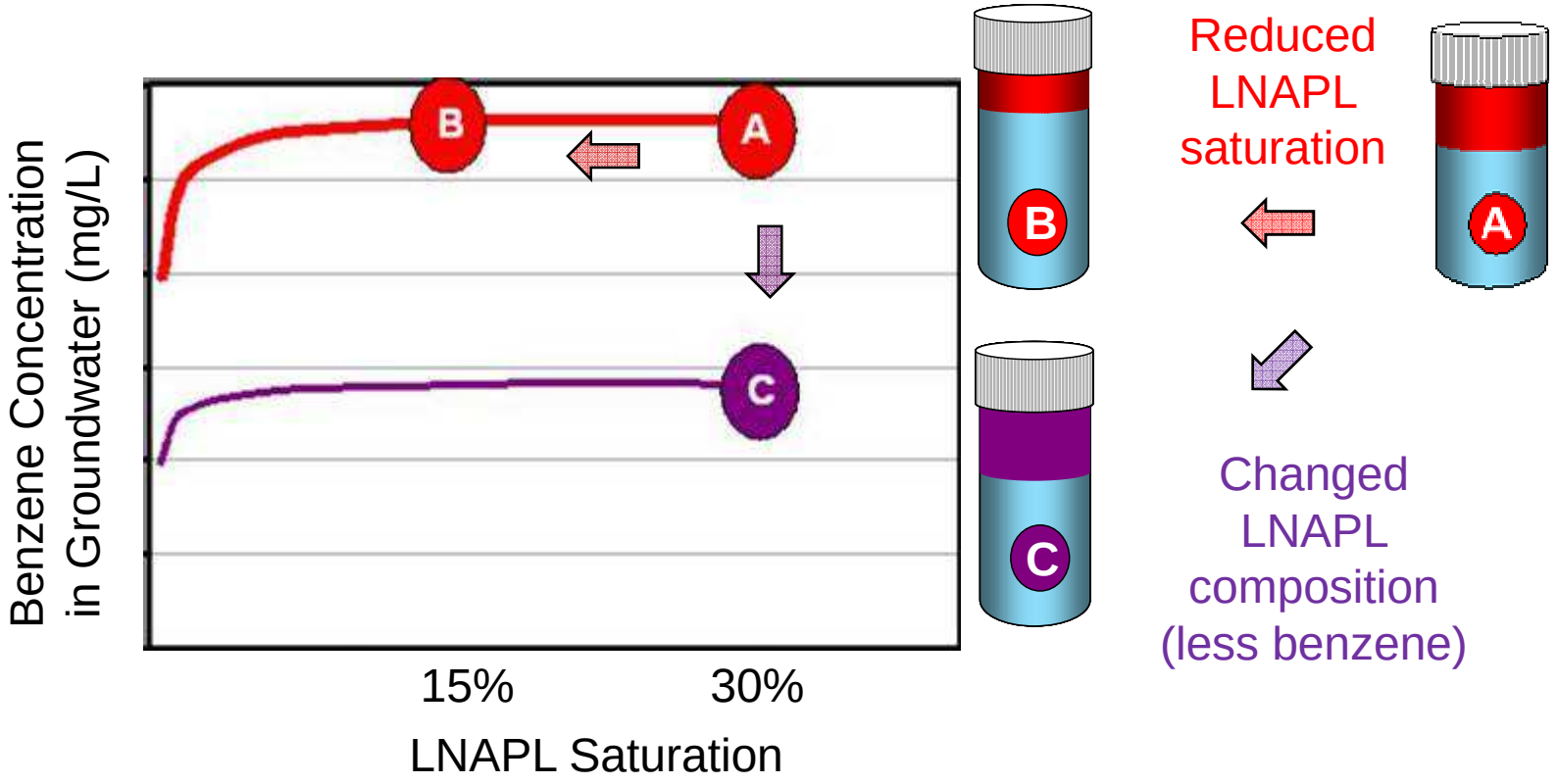


ASTM LNAPL Transmissivity Standard (E2856-13)

- Increase Accuracy of calculations for LNAPL Transmissivity
- Identify critical assumptions and best practices
- Resolved various approaches into a more unified practice
- Include multiple methods in a single standard to provide comparison of methods
- Provide standardization to generate a consistent and larger database of information
- Methods include:

1. Baildown/Slug Tests (Lundy & Zimmerman 1999, Huntley, 2000 & Kirkman 2012)
2. Recovery System Data (Charbeneau, 2007)
3. Manual Skimming Tests
4. Tracer Tests (Sale, 2007)

LNAPL Concern – ITRC introduced composition vs saturation concern



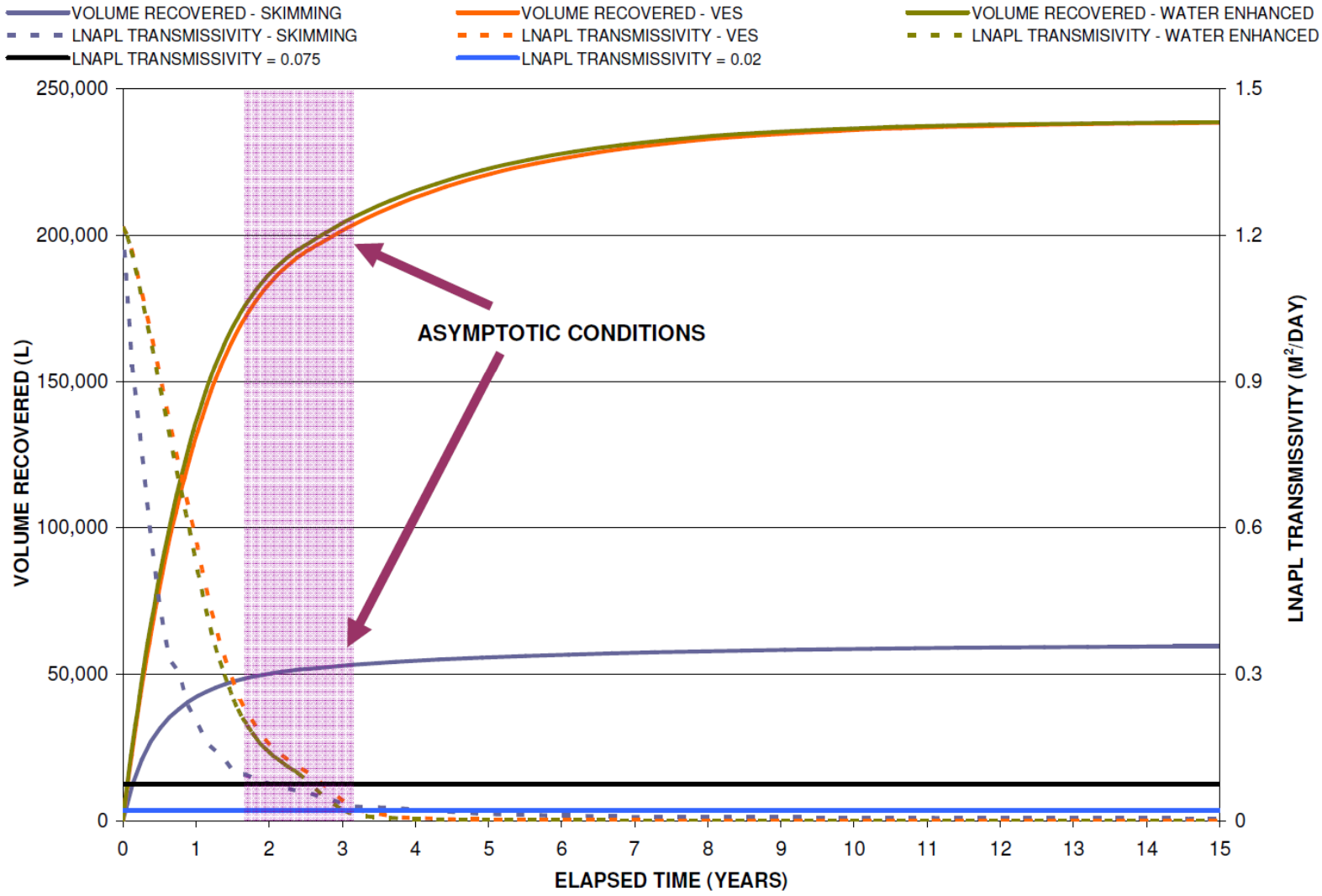
Source: Dr. Sanjay Garg
and ITRC LNAPL training

LNAPL Transmissivity and Endpoints for Hydraulic Recovery

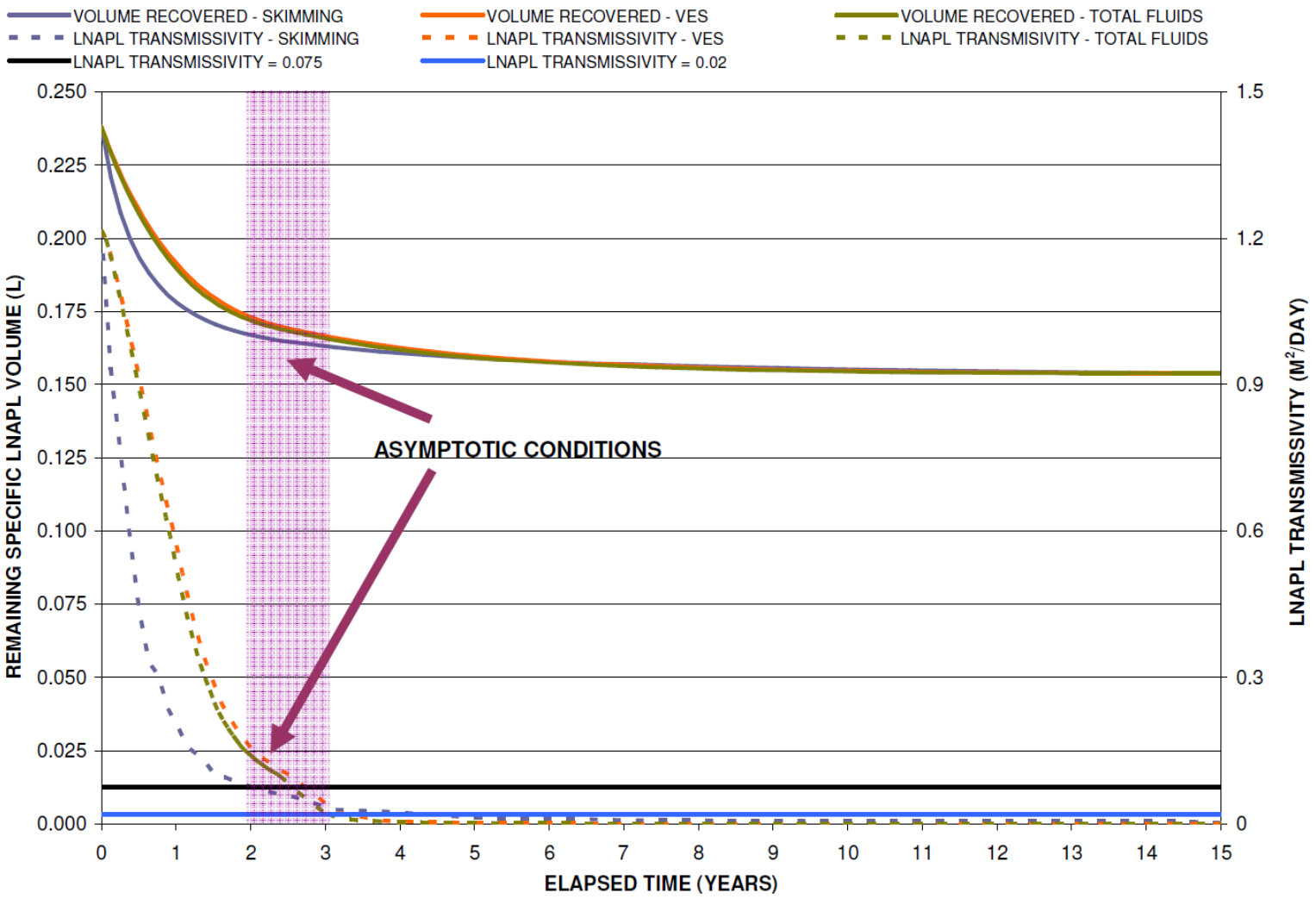
ITRC Endpoint Range 0.1 to 0.8 ft^2/day

- Represents the LNAPL transmissivity that occurred at multiple sites that were closed with the following support data/evidence
  - LNAPL Recovery was asymptotic and small compared to residual LNAPL in place
  - No risk to receptors via vapor or dissolved phase existed
  - Remaining LNAPL was stable and not migrating
  - Institutional controls were in place to prevent exposure
    - Land/ groundwater use restrictions or;
    - Active facilities ensured land use would remain industrial
  - On going remediation would not significantly improve site conditions
    - Plume already stable
    - No complete pathways / risk to receptors
- **Following Closure of LNAPL Transmissivity data was compiled and reviewed to generate the empirical ITRC range**

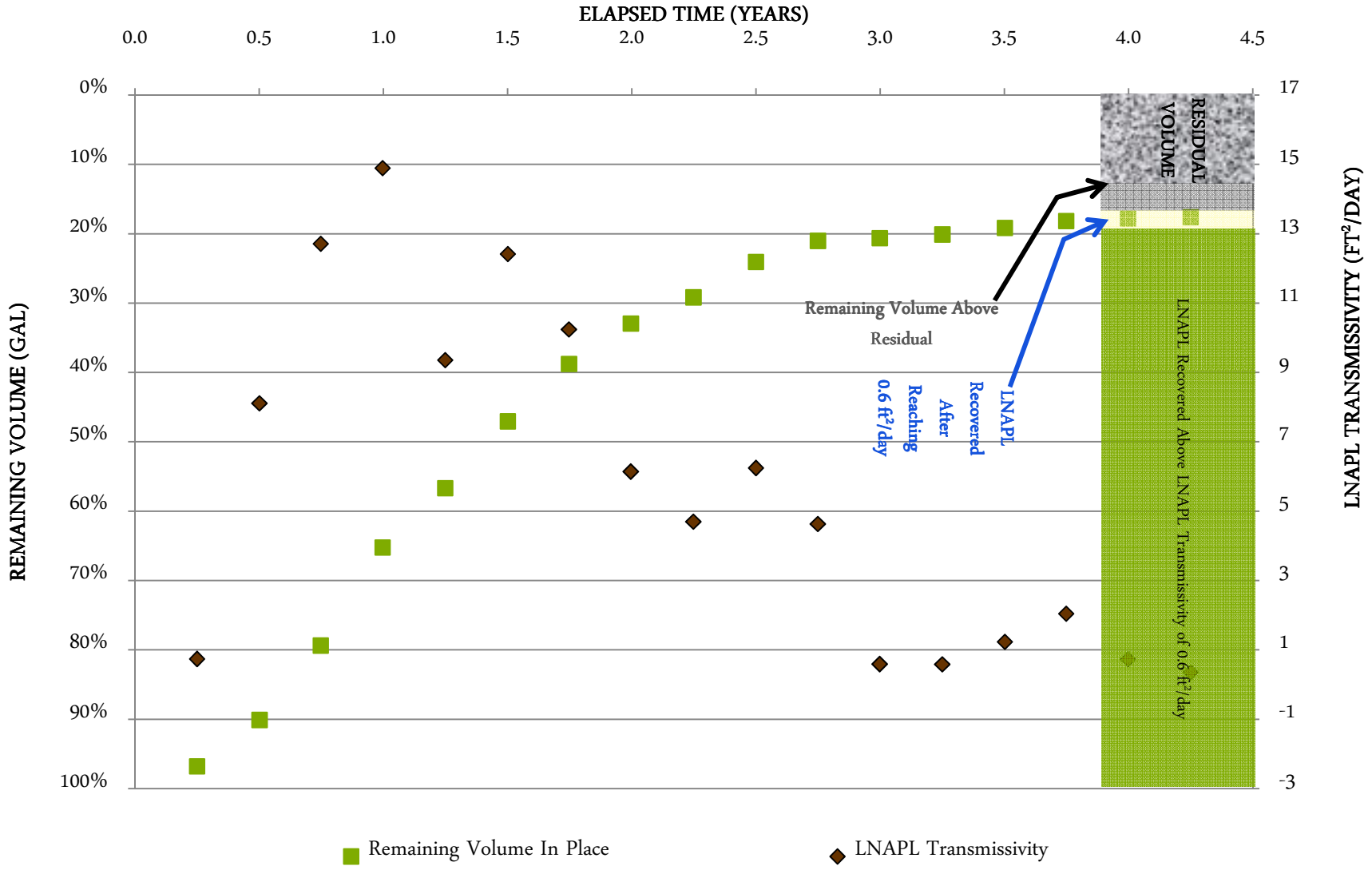
Stop Metric Example

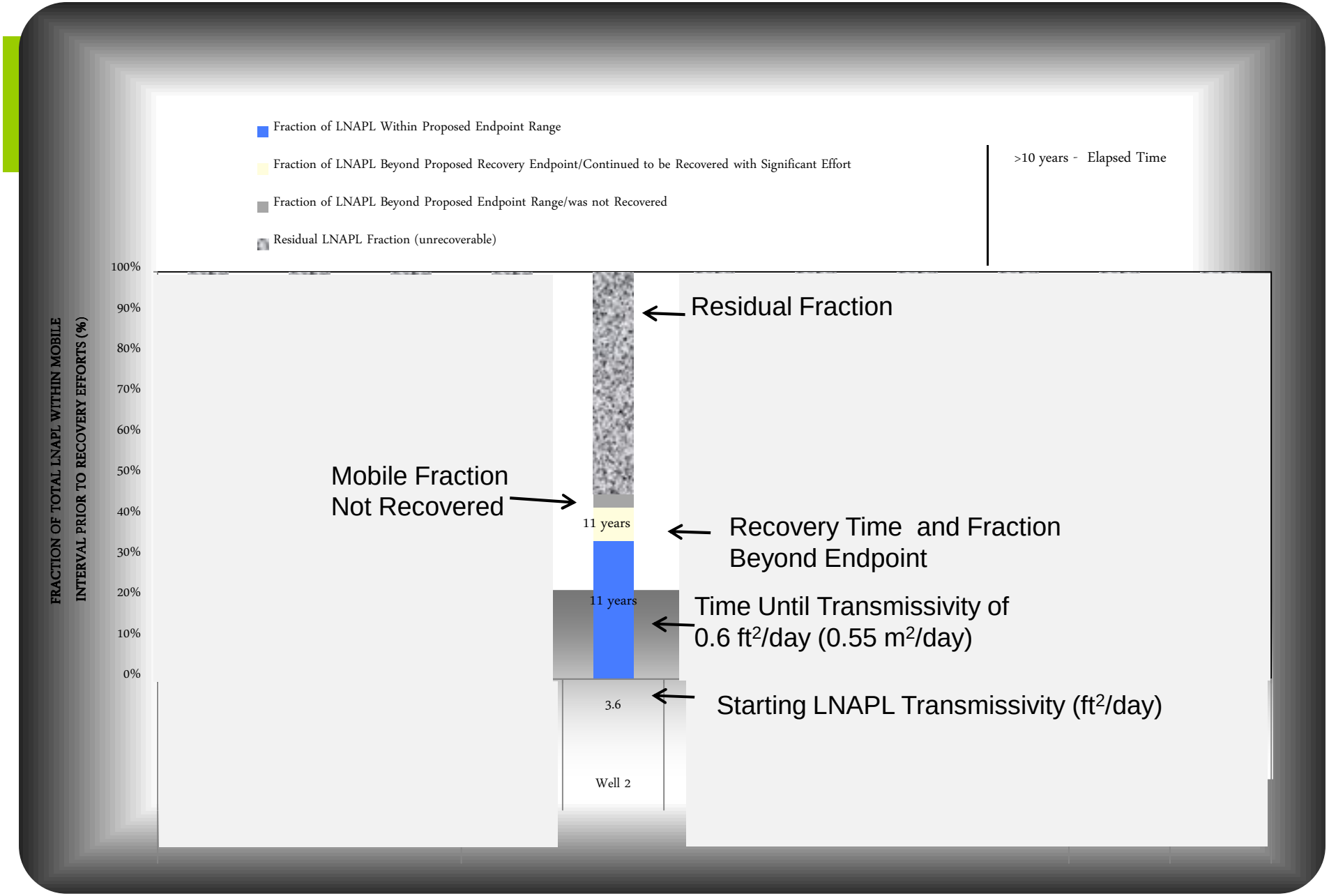


What Fraction Can Be Removed for a Given Starting LNAPL Transmissivity



Reversed Decline




Fraction of LNAPL Within Proposed Endpoint Range
Fraction of LNAPL Beyond Proposed Recovery Endpoint/Continued to be Recovered with Significant Effort
Fraction of LNAPL Beyond Proposed Endpoint Range/was not Recovered
Residual LNAPL Fraction (unrecoverable)
>10 years - Elapsed Time
FRACTION OF TOTAL LNAPL WITHIN MOBILE INTERVAL PRIOR TO RECOVERY EFFORTS (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Residual Fraction
Mobile Fraction Not Recovered
11 years
Recovery Time and Fraction Beyond Endpoint
11 years
Time Until Transmissivity of 0.6 ft²/day (0.55 m²/day)
3.6
Starting LNAPL Transmissivity (ft²/day)
Well 2

LNAPL Transmissivity vs Residual Fraction

NOTES:

1. RECOVERABLE LNAPL VOLUMES ARE BASED ON DECLINE CURVE ANALYSIS, MASS BALANCE AND MODEL CALIBRATION
2. RESIDUAL SATURATIONS ARE BASED ON SOIL CORE ANALYSES AND/OR MODEL CALIBRATION TO FIELD DATA
3. MODEL CALIBRATION INCLUDED, SOIL AND FLUID TYPE, AND LNAPL TRANSMISSIVITY DATA

Summary

- LNAPL transmissivity can be used as a start or stop metric for Maximum Extent Practicable (Source Reduction via Hydraulic Recovery)
- Guidance has been improved over the past twelve years and provides a good foundation to
  - Improve accuracy of LNAPL transmissivity estimates
  - Provide multiple methods to estimate LNAPL transmissivity throughout the life of a site
- ITRC range combined with site LNAPL transmissivity data provides an absolute reference point for hydraulic recovery/transmissivity values
- Sites exhibiting LNAPL transmissivity value below 0.8 ft^2/day with existing recovery systems should consider the effectiveness of continued hydraulic recovery in reducing remaining LNAPL source mass

Thank you

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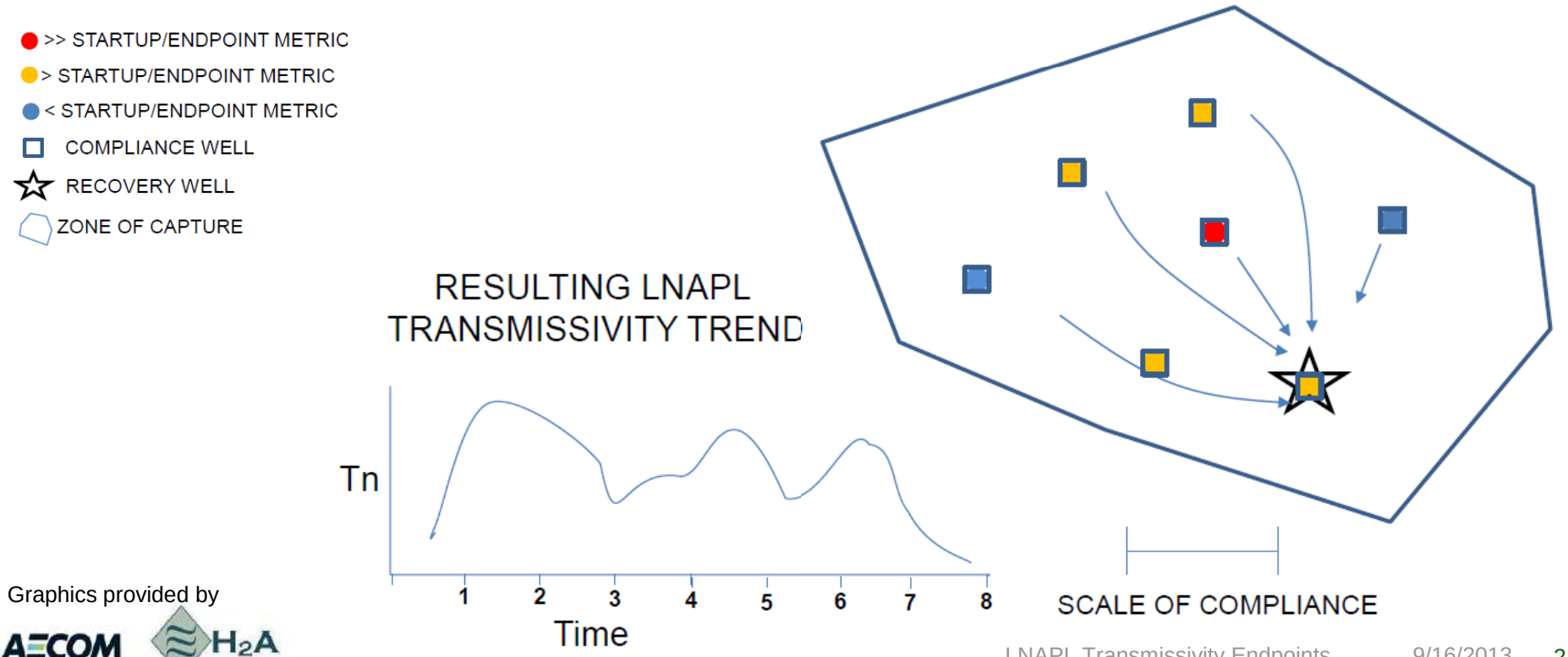
Remedial Performance Application - Scenario 2

- Weak decline supports using individual well measurements (e.g., baildown tests) to measure LNAPL transmissivity across the plume



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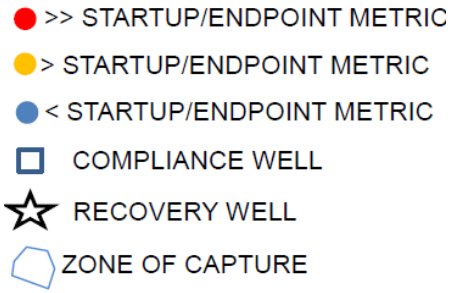
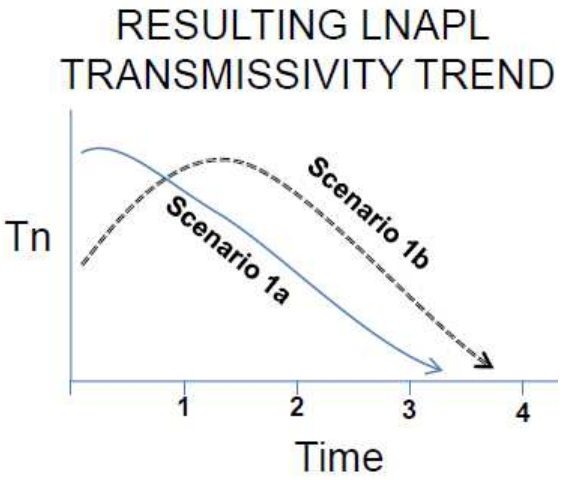
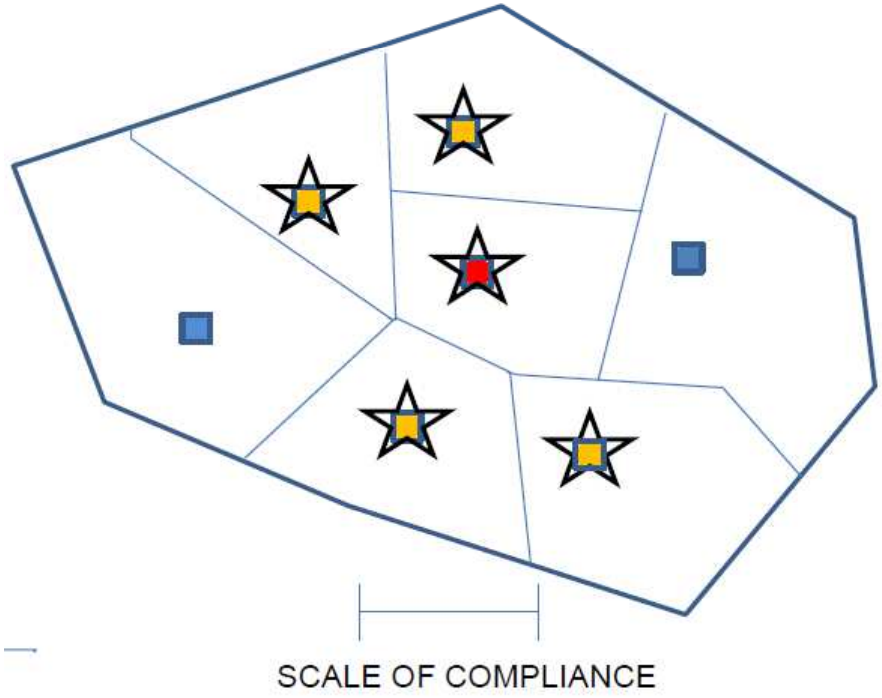
Remedial Performance Application - Scenario 1

- Strong decline indicates recovery system is well representative of capture zone







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