Use of LNAPL Transmissivity to Evaluate Performance of Free-Product Recovery Systems

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Site Background

- Petroleum Refinery Located in Midwest and Operated from 1941 to Early 2000's
- Subsurface Geology
  - Large River Valley (~175 square miles)
  - Fine-Grained Alluvial Deposits Overlies Coarser Grained Glaciofluvial Deposits
- Hydrogeology
  - Unconsolidated Aquifer (Transmissivity [T_w] = ~1,000 to 75,000 ft^2/day)
  - River is the Primary Hydraulic Boundary
  - Groundwater Surface Fluctuates Across the Site ~3 to 14 feet
- Historic Releases of Petroleum Over the Period of Refinery Operations
- LNAPL Hydraulically Recovered Using Skimmer Pumps (SPR), Periodic Manual Removal (via Vacuum Truck) and Multiple-Phase Extraction (MPE) Systems (Fixed-Based and Mobile)
- ~1,500,000 Gallons Recovered Since 1994

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Skimmer Pump Recovery (SPR) – Site Examples

- Baildown Test Data Analyzed – *User Guide for API LNAPL Transmissivity Workbook and Spreadsheet: A Tool for Baildown Test Analysis* (Pre-Publication Draft, September 2012)
- Recovery-Based Data Analyzed – *Standard Guide for Estimation of LNAPL Transmissivity* (ASTM E2856-13)
- SPR-001
  - Confined LNAPL
  - 8 Years / ~73,500 Gallons Recovered (~130 to less than 0.5 GPD)
  - Recovery-Based / Baildown Comparison – Similar Trend
- SPR-002
  - Unconfined to Confined LNAPL
  - 9 Years / ~15,000 Gallons Recovered (~15 to less than 0.5 GPD)
  - Recovery-Based / Baildown Comparison – Similar Trend

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LNAPL Skimming – Recovery Data Analysis

- Assumptions:
  - Fluid Levels at Equilibrium
  - SPR System Maintains Constant Drawdown and Zero LNAPL Thickness
  - Maximum Estimated Drawdown Based on Equations for Confined and Unconfined Conditions
  - $l_n(R_{oi}/r_w)$ = 4.6 (Charbeneau, 2007 and ASTM, 2013)
  - LNAPL T_n within One Order of Magnitude of Actual LNAPL Transmissivity Value

$$T_n = \frac{Q_n ln\left(\frac{R_{oi}}{r_w}\right)}{2\prod s_n}$$

Equation 16(ASTM, 2013)

T_n = LNAPL transmissivity (ft^2/day)
Q_n = Measured LNAPL removal rate (ft^3/day)
s_n = Estimated LNAPL drawdown (ft)
R_{oi} = radius of influence (ft)
r_w = well radius (ft)
b_n = LNAPL thickness in well (ft)
b_{nf} = LNAPL thickness in formation (ft)
p_n = LNAPL density

$$s_{n\_unconfined} = b_n(1 - p_n)$$

$$s_{n\_confined} = b_{nf}\,(1 - p_n)/p_n$$

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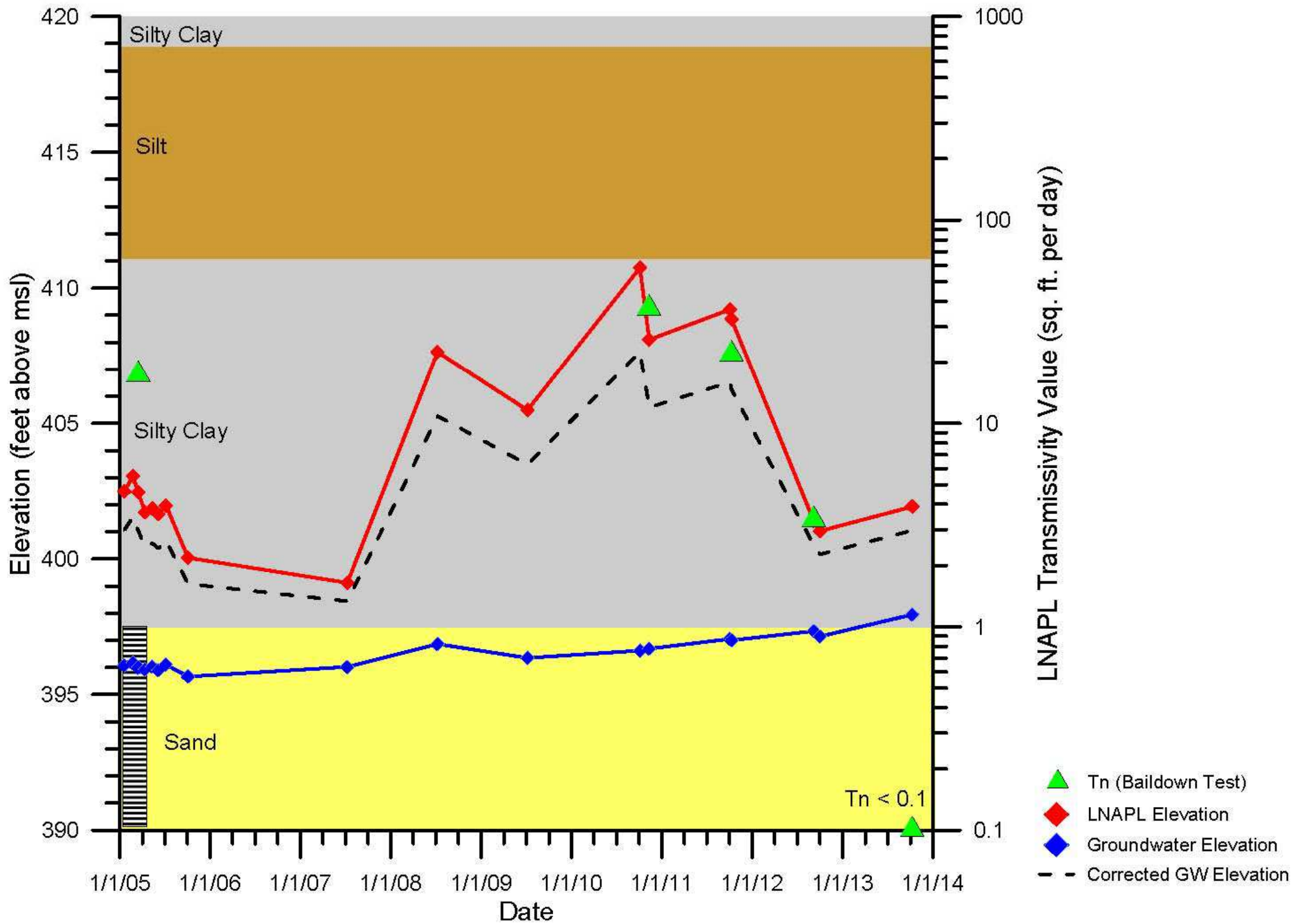
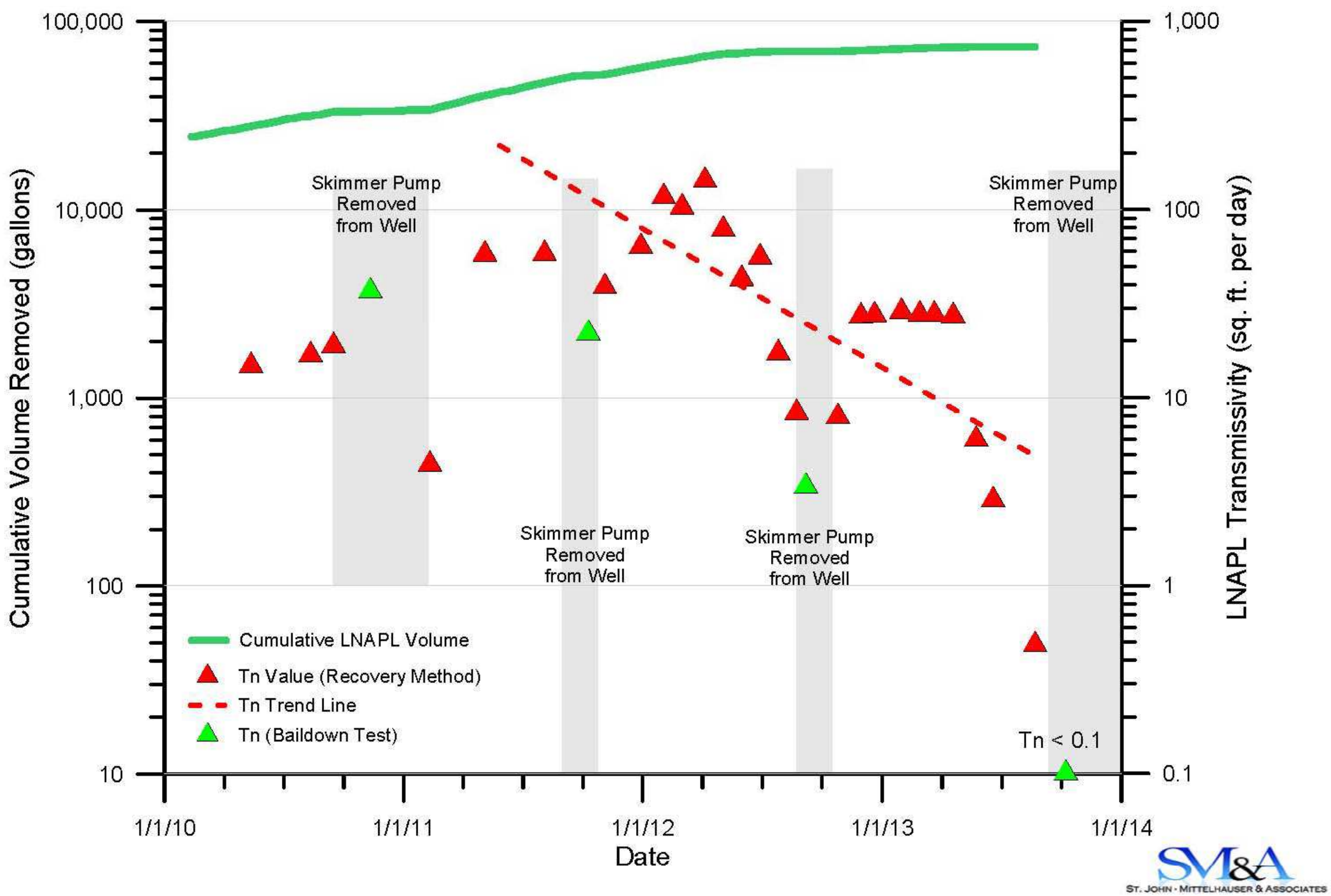
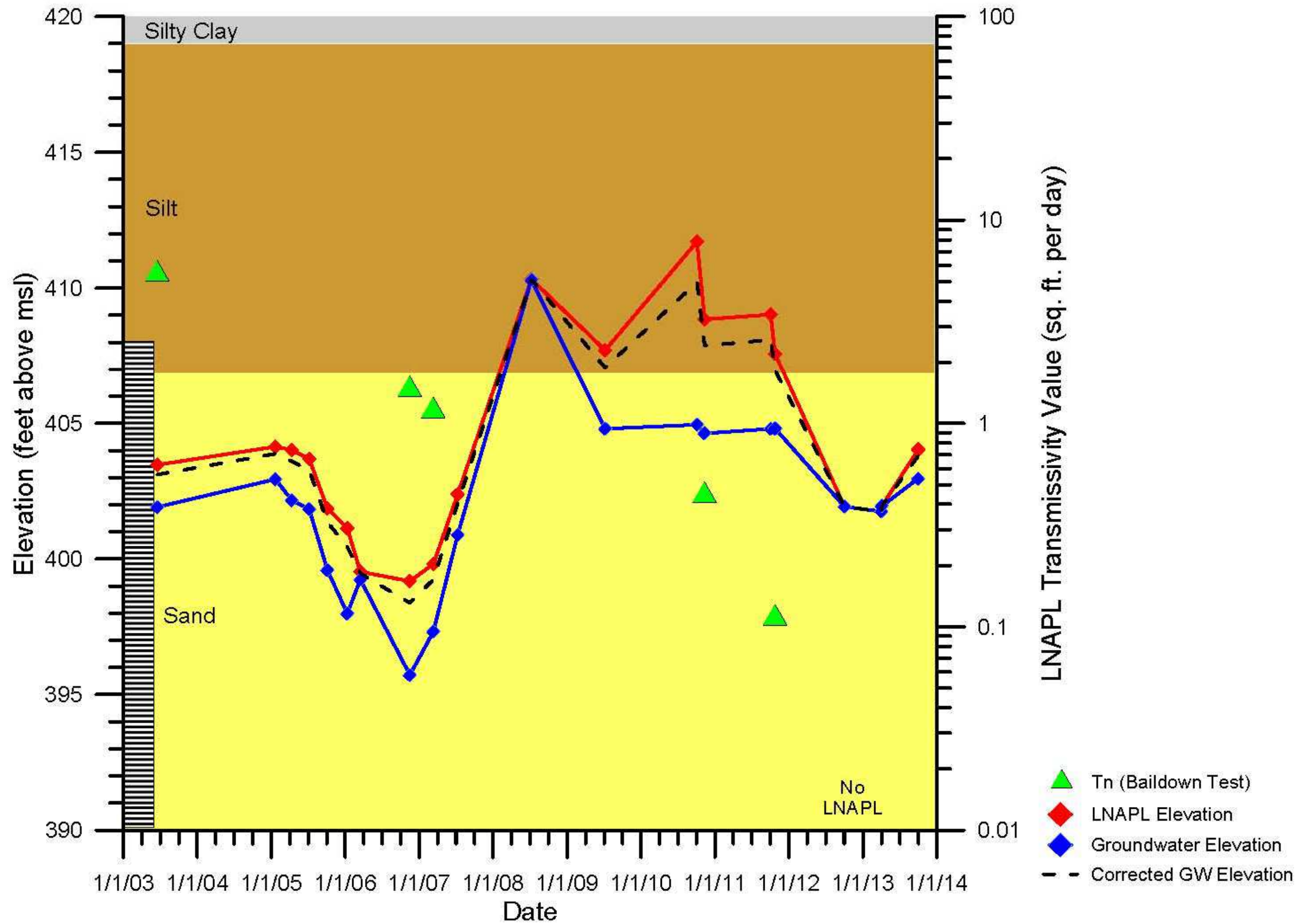
Fluid Elevations and Tn Values at SPR-001



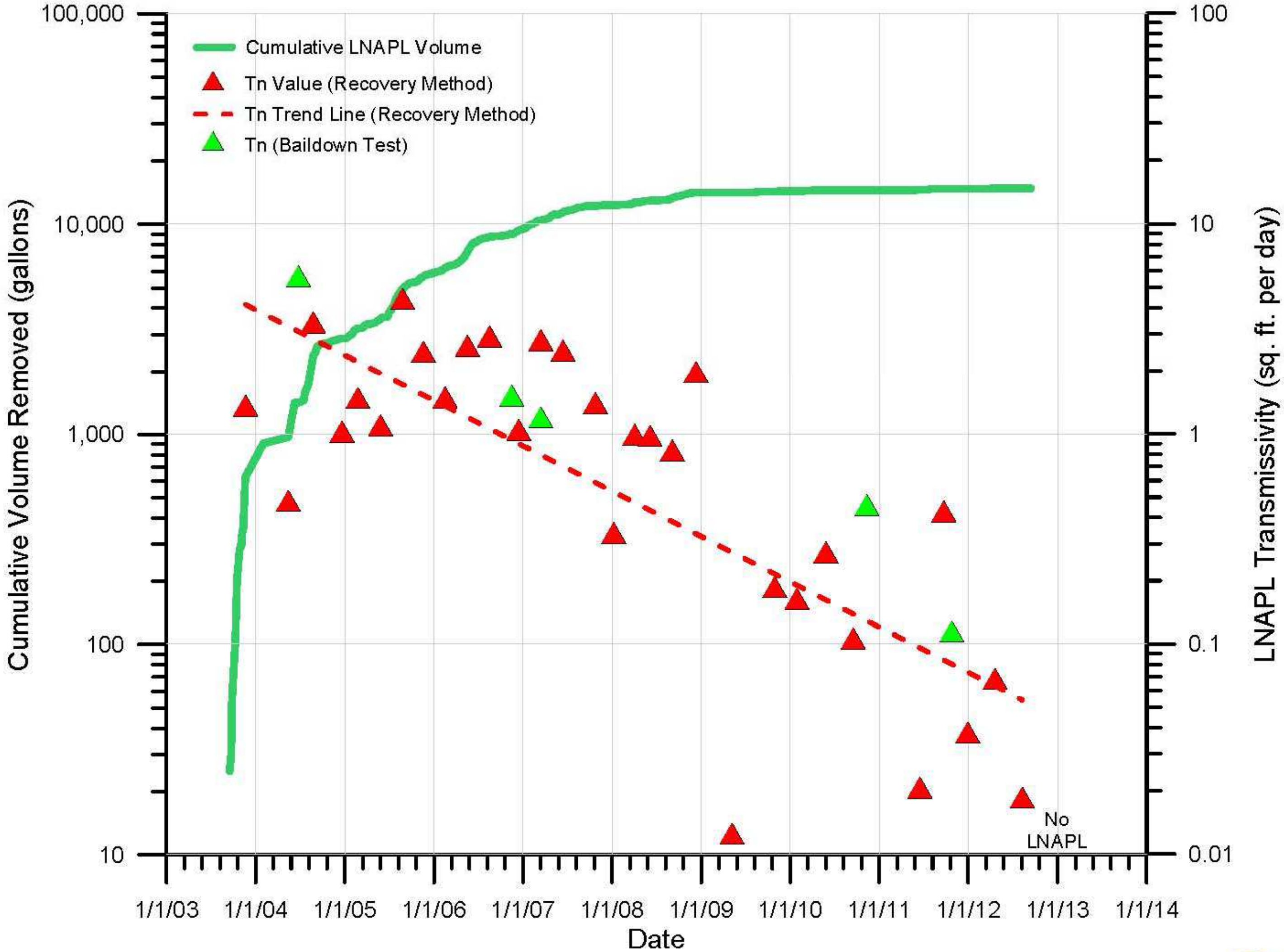
Cumulative LNAPL Removal and Tn at SPR-001



Fluid Elevations and Tn Values at SPR-002



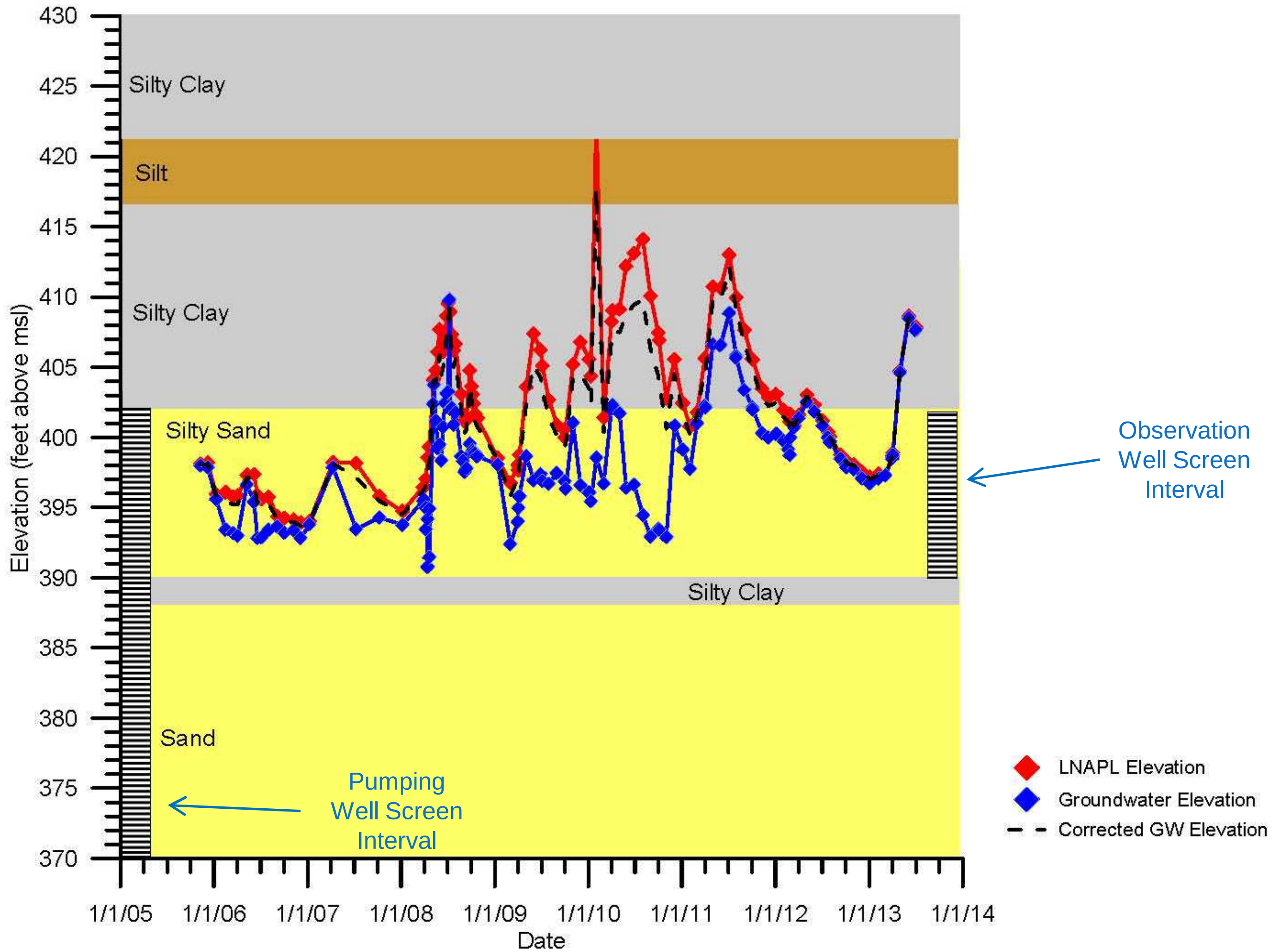
Cumulative LNAPL Removal and Tn at SPR-002



Dual Pump Recovery (DPR) – Site Example

- Large Diameter Pumping Well (DPR-001) – Upper 30 feet of Aquifer
- Groundwater Pumping Rates Ranged from 85 to 220 GPM
- Pneumatic Skimmer Pump Installed First Year
- 7 Years / ~118,000 Gallons of LNAPL Recovered (~300 to less than 0.5 GPD Average)
- Variable Recovery-Based Trend

Observation Well Fluid Elevations Near DPR-001



Note: Fluid Elevations from an observation well located ~5 feet from DPR-001.

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Water-Enhanced LNAPL Recovery – Data Analysis

- Dual-Pump Recovery
- Assumptions:
  - Aquifer Transmissivity is 19,000 ft^2/day (based on pumping tests)
  - Water Induced Drawdown is Substantially Greater than Skimming Induced Drawdown

$$T_n = \frac{Q_o T_w p_r}{Q_w}$$

Equation 21 (ASTM, 2013)

T_n = LNAPL transmissivity (ft^2/day)
T_w = Aquifer transmissivity (ft^2/day)
Q_o = Measured LNAPL removal rate (ft^3/day)
Q_w = Measured water discharge rate (ft^3/day)
p_r = LNAPL-water density ratio

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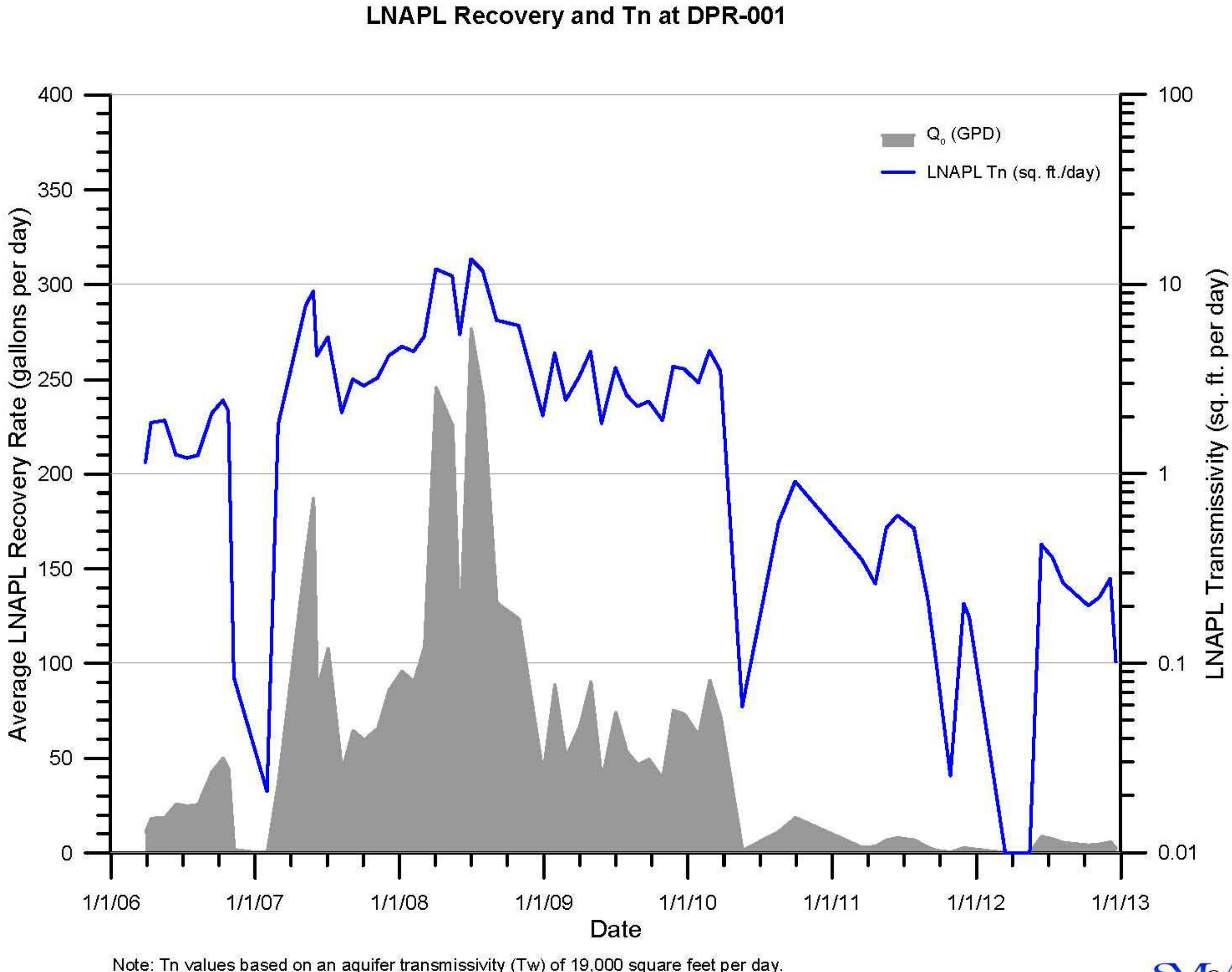
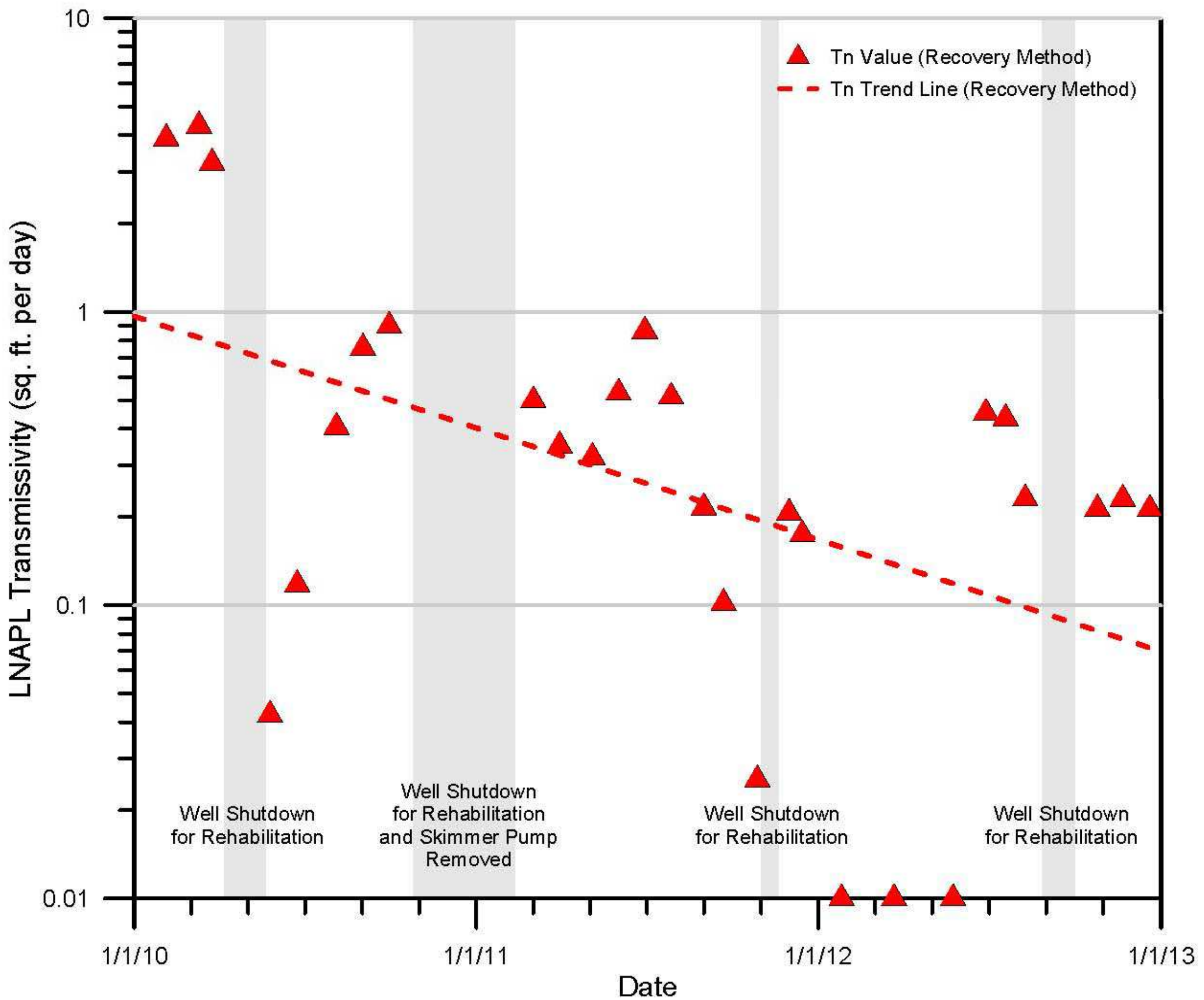
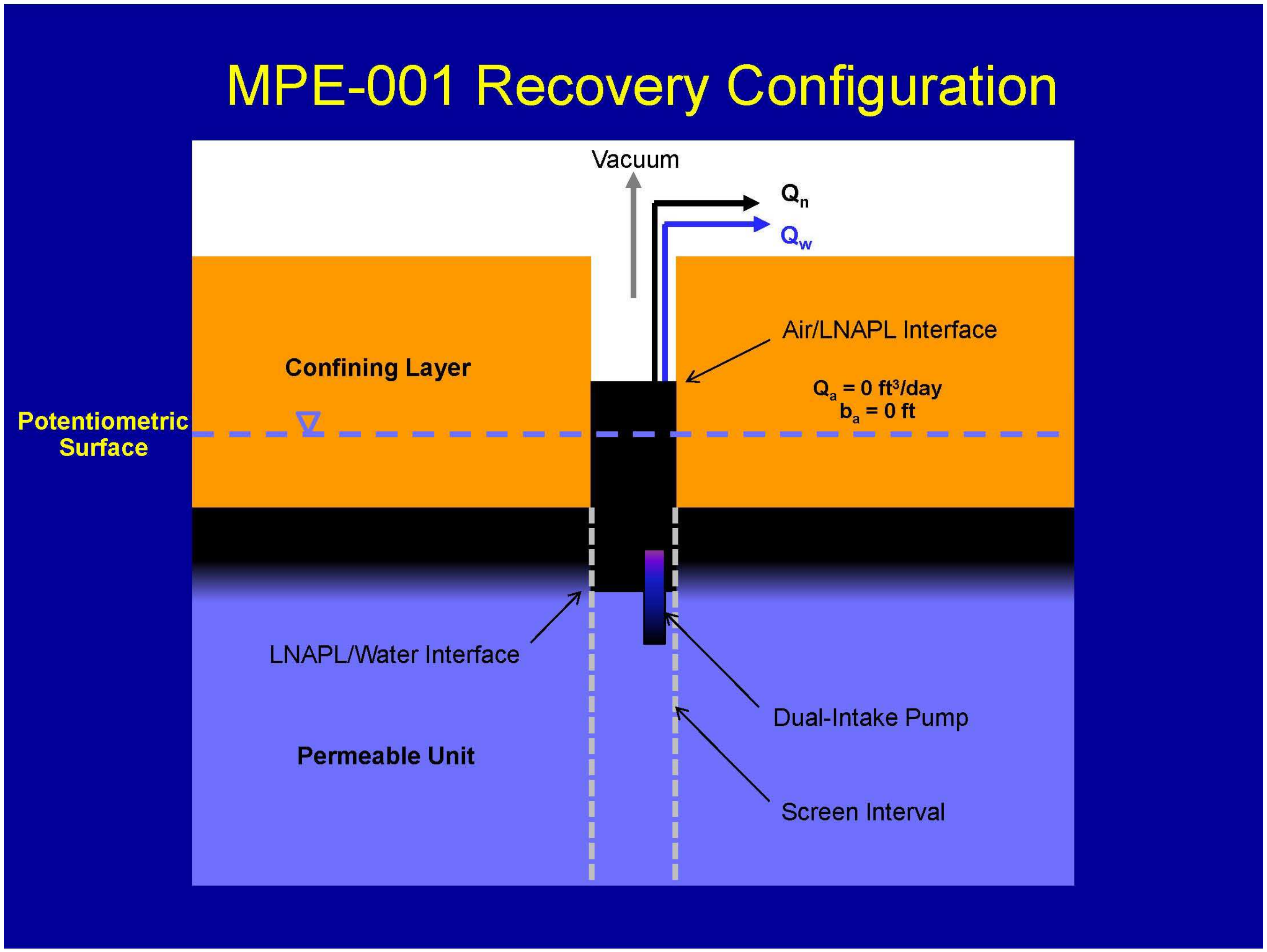

LNAPL Recovery and Tn at DPR-001
Average LNAPL Recovery Rate (gallons per day)
LNAPL Transmissivity (sq. ft. per day)
Date
Qo (GPD)
LNAPL Tn (sq. ft./day)
400
350
300
250
200
150
100
50
0
100
10
1
0.1
0.01
1/1/06
1/1/07
1/1/08
1/1/09
1/1/10
1/1/11
1/1/12
1/1/13
Note: Tn values based on an aquifer transmissivity (Tw) of 19,000 square feet per day.

Recovery-Based LNAPL Tn at DPR-001
(2010 through 2013)



Multiple Phase Extraction (MPE) – Site Example

- Mobile Low-Flow Dual Phase Extraction System (MPE-001)
- Confined LNAPL
- 2.5 Years / ~280,600 Gallons Recovered
- Recovery-Based / Baildown Comparison – Similar Trend



Well Diameter = 4 in.

Well Screened below Confining Layer (L = ~11 feet)

Average Well Head Vacuum = 116 in. W.C.

Q_w = 7 to 8 GPM

Q_n = ~2,000 to 230 GPD

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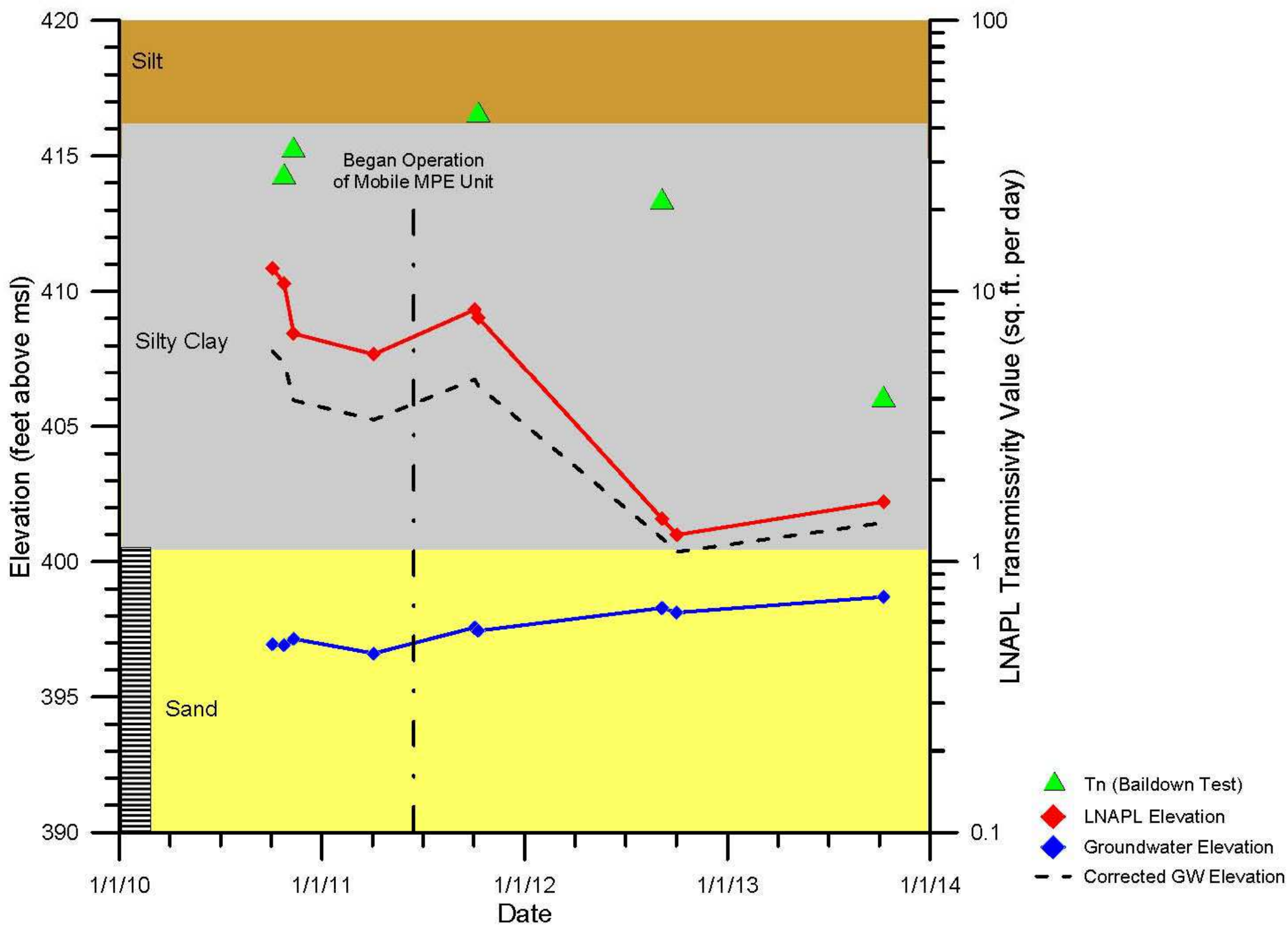
Fluid Elevations and Tn Values at MPE-001



Water and Vacuum-Enhanced LNAPL Recovery Data Analysis

- LNAPL in Formation is Confined
- Assumptions:
  - Fluid Levels at Equilibrium
  - No Air Discharge From Vadose Zone or Formation ($Q_a = 0\ ft^3/day$)
  - No Open Well Screen Above LNAPL Level (b_a = 0 feet)
  - LNAPL Tn Calculated Based on Fluid Recovery Ratios
  - Utilized Water Enhanced Recovery Method of Calculating LNAPL Tn

$$T_n = \frac{Q_n p_r}{\frac{\mu_{ar} Q_a}{k_{ra} K_w b_a} + \frac{Q_w}{T_w}}$$

Equation 23 (ASTM, 2013)

$$T_n = (Q_n/Q_w)\ T_w\, p_r$$

$$where,\ T_w = K_w\, L$$

(Hawthorne, 2013)

T_n = LNAPL transmissibity (ft^2/day)
T_w = Aquifer transmissivity (ft^2/day)
K_w = Aquifer conductivity (ft/day)
L = Wetted interval along well screen (ft)
Q_n = Measured LNAPL removal rate (ft^3/day)
Q_w = Measured water discharge rate (ft^3/day)
p_r = LNAPL-water density ratio
k_{ra} = Air-phase permeability
μ_{ar} = Air-water viscosity ratio

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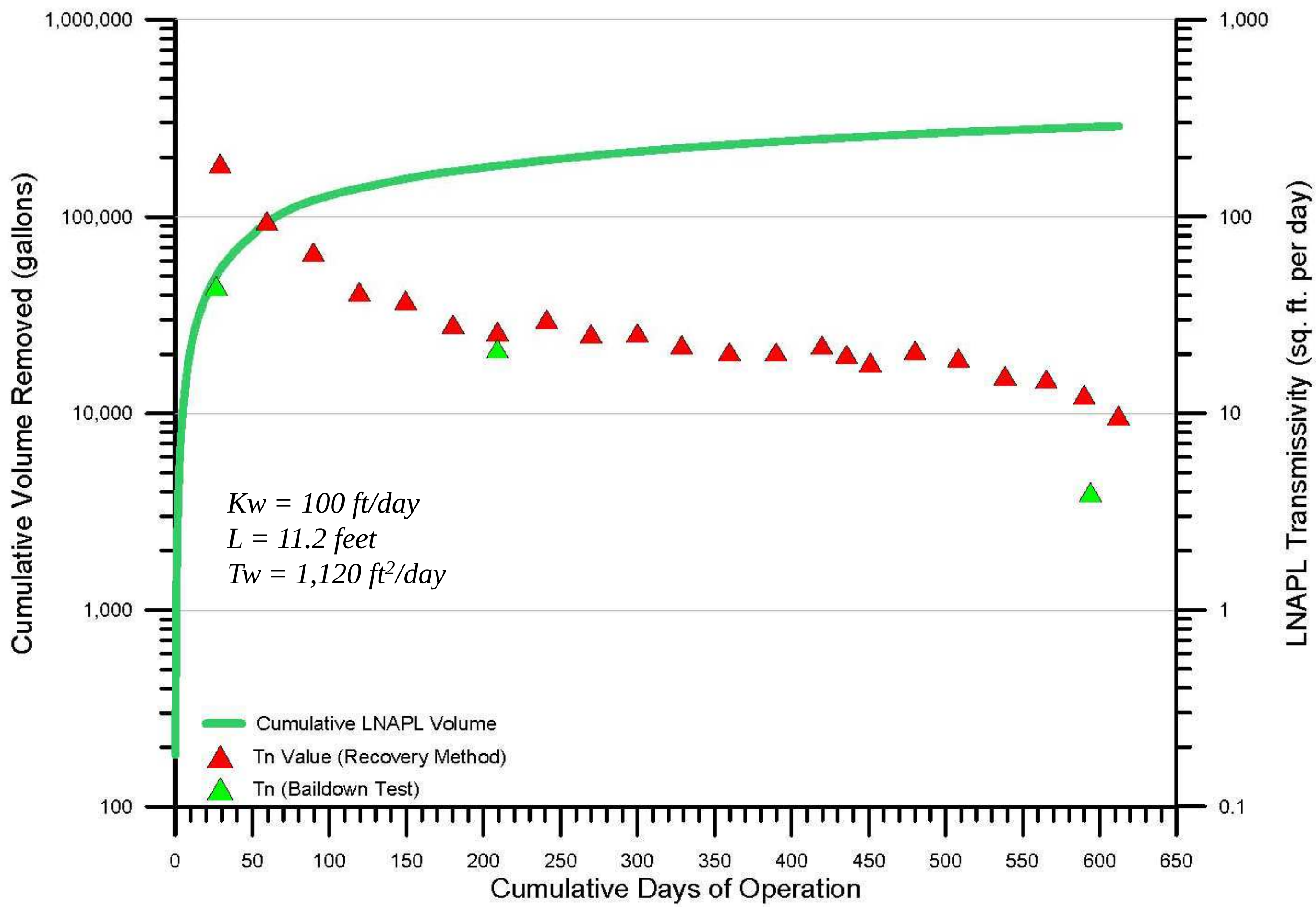
Cumulative LNAPL Removal and Tn at MPE-001



Summary

- LNAPL Transmissivity is a Useful Metric for Evaluating the Performance of a Variety of Hydraulic Recovery Systems
- Provides Another Line of Evidence for Determining When Endpoints or Decision Points are Reached ("…to the extent practicable.")
- Recent ASTM and API Guidance Provides Consistent Procedures for Collecting Data, and Calculating and Analyzing LNAPL Tn Values
- Periodic Baildown Testing Should be Performed to Confirm Recovery-Based LNAPL Tn Trends
- Consistent Operation and Maintenance of Recovery Systems and Wells is Critical for Improving Accuracy of Recovery-Based LNAPL Tn Data

Thank You!
Any Questions?

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