Transmissivity as a Primary Metric for LNAPL Recovery – Case Study Comparison from Short-term and Long-term Recovery Data

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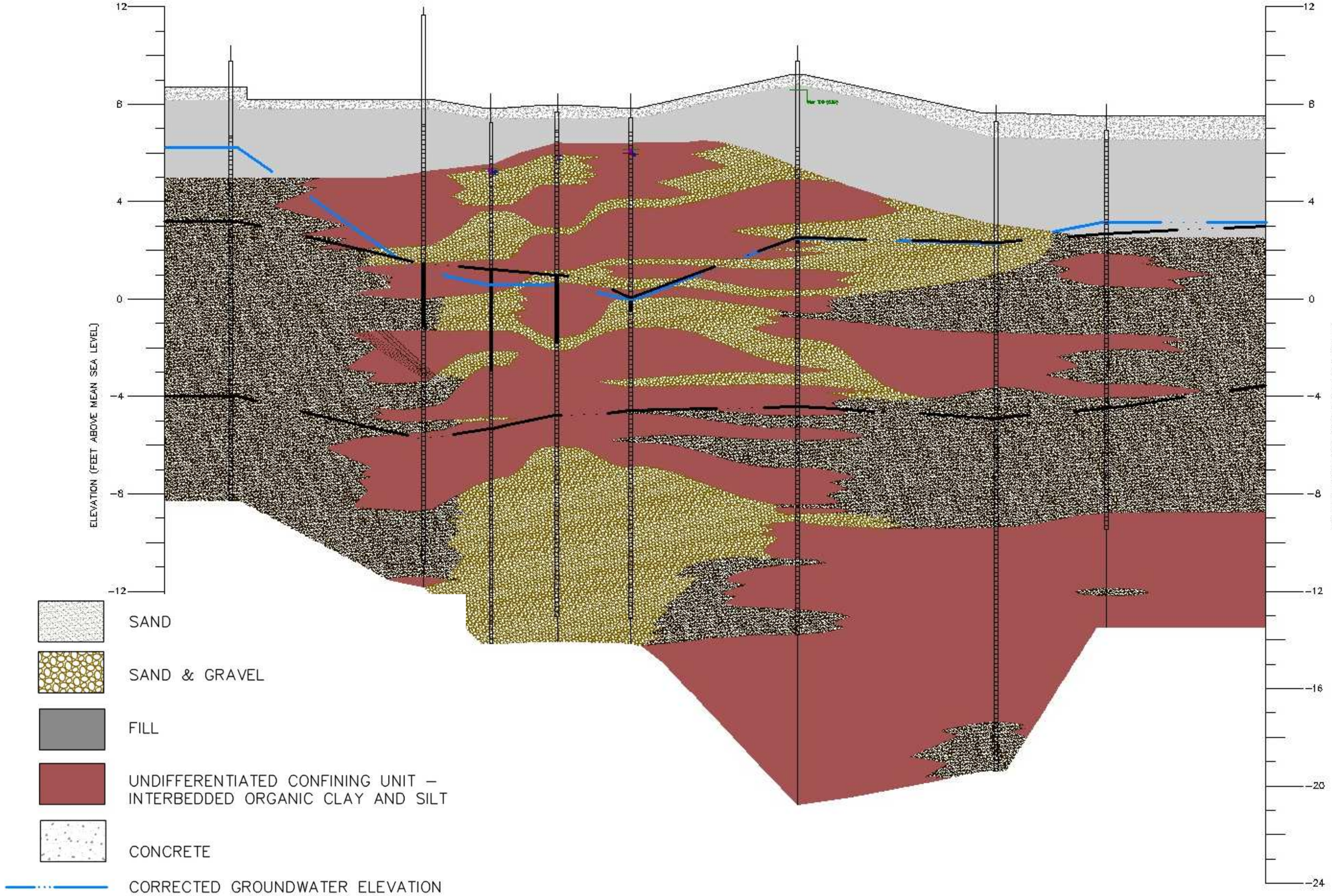
Presentation Outline

- Overview and Background
- Case Study Review
- Short-Term and Long-Term Data Testing Methods
- Data Review, Findings and Conclusions

Site Background – General

- Active refinery in operation for 100 plus years
- Site Hydrogeology
  - Groundwater Table – 5 to 22 feet below grade
  - Direction – North to South/Southeast
  - One in two wells contain LNAPL, light-end to heavier petroleum constituents with varying degrees of weathering
- LNAPL recovery is ongoing for 30 plus years

Site Background – Hydrogeology



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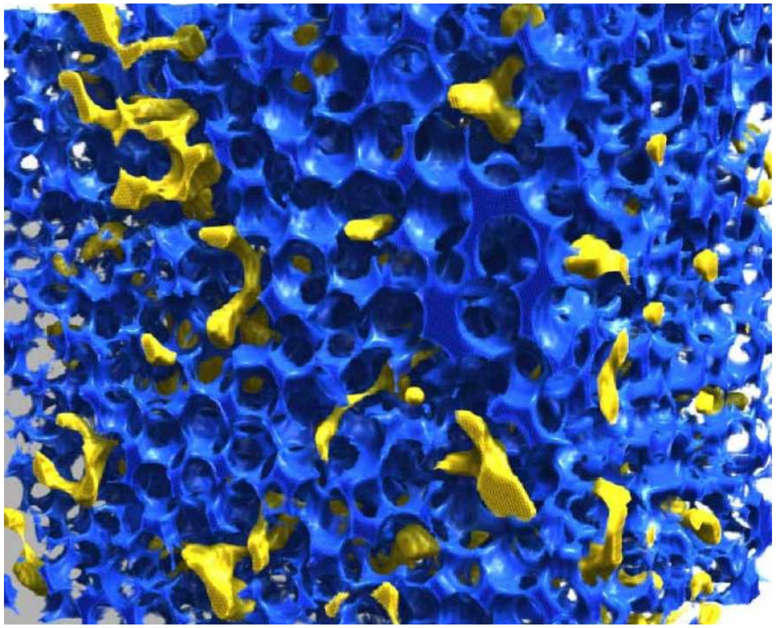
Case Study Review

- Pilot Prioritization Approach
  Identify areas of LNAPL accumulation and remedial action based on level of risk (i.e., receptors, migration impact to groundwater)
- Establish Baseline Transmissivity (Tn)
  - Baildown Testing
    - Testing methods and data evaluation
- Establish long-term well-specific or area-specific Tn
  - Long-Term Methods (Recovery Data Analysis)
    - Testing methods and data evaluation
- Assess trends and continue short-term and long-term evaluation of Tn as a primary metric for site-wide evaluation

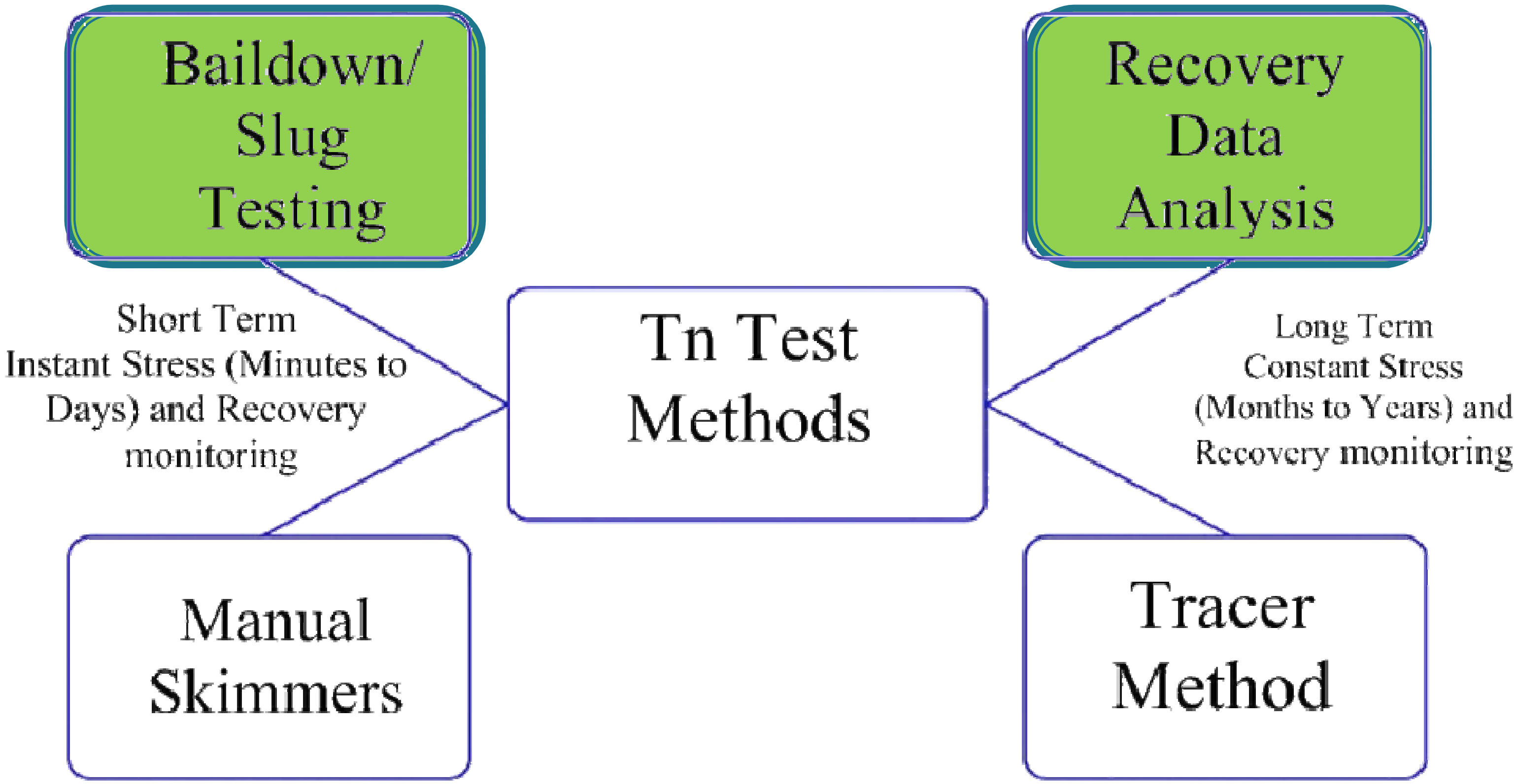
Transmissivity (Tn)

- Estimation of volume of LNAPL at the existing kinematic viscosity that will move in a unit time under a unit hydraulic gradient through a unit width of aquifer [ASTM, 2013]
- Direct indicator of recoverability (i.e., the aquifer yield and flow of LNAPL from formation to well)
- Summary metric based on aquifer properties, LNAPL physical properties and LNAPL saturation over a given interval
- Mass Recovery Rate also proportional to Tn (i.e., suitable for long-term data)



LNAPL Ganglia at Res. Sat. Blue – Water
Yellow – LNAPL
Dr. Singh et. al.

Transmissivity (Tn) Estimation



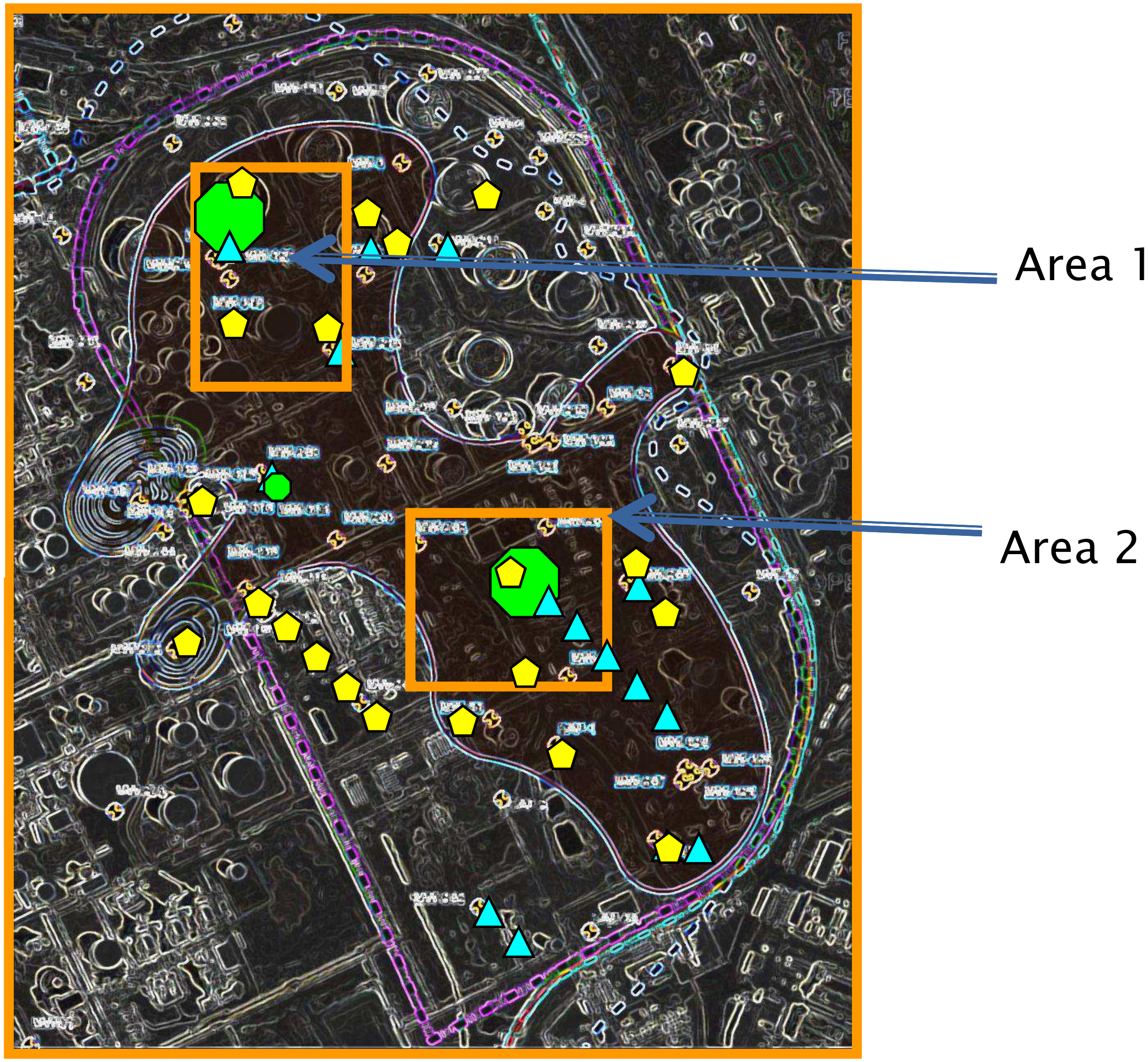
Case– Study Areas

Plume Size

85 Acres

Composition

Light End Petroleum Hydrocarbons



Baildown locations

Pilot Testing

Skimmer locations

Tn Short-Term Data – Baildown Testing

<u>Selection Criteria:</u>

- Wells with 0.5 foot of LNAPL and in equilibrium
- Wells screened and developed – in communication with surrounding aquifer

-LNAPL from borehole (well plus filter pack) removed using peristaltic pump, bailers or vacuum trucks

- Monitor LNAPL layer recovery over time to up to <u>100% recovery</u> (critical for data analysis)
- 50 locations site-wide (study limited to 18 wells)

Tn Short-Term Data- Baildown Testing

- Data Tools:
  - AQTESOLV
    - Similar to groundwater pumping test evaluation
    - Adjust for LNAPL Density (Becker and Lyverse, 2002)
  - API Workbook (2012)
    - Spreadsheet and solver tool
    - Iterative process in establishing Tn
    - Suitable for unconfined (decreasing discharge), confined and perched LNAPL (constant discharge) conditions
    - Methods
      - CJ, CBP and BR

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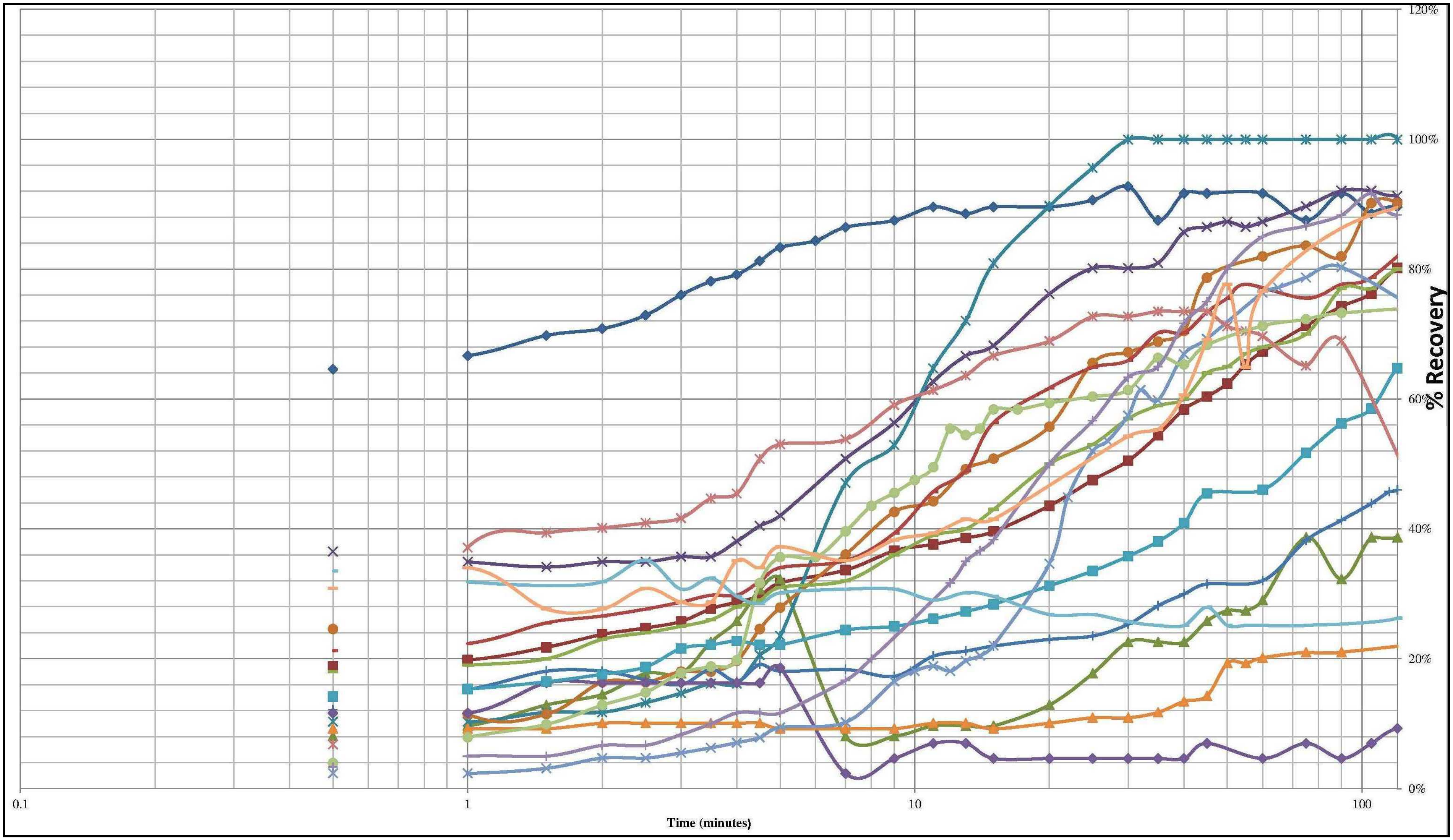
Tn Short-Term Data- Baildown Testing

- Important items to consider for data evaluation
  - Initial LNAPL Drawdown
  - Purge Volume (theoretical and field)
  - Type of LNAPL Conditions
  - Filter Pack Drainage
  - Drawdown versus Discharge Evaluation
  - Tidal Fluctuations (if you are near a waterbody, river, stream, ocean)

Baildown Testing Results – Recovery Rate Vs. Time



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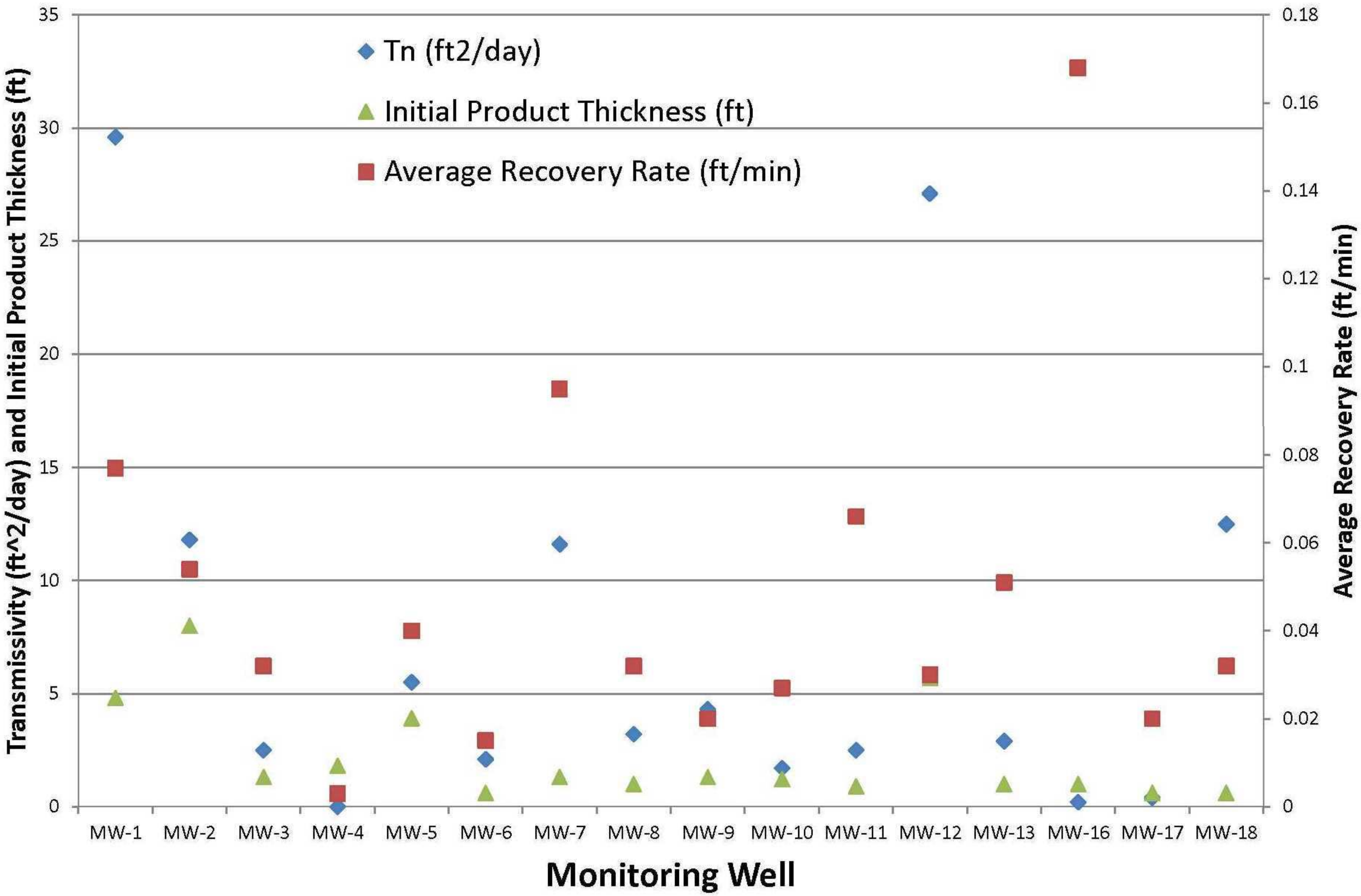
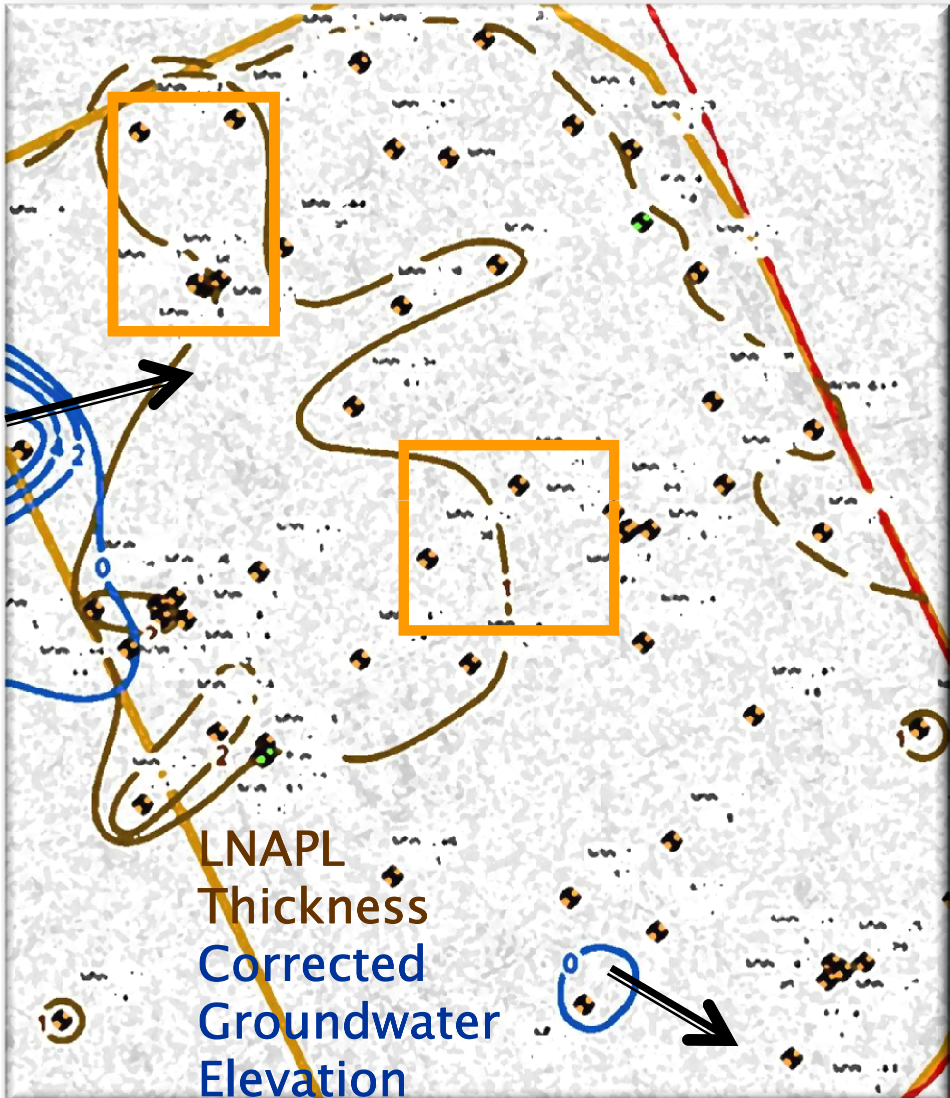
Baildown Testing Results – Tn

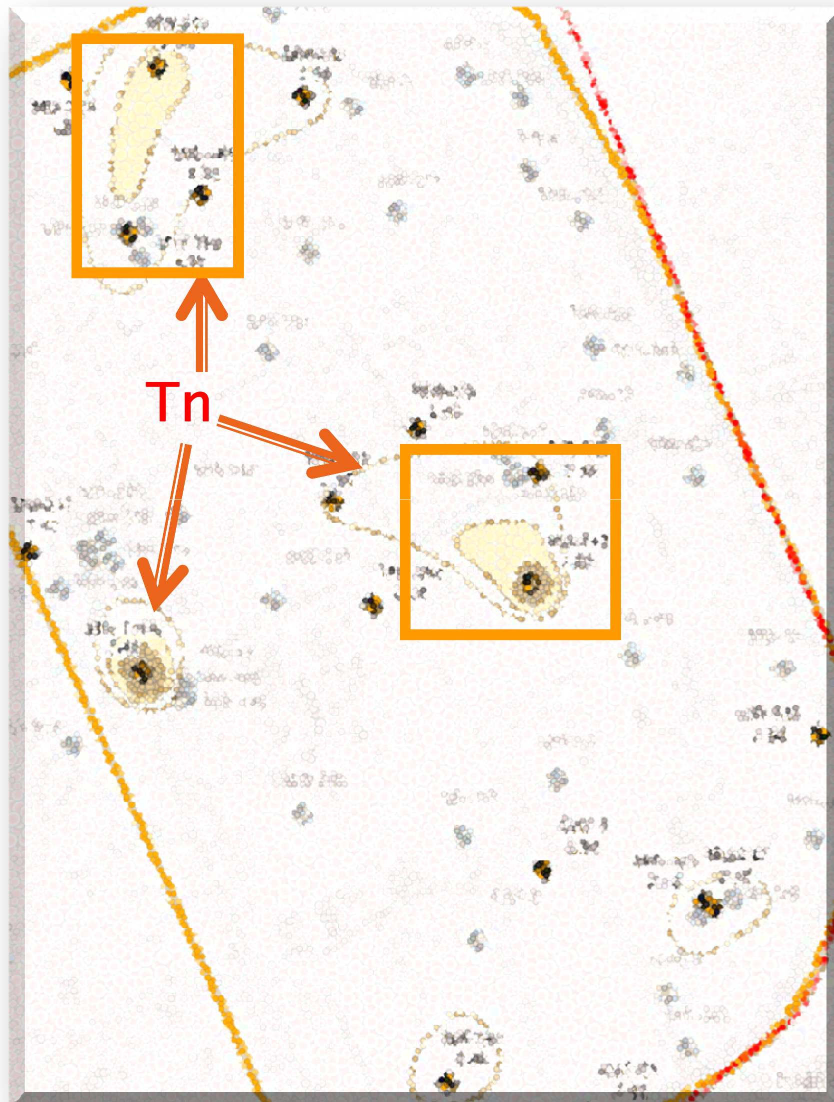


Baildown Testing and Tn Results

Well ID	Tn (ft^2/day)	Average Recovery Rate (ft/min)	Initial Product Thickness (ft)	Percent Recovery at 120 minutes (%)
MW-1	29.6	0.077	5.8	~ 85%
MW-2	11.8	0.054	8.0	~ 80%
MW-3	2.5	0.032	1.3	~ 90%
MW-4	0.0	0.003	1.8	~ 25%
MW-5	5.5	0.040	3.9	~ 45%
MW-6	2.1	0.015	0.6	~ 85%
MW-7	11.6	0.095	1.3	~ 60 %
MW-8	3.2	0.032	1.0	~ 75 %
MW-9	4.3	0.020	1.3	~ 80 %
MW-10	1.7	0.027	1.2	~ 30 %
MW-11	2.5	0.066	0.9	~ 80%
MW-12	43.7	0.030	4.5	~ 100%
MW-13	2.9	0.051	1.0	~ 80%
MW-16	0.2	0.168	1.0	~ 25%
MW-17	0.4	0.020	0.6	~ 40%
MW-18	12.5	0.032	0.6	~ 90%

Apparent LNAPL Thickness Vs Tn





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Active LNAPL Recovery Systems

- LNAPL Skimming (Stationary and Mobile)
- Multi-Phase Extraction
- Dual-Phase Extraction
- Vacuum Truck Program ("pulsed" MPE)
- Low-vacuum Extraction

This presentation limited to skimmer short -term and long-term comparison

Long-Term Data Tn – Recovery Systems

- Minimum criteria:
  - Well-operated LNAPL recovery system
  - Effective O&M data collection and analysis
  - Understanding of LNAPL distribution and thickness (bn) of the mobile oil interval
- Tn estimation from Skimmer ASTM (2013)

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

where

T_n = LNAPL Transmissivity (L^2/t), Q_n = measured LNAPL recovery rate (L^3/t),
R_{oi} = radius of influence (L), r_w = well radius, ln (Roi/rw) = 4.6
s_n = LNAPL drawdown at time t (L), bn= gauged LNAPL thickness
bnf= formation thickness
s_n = bn (1- rho) [unconfined] s_n = bn rho/(1-rho) [confined] s_n= bnf [perched]

Case Study Areas 1 and 2 Review

- Identified based on baildown testing Tn at areas near MW-1 and MW-12 and LCSM understanding
- Completed pilot testing and installed full-scale system
- Area 1 – Stationary and Area 2 – Mobile Skimmers:
  - Recovery rate: ~10 to 150 gallons per day
  - Radius of influence: ~ max. 20 feet
  - All wells: unconfined conditions

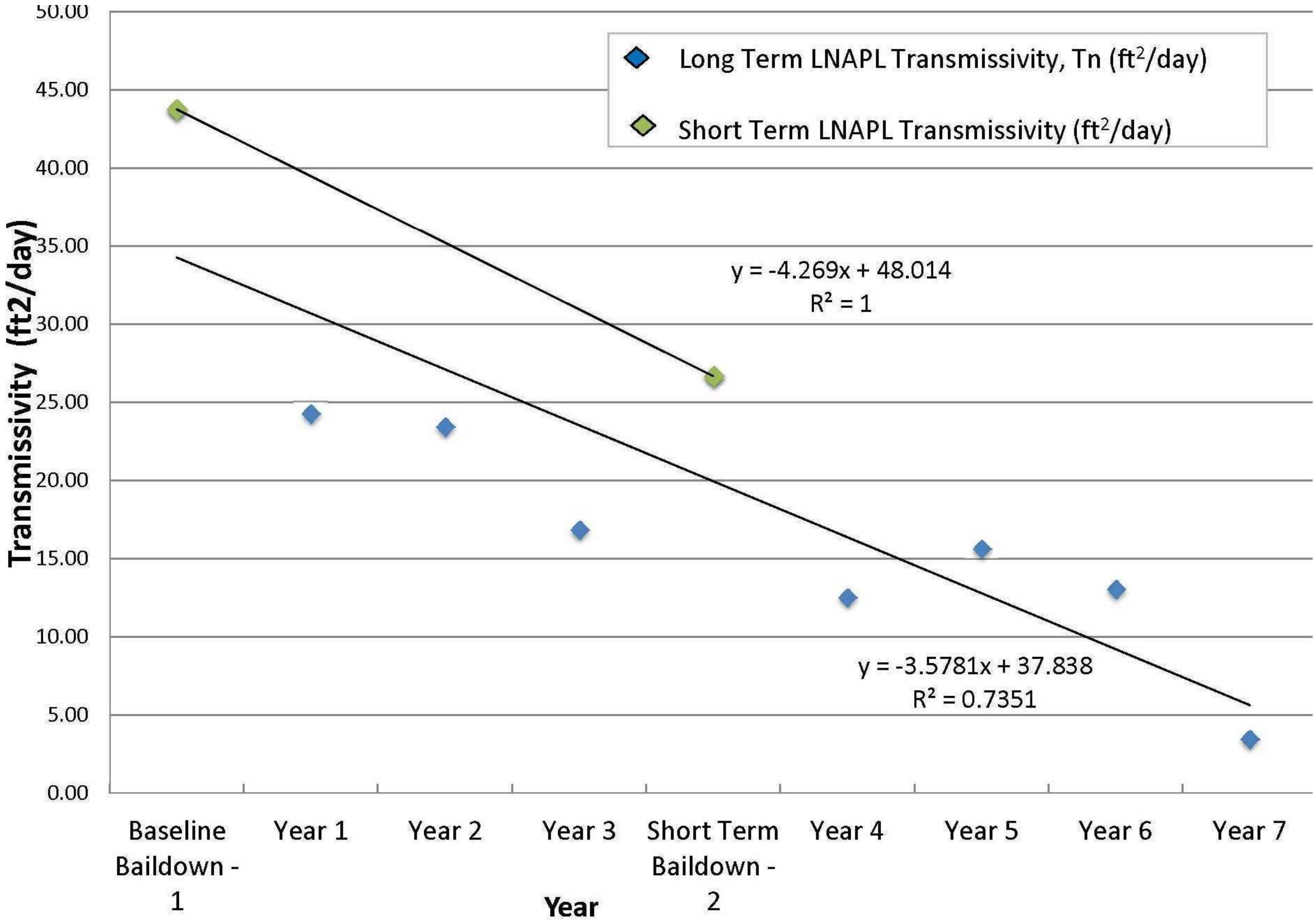
Area 1 and 2 Summary

- Short-Term Recovery Data Baildown Testing
  - Baildown testing – Baseline and Interim (every three to four years)
  - Data analysis by API workbook
- Long-Term Recovery Data
  - Area 1 from stationary pneumatic skimmers (in operation for seven years)
  - Area 2 from mobile pneumatic skimmers (in operation for two years)
  - O&M data normalized for temporal variations and shutdown conditions
  - Drawdown (sn) based on equilibrium fluid levels and O&M system adjustments

Area 1 – Short-/Long-Term Results

Well Id	Recovery Rate (cu.ft./day)	Tn (ft^2/day)
Baseline Baildown - 1	5.0	43.74
Long-Term – Year 1	4.6	24.25
Long-Term – Year 2	4.5	23.40
Long-Term – Year 3	3.2	16.84
Short-Term Baildown - 2	3.1	26.67
Long-Term – Year 4	2.4	12.52
Long-Term – Year 5	3.0	15.62
Long-Term – Year 6	2.5	13.01
Long-Term – Year 7	0.7	3.47
Short-Term Baildown - 3	To be Conducted	

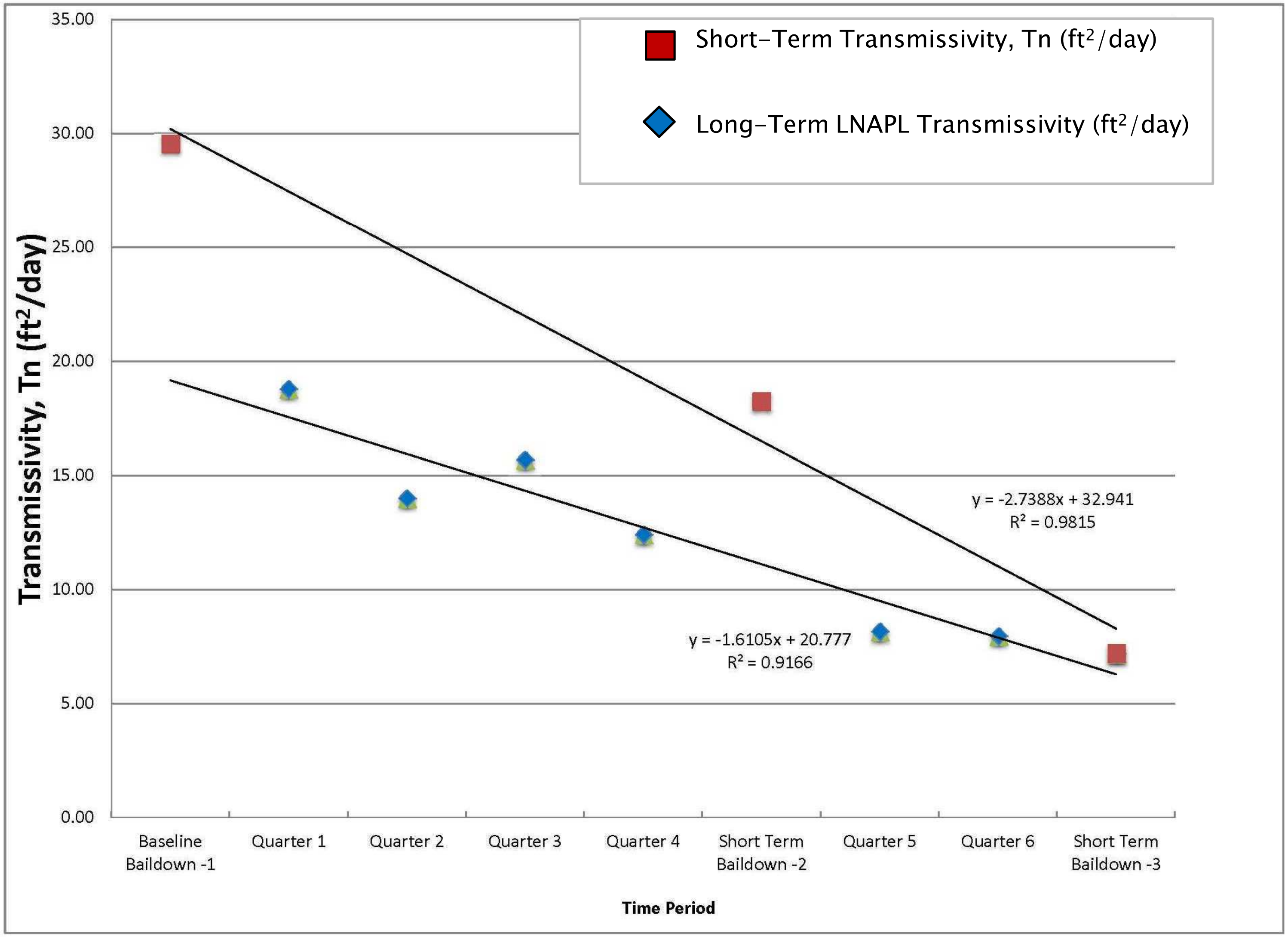
Area 1 – Skimmer Tn Results



Area 2 Short-/Long-Term Results

Well Id	Recovery Rate (cu.ft./day)	Tn ft2/day)
Baseline Baildown -1	8.5	29.6
Quarter 1	5.4	18.8
Quarter 2	4.0	14.0
Quarter 3	4.5	15.7
Quarter 4	3.6	12.4
Short-Term Baildown - 2	2.6	18.2
Quarter 5	2.3	8.2
Quarter 6	2.3	8.0
Short-Term Baildown - 3	2.1	7.1

Area 2 – Skimmer Tn Results



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Findings and Conclusions

- Comprehensive LSCM is necessary
- Critical Considerations
  - Evaluate Geology and Preferential Pathways
  - Understand Age, Degree of Weathering and Chemical/Physical Characters of LNAPL
  - Reconcile Aquifer Heterogeneities. A foot of LNAPL in gravel and sand is different than a foot of LNAPL in silt
  - Assess Saturation Levels in Area/Well

Findings and Conclusions

- Baildown testing Tn highly dependent on varying factors (i.e., soil and product type, geologic setting, individual well conditions and data evaluation tools)
- Computed Tn results can vary under similar conditions at different locations. Repeat testing and/or LCSM review is necessary
- Tn estimation from short-term data relies heavily on careful collection of field data and competent data analysis

Findings and Conclusions

- Tn estimation from long-term data depends on system O&M and accurate site-specific parameters
- Overall, Tn is a streamlined parameter than can be used for design, start-up and shutdown of recovery systems
- Further Analysis
  - Propose using Tn as a resource allocation tool and budgeting ($s spent versus LNAPL recovery in consideration of program parameters – risk, migration etc.)
  - Tn evaluation ongoing for all other LNAPL recovery systems (MPE, DPE, Vacuum truck etc.)

THANK YOU

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