HOW TOMORROW MOVES

GIS-Based Method for High-Resolution Mapping of LNAPL Plume Transmissivity, Recoverability, and Longevity:

Case Study at CSXT Stadium Project

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HOW TOMORROW MOVES

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PROPERTY HISTORY

1890-1902: Louisville and Nashville Railroad Company (L&N)

1902-1905: Development of the South Louisville Shops

1905-1980'S: South Louisville Shops Hub of L&N Construction and Maintenance Operations

1980'S: L&N was Merged into Seaboard System Railroad and Seaboard was Subsequently Merged with Chessie System to Create CSX Transportation, Inc. (CSXT)

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PROPERTY TRANSFER

1996: CSXT Transferred 92 Acres to the University of Louisville for Construction of a Football Stadium and Athletic Training Facilities

CSXT retained environmental liabilities pursuant to the Purchase & Sale Agreement and associated Kentucky Department of Environmental Protection (KDEP) –Approved Remedial Action Plan (RAP) and Risk Management Plan (RMP)

On-Going KDEP Required Remedial Activities per the RAP

- Cap Construction & Maintenance
- Free Product Recovery & Down-Gradient Groundwater Monitoring
- Stadium Construction & Future Excavations/Construction in accordance with the May 23, 1996 procedures in the RAP
- Annual Reporting

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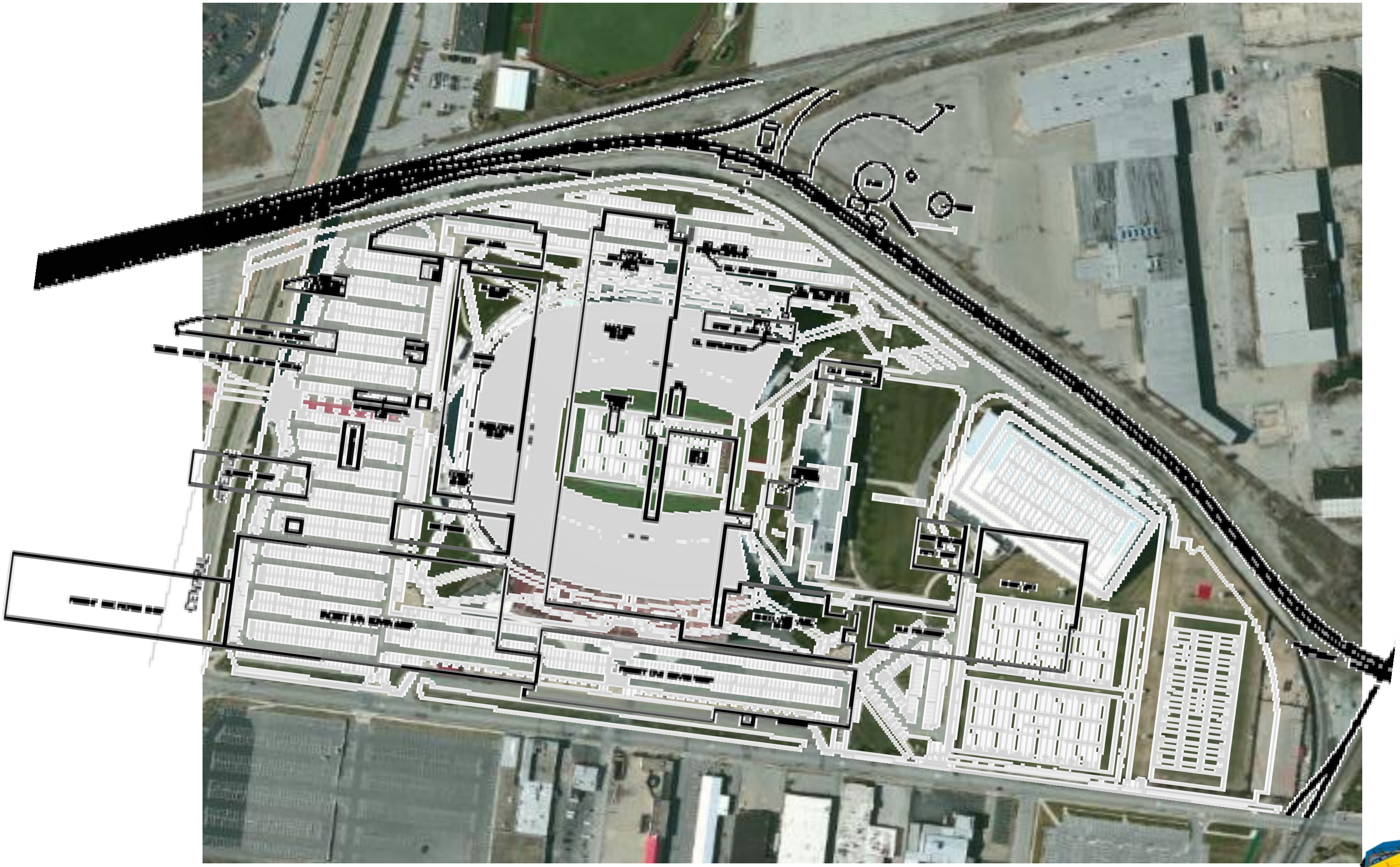
STADIUM CONSTRUCTION (1996-1998)



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PROJECT ACCOLADES

Winner of 1999 Phoenix Award
from Pennsylvania DEP

Created in 1997, the Phoenix awards honor groups that develop significant brownfields sites. "They seek to recognize innovative yet practical remediation projects, which bring blighted, old commercial and industrial sites back to productive use."

www.dep.state.pa.us/hosting/phoenixawards

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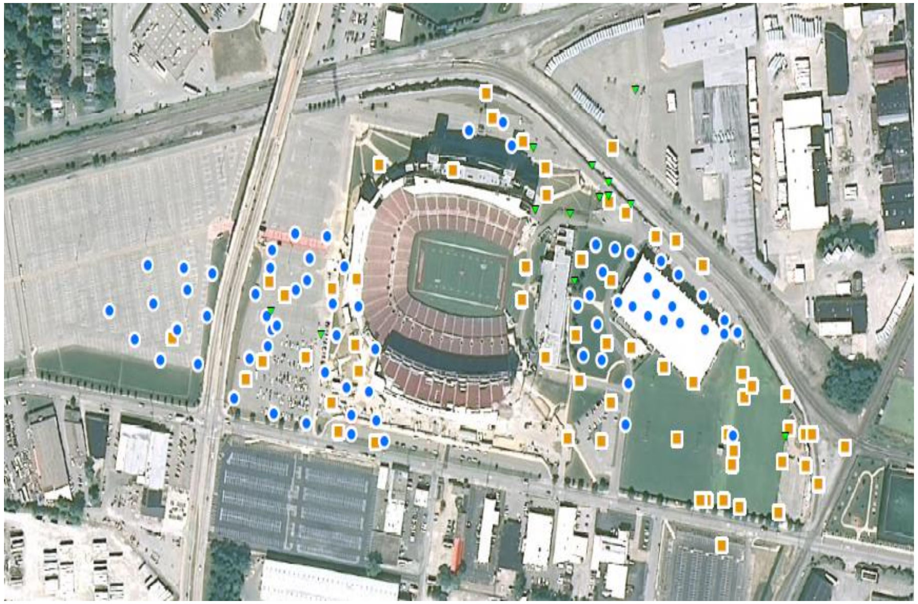
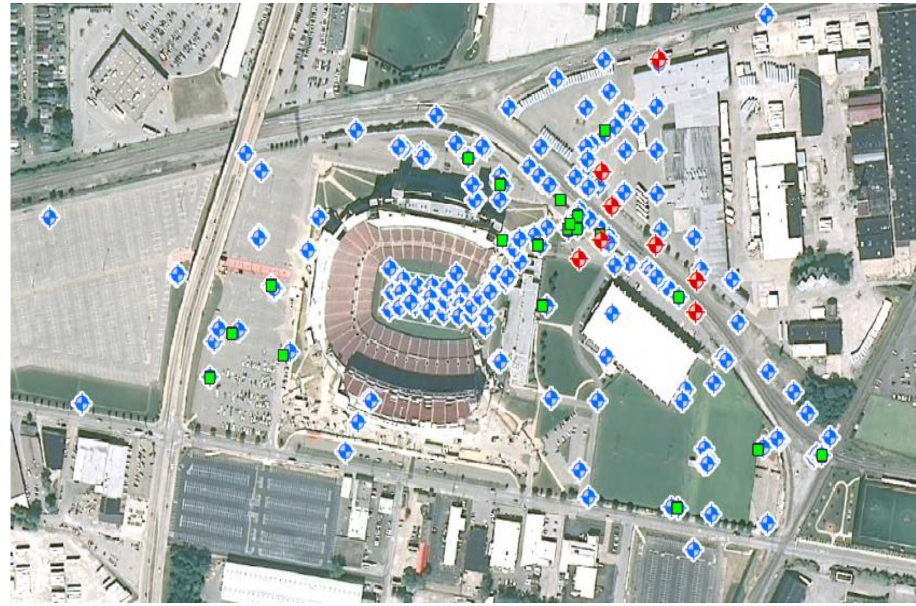
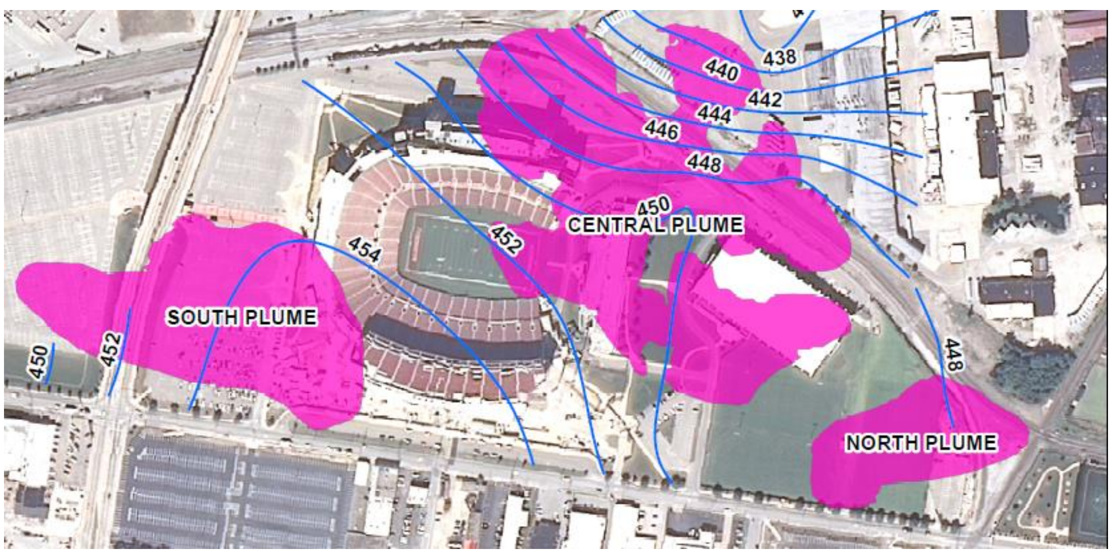
EXTENSIVE INVESTIGATIVE / REMEDIAL ACTIVITIES







LNAPL MODELING PRESENTATION OUTLINE

Conceptual Site Model

- LNAPL Impact and Properties
- Conceptual Geologic Model & Hydrogeology
- Capillary Properties of Soil/Sediment

LNAPL Modeling

- Applying the LNAPL Distribution and Recovery Model using GIS
- LNAPL Specific Volume Mapping
- LNAPL Transmissivity Discussion and Mapping
- Natural Source Zone Depletion Model Based on Well Gauging Data and Specific Volume Mapping

Conclusions & Discussion

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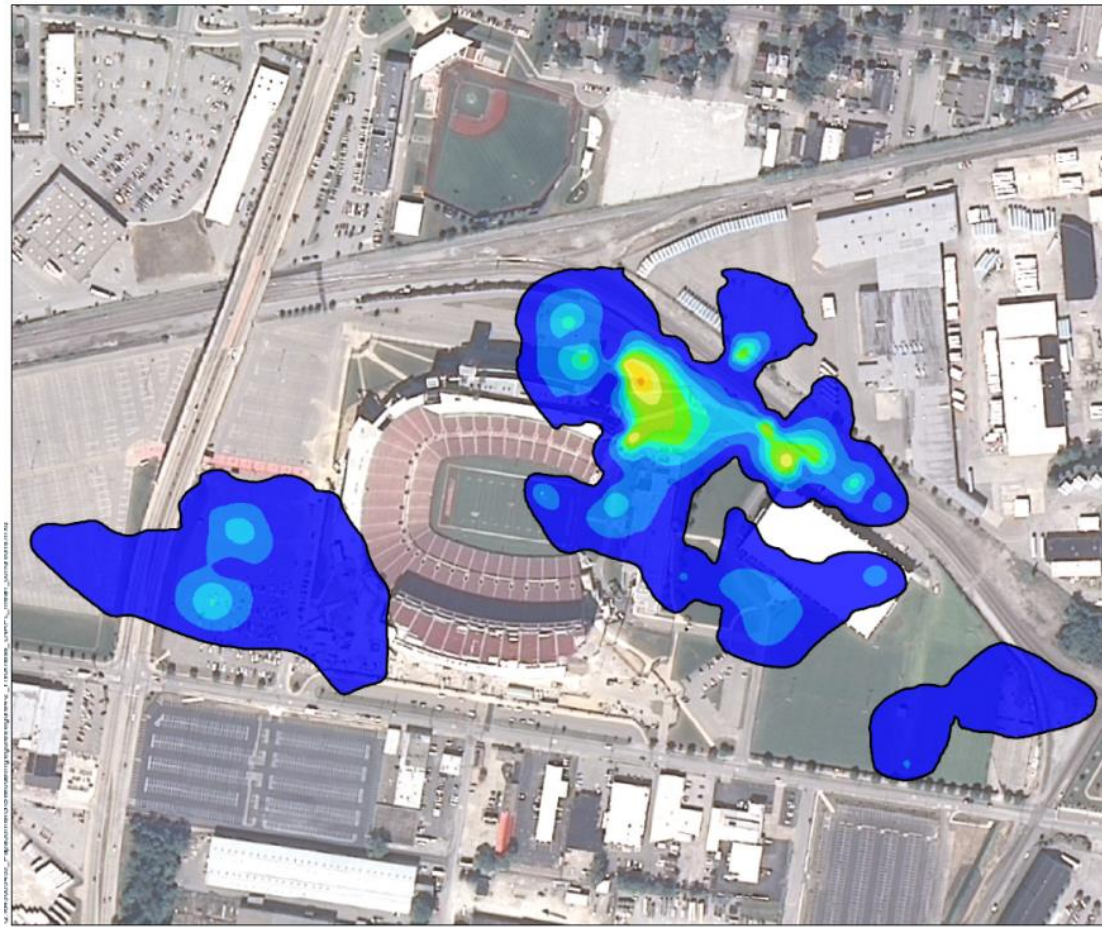
MEAN LNAPL THICKNESS

Thickness (feet) of LNAPL

- 0.1 - 1.0
- 1.1 - 2.0
- 2.1 - 3.0
- 3.1 - 4.0
- 4.1 - 5.0
- 5.1 - 6.0
- 6.1 - 7.0
- 7.1 - 8.0
- 8.1 - 9.0
- 9.1 - 10.0
- 10.1 - 11.0



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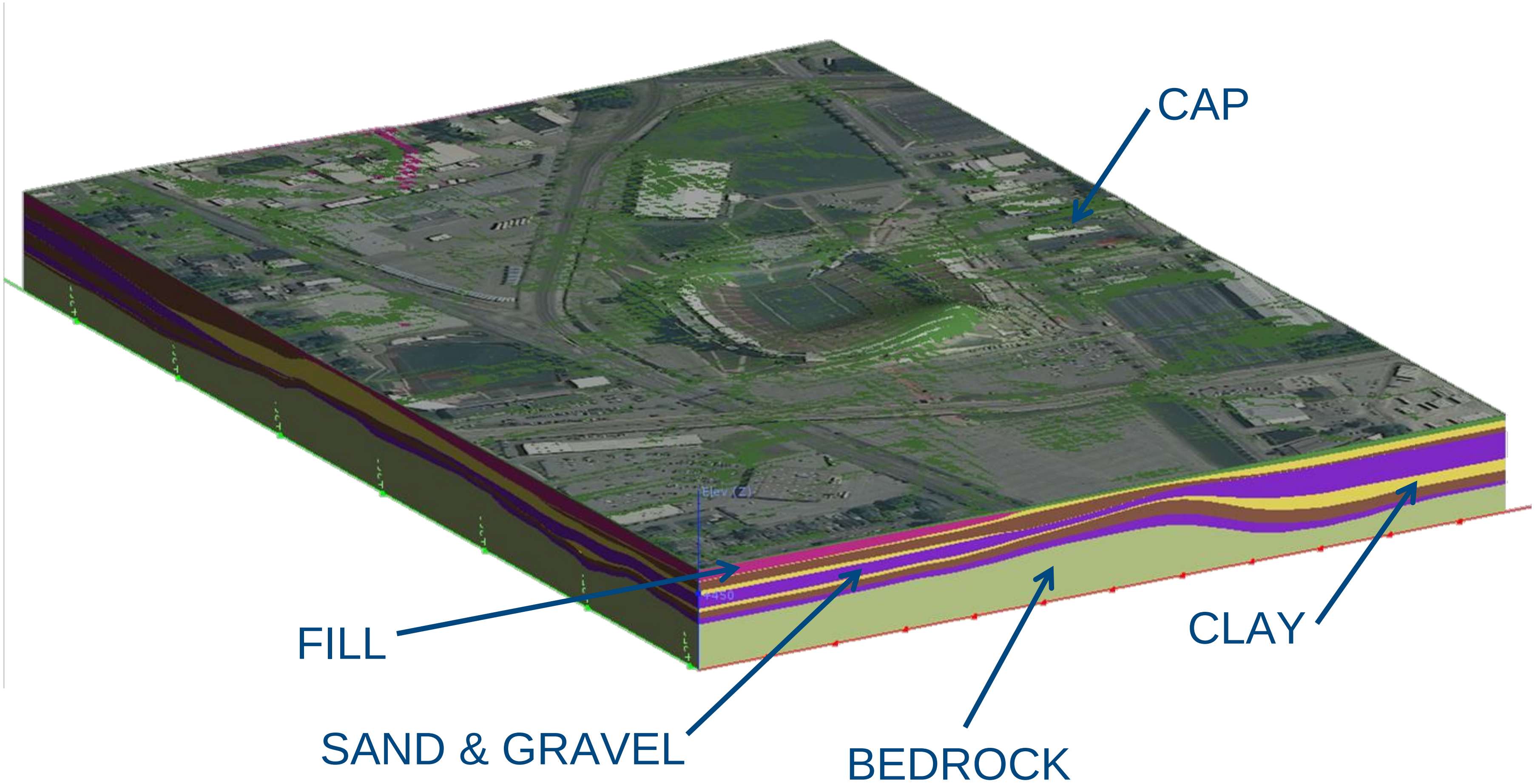
SELECTED SITE-SPECIFIC LNAPL PROPERTIES

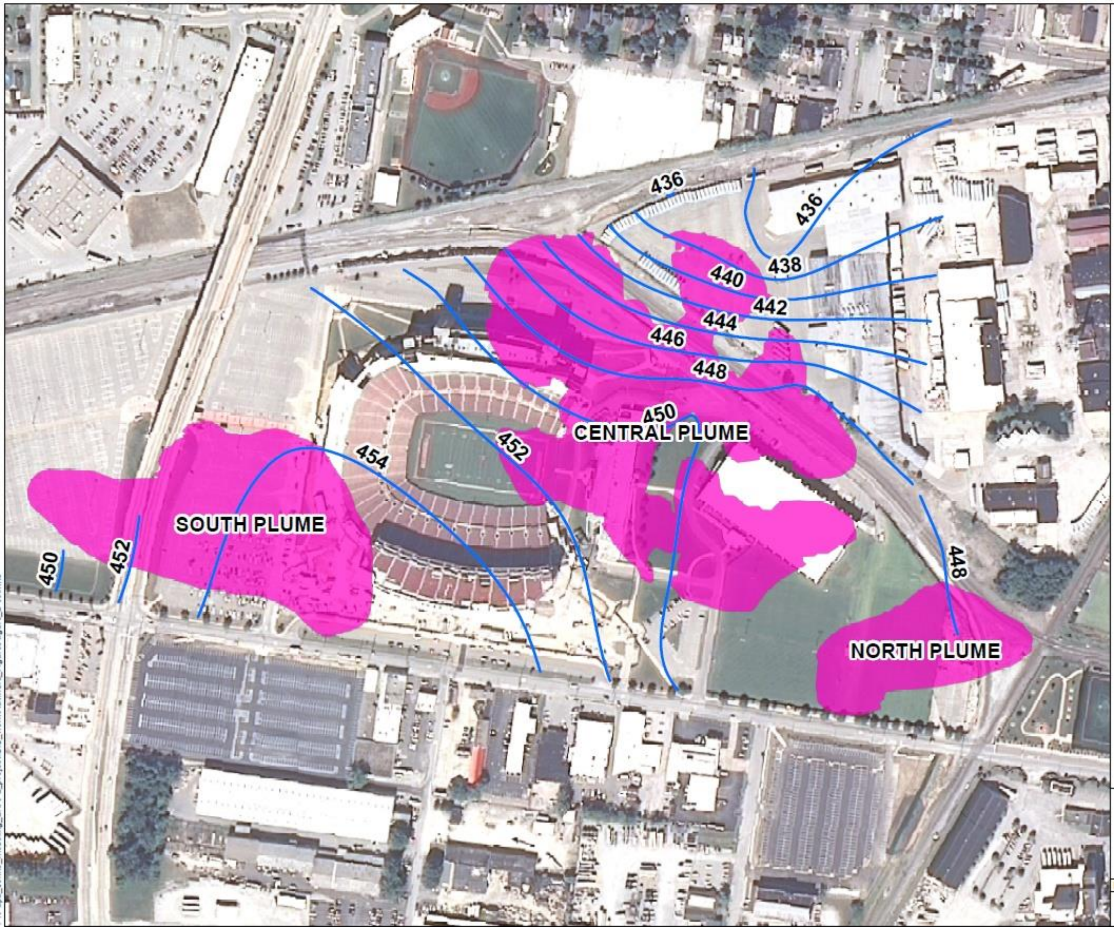
Property Name	Property Value
Hydrocarbon type	Weathered diesel oil
Density (g/cc)	0.862
σ_{nw} (dyne/cm)	13.2
σ_{na} (dyne/cm)	28.9
μ_n (centiPoise)	5.63

3D CONCEPTUAL GEOLOGIC MODEL



MEAN GROUNDWATER LEVEL ELEVATIONS

- Based on ***Mean*** Static Groundwater Pressures
- LNAPL Thickness Scaled to Water Pressure
- 20 Select Well Locations Used
- Elevations Grid Generated with Surfer® for Input to Model



SELECTED SITE-SPECIFIC SOIL PROPERTIES

Soil Category	Code	α (1/ft)	n (-)	m (-)	S_{wr}	S_{nr}	K_{LNAPL} (Ft/d)	Porosity (%)
CAP	1	0.18	1.72	0.42	0.41	0.03	0.22	24.7
FL	2	0.37	2.20	0.55	0.15	0.03	1.28	28.1
CL	3	0.18	1.72	0.42	0.41	0.03	0.22	24.7
SG	4	0.37	2.20	0.55	0.15	0.03	1.28	28.1
FI	5	0.46	1.33	0.25	0.11	0.04	0.30	20.2
BR	6	0.18	1.72	0.42	0.41	0.00	0.00	20.0

Notes:

1) α and n are van-Genuchten parameters.

2) m is a van-Genuchten parameter, and it is defined as: m=1-1/n.

3) S_{wr}: residual water saturation

4) S_{rn}: residual LNAPL saturation

5) K_{LNAPL}: LNAPL hydraulic conductivity

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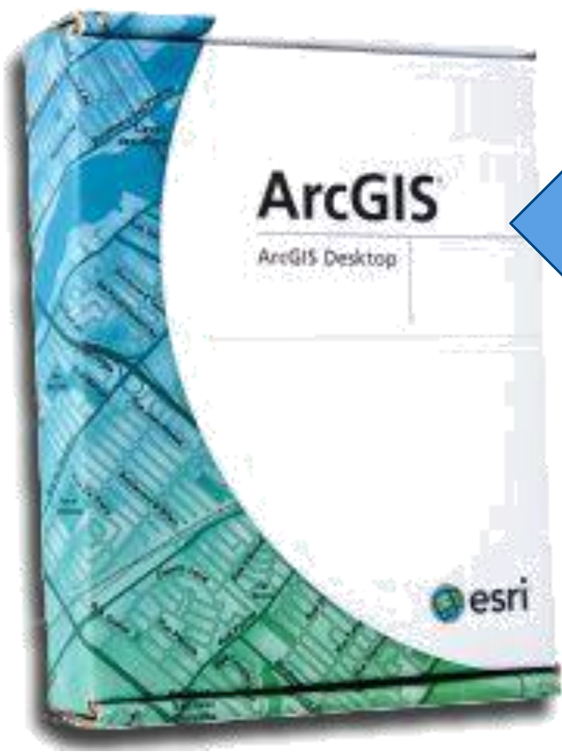
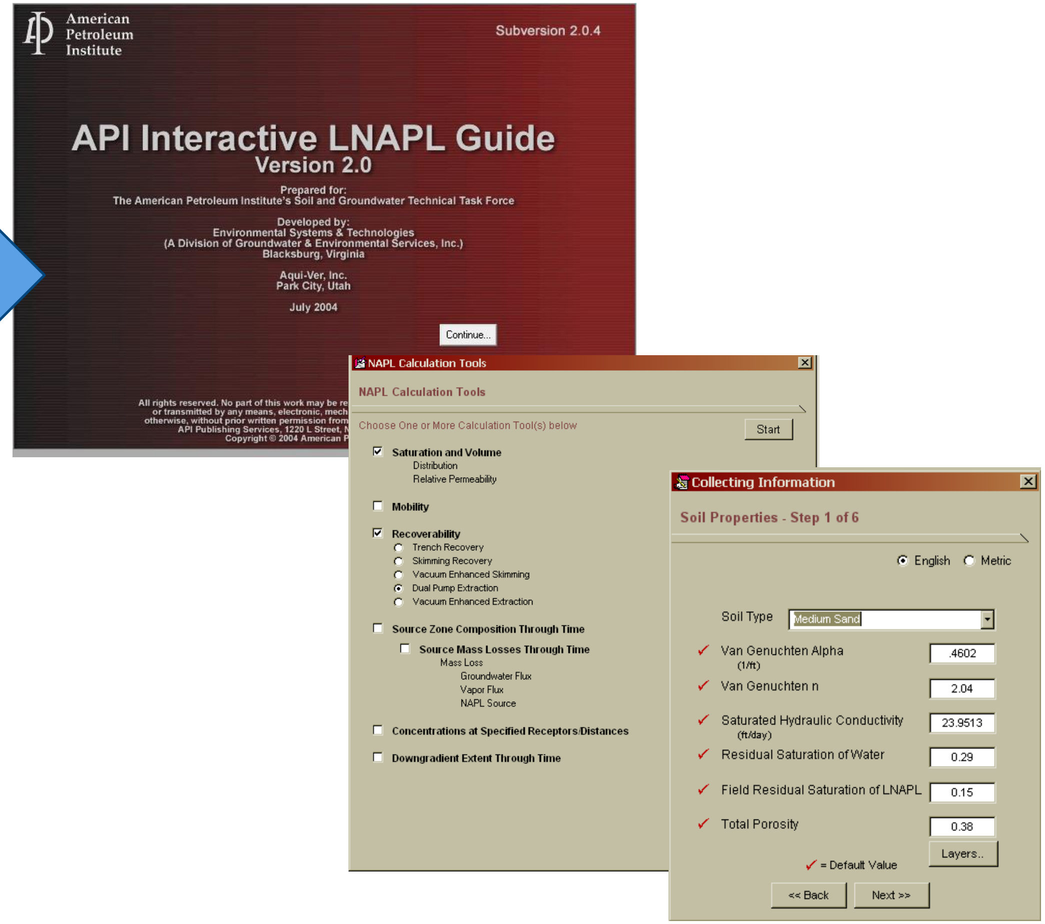
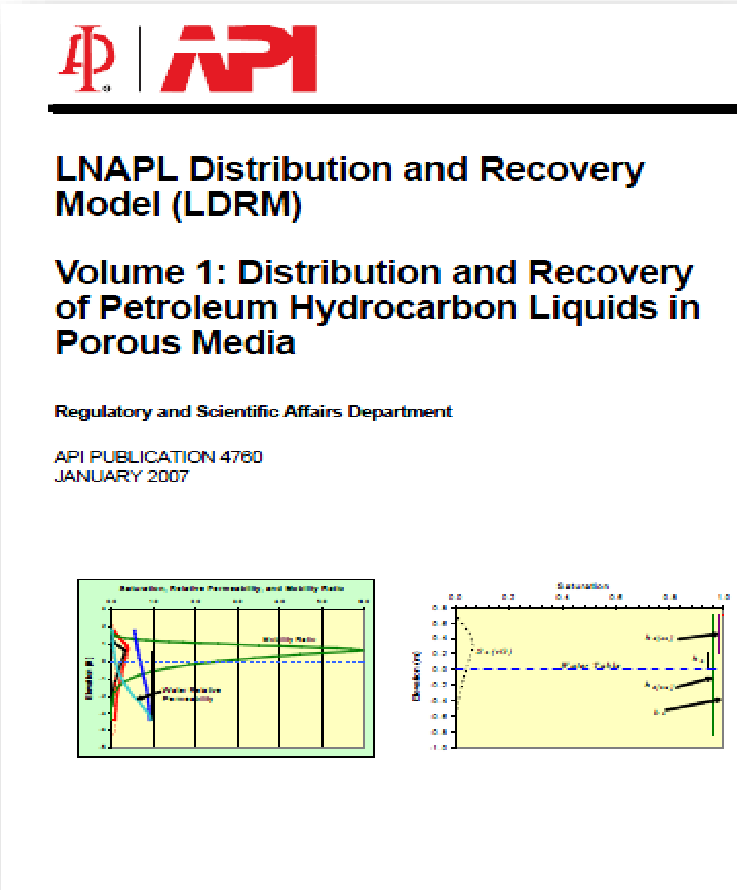
API EQUATIONS APPLIED SPATIALLY VIA GIS





API EQUATIONS APPLIED SPATIALLY VIA GIS


LNAPL Distribution and Recovery Model (LDRM)

Volume 1: Distribution and Recovery of Petroleum Hydrocarbon Liquids in Porous Media

Regulatory and Scientific Affairs Department

API PUBLICATION 4760
JANUARY 2007

API LDRM

- Analytical LNAPL Model
- One-Dimensional (Quasi 1D)
- Proven Results
- Provides Good and Reliable Estimates

API EQUATIONS APPLIED SPATIALLY VIA GIS

Use GIS to “Build” API LDRM Input Node-by-Node

Each Node Contains Site Specific Data Honoring:

- Geologic Heterogeneity
- Liquid Pressure Gradients
- LNAPL Thickness

Aggregate of Nodal Solutions Refine the Picture

Support Site Management Decisions

SOIL HORIZONS INTERSECTING LNAPL-AIR INTERFACE

Elevation of Surface Calculated at Each Node as:

- $WLE_{mean} + t_{LNAPL}(1-SG_{LNAPL})$

10-ft X 10-ft Grid

- Cap
- Fill
- Clay
- Sand & Gravel
- Fines
- Bedrock

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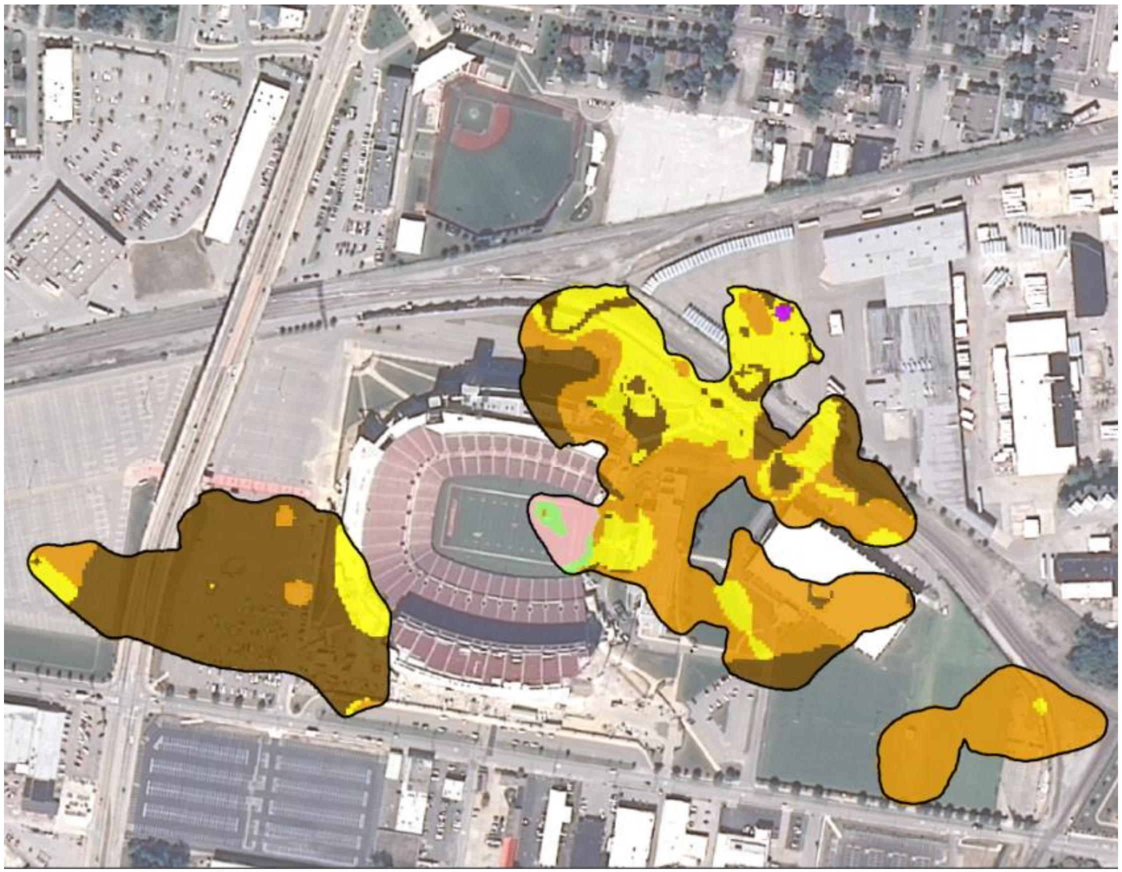
SOIL HORIZONS INTERSECTING LNAPL-WATER INTERFACE



Elevation of Surface Calculated at Each Node as:

- $WLE_{mean} - SG_{LNAPL} {}^{*} t_{LNAPL}$

10-ft X 10-ft Grid

- Cap
- Fill
- Clay
- Sand & Gravel
- Fines
- Bedrock

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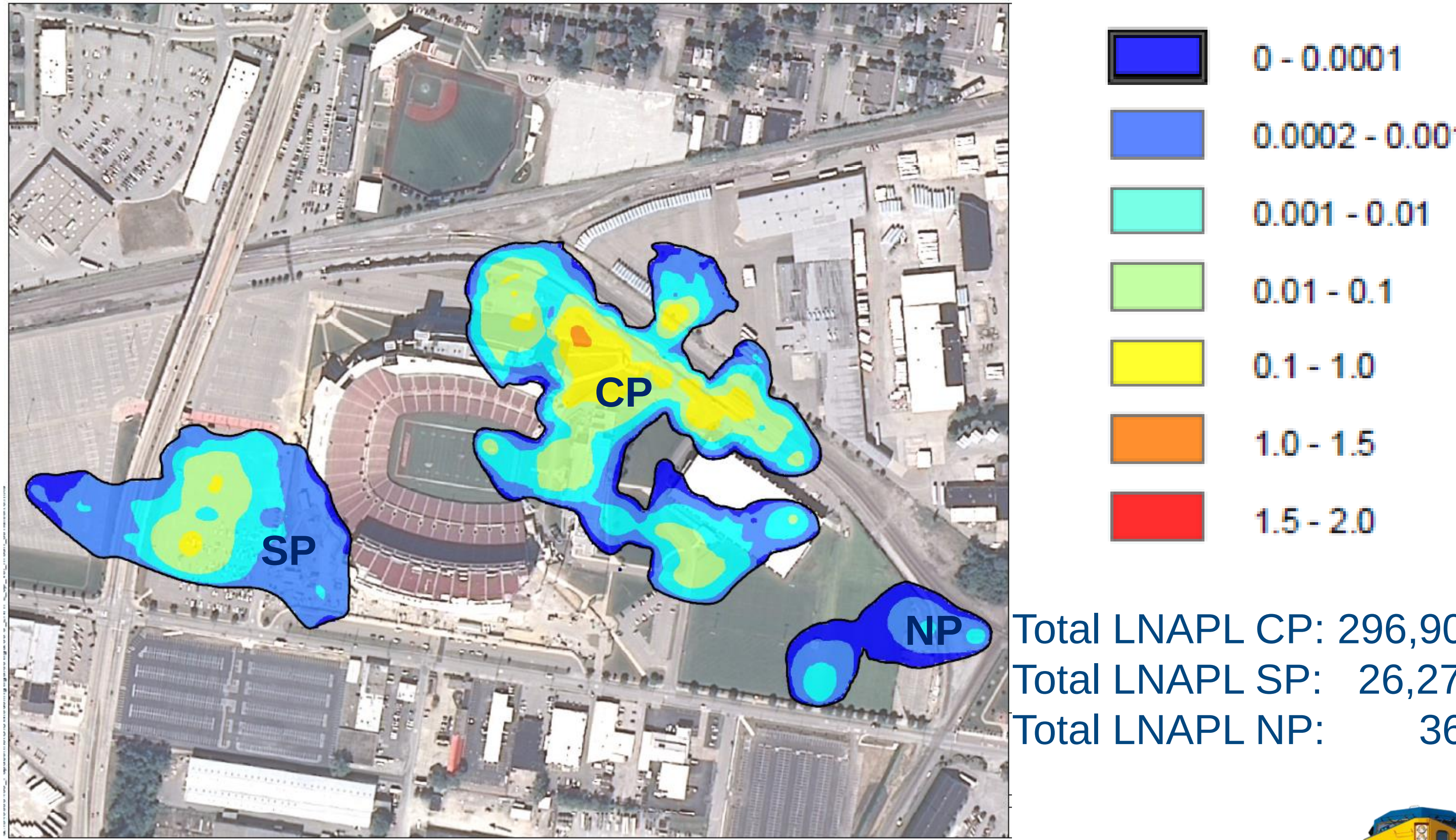
LNAPL SPECIFIC VOLUME DISTRIBUTION (FT^3 OF LNAPL / FT^2 OF PLUME)



Total LNAPL CP: 296,900 gallons
Total LNAPL SP: 26,270 gallons
Total LNAPL NP: 365 gallons

NOTE: CP- Central Plume, SP- Southern Plume, NP – Northern Plume

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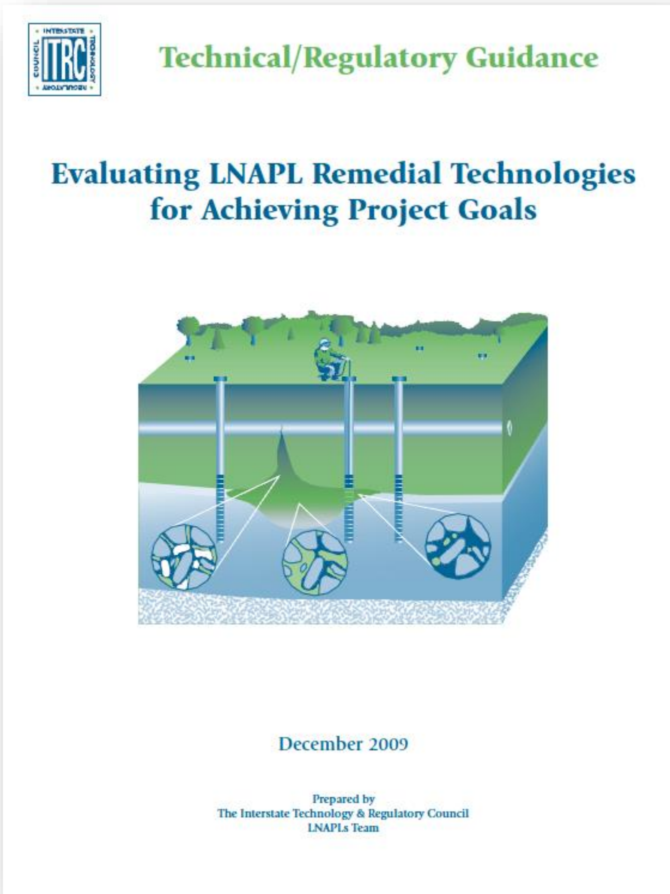
LNAPL TRANSMISSIVITY

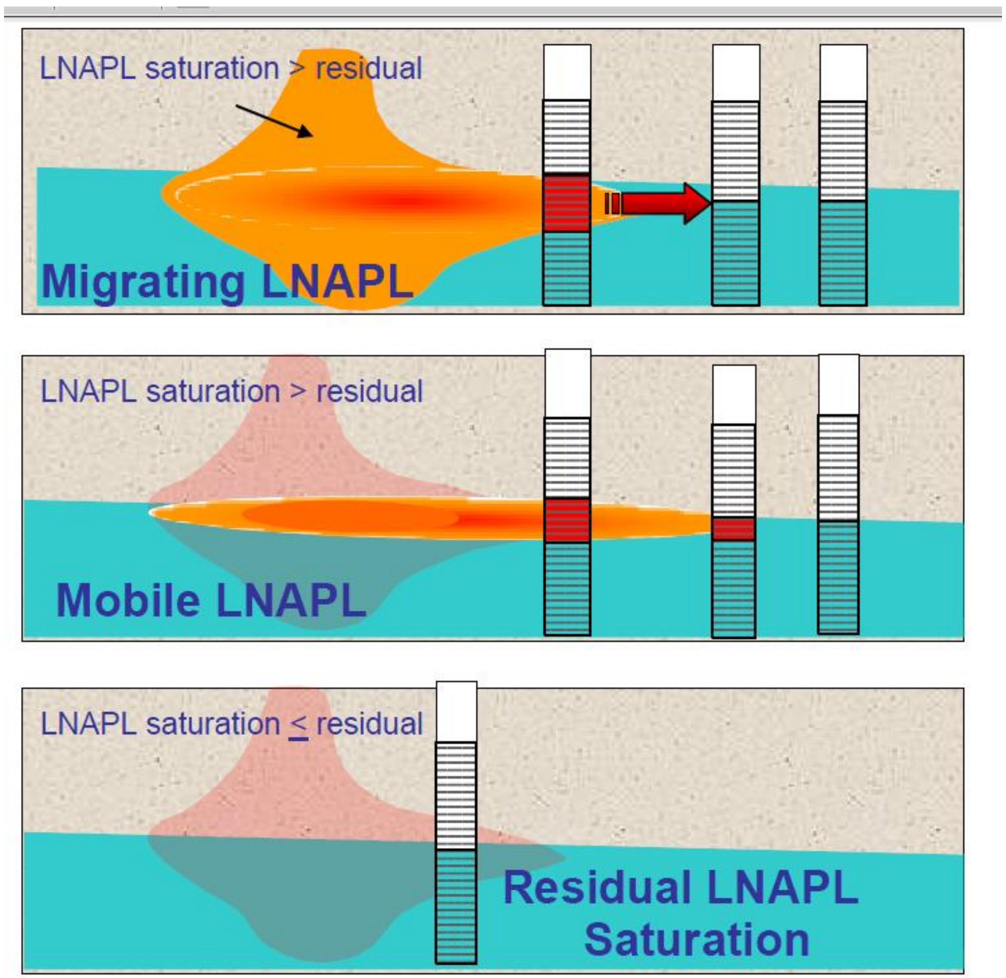


ITRC GUIDANCE

…There is little migration risk associated with a well with an LNAPL transmissivity (Tn) of ***0.015 ft²/day***.

…ITRC LNAPL team members' experience indicates that hydraulic or pneumatic recovery systems can practically reduce Tn to values ***between 0.1 and 0.8 ft²/day***.

MIGRATING VS. MOBILE LNAPL – ITRC GUIDANCE



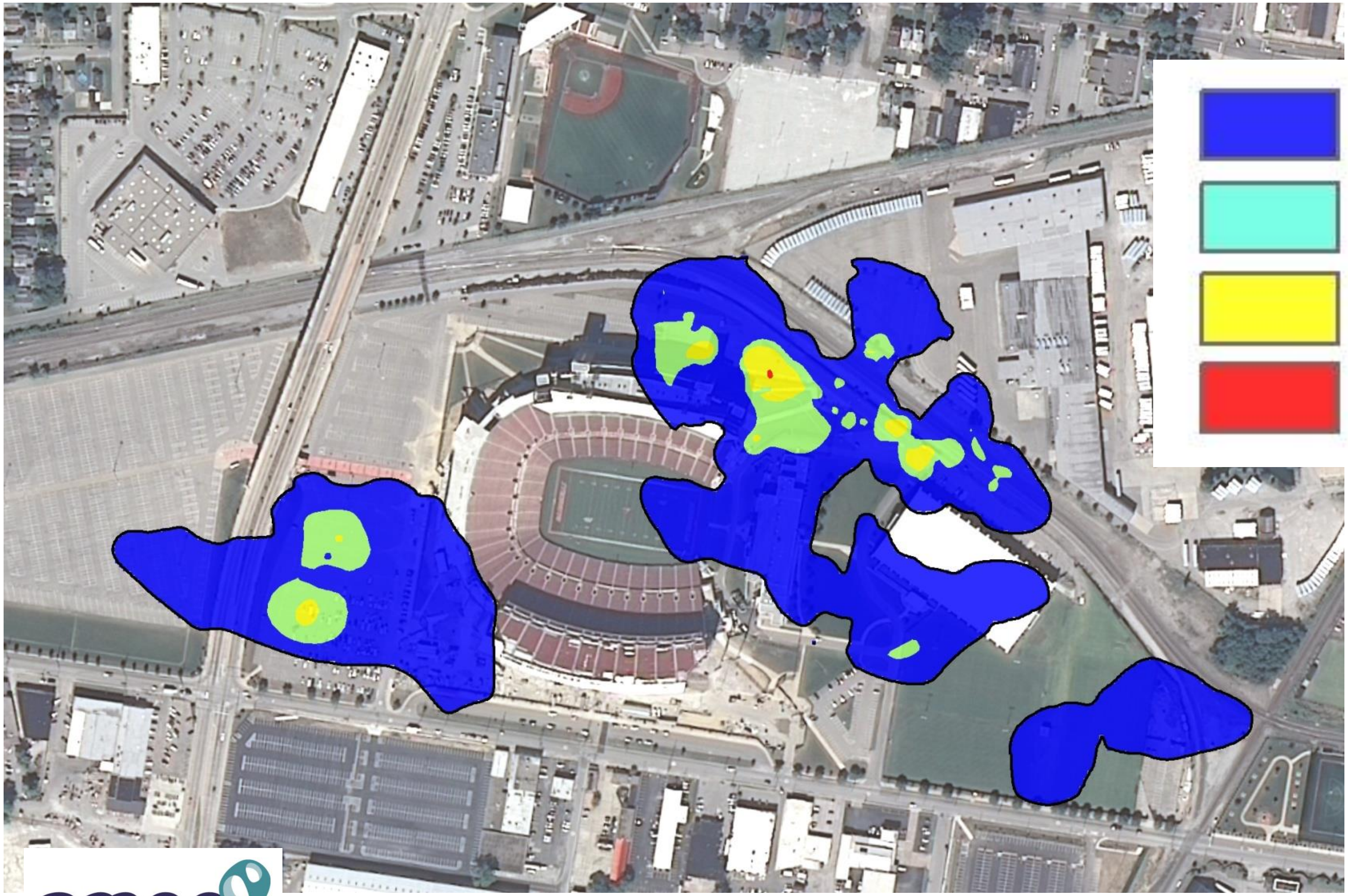
Migrating LNAPL

- Observed to Spread or Expand
- Results in an Increased Volume of the LNAPL Extent
- Indicated by Time-Series Data

Mobile LNAPL

- LNAPL Exceeds the Residual Saturation
- Not All Mobile LNAPL is Migrating LNAPL

LNAPL TRANSMISSIVITY (FT^2/DAY)



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NATURAL SOURCE ZONE DEPLETION (NSZD)

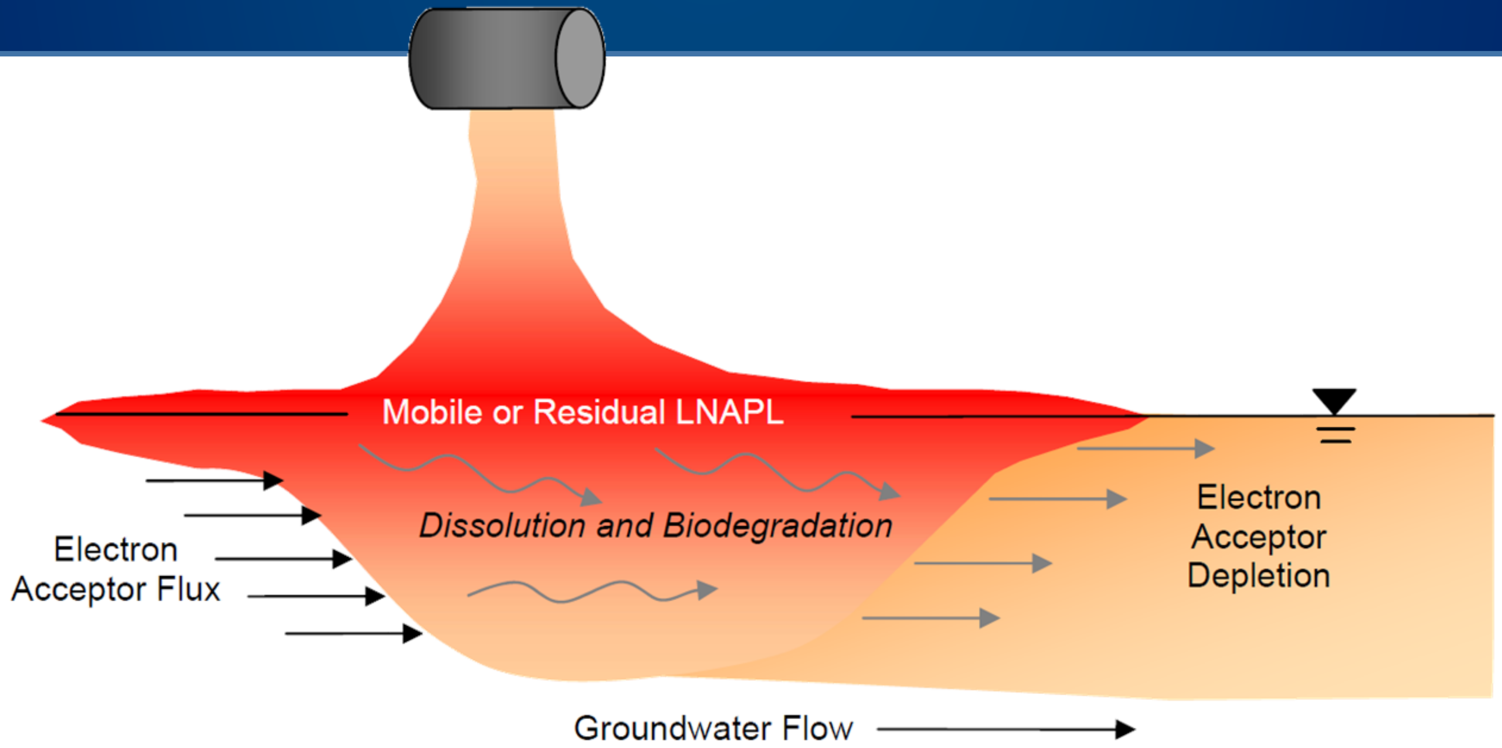

Figure 2-1. Groundwater transport–related NSZD processes.

FROM: ITRC. 2009. *Evaluating Natural Source Zone Depletion at Sites with LNAPL.*

ASSESSING NSZD & ITS SPATIAL DISTRIBUTION

Use Gauging Data and the GIS/API Integrated Specific-Volume Model to Estimate NSZD Rates During Periods of Monitoring (up to 20 years)

Determine Relationship Between Observed NSZD Rates and LNAPL Thickness

Assess Spatial Distribution of NSZD

ESTIMATING OBSERVED NSZD RATE

Estimate Initial & Final LNAPL Thicknesses

- Best Fit Curve through Gauging Data
- Normalize for Water Table Fluctuations

Use LDRM-GIS Model at Well Location to Estimate Initial & Final Specific Volumes at Well Locations

Divide Difference Between Initial & Final Specific Volumes by Period of Record to Determine Observed NSZD Rate

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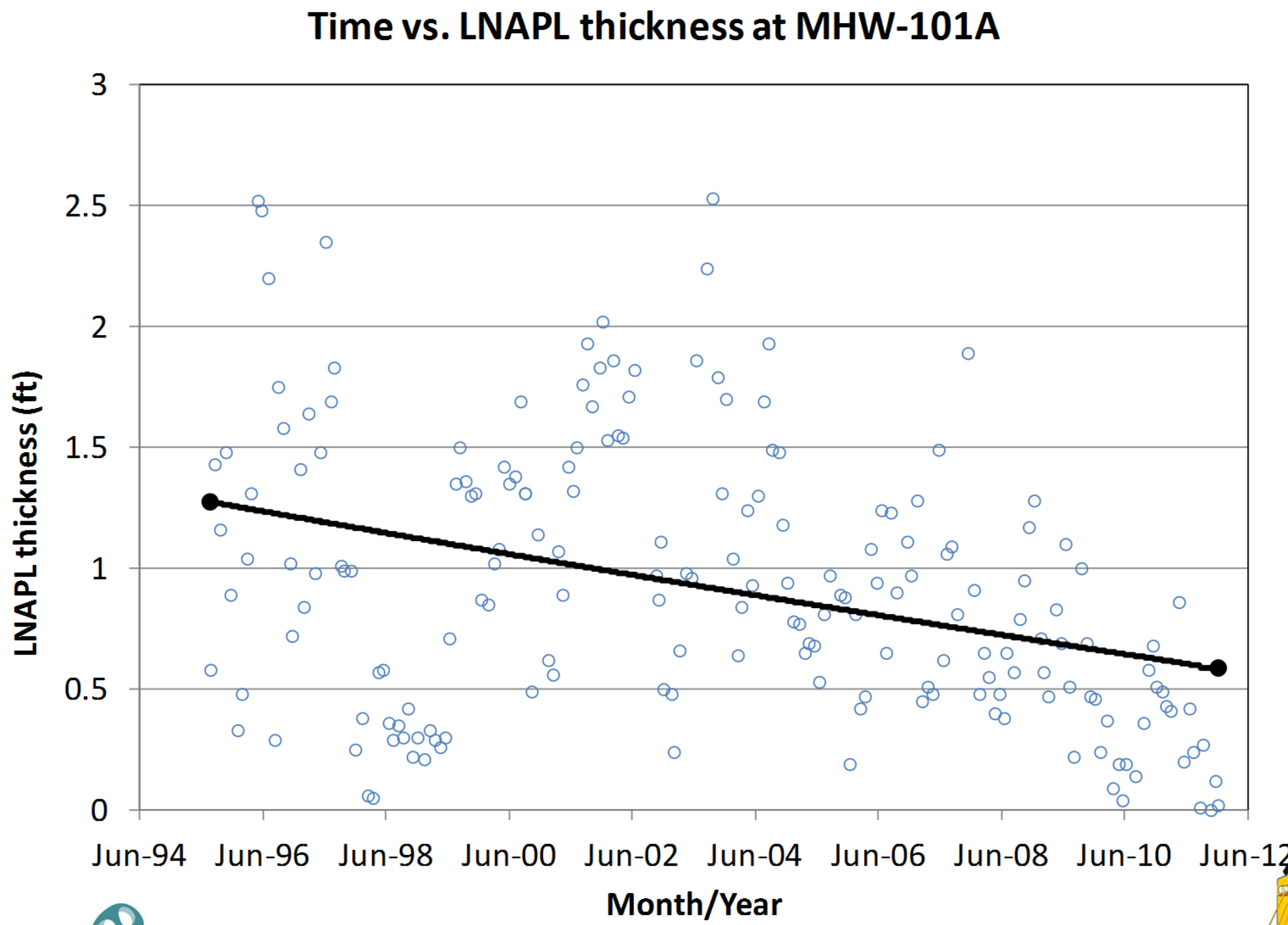
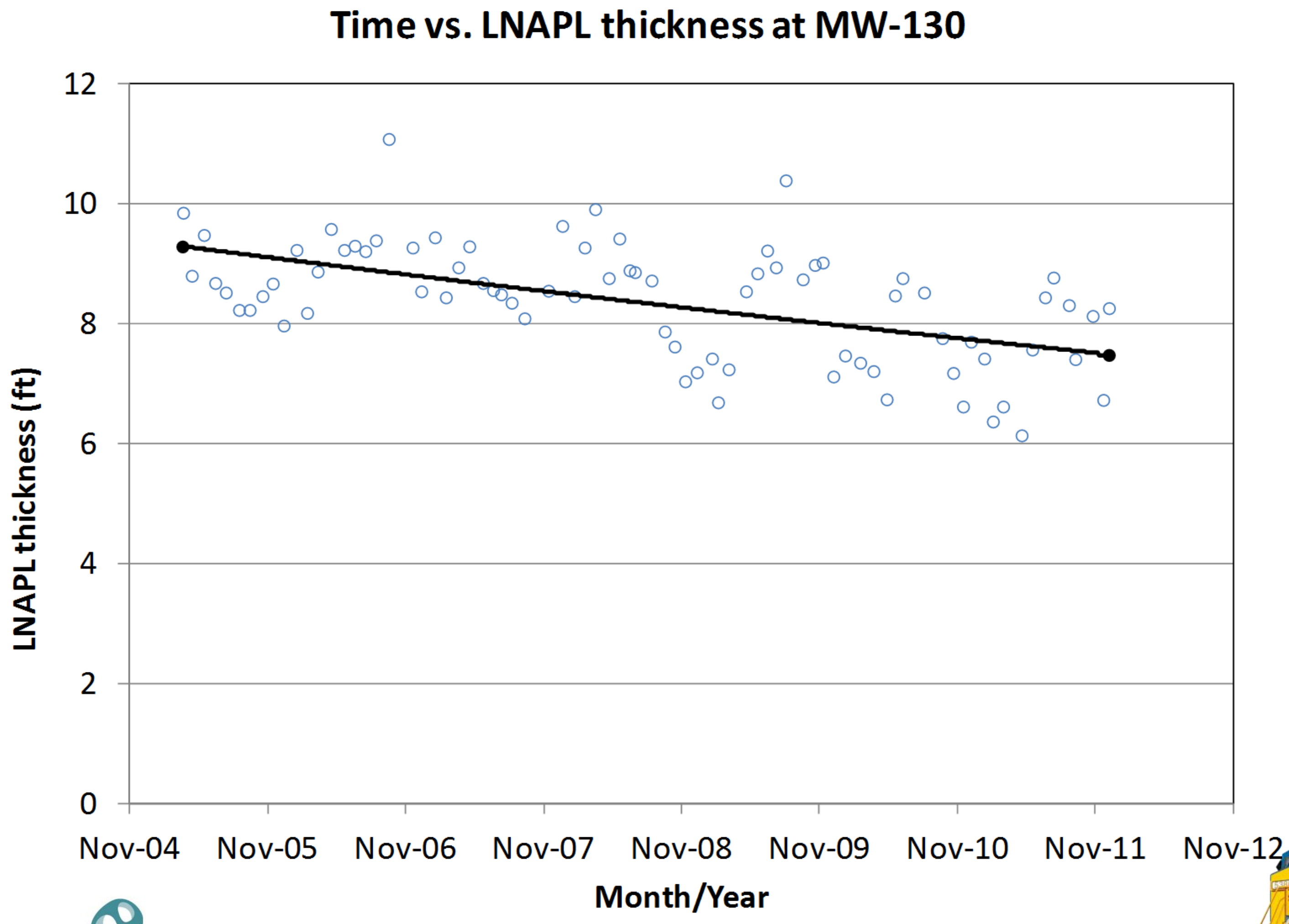
EXAMPLE OF GAUGING DATA & BEST-FIT CURVE - 1 OF 2



EXAMPLE OF GAUGING DATA & BEST-FIT CURVE - 2 OF 2

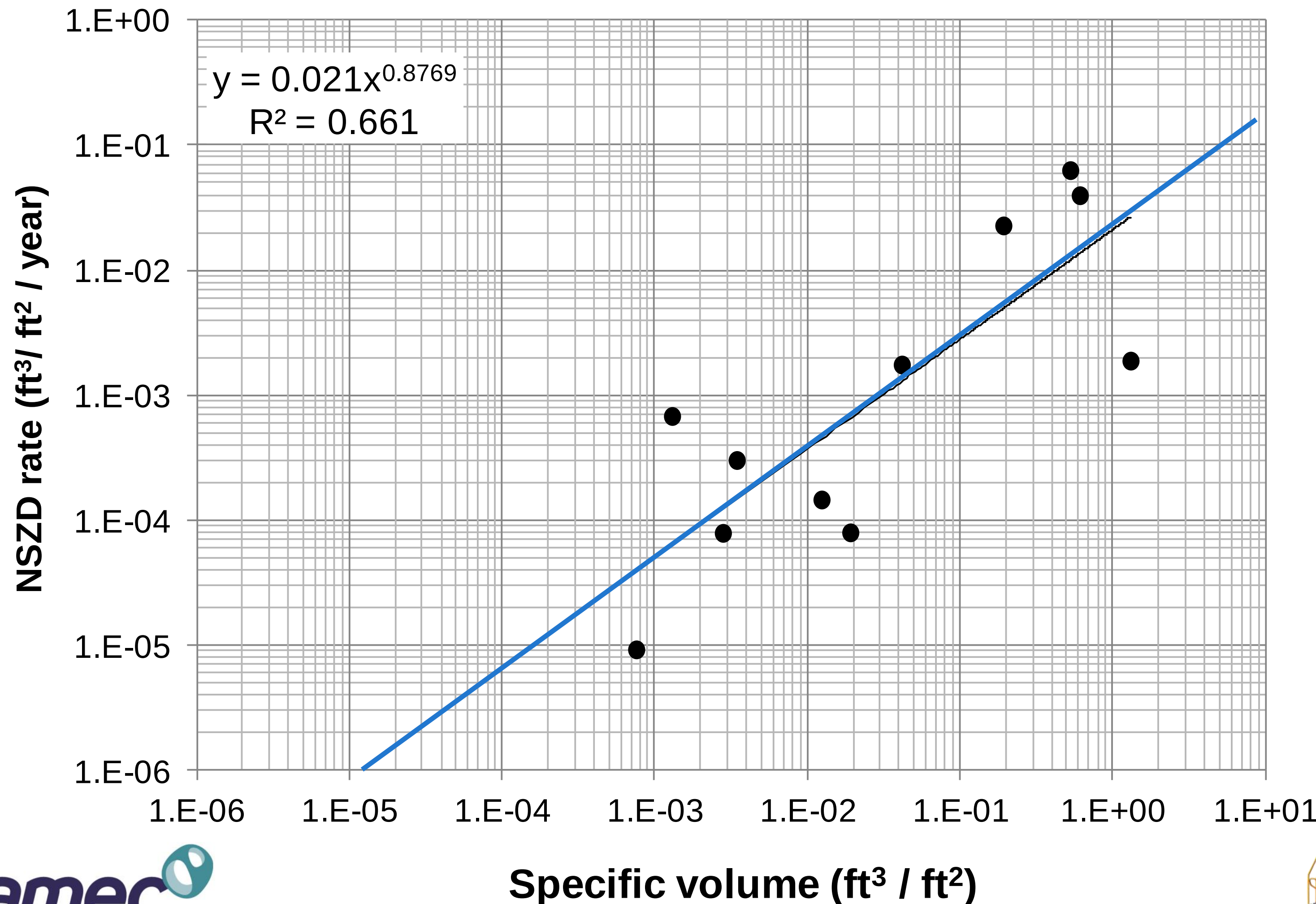


WELLS SELECTED FOR NSZD RATE CALCULATION

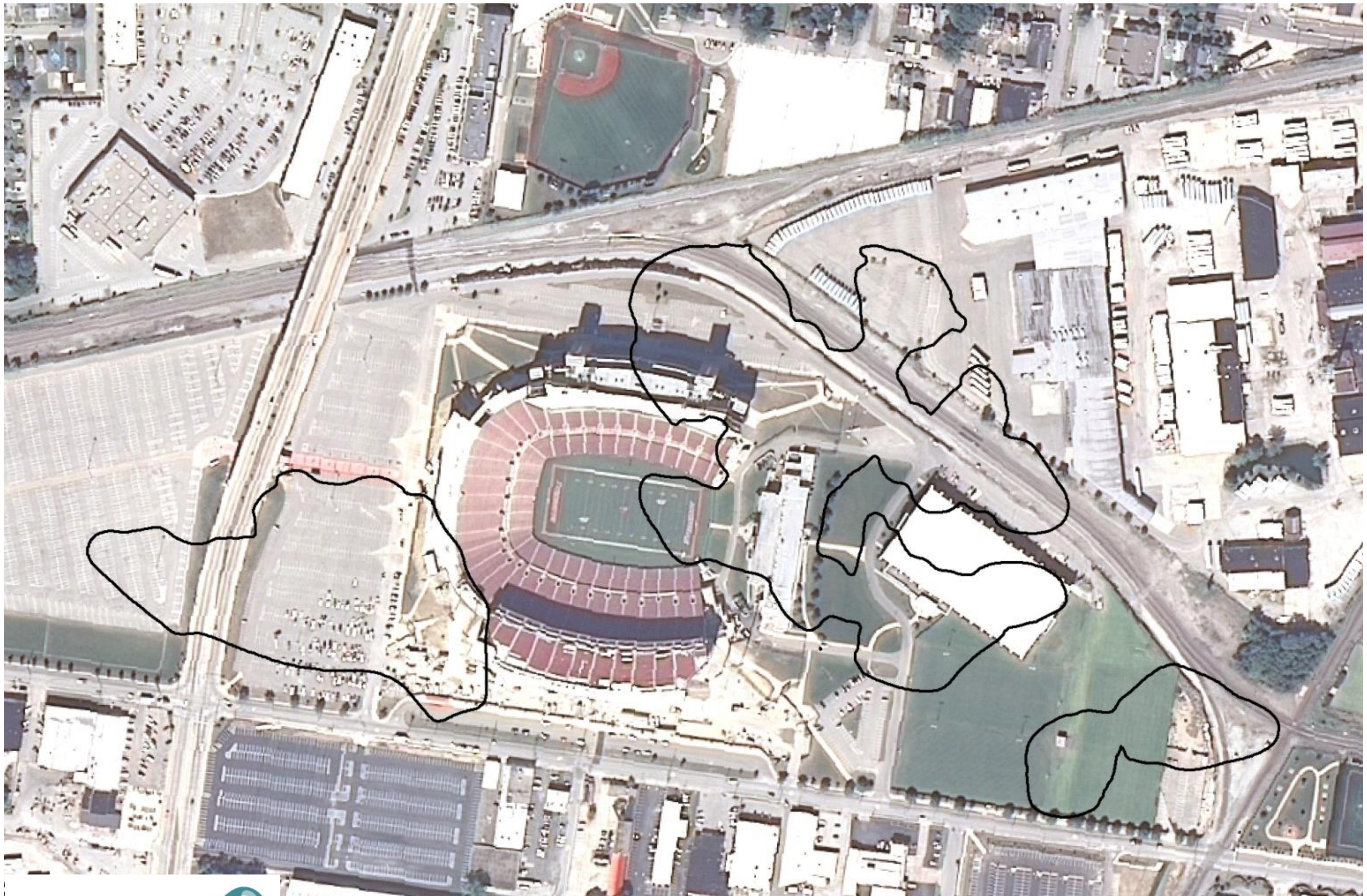
Eleven (11) Wells Selected

Period of Record Vary Between 5 and 17 Years

RELATIONSHIP BETWEEN OBSERVED NSZD RATE AND SPECIFIC VOLUME



SPATIAL DISTRIBUTION OF NSZD



YEARS* TO NSZD

- 250+
- 201 - 250
- 151 - 200
- 101 - 150
- 51 - 100
- 0 - 50

* Years to Reach a Target Specific Volume Equivalent to LNAPL Thickness of 0.01 Feet

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SUMMARY OF LNAPL PLUME LONGEVITY RESULTS

LDRM Coupled with Long-Period LNAPL Gauging Data can be Used to Estimate Site-Specific NSZD Rates

Site-Specific NSZD Rates Estimated Using Gauging Data Range Across Four Orders of Magnitude

NSZD Rates Decrease Non-Linearly with Respect to LNAPL Thickness

NSZD is Estimated at ~300 Years

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SUMMARY OF LNAPL PLUME LONGEVITY RESULTS

Compares Favorably with Longevity Estimates Using LNAST (API LNAPL Dissolution & Transport Screening Tool) to Assess LNAPL Averaging Boxes Around the Thickest Areas of the Plume

NSZD Rates Estimated Using Gauging Data are 2 to 4 Orders of Magnitude Lower Than Rates Estimated Using CO2-Flux Style Methods

- Sihota, N. J.; Singurindy, O.; Mayer, K. U., CO2-Efflux Measurements for Evaluating Source Zone Natural Attenuation Rates in a Petroleum Hydrocarbon Contaminated Aquifer. ES&T, 2011
- McCoy, K.; Zimbron, J., Sale, T., Lyverse, M.; Measurement of Natural Losses of LNAPL Using CO2 Traps. Groundwater, 2014

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CONCLUSIONS

LNAPL Volume

- ~323,000 gallons
- ~92% in CP, ~8% in SP, and <0.1% in NP

Approximately 65% of LNAPL Is Mobile

- ~209,000 gallons
- 94% of Mobile LNAPL is in CP

Site-Specific NSZD Rate Applied to GIS

- NSZD CP ~300 years, SP ~200 years, NP ~70 years

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IMPROVING CONFIDENCE AND ONGOING WORK

Push-Pull Tracer/Respirometry Tests

- Conducted at Six Wells
- In-situ Measurements of Conductivity, Dispersivity, and Terminal Electron Acceptor Utilization

Constructed and Calibrated 3D Multi-phase Flow and Reactive Transport Model

- Constructed using MODFLOW-SURFACT
- API-LDRM Model Used to Build and Initialize MODFLOW-SURFACT Model
- Calibrated to Historic Groundwater Pressures and Push-Pull Test Results
- Used to Define and Predict LNAPL Plume NSZD

HOW TOMORROW MOVES