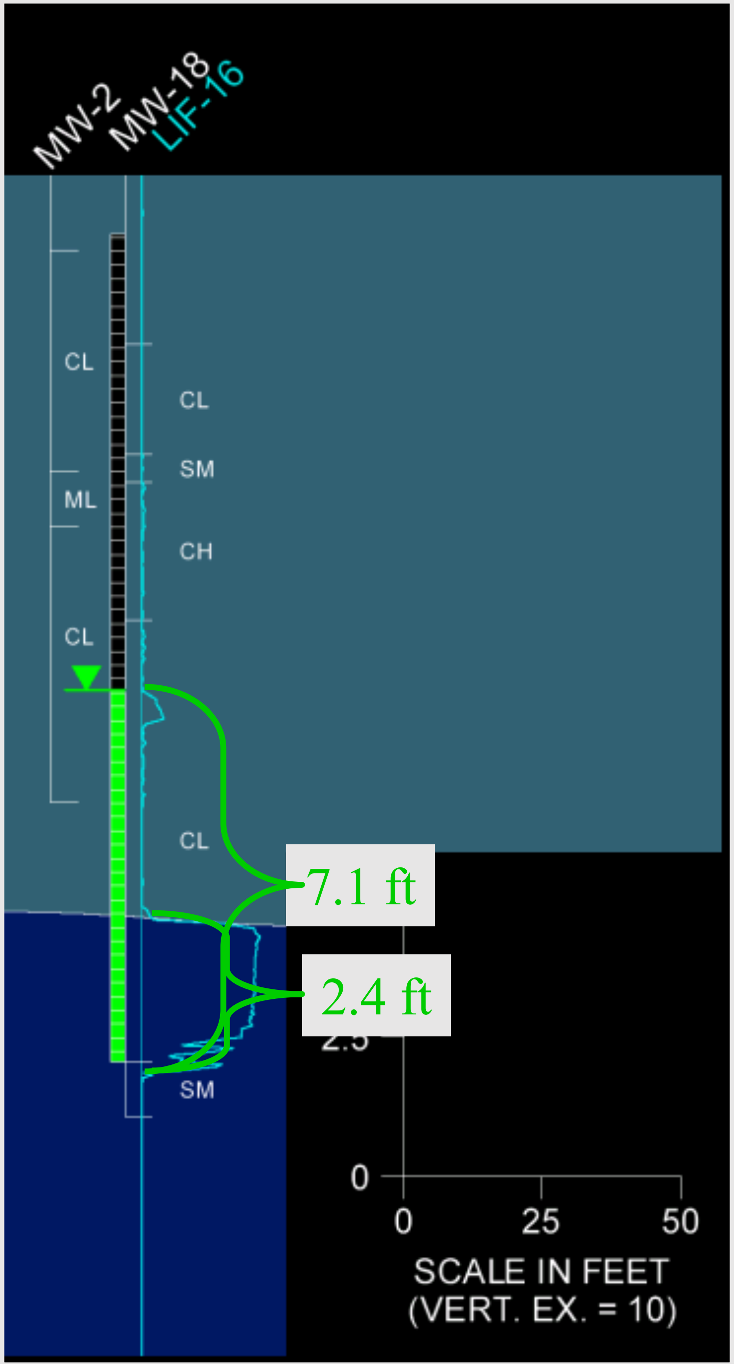
Key Considerations for HRSC

- The Role and Risk associated with monitoring wells
- Understanding groundwater analytical results
- Review Historical Site and Remediation System Performance data
- Effective Identification and Residual mapping
- Importance of understanding heterogeneity
- Screening for PVI

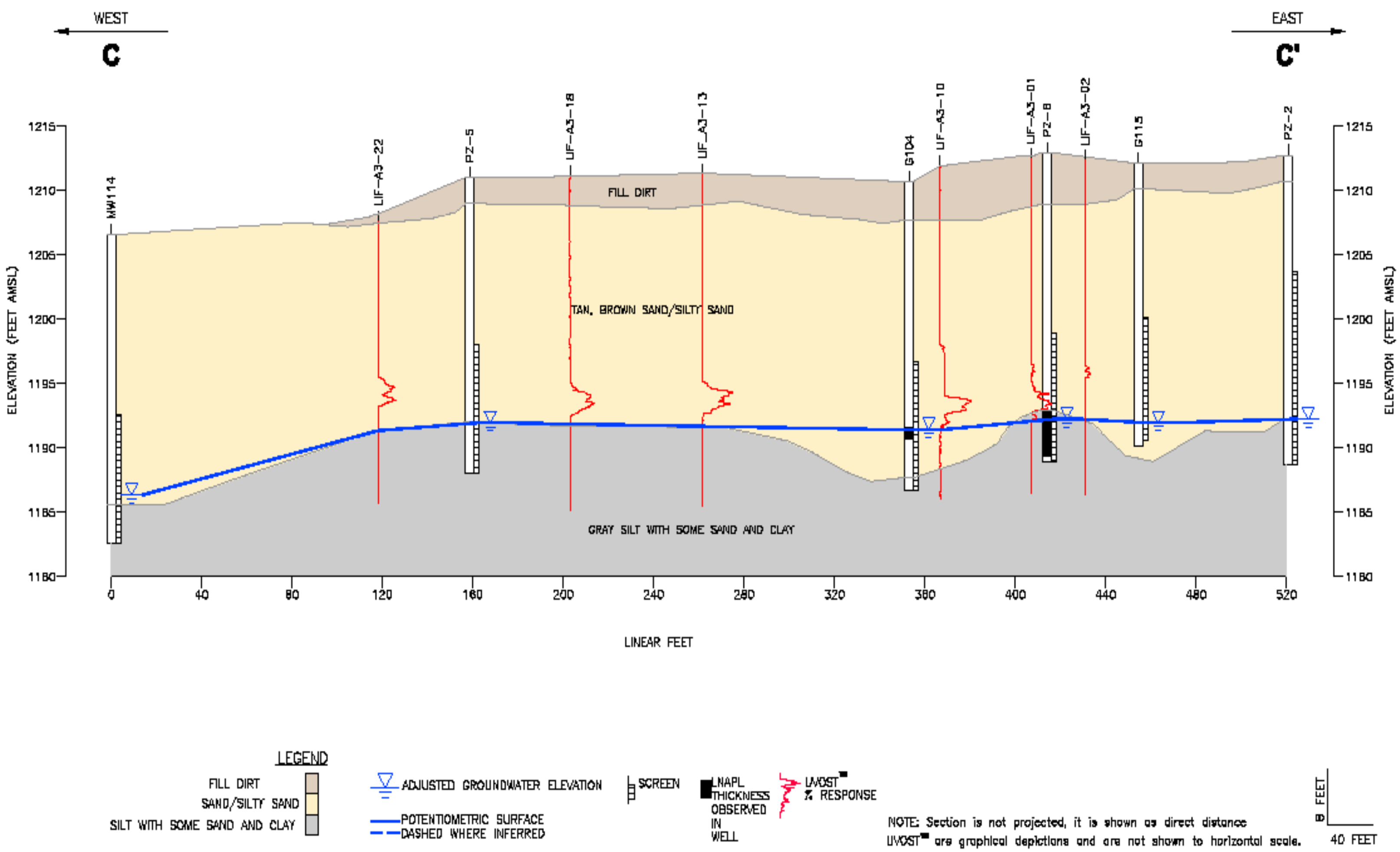


MW-2
MW-18
LIF-16
CL
ML
CL
CL
SM
CH
CL
SM
7.1 ft
2.4 ft
0
0
25
50
SCALE IN FEET
(VERT. EX. = 10)

Where is the LNAPL

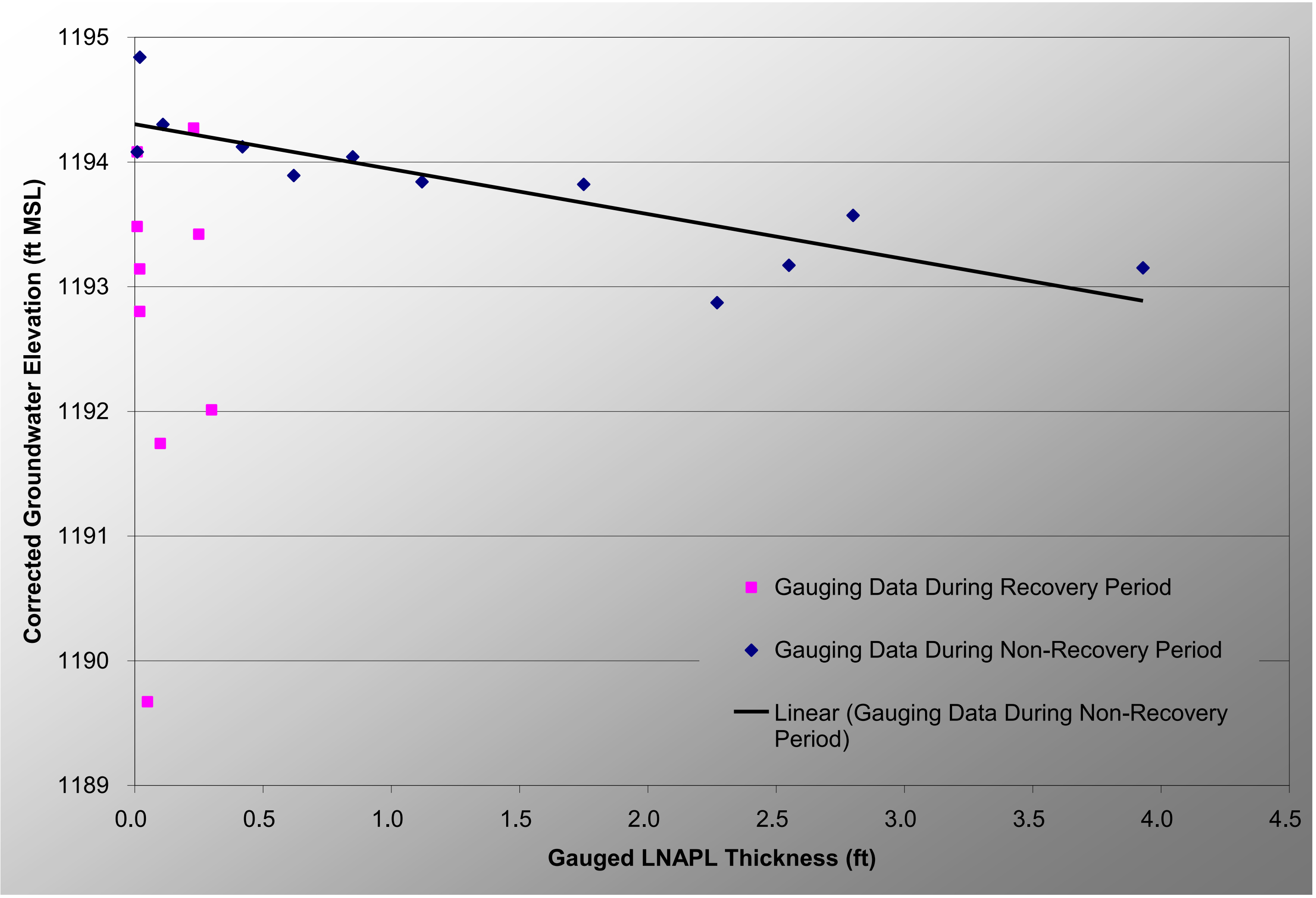
Above or Below the Water-table

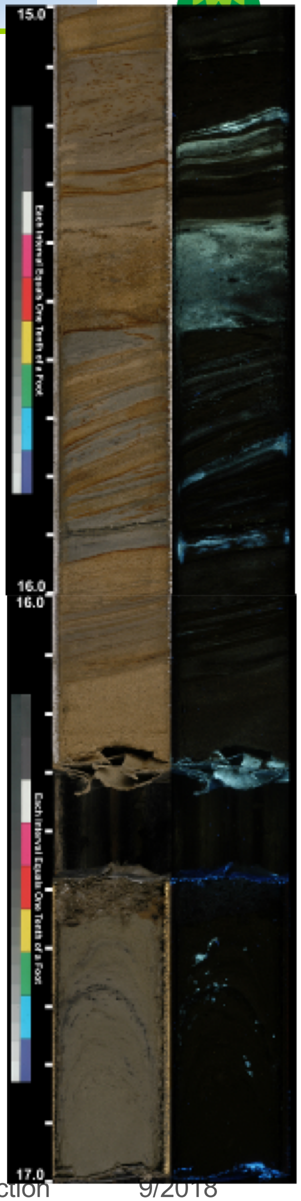
Remedy Selection LCSM: Where is Source Mass



Core Photography Supports the Diagnostic Gauge Plot Results

Remedy Selection LCSM: Where is Source Mass





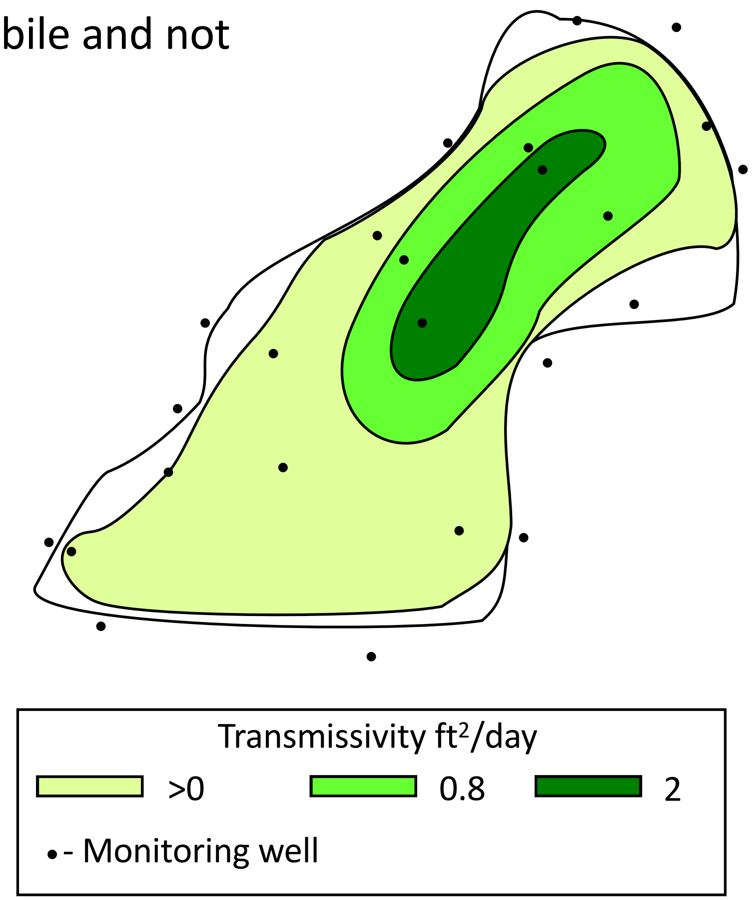
Additional discussion provided in Applied NAPL Science Review Publications
http://www.h2altd.com/ansr
http://www.icontact-archive.com/IXYNsGudxSsIUD6HuogSpblft2mtIAJM
http://www.icontact-archive.com/IXYNsGudxSsIUD6HuogSpZNh4o-1M1kZ

How does High Resolution Improve remedy Selection?

From ITRC, 2018b

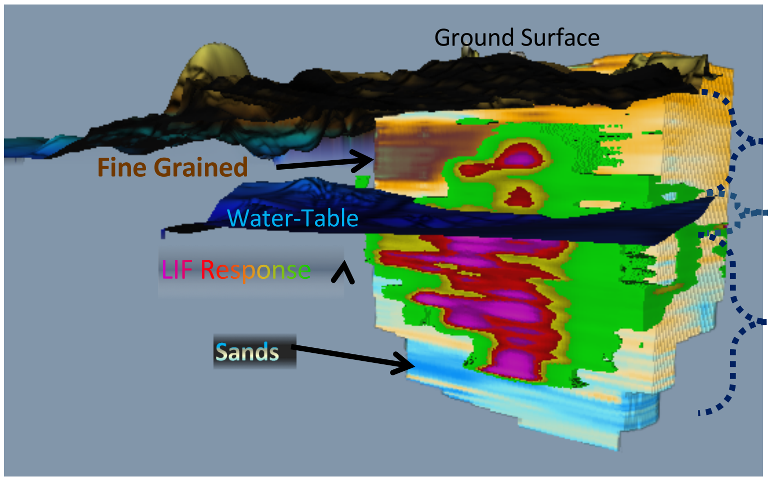
Remedy Selection LCSM: Where is Source Mass

- LNAPL is a source to dissolved plume
- LNAPL Tn is above 0.1 to 0.8 ft^2/day but is stabile and not migrating
- Should we implement LNAPL Recovery?



Fraction of Mobile Vs Residual Hydrocarbon

From ITRC, 2018b

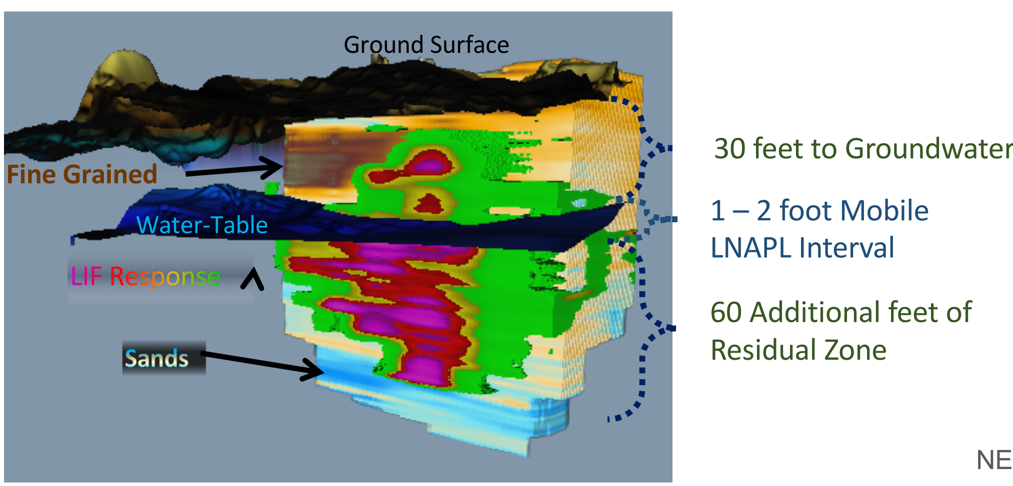


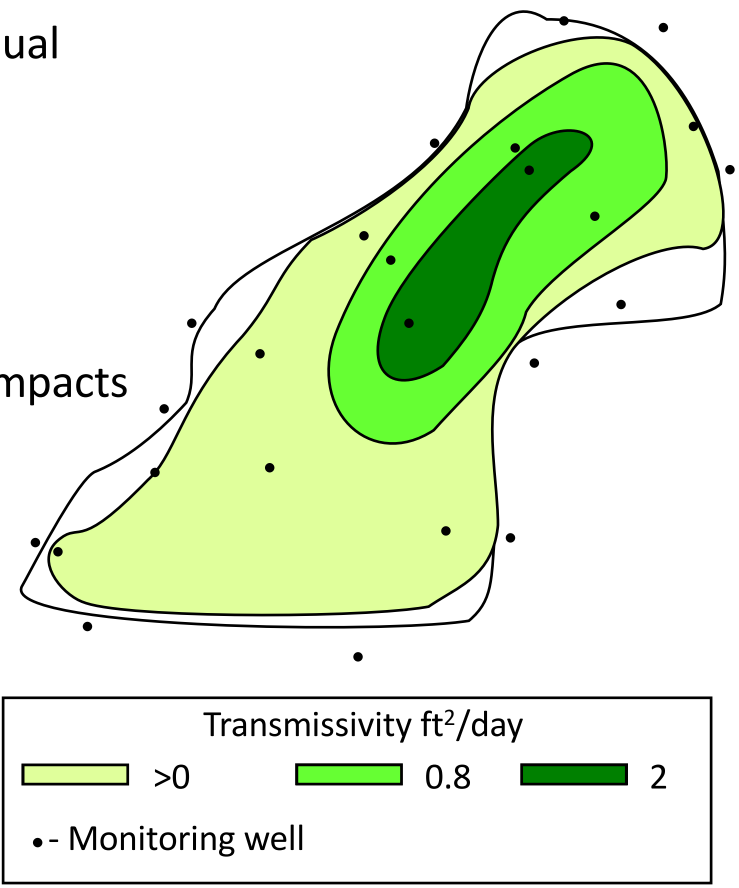
- The 1-2 feet of mobile LNAPL thickness << 90 feet of residual vadose and saturated impacts
- What about
  - 0.2 foot of mobile LNAPL ? 4 feet of residual LNAPL
    - Data such as TPH or saturation in mobile interval and above and below the water-table can indicate relative fractions
    - Models such as the LDRM model by API can also help evaluate

Map the Residual, Map All of the source mass

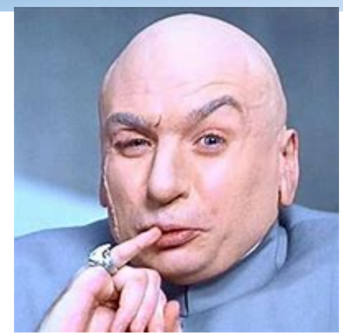
After ITRC, 2018b

- Residual LNAPL needs to be considered in remedies
- Most sites do not have significant mobile LNAPL
- Most sites have dissolved impacts.. sourced by residual
- **Why do we delineate with wells and not HRSC?**
  - HRSC will identify residual and mobile LNAPL
- **Why do we not sample soil below the water-table?**
  - Majority of dissolved phase originates from soil impacts below water-table

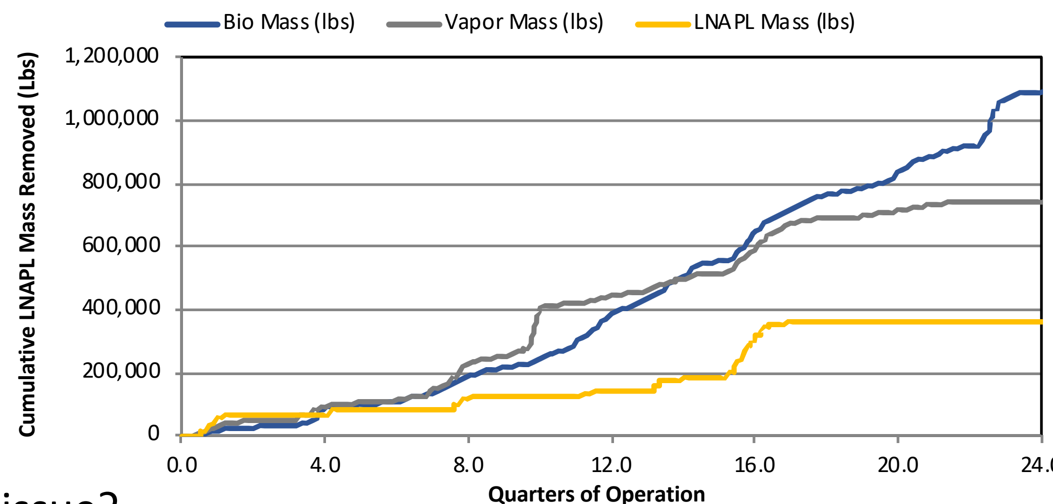




Review Historical Remediation Performance & Understand Heterogeneity



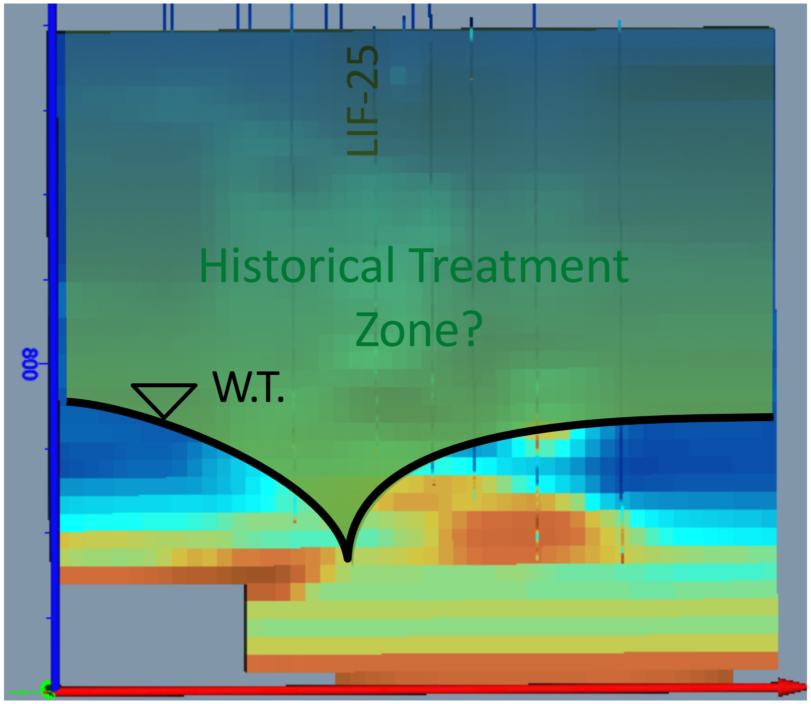
- Multi-phase extraction, *1 Million Dollars*
- Vapor, Bio and LNAPL rates declining
- We still have benzene in GW
- GW extraction still protects receptors
- **What Now?**



- Where is the mass causing our issue?
- MPE, does it remediate smear zones below the water-table?
- What is the benzene concentration in the vapor effluent?

Scope for Remedy Optimization?

- CPT & LIF indicated the age old adage 90% of flow occurs through 10% of subsurface
- Lets focus on contaminant mass flux
  - Multi-level wells
  - Compositional Soil Sampling
  - Vertical interval specific GW flow velocity
- Overall intent focus next remedy on the thin coarse interval over bedrock to achieve GW standards.

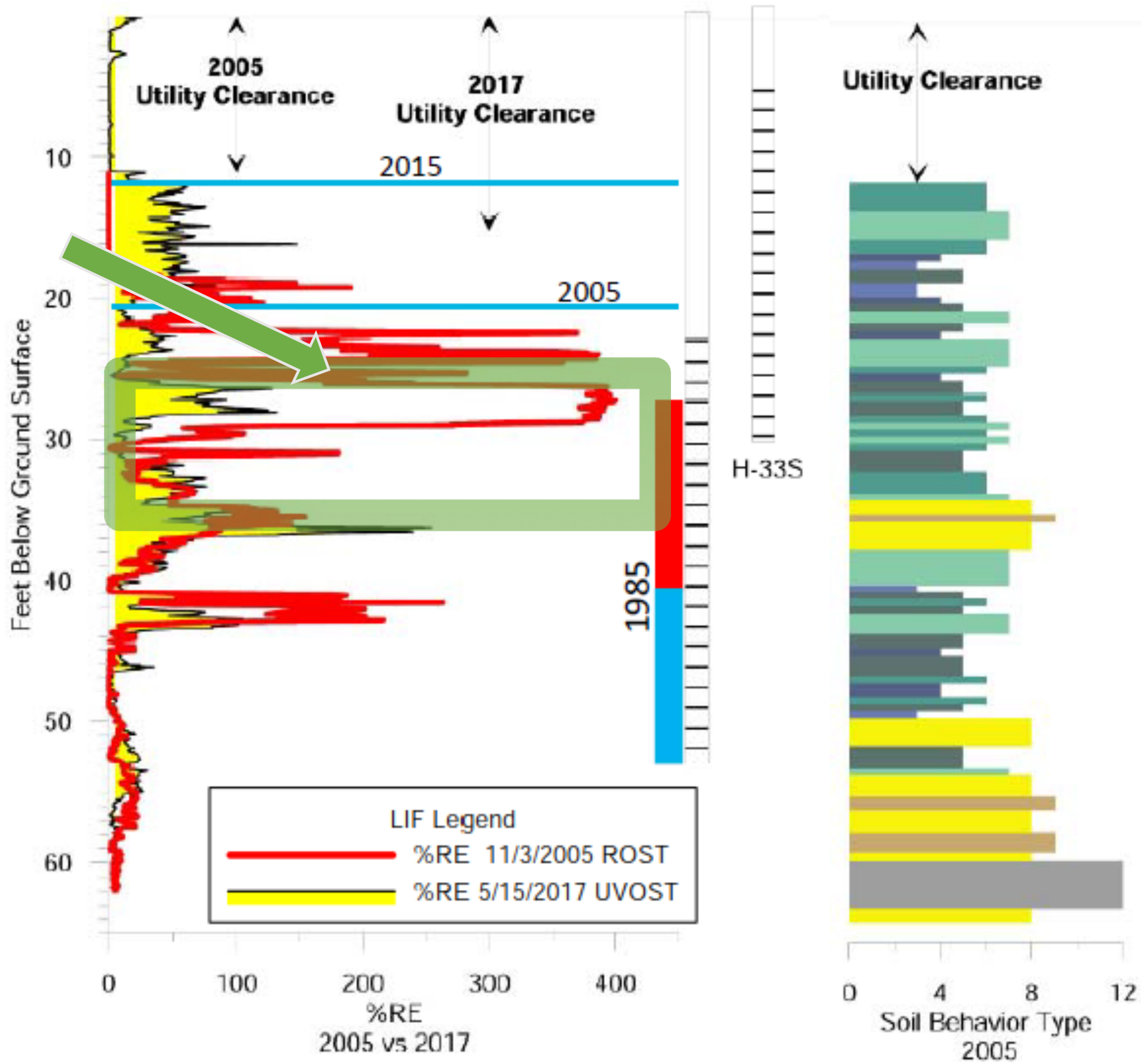


What Fraction was Targeted?

- LIF profile from 2005 and 2015

Approximate gauged LNAPL Interval 1996

- 168 gallons LNAPL recovered between 2005 LIF and 2015 LIF borings
- Water-table rose from 25 ft bgs to 20 ft bgs from 1995 to 2005 &;
- Water-table rose from 20 ft BGS to ~12 ft BGS between 2005 and 2015



After Stumpf et al., 2018

We’ve Done HRSC, What about Remedy Selection

Outline

- Why Does the CSM Evolve?
- Remedy Selection CSM
- Remedial Mechanisms (Vapor, Biodegradation, Recovery, Injection)

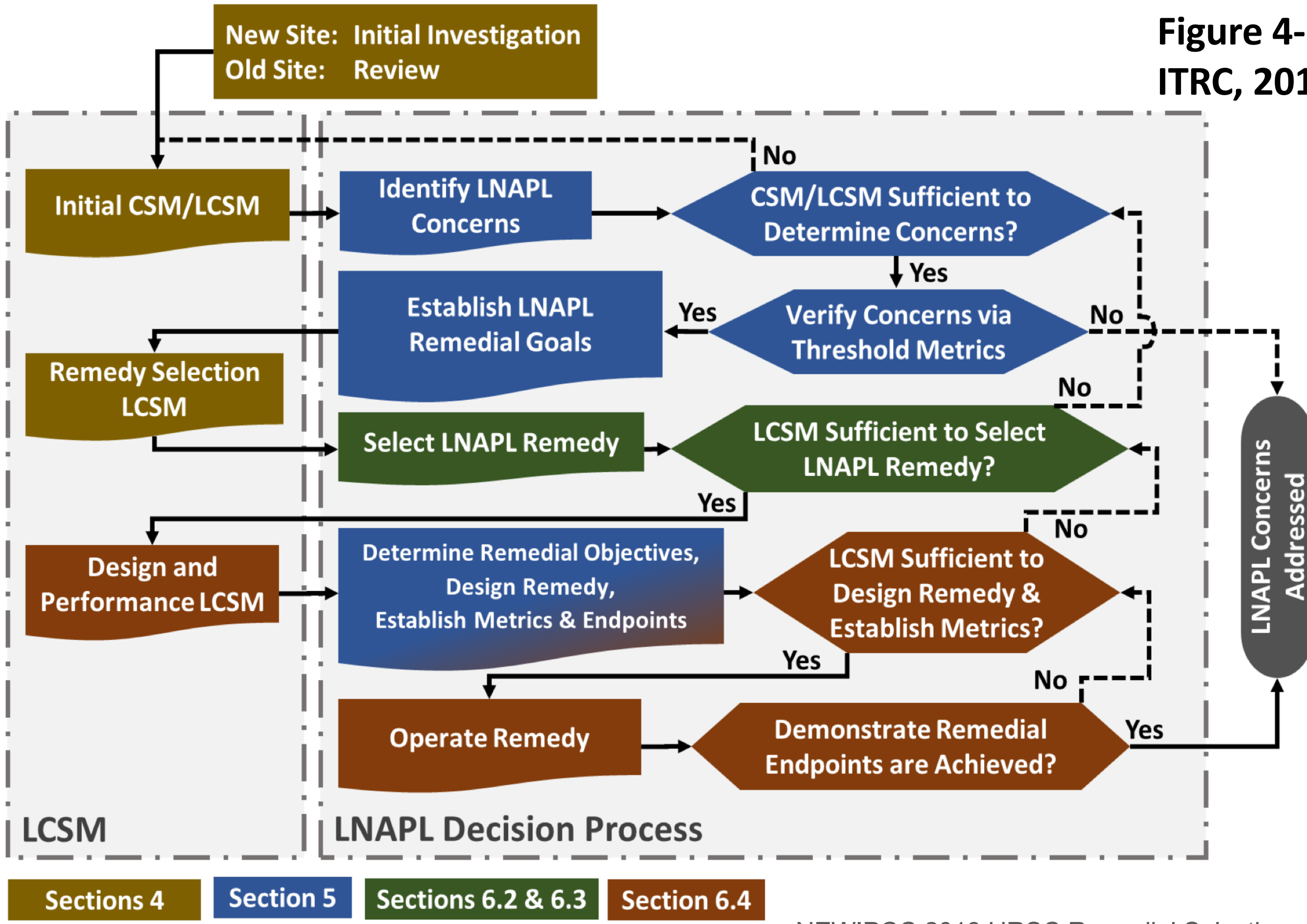
The Living CSM…LCSM

After ITRC, 2018b

LCSM Evolution

- The LCSM is continually updated, but each update represents a focus specific to that project phase

Figure 4-1, LNAPL-3
ITRC, 2018a



Initial LCSM

From ITRC, 2018b

Initial LCSM

- Overall, the Concerns portion of the LCSM are typically well developed and mature
- Recent improvements in this area include
  - PVI (PVI IBT)
    - Screening distances (ITRC, 2015)
  - Natural Source Zone Depletion
  - Plume stability & NSZD (IBT#1)
  - LNAPL transmissivity to improve understanding of recoverability as related to maximum extent practicable
  - Sheens – Related Appendix in LNAPL-3
- Ongoing Development
  - TPH guidance is being updated

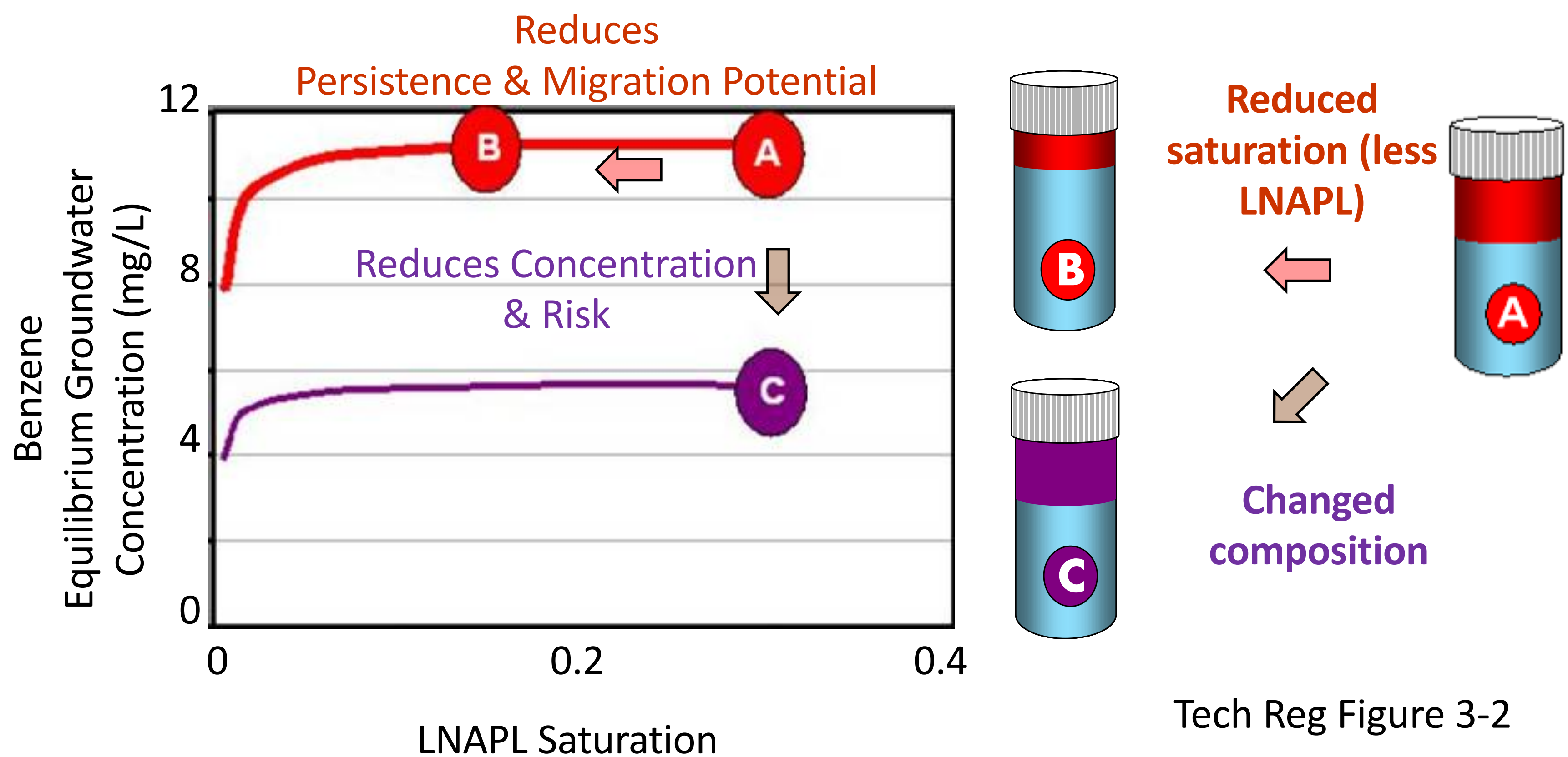
- Recommended completeness test for Initial LCSM
  - LCSM should be able to inform a series of typical questions
  - Amount of detail for a given question is decided by asking “is there sufficient understanding to enable **Decision Making?”**

Review of Concerns

- Saturation
  - LNAPL Plume Stability
  - Maximum Extent Practicable
  - TPH / CSAT- soil
- Compositional Change
  - Dissolved phase concentration
  - Vapor Intrusion
  - COC specific soil
  - TPH soil

Contrast Between Composition And Saturation Objectives

From ITRC, 2018b



Tech Reg Figure 3-2

Key Point: Abatement of dissolved or vapor concentration is dependent on change in composition (mole fraction) and not saturation (unless almost all LNAPL is removed)

Remedy Selection Should be Informed by the LCSM not just the Concern

From ITRC, 2018b

Remedy Selection LCSM

1. Where is the Source Mass?	
	A. Homogenous Permeable Soil
	B. Interbedded within coarser zones that are surrounded by finer grained layers
	C. Within low permeability media, secondary porosity, fractures, karst
	D. Is the LNAPL source distributed above or below the water-table
2. What Is Nature of the Source?	
	A. Volatile and/or Soluble
	B. Biodegradable
	C. Mobile vs Residual Fractions
3. What is Achievable for a Given Technology?	
	A. Mobility-Based Limit
	B. Volatility-Based Limit
	C. Solubility-Based Limit
	D. Biodegradability-Based Limit
	E. Other – Safety, Depth, Sustainability (e.g., community impact, energy/resource use).
	E. Design Data – Radius of Treatment, Waste Production/Treatment

Characterize the Site for Metrics Related to Remedial Mechanisms

Remedy Selection LCSM: Where is The Source

- Generally all technologies rely on
  - LNAPL Distribution
  - Soil Profile
  - Water-table
  - Seasonality
- The resolution of characterization for remediation is higher than for concerns (excluding excavation)
  - Concerns checks if a concentration is present
  - Remediation needs to understand how to remove that concentration

Characterize the Site for Metrics Related to Remedial Mechanisms

From ITRC, 2018b

Remedy Selection LCSM: Nature of the Source

Remedial Mechanism	Characterization Data
– LNAPL Recoverability	– LNAPL Transmissivity – Mobile vs Residual
– Vapor Extraction	– Vapor Pressure
– Air Sparging	– LNAPL Composition

– Biodegradation
  – Biovent
  – BioSparge
  – NSZD
	– Compound Specific Biodegradation Rate
	– CO_2 Efflux / NSZD data
	– Respiration Rate

The Remedy Select LCSM can indicate relative remedial efficacy

The Thought Process for Remedial Selection

Desktop Calculations

- Provide a good screening level evaluation of relative performance
- Cost effective
- Improved when we collect some targeted site characterization (slide above)
- Help Identify if Pilot is needed

Pilot Tests

- Are more accurate and informative
- Pilot Tests are more Costly

Remedy Selection Needs Improvement
This Starts with the LCSM

From ITRC, 2018b

Remedy Selection LCSM

- Our concerns are known,
- We know the Remedial Technology Types
- Ok, move ahead with remediation?!? Give it a shot?

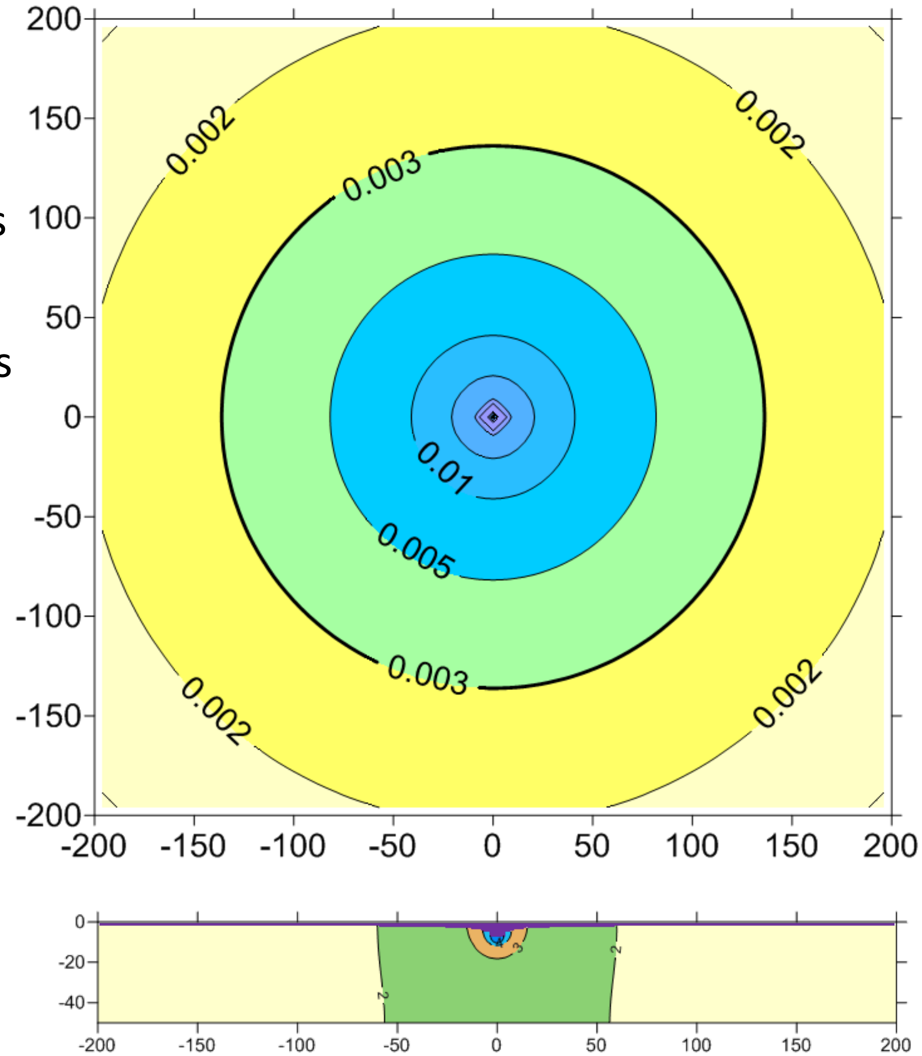
- LNAPL in Well
- No Migration

Vacuum- Truck It Out

Insufficient data often exists even with a completed Concerns focused Initial LCSM to select a remedy that will achieve remedial goals

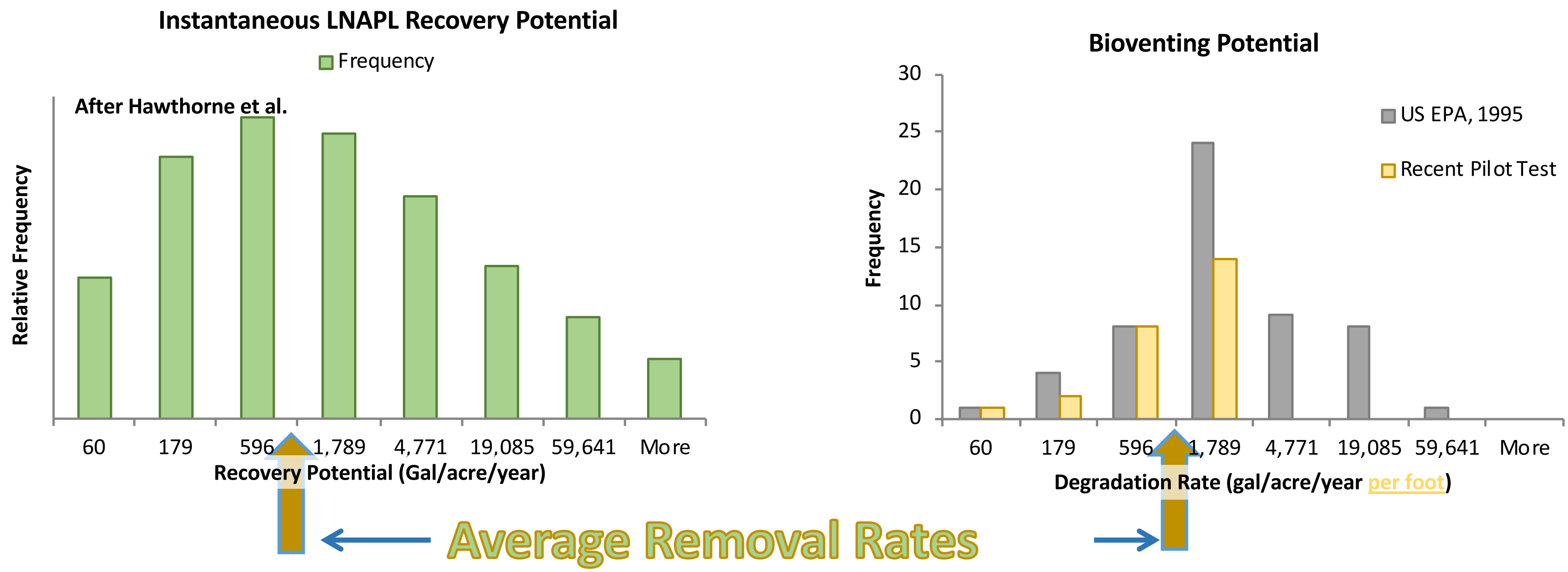
Magnitude of Single Point Drawdown - Incomplete Perspective

- 7.3 feet of drawdown doesn't reflect the two adjacent figures
- The induced drawdown distributes across a large area
- The resulting magnitude of the gradient is much smaller at larger radii
- Perhaps drawdown is not the correct metric for remedial aggressiveness
- Most practitioners are not extracting water at retail; however, are there other misleading metrics out there?



No Vertical Exaggeration

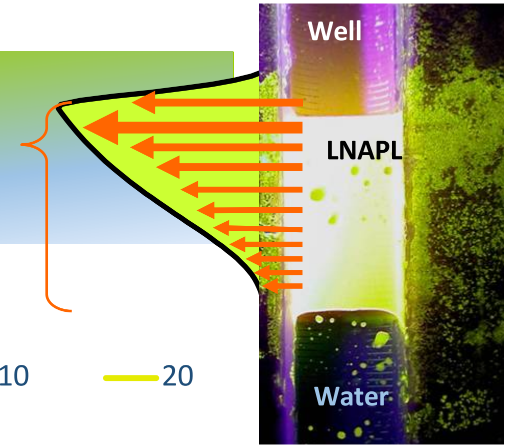
Improved Comparison of Biodegradation to Recovery of Petroleum



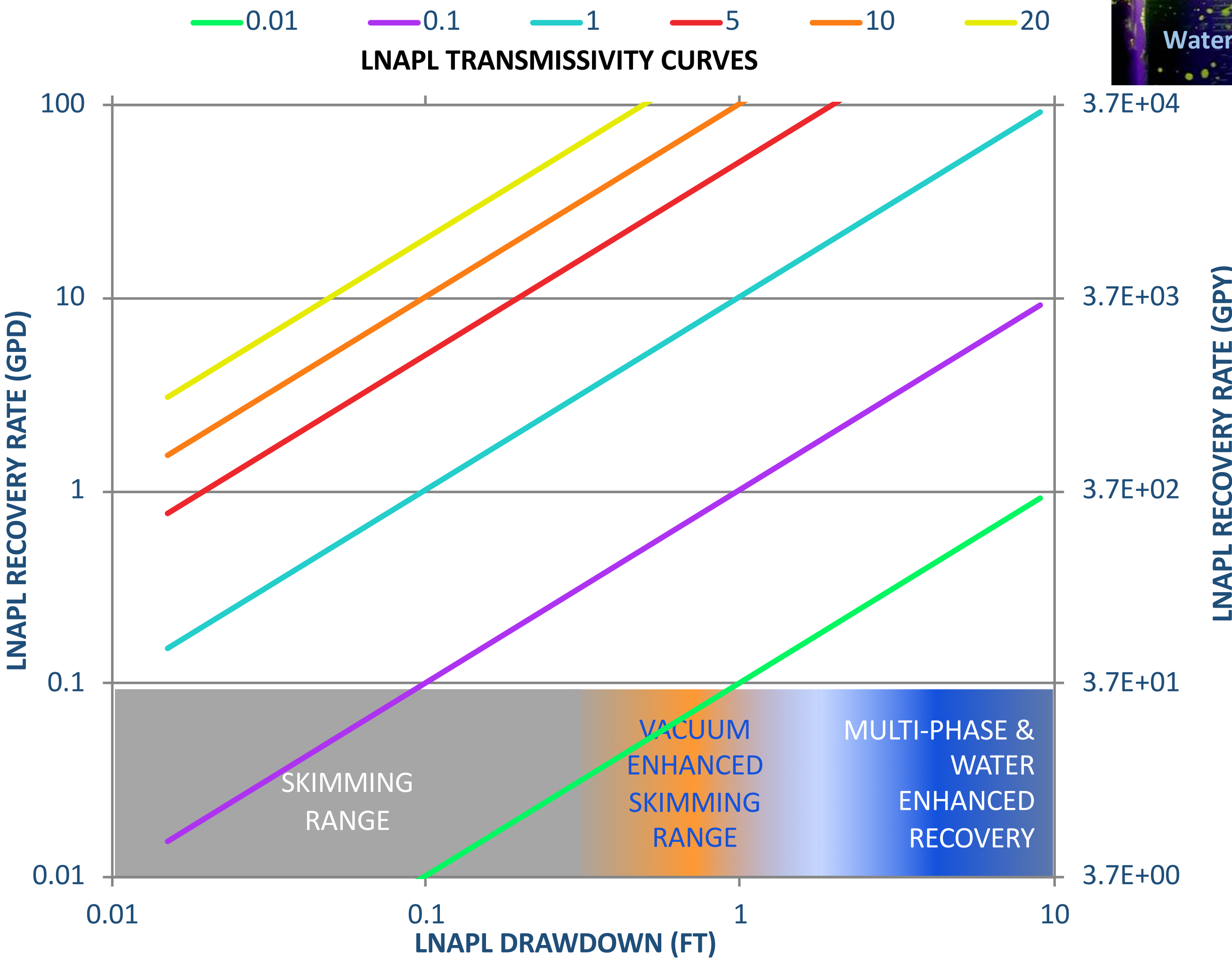
- Average INITIAL LNAPL recovery rate ~ Average Bioventing rate FOR 1 FOOT OF SOIL TREATMENT
- Note Initial Bioventing rates often represent methane degradation
- Rates lower once methane reserve is depleted
- Perhaps we should be doing push-pull respiration tests with air and helium rather than or in addition to baildown tests

LNAPL Transmissivity Rate Reference

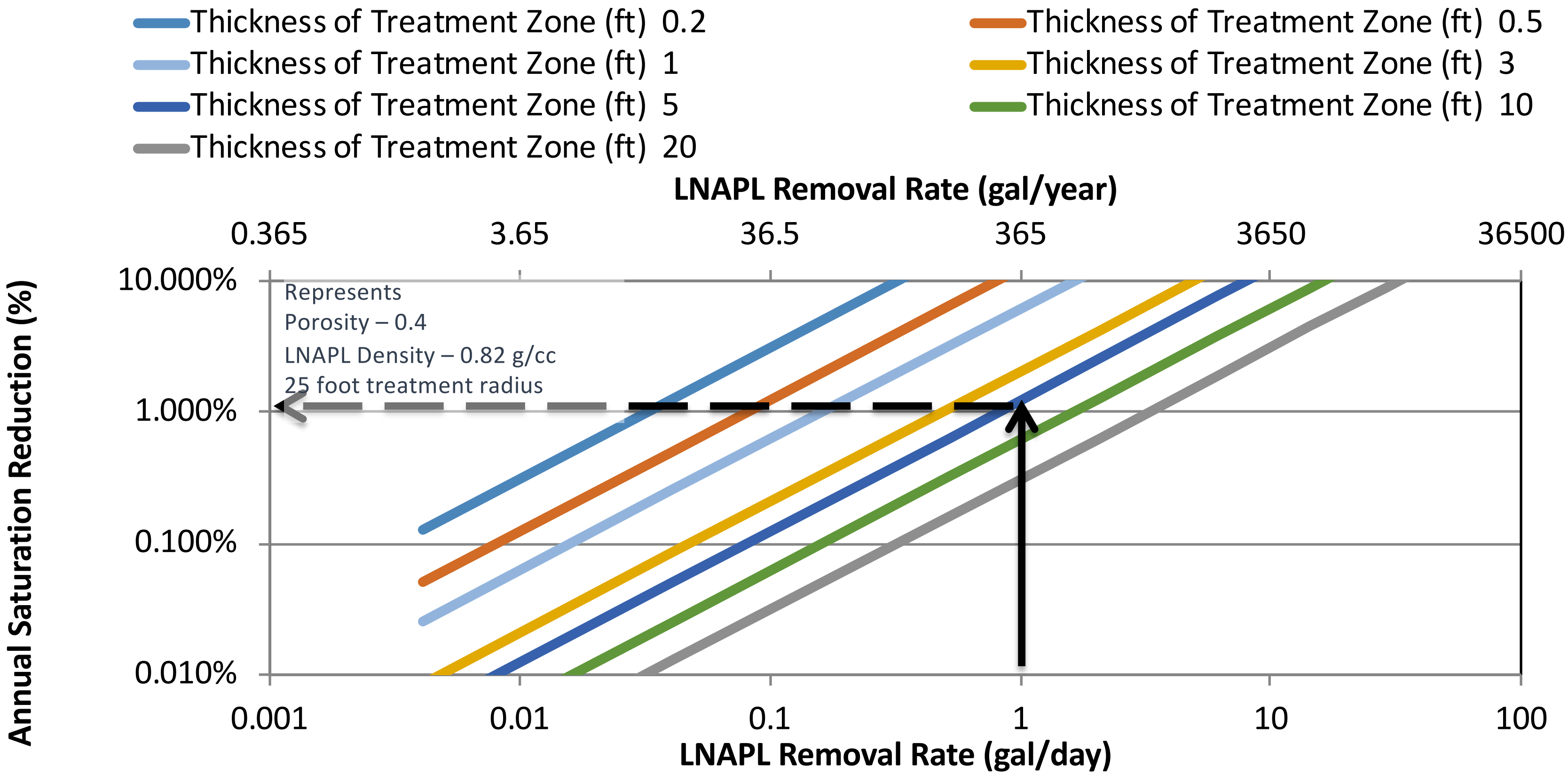
$T_o = \sum K_o \Delta b_o$



- LNAPL Transmissivity accounts for
  - Thickness of mobile LNAPL
  - Fraction of pores occupied by LNAPL
  - Permeability of the soil
  - LNAPL density
  - LNAPL viscosity
- Skimming LNAPL at 0.1 ft²/day results in less than 200 GPY recovered
- Skimming LNAPL at 5 ft²/day results in 7300 GPY

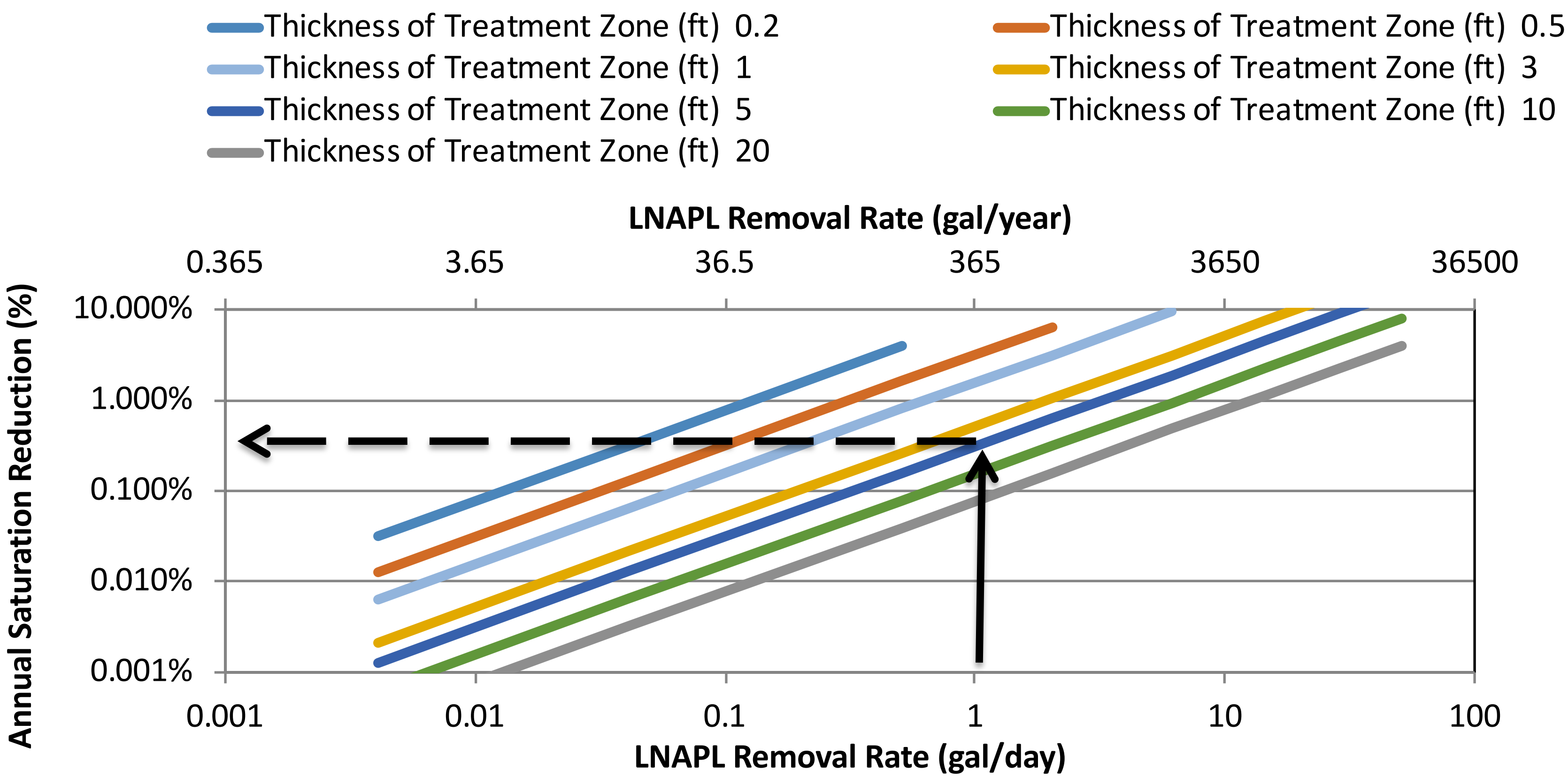


What Does A Given Rate Mean to the subsurface



- **Represents an initial removal rate effectiveness for remedial selection screening**
- **Most Remedial Mechanisms decrease in Removal rate as mass is removed**
- **Graph can be utilized whether the recovery represents vapor, biodegradation or liquid removal.**
- **Its up to the practitioner to accurately characterize the thickness a remedy is actually treating**

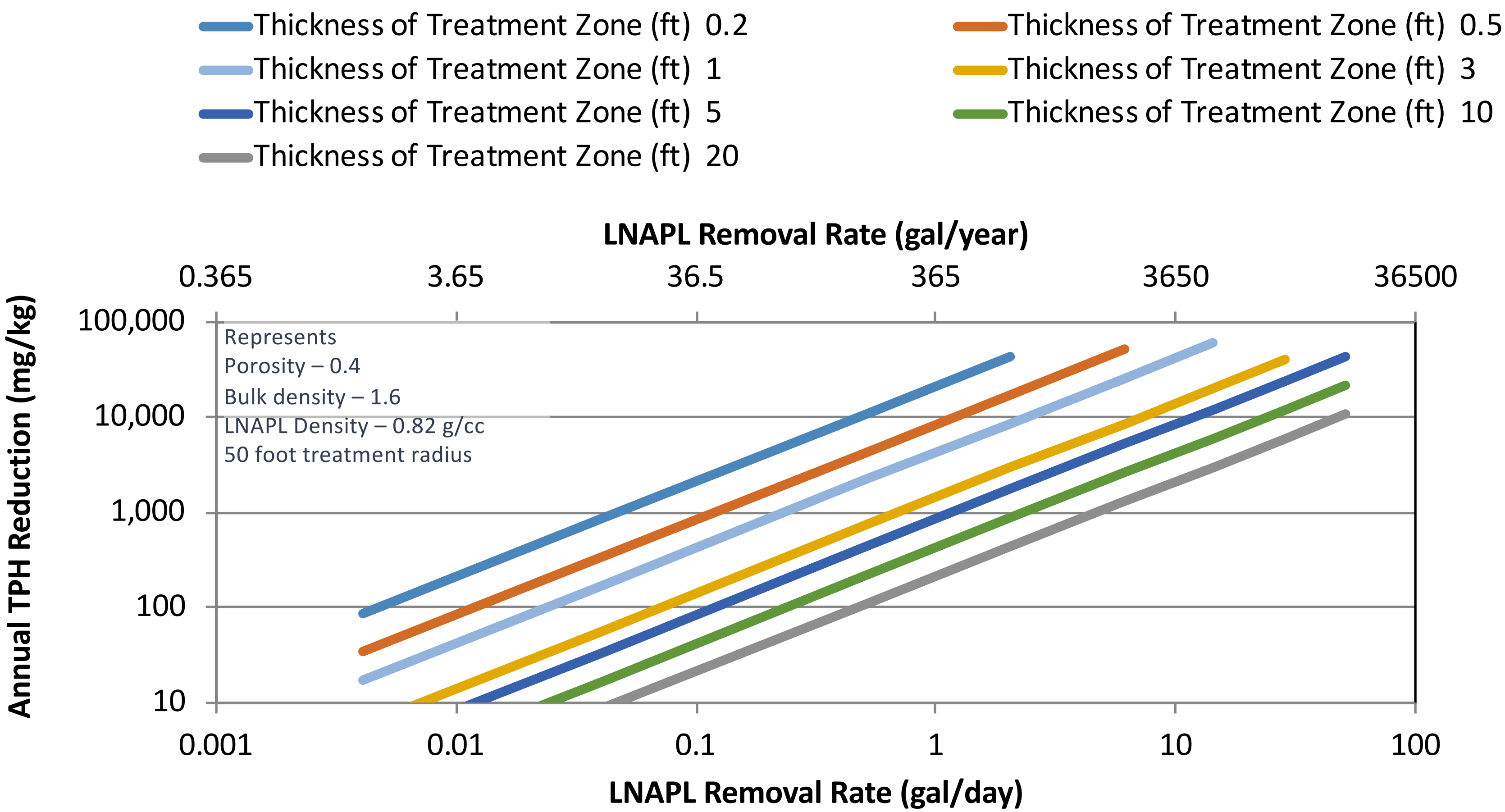
Same Graph for 50 foot Radius of Treatment



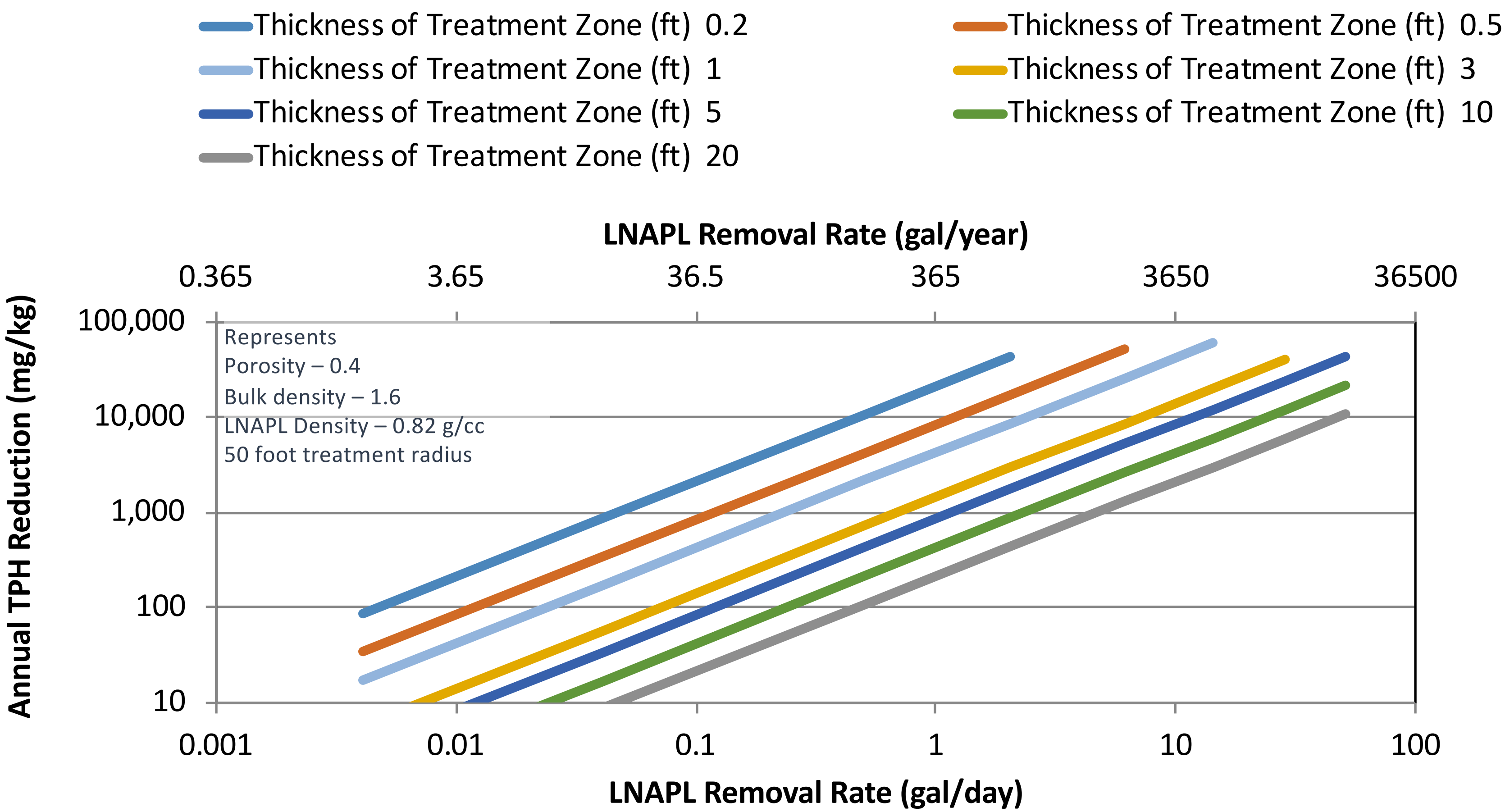
- Rates of Saturation change ΔS_n is equal to Remediation rate over Soil volume (V_s) and porosity (n)
- If Area (A) changes rescale value for new area
- Thickness (b_n)

$$\Delta S_n = \frac{Q}{V_s\, n} = \frac{Q}{A\, b_n n}$$

Same Graph but Related to TPH instead of Saturation



Same Graph but Related to TPH instead of Saturation

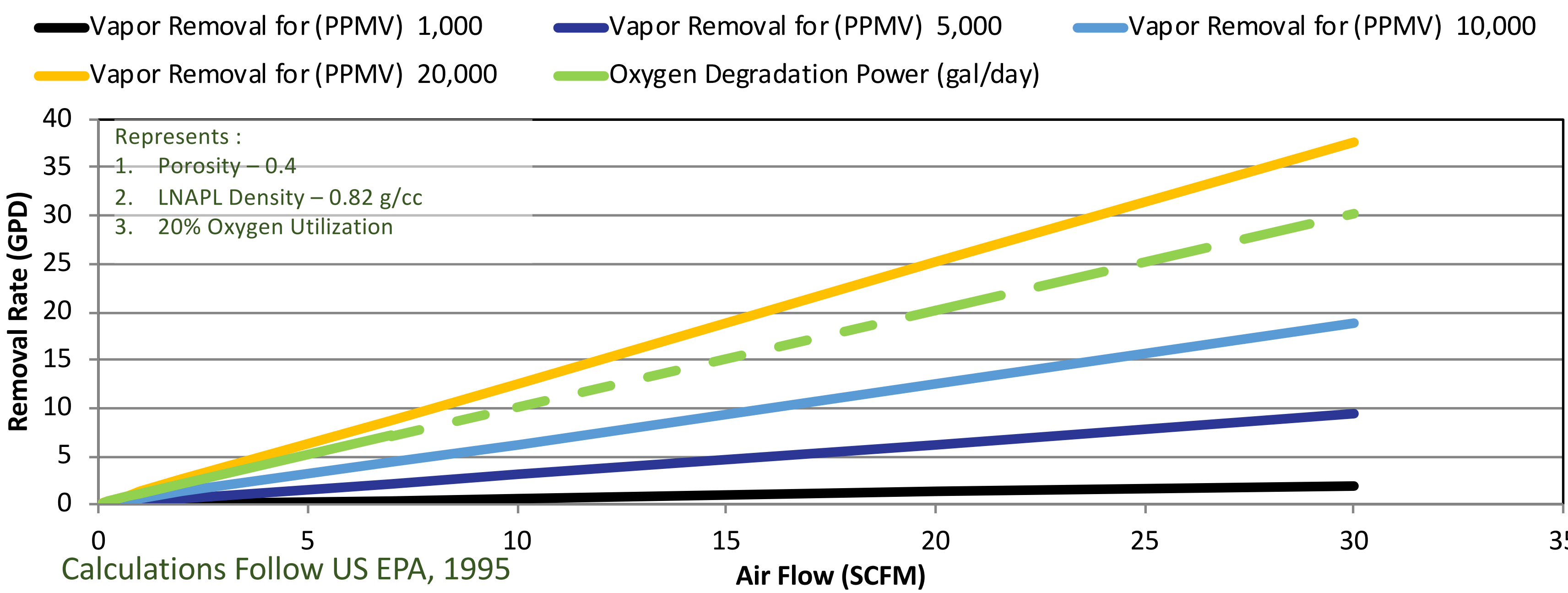


What Was my point with all of that?

- Leading metrics are useful for understanding performance
  - Transmissivity is a leading metric for recovery rates
  - Tn values of 0.3 to 0.8 ft2/day often correspond to the majority of LNAPL being residual.
  - See ASTM E2856-13 and ITRC LNAPL-3 (2018) Transmissivity Appendix for more information
- Wouldn't it be nice to have leading metrics for other mechanisms than just recovery

- Good News, we have had them for years!

Soil Vapor Extraction and Biodegradation (Does not consider Vapor Surfacing)



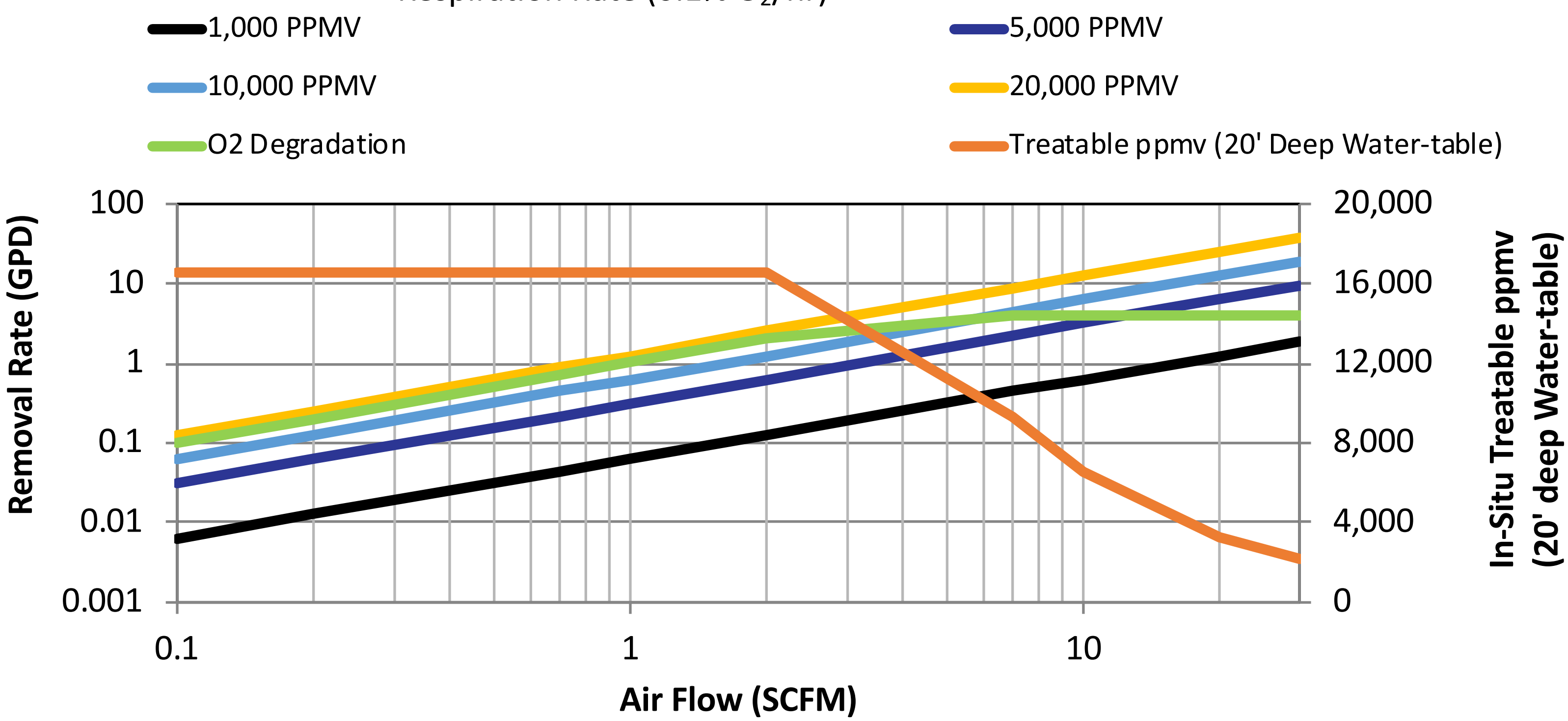
- Biodegradation occurs whether air is injected or removed
- SVE systems should measure CO2 and VOC concentrations to ensure optimized operation, and minimize propane / oxidizer cost
- While subsurface characteristics (depth to water-table, soil type) affect the outcome
- Biodegradation can account for vapors up to ~16,000 ppmv at low flow rates and Deep Water-table/ Impacts

Maximum Biovent Rate For A Specific Scenario – Designed to prevent vapor surfacing

- Increased Air Flow
  - Increases soil gas velocity & Reduces time for biodegradation prior to air to surfacing

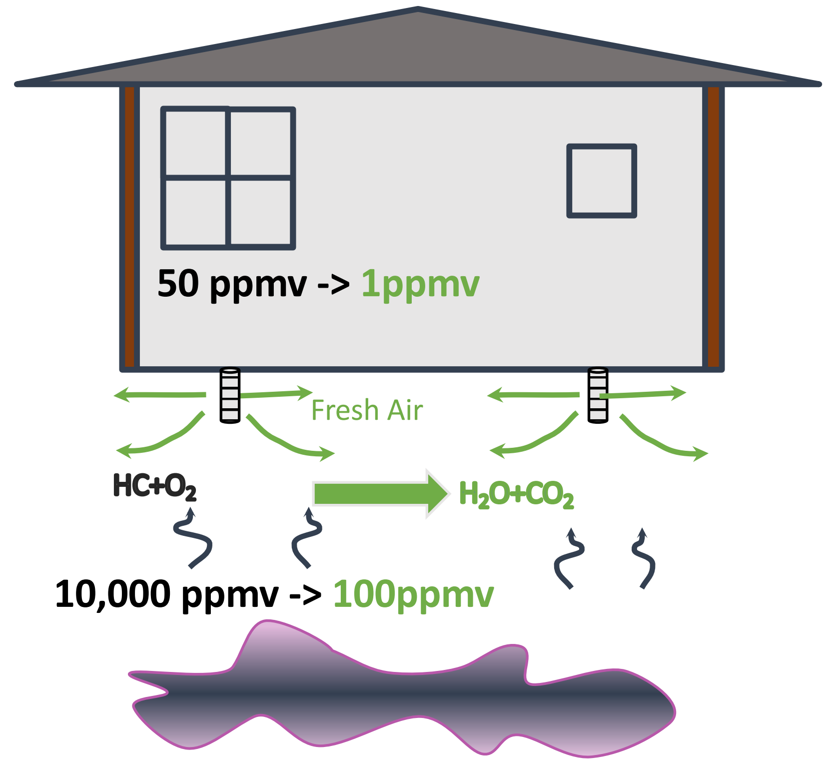
Scenario

5 feet vadose zone impacts near water-table
Water-table at 20 feet deep
Homogeneous Soil
10:1 horizontal to vertical permeability
Respiration Rate (0.1% O_2/hr)



Bioventing and PVI

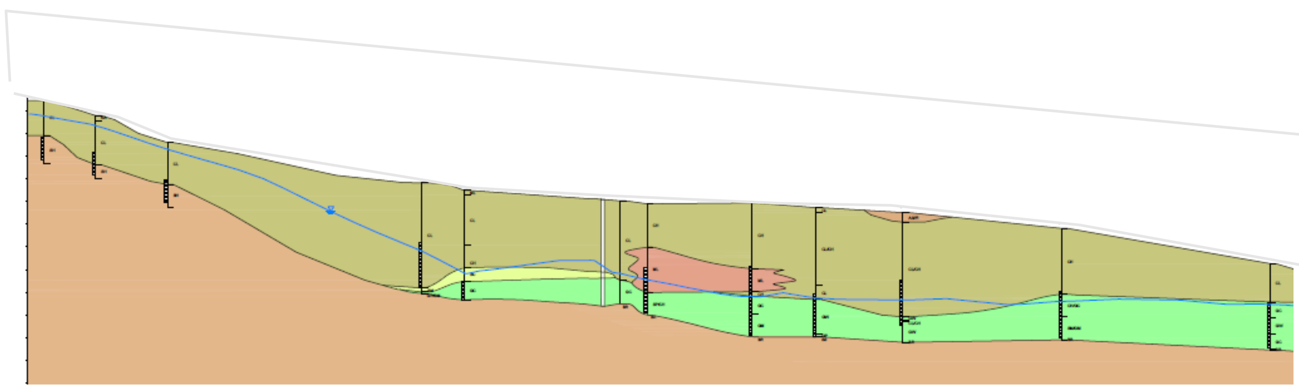
- Increased air flow (1 scfm) provides oxygen to degrade hydrocarbon vapors
- Practitioners increasingly utilizing bioventing as a vapor mitigation remedy
- Rather than drawing vapors out and towards the building, the air flow beneath provides oxygen under the building to enhance degradation



Designed and Implemented by
212 Environmental LLC

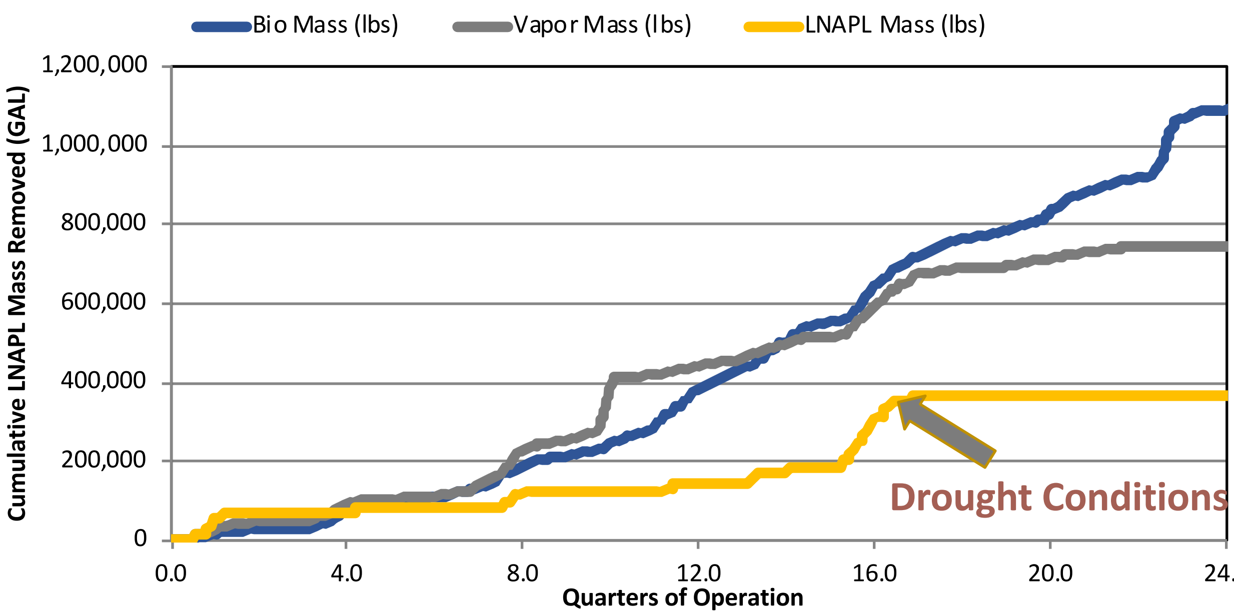
Site 3 – MPE within Terraced and Channelized Deposits

- Multi-phase extraction system intended to address historic gasoline release
- Water-table fluctuations affect all remedial mechanisms
- Biodegradation out performs vapor removal and LNAPL recovery mechanisms



Site 3 – Biodegradation Out Competes Vapor and Liquid Recovery for Gasoline Range LNAPL

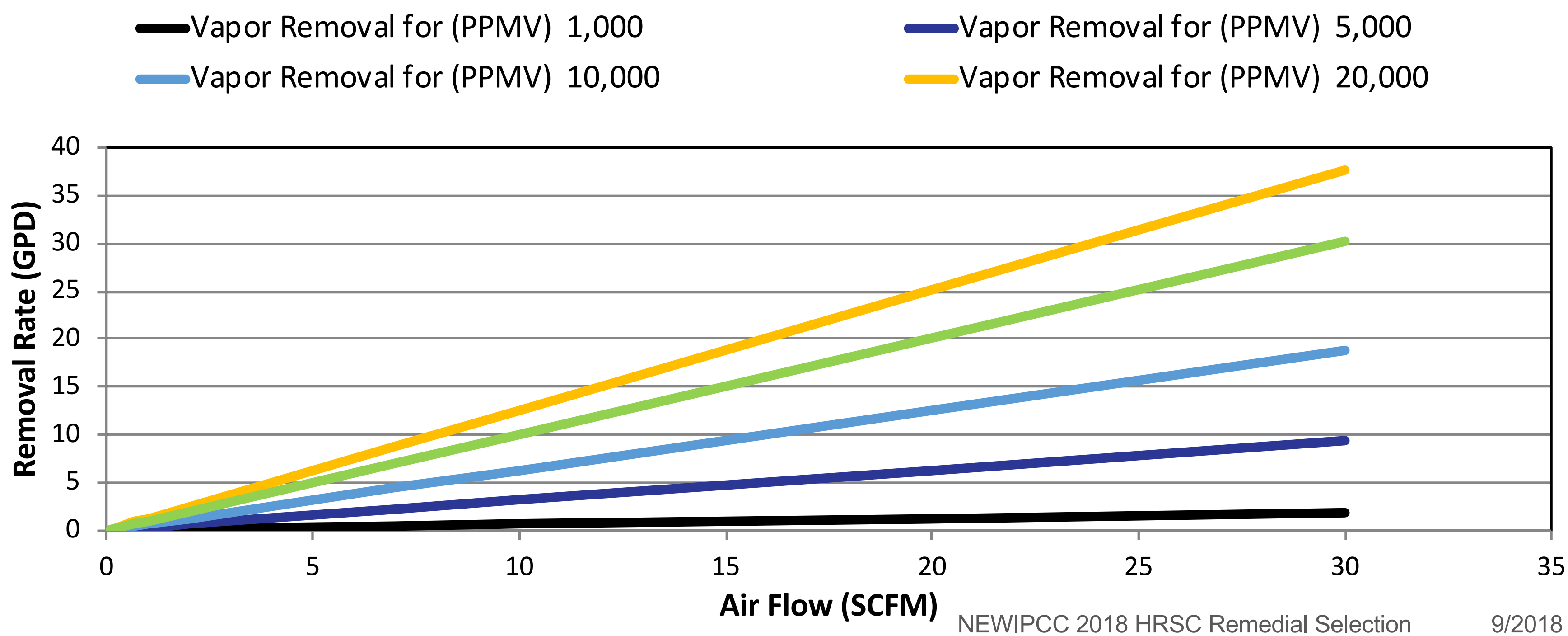
- Note Initial LNAPL recovery rate higher than both, Long-term this rate decreased the most.
- What Mechanisms will prevail beyond Instantaneous Rates?



- Good Conceptual Models are Needed to Forecast Performance

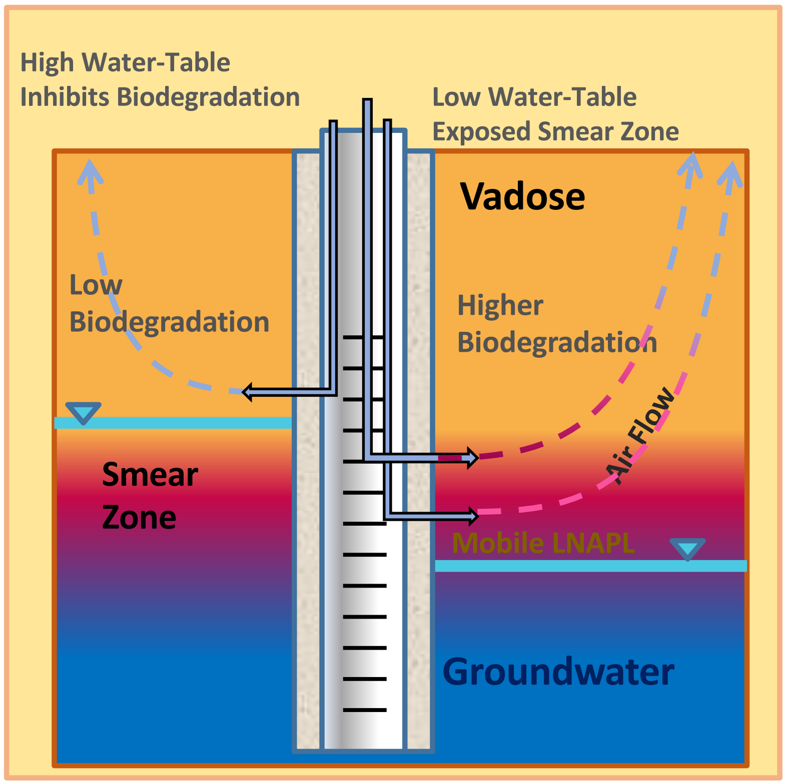
We’ve discussed At & Above the Water-Table, What about Below

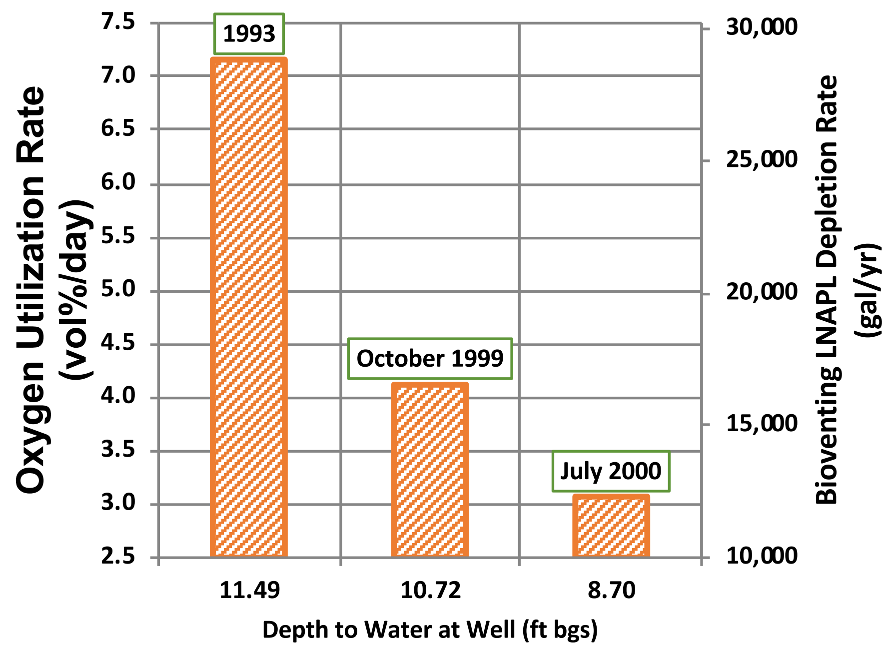
- Air Sparging/ BioSparging,
  - Air flow still applies
  - Oxygen degradation power still applies, but may need to scale back the amount of oxygen utilized, Within a month oxygen % may represent 2-6 percent concentration decrease. (current pilot)
- Pilot tests are useful



Site - Biovent and Water-table Fluctuations

- Oxygen Diffusion across water-table may not be practical use of bioventing
- Seasonality concept is applicable to other technologies





Injection Technologies

- Consider ISCO

"The results of this Colorado study suggest that the lack of success, at least at 15 of the 20 sites selected, was due to incomplete or insufficient site characterization and/or pilot testing leading to insufficient oxidant delivery volumes and concentrations, determination of the effective radius of influence, or determination of vertical intervals to be treated. Therefore, the ISCO technology may have been appropriate in each case although the inadequate preparation for and implementation of the technology was the reason for the failure of ISCO at the site."

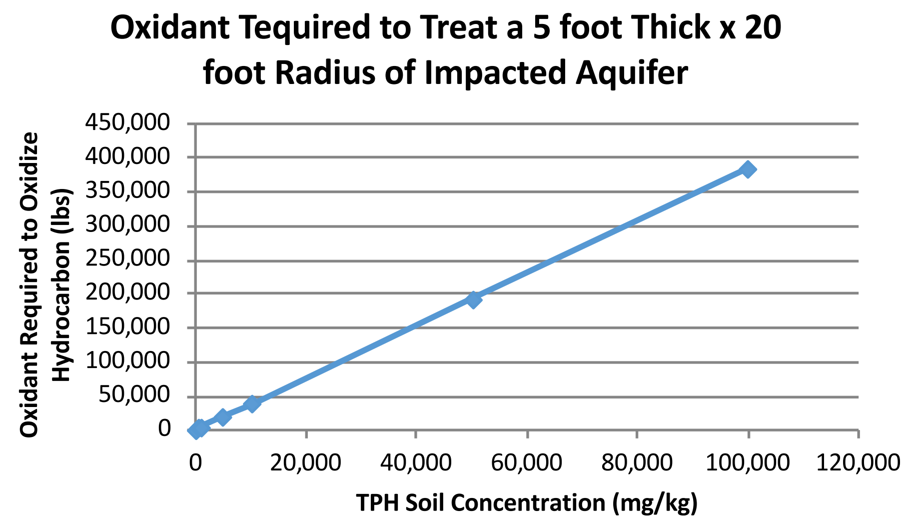
- **The evaluation did not consider the magnitude of LNAPL in place as residual**
- This applies to all injection technologies

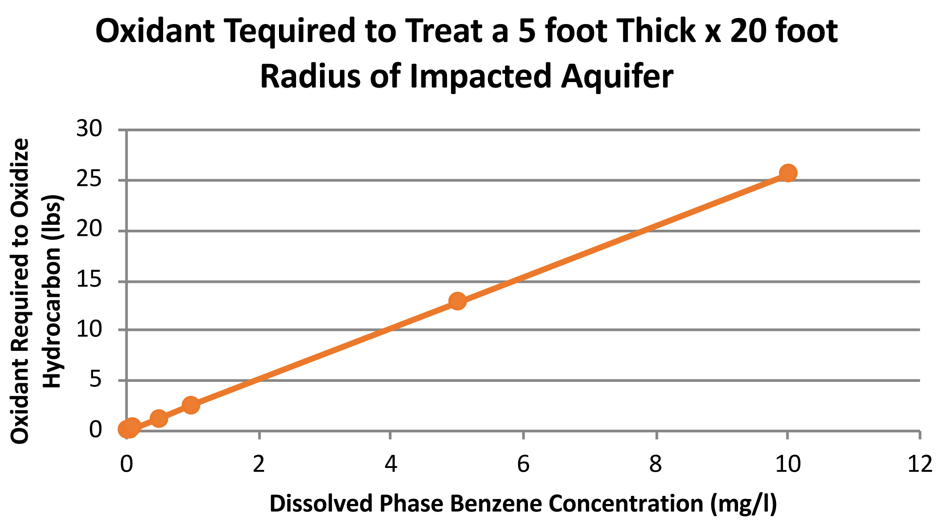
https://clu-in.org/download/techfocus/chemox/ISCO-petroleum-guide.pdf

Additional Metrics are Required

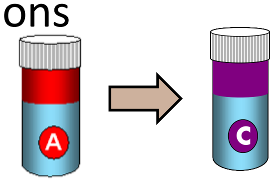
If we only look at post concentrations how do we predict success

- Soil concentration, residual LNAPL footprint are useful metrics
- Other injection technologies such as activated carbon injection still need to understand residual mass





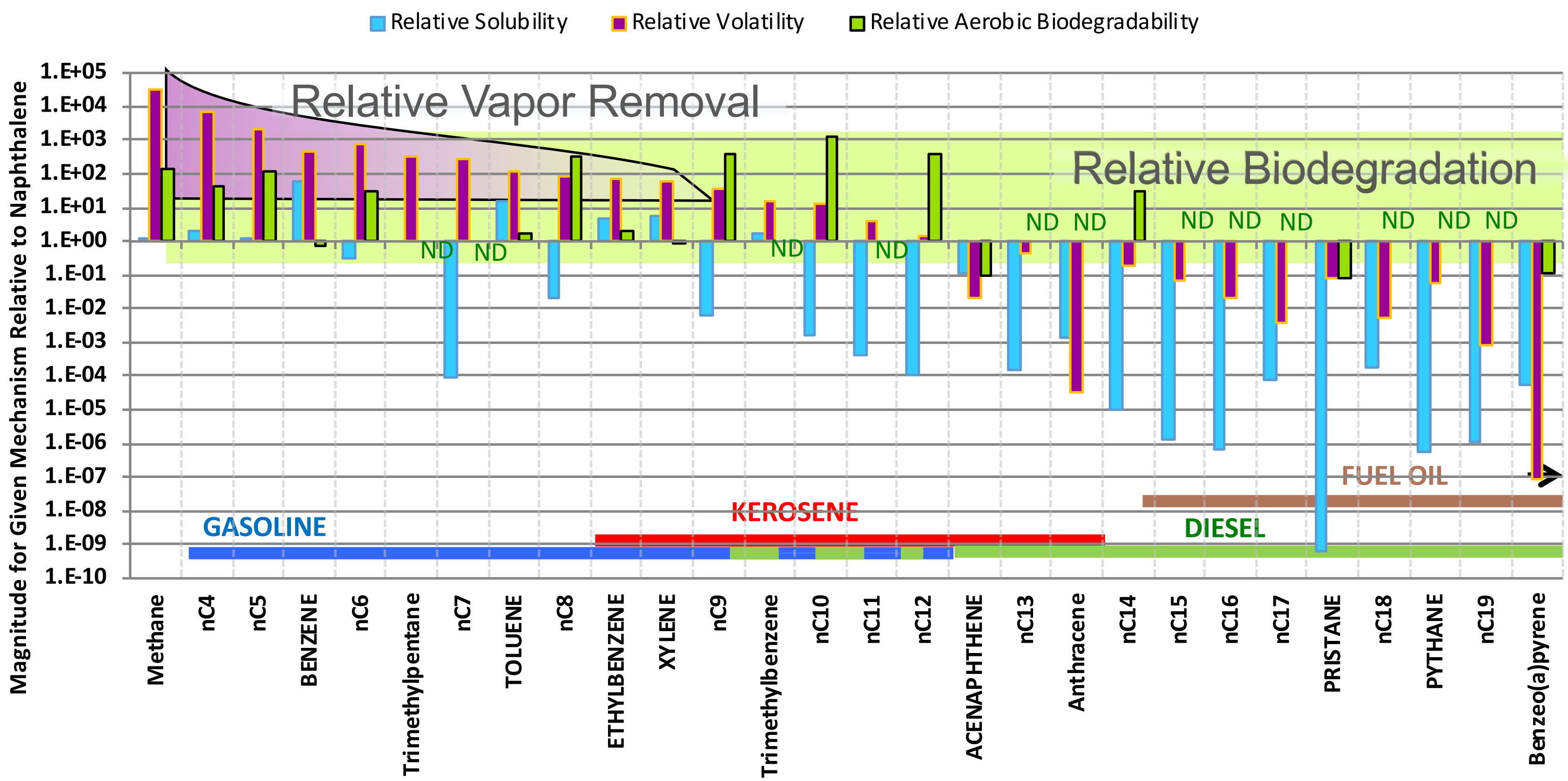
- Consider compositional change and the specific COC of concern
- Bench scale tests can support the fraction required for treatment to reduce GW concentrations



LNAPL Composition - Characterizes Vapor Removal and Biodegradation Mechanisms

From ITRC, 2018b

Remedy Selection LCSM: Nature of the Source



MOST VOLATILE & SOLUBLE

LEAST VOLATILE & SOLUBLE

BIODEGRADATION OCCURS THROUGH THE HYDROCARBON RANGE

References

- Thank you to Jonathan Smith and Mahsa Shayan for Their Contribution

- Leeson and Hinchee, *Bioventing Principles and Practice,* United States Environmental Protection Agency, EPA/540/R-95/534a, 1996.
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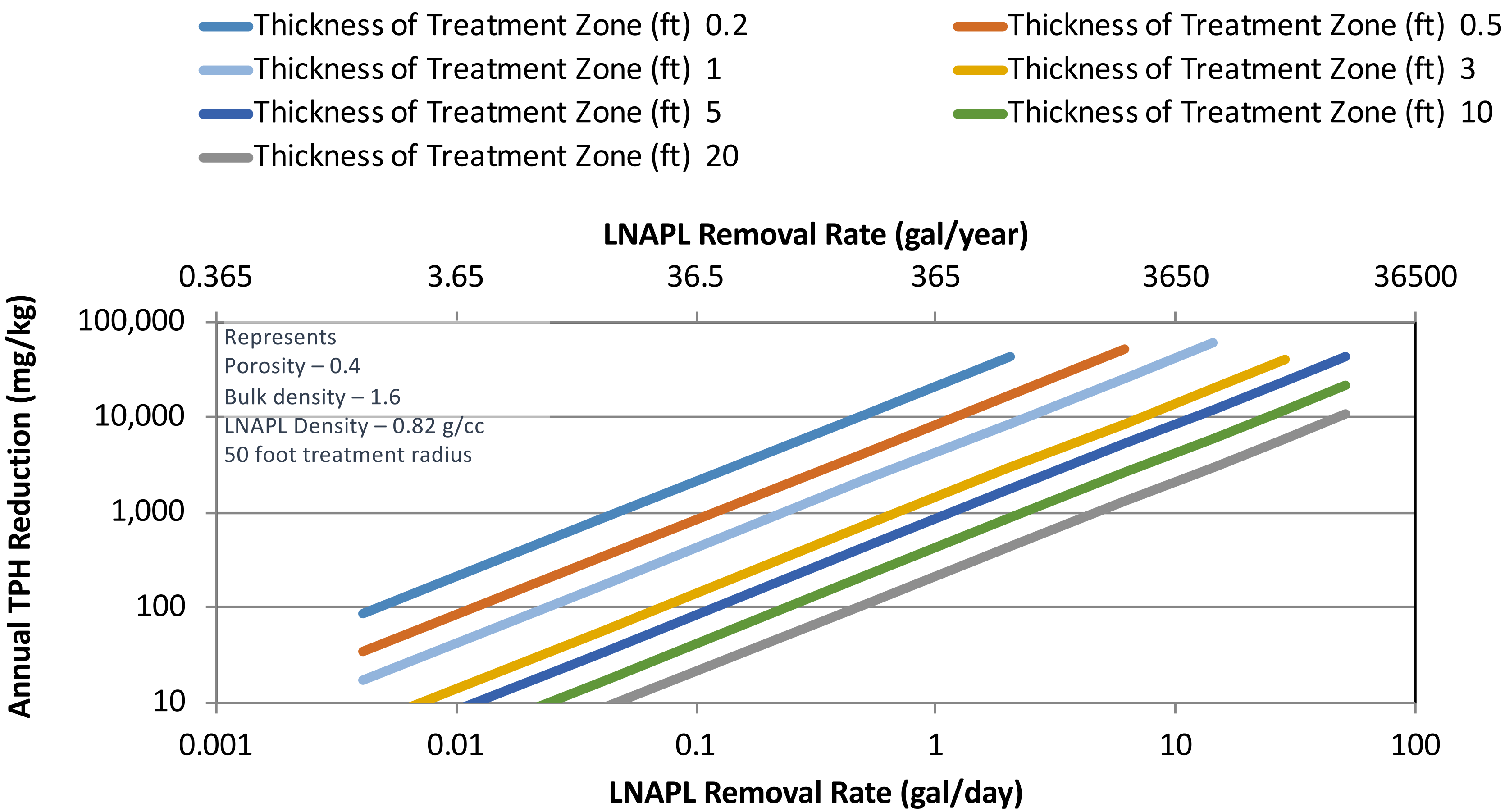
- Stumpf, P. ; Ganna, S.; Lentini , J., Shen, C.; Kannappan, R.; *Comparison of Laser Induced Fluorescence Profiles Following a Decade of LNAPL Recovery,* Battelle Chlorinated and Recalcitrant Compounds Conference, 2018
- ITRC, 2018a – *LNAPL-3: LNAPL Site Management: LCSM Evolution, Decision Process, and Remedial Technologies*, Interstate Technology and Regulatory Council, May 2018
- ITRC, 2018b - *Connecting the Science to Managing LNAPL Sites a 3 Part Series*, Interstate Technology and Regulatory Council, May 2018

Attachments

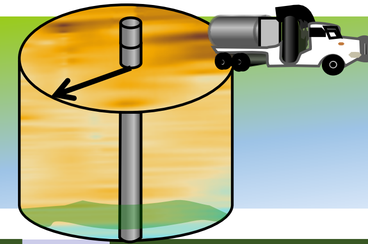
What Does A Given Rate Mean to the subsurface



CASE STUDY

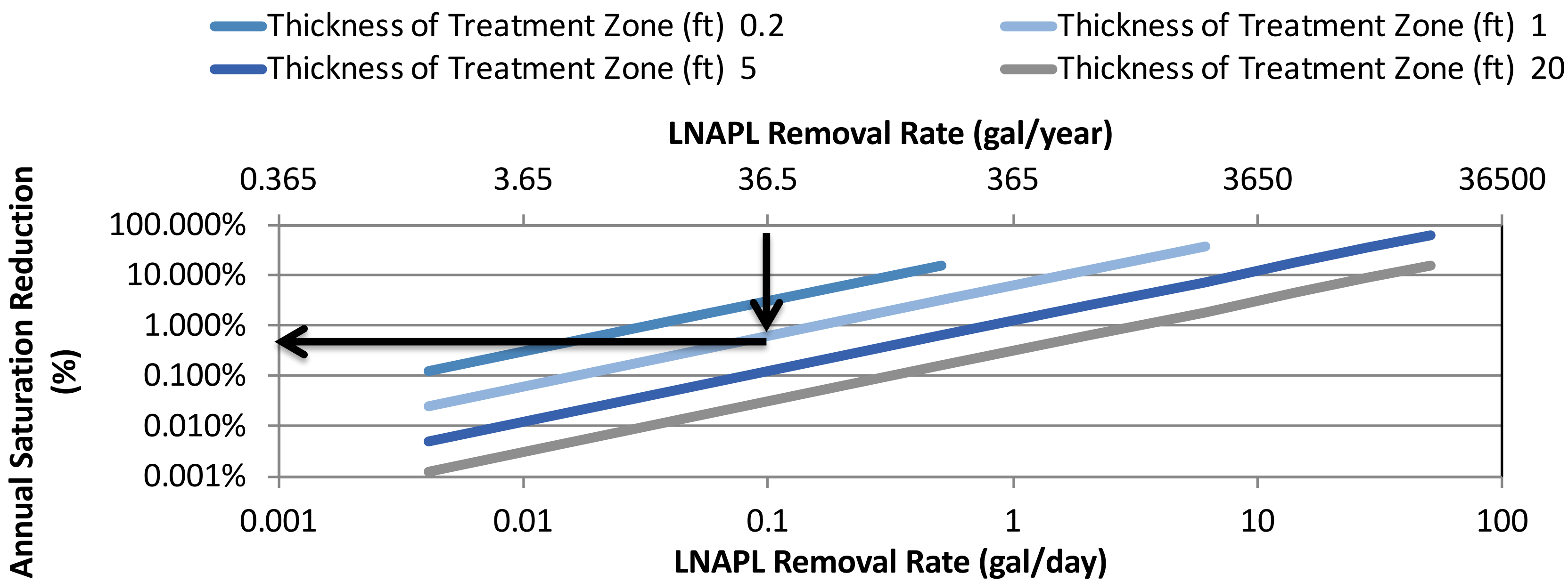
Vacuum Truck Evaluation

After ITRC, 2018b



Above Ground

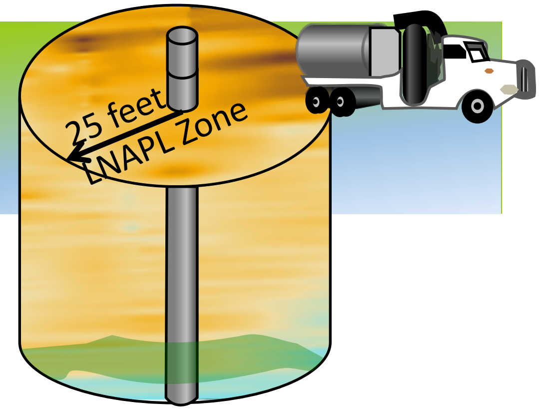
Well with LNAPL	Monthly Vacuum Truck	Monthly Volume Produced Stored + Induced Flow
Thickness = 1.4 feet **T_n = 2 ft^2/day** **Volume in well = 1.4 gal**	Drawdown - 2 feet Time – 1 hour 25 ft Radius of Treatment (ASTM E2856-13)	1.4 gallons +1.7 =3.1 gal/month 36.2 gal/year



- Vacuum Truck Effort results in 0.4% saturation reduction across 25 foot Radius 1st year
- 15 years required to reach 0.8 ft^2/day

Vacuum Truck Evaluation

After ITRC, 2018b



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Below Ground

- 2 feet of Mobile LNAPL interval
- Saturation varies between 8% and 45%
- 8 % Residual Saturation
- 27% Average Mobile Saturation
- 5 feet of Residual Smear Zone

- API LDRM Model with Published Values for soil and LNAPL parameters
- Calibrated to LNAPL Tn field value
- 1 hour of time outside of Field Tn Testing

- Active Skimming reaches LNAPL Transmissivity of 0.8 ft2/day in 0.8 years

See Table 4-4 in ITRC LNAPL-3 for Estimation Tools

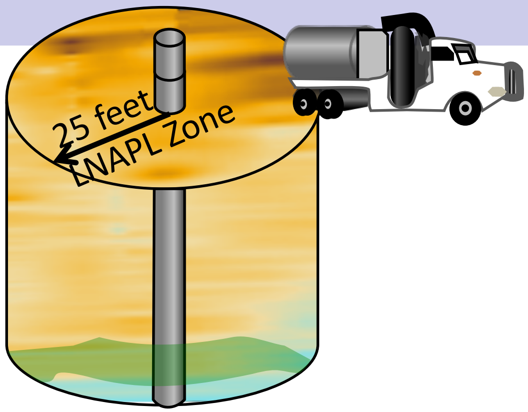
Vacuum Truck Evaluation

After ITRC, 2018b

Above Ground

Well with LNAPL	Monthly Vacuum Truck	Monthly Volume Produced Stored + Induced Flow
Thickness = 1.4 feet **T_n = 2 ft²/day** **Volume in well = 1.4 gal**	Drawdown - 2 feet Time – 1 hour	1.4 gallons +1.7 =3.1 gal/month 36.2 gal/year

(ASTM E2856-13)



- Vacuum Truck Effort results in 0.4% saturation reduction across 25 foot Radius each year
- 15 years required to reach 0.8 ft²/day
- Active Skimming reaches it in 0.8 years

Below Ground

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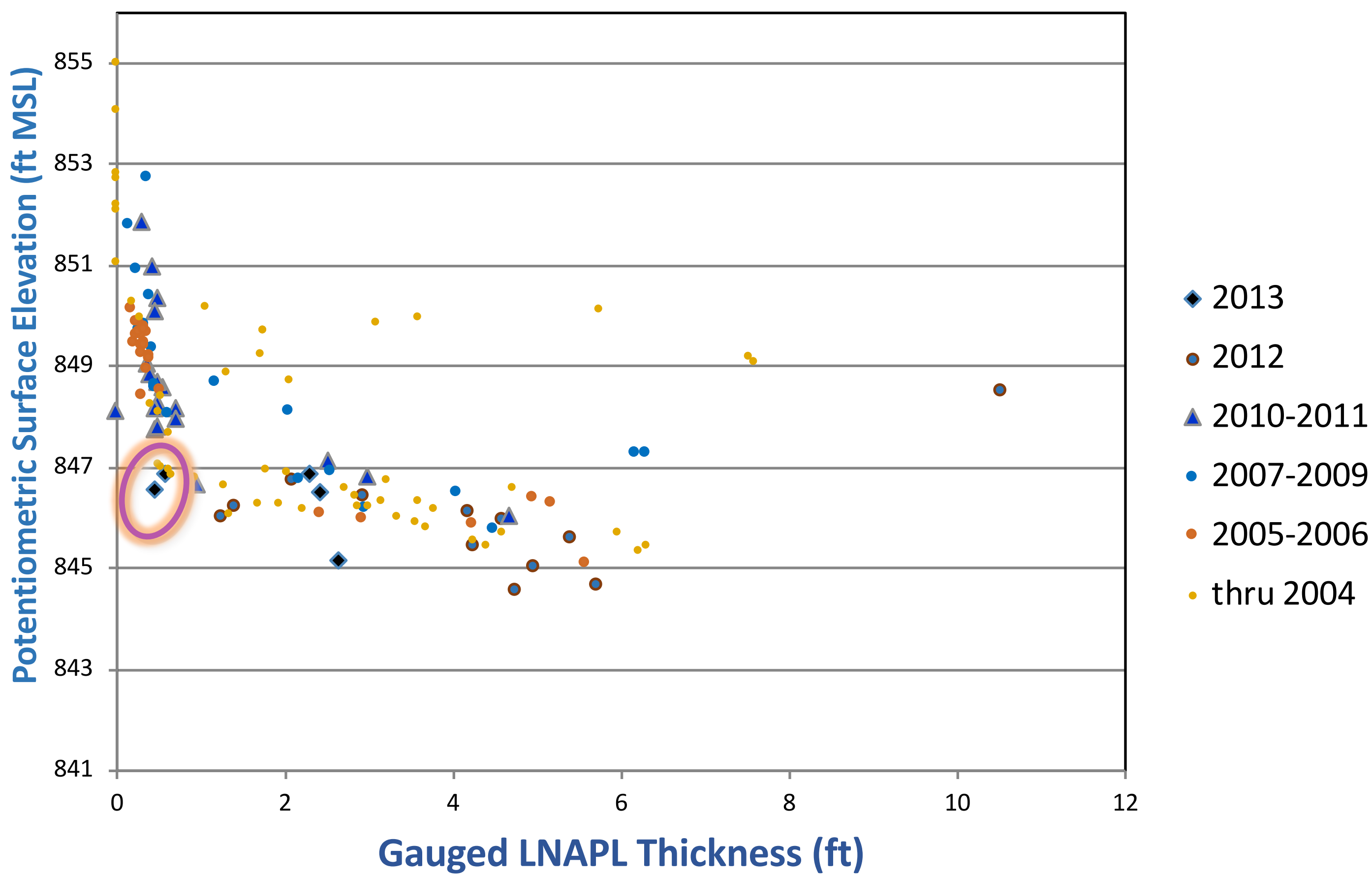
Thickness is not a Preferred Metric as it is not solely related to recoverability

- Socks in wells do little to ensure closure and inhibit the conceptual model
- VLR does little to affect long-term LNAPL thicknesses



Gauged LNAPL Thickness

- Does Indicate if mobile LNAPL is present
- Does not indicate if residual mass is present
- Changes in thickness do not consistently indicate changes in impact
  - Vertical redistribution of LNAPL or LNAPL head in the well
  - Water-table plays a big role
- Define the appropriate remedial metric
  - Directly related to impact or risk
  - Measurable

Vacuum Trucks

- Often can not measure volume of LNAPL recovered,
- 0.1 ft of thickness in a vacuum truck tank represents ~6 ft^3 of LNAPL or 45 gallons
- What is the remedial metric
  - Annual Baildown testing for LNAPL Transmissivity
  - Resampling of soil for changes in TPH concentration
- Gauged thickness is low cost but misses residual and doesn't account for water-table changes