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2019 Bioremediation Symposium | April 15-18 | Baltimore, Maryland

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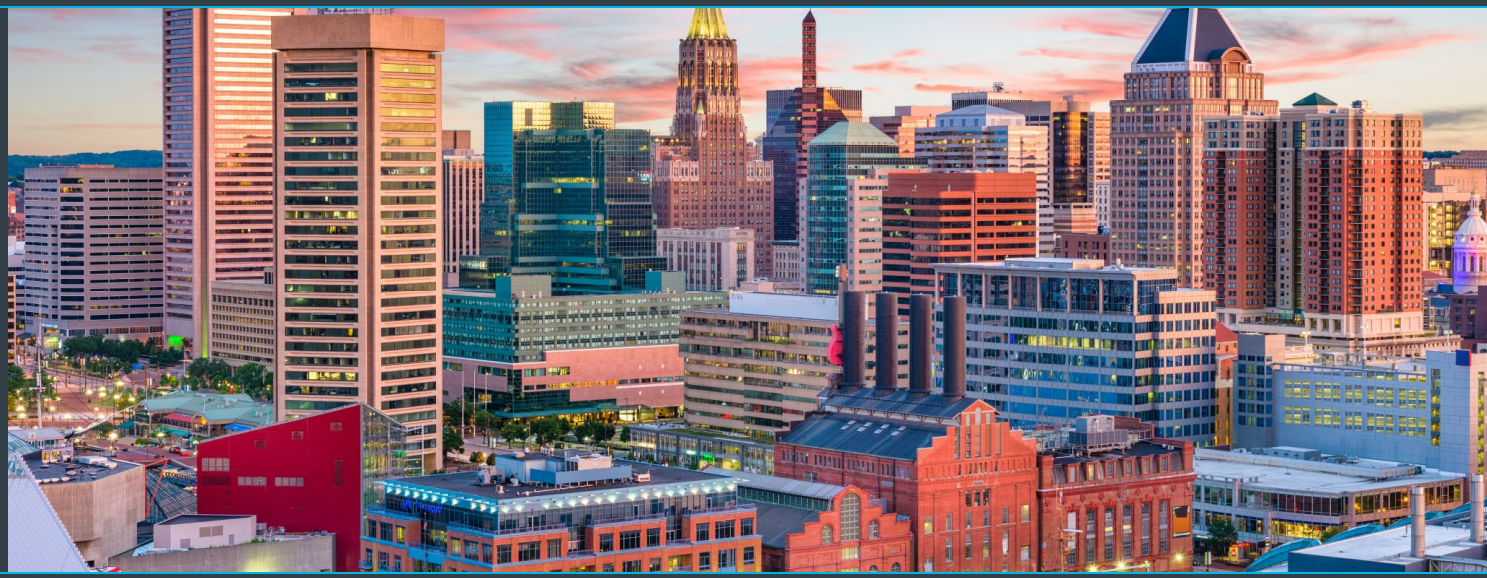


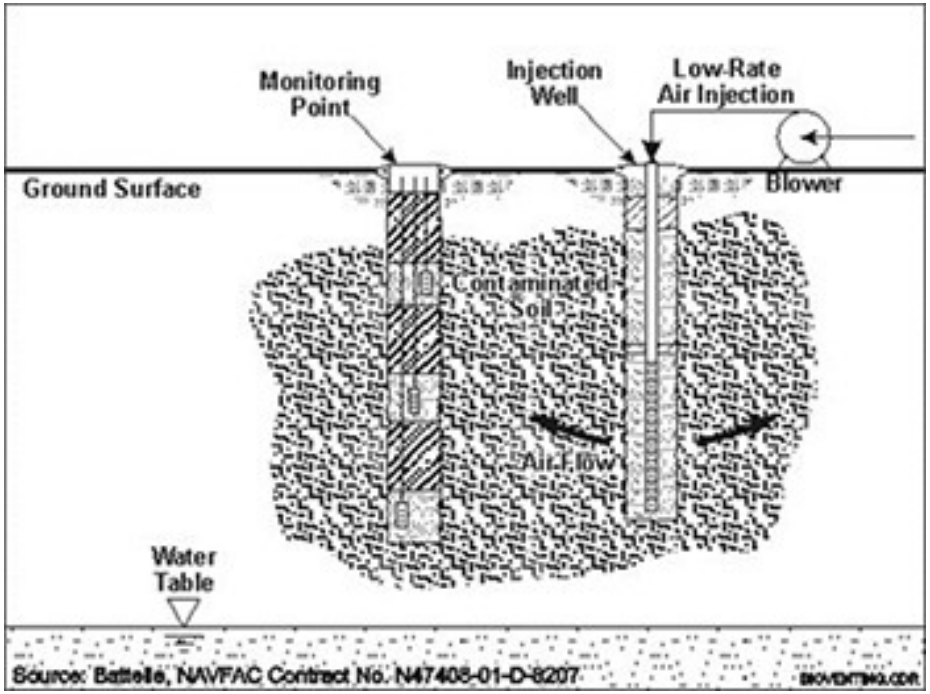
Rethinking Bioventing
It's Not Just for BTEX and TPH in Soil

Steven Gaito, Brad Koons, Jonathon Smith, AECOM
Andrew Kirkman, BP RET

April 18, 2019

Bioventing

- Traditionally considered a remedy for aerobically degradable contaminants in in vadose zone
  - Cost effective for petroleum hydrocarbons in the vadose zone
- Not considered applicable at sites with mobile LNAPL



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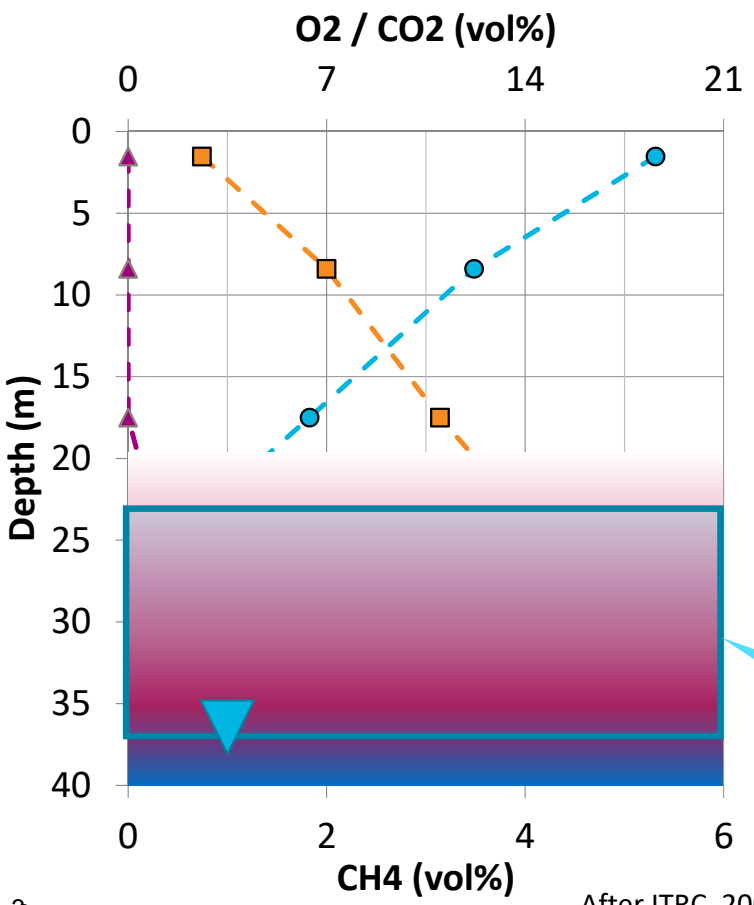
But Can Bioventing Address Mobile LNAPL?
Enhancing NSZD



After ITRC, 2009

- A basic check for biovent effectiveness is to determine if the system is oxygen limited
- Oxygen depletion is a result of NSZD
- Oxygen is consumed by petroleum degraders and methanotrophs
- Bioventing supports both of these microbial communities

Oxygen Limited Zone

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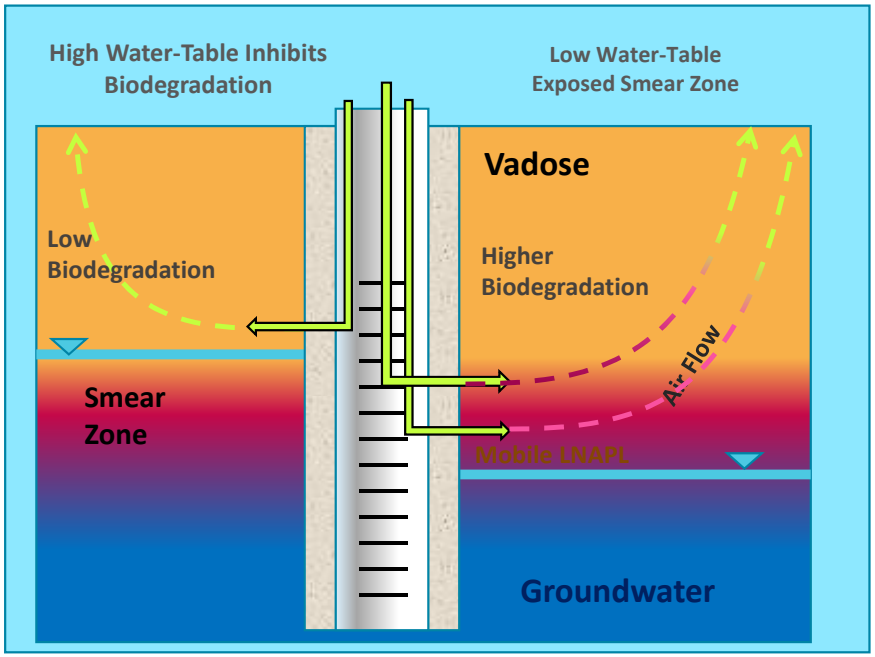
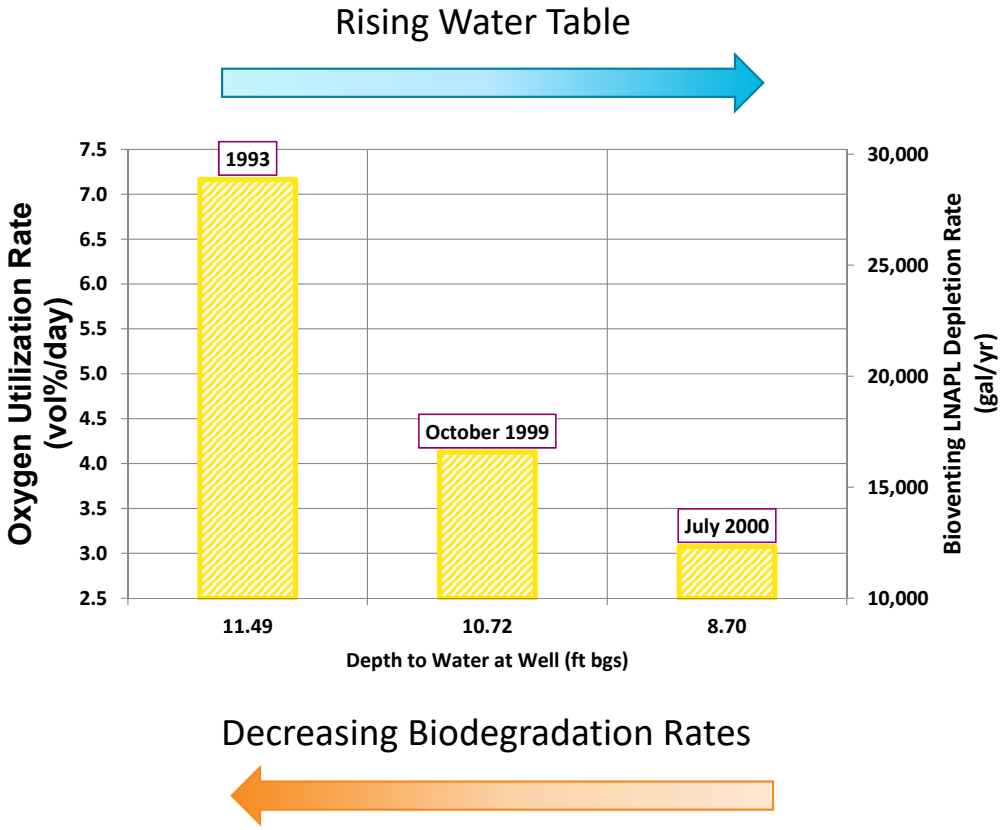
Biovent and Water-table Fluctuations





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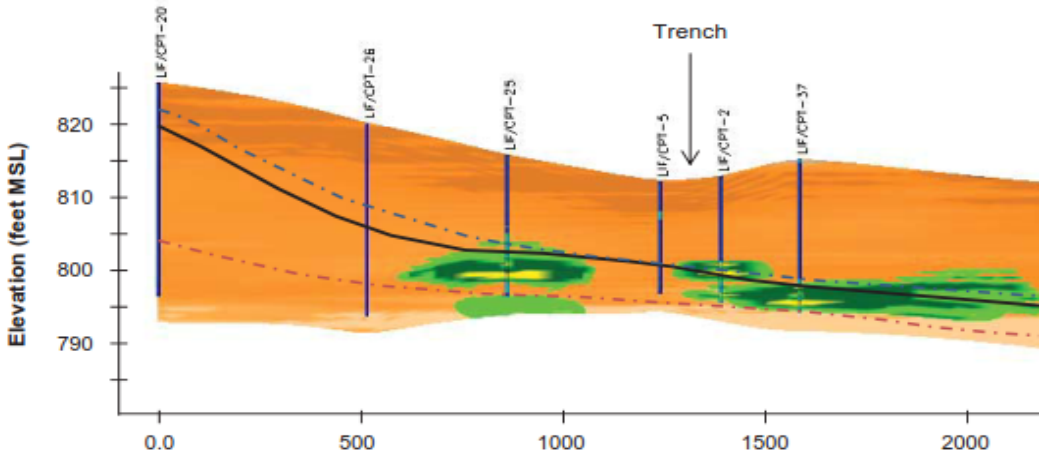
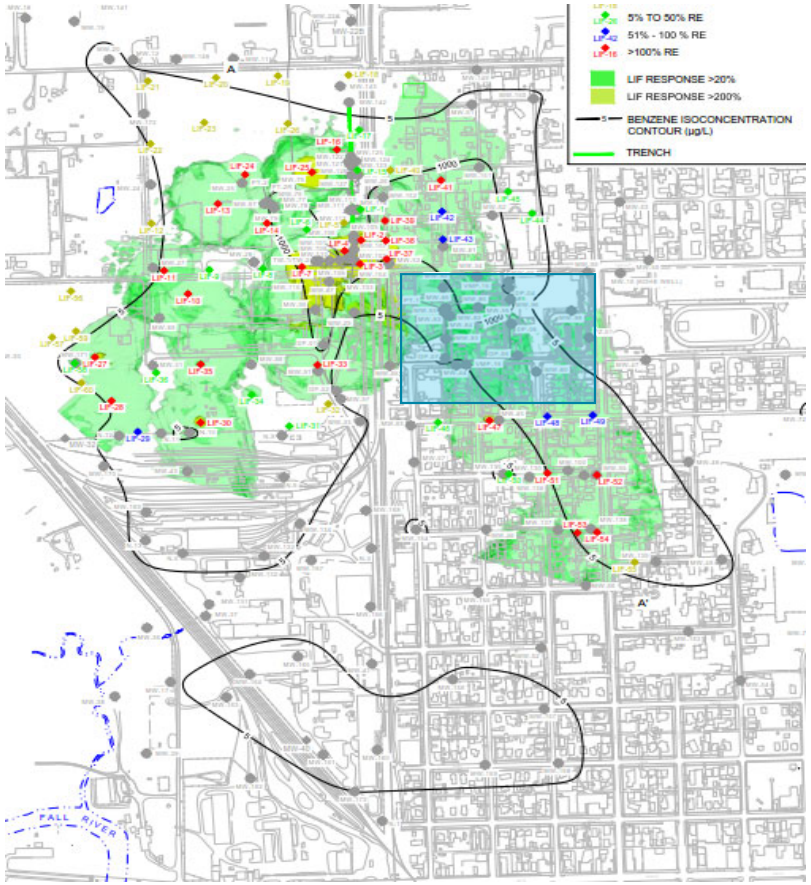
Multiphase Extraction (MPE)
Former Refinery

– LNAPL present in unconfined alluvial gravel

– 6.5-acre remediation system operated from 2002 to 2015

- Groundwater, LNAPL, and soil gas extracted
- 8 recovery wells and a trench
- 33 gpm liquid and 1,100 scfm soil gas extraction





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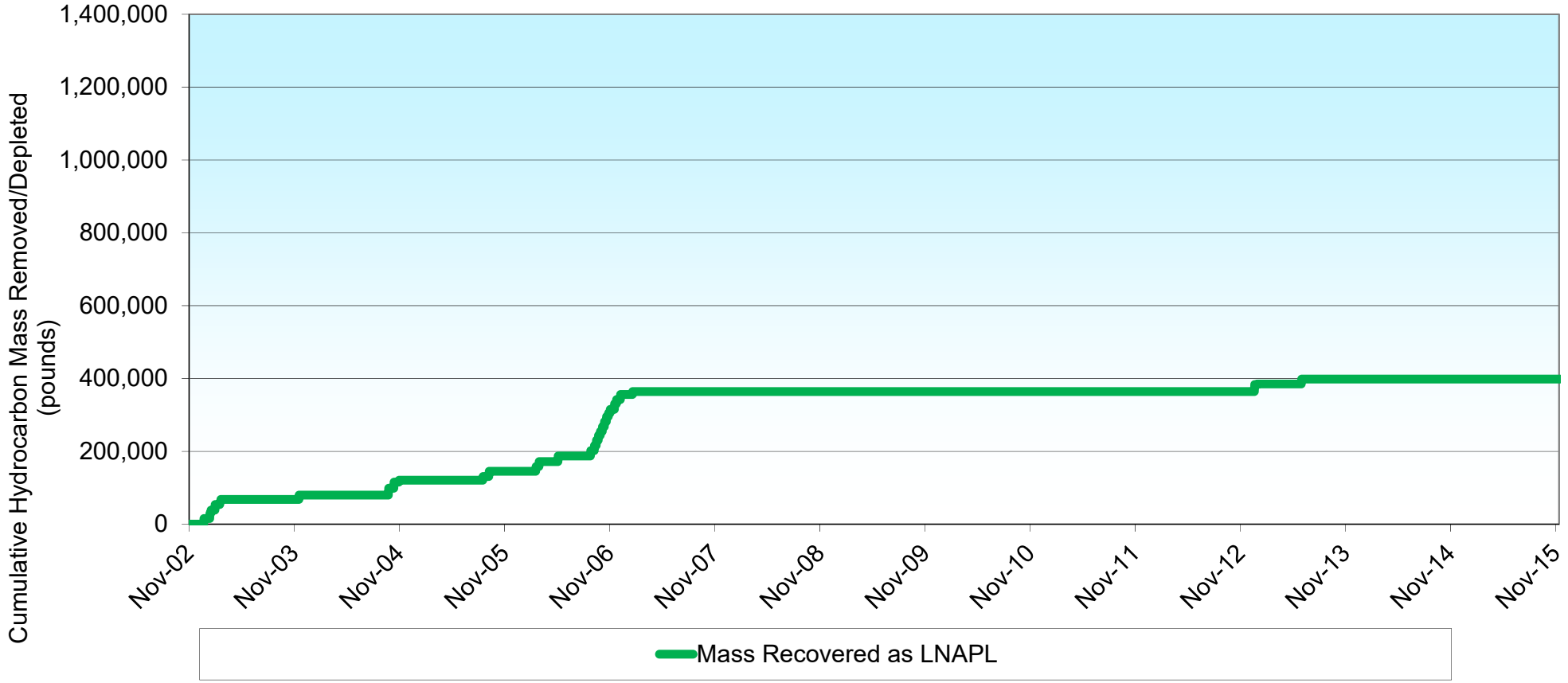
Mass Depletion Mechanisms
Multiphase Extraction (MPE) at a Gasoline Plume



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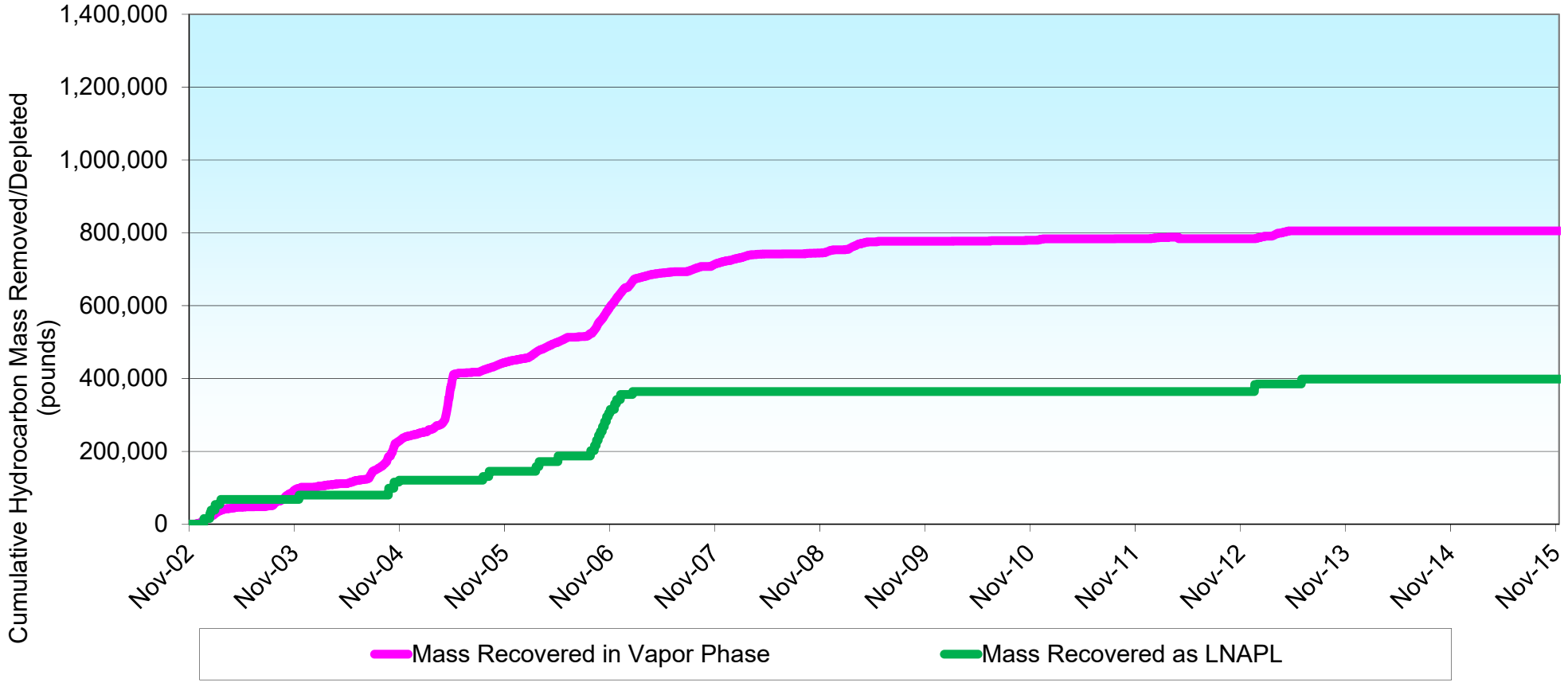

Vapor recovery twice as effective as hydraulic recovery.

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Mass Depletion Mechanisms
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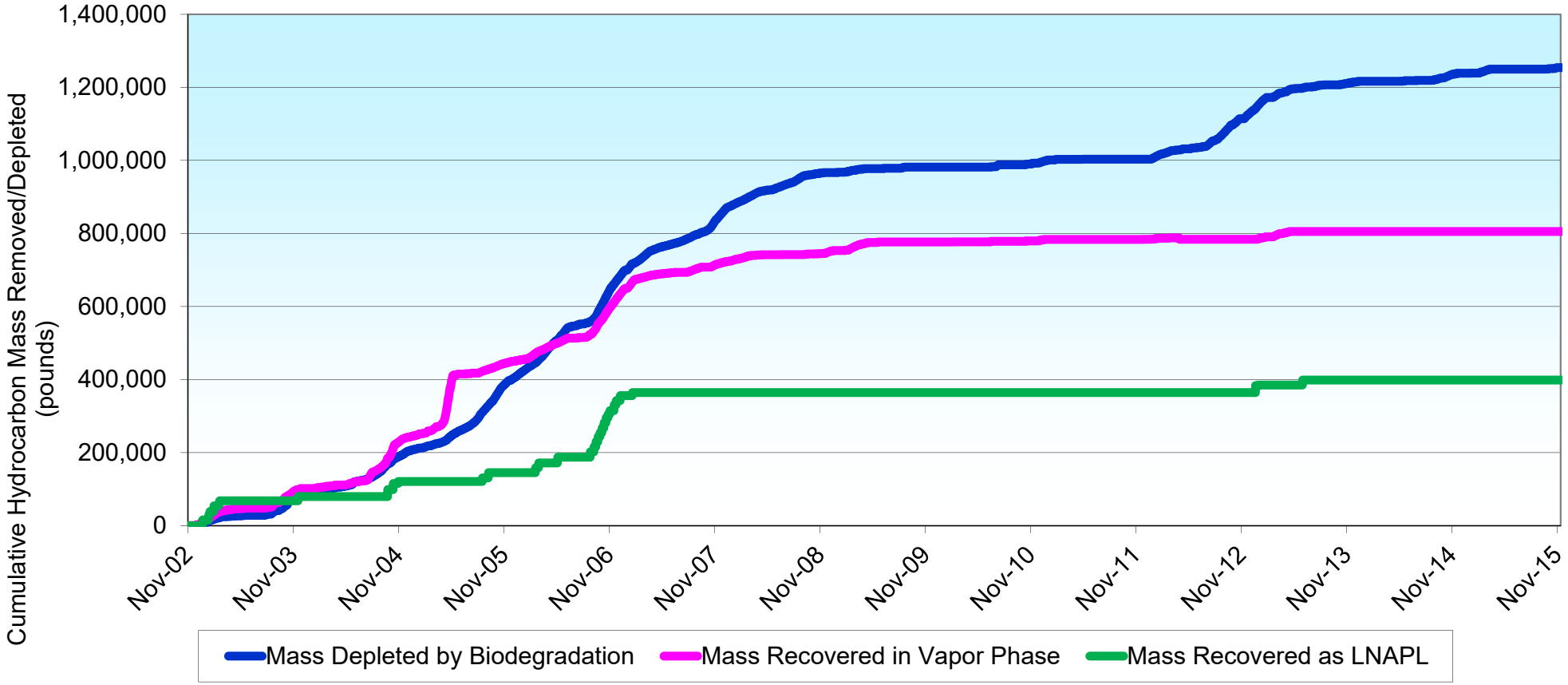

Biodegradation most effective mechanism

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Mass Depletion Mechanisms
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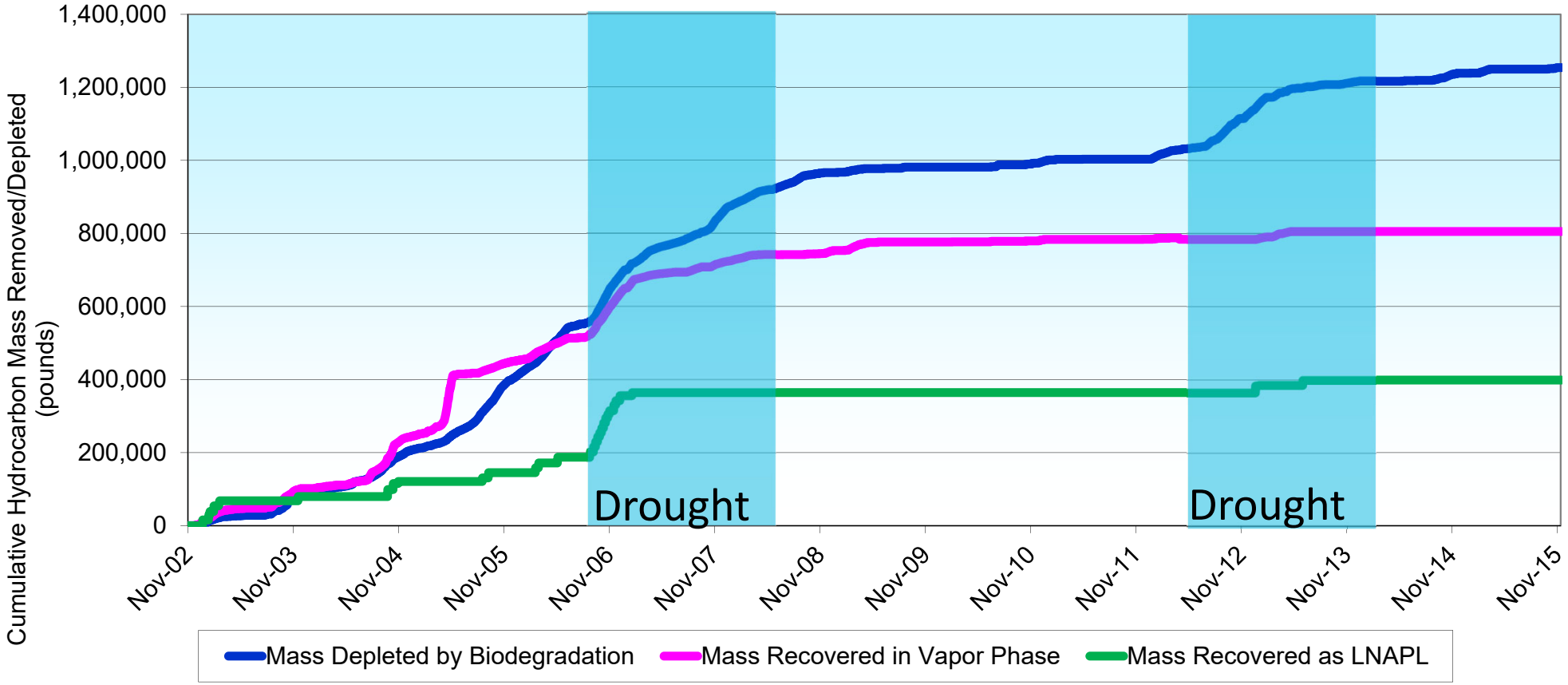
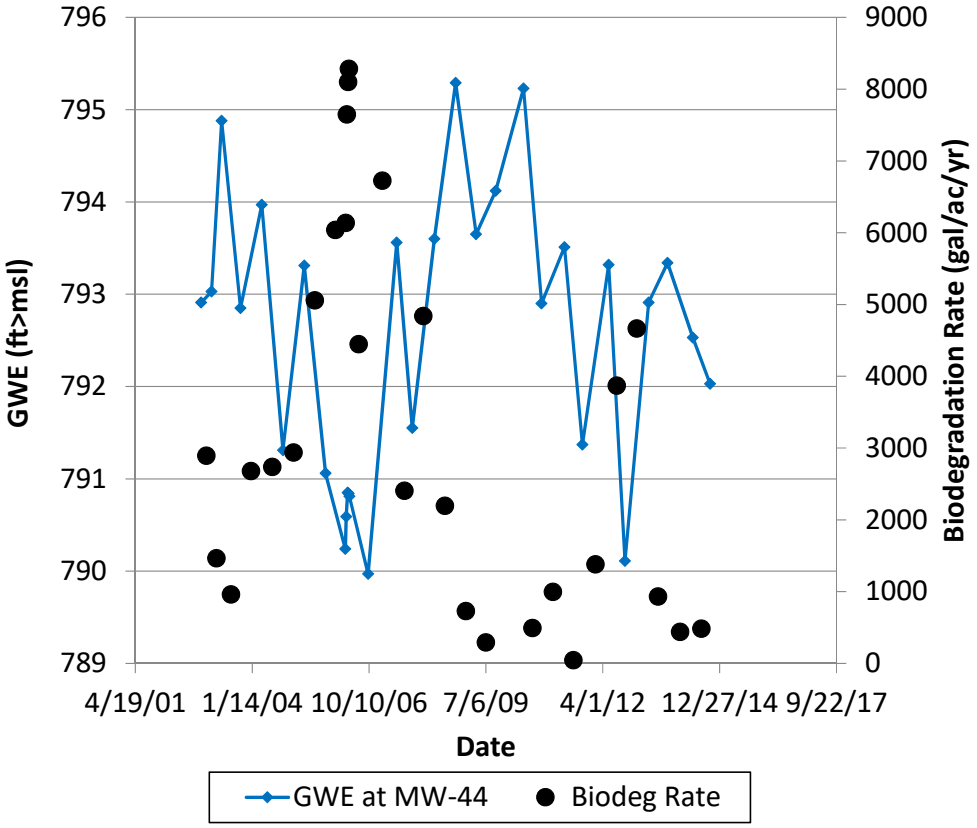
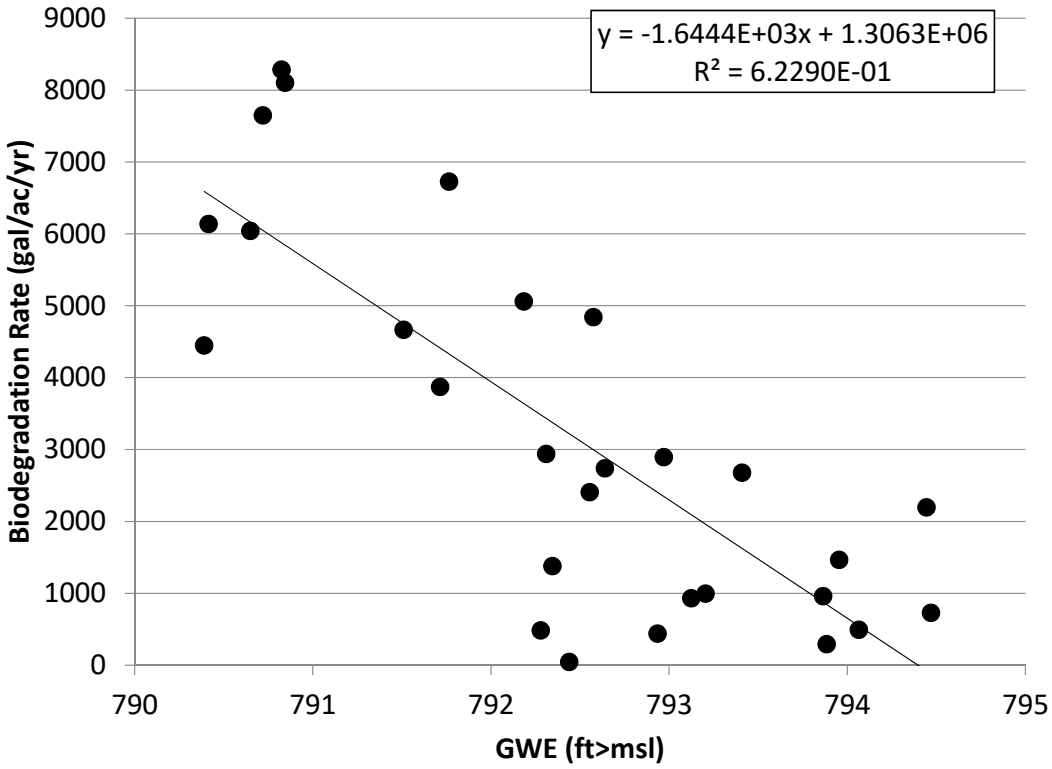


Rates rebound, but only biodegradation was effective during 2nd drought

Bioventing and Water Table Fluctuations





Reduction in rate is related to exposed smear zone.

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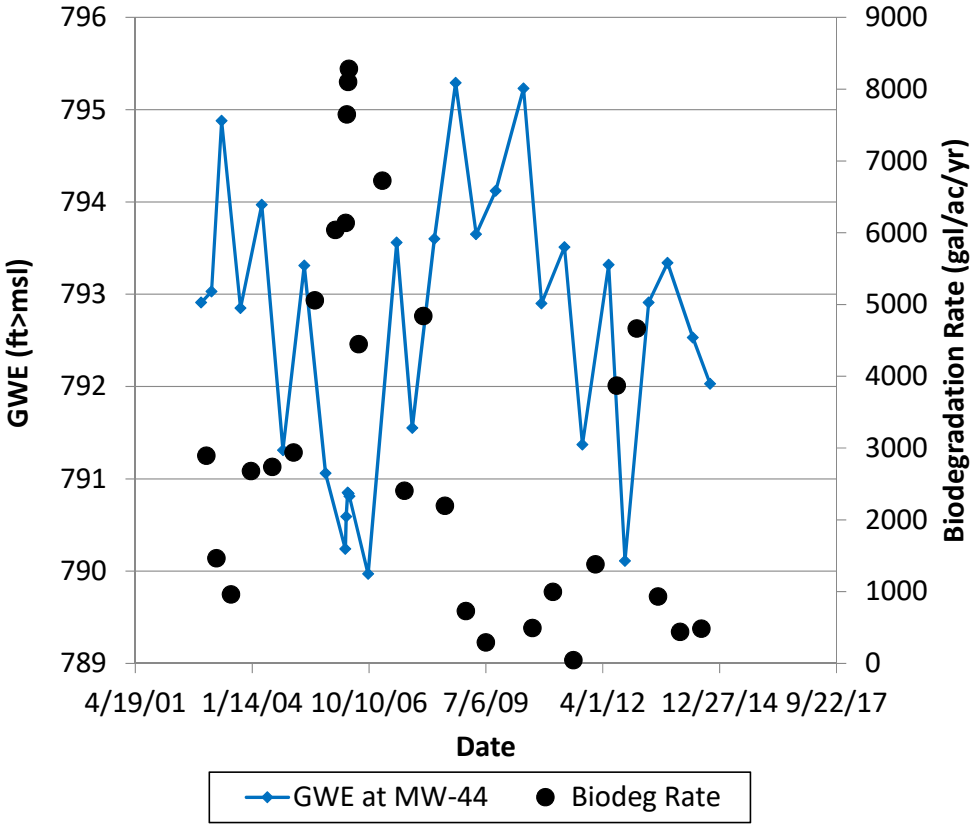
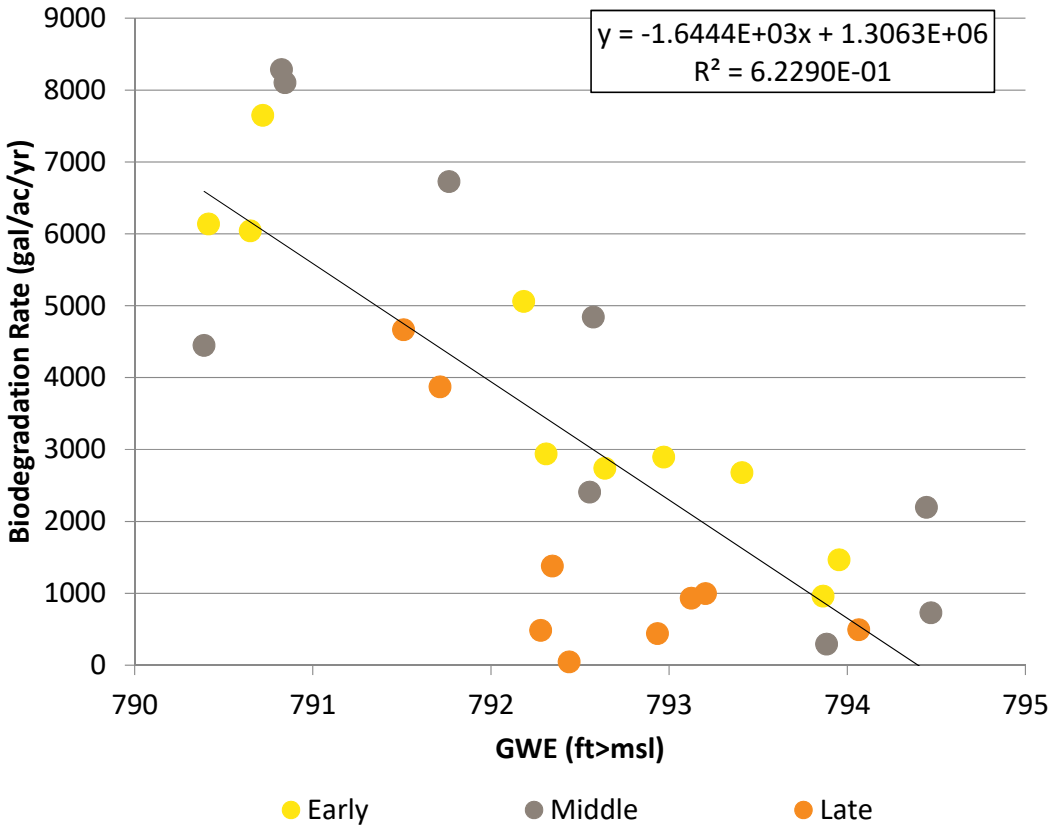
Bioventing and Water Table Fluctuations





Reduction in rate is related to exposed smear zone.

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01

Performance Monitoring

- In-situ respiration tests
- Steady state oxygen utilization
- Temperature

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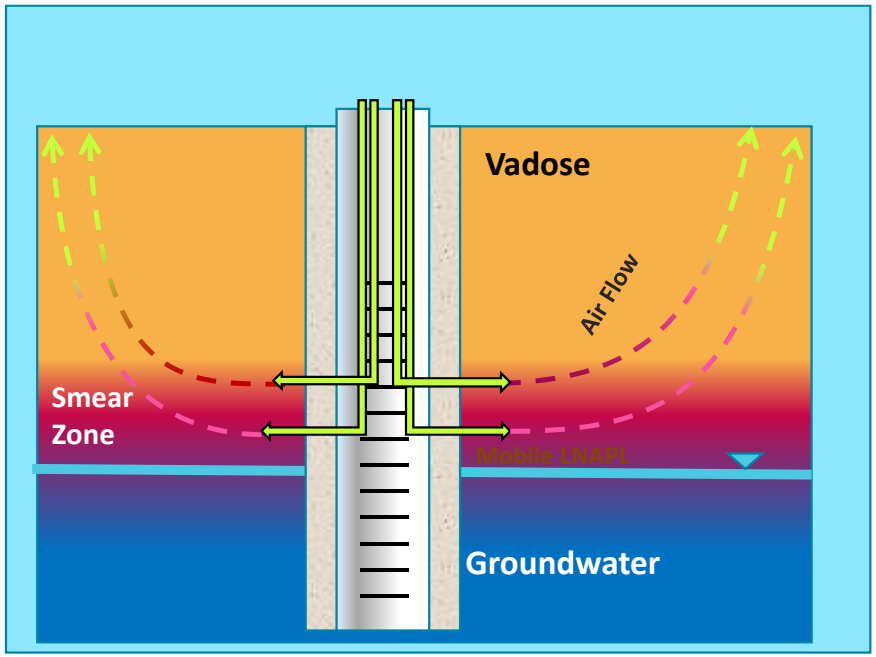
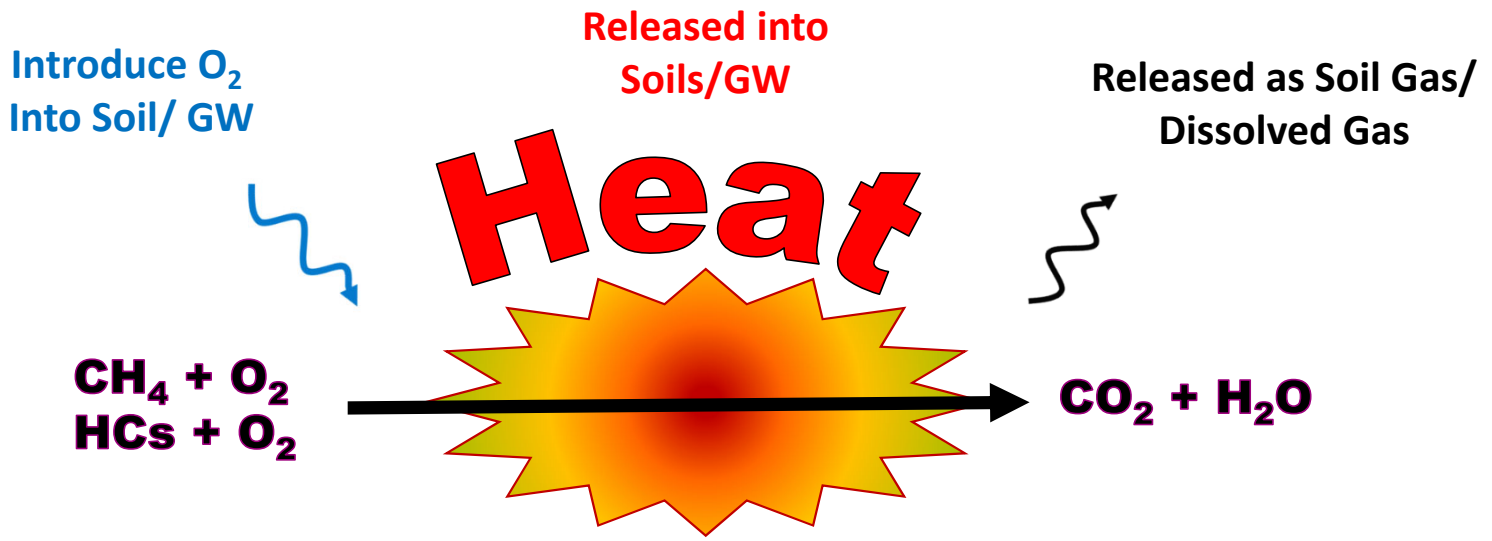
Bioventing

- Injecting/extracting air to create aerobic environment
- Design similar to air-sparge/soil vapor extraction (AS/SVE)
  - Extraction/Injection ROI
  - Oxygen concentration
    - Greater than 5%
- Extraction
  - Treatment may be necessary
  - High quality monitoring data
- Injection
  - No treatment
  - More challenging monitoring
    - Traditional methods



Principles of Bioventing Performance Measurement



Modifed from Ririe (2013)

In-Situ Respiration Rate Test

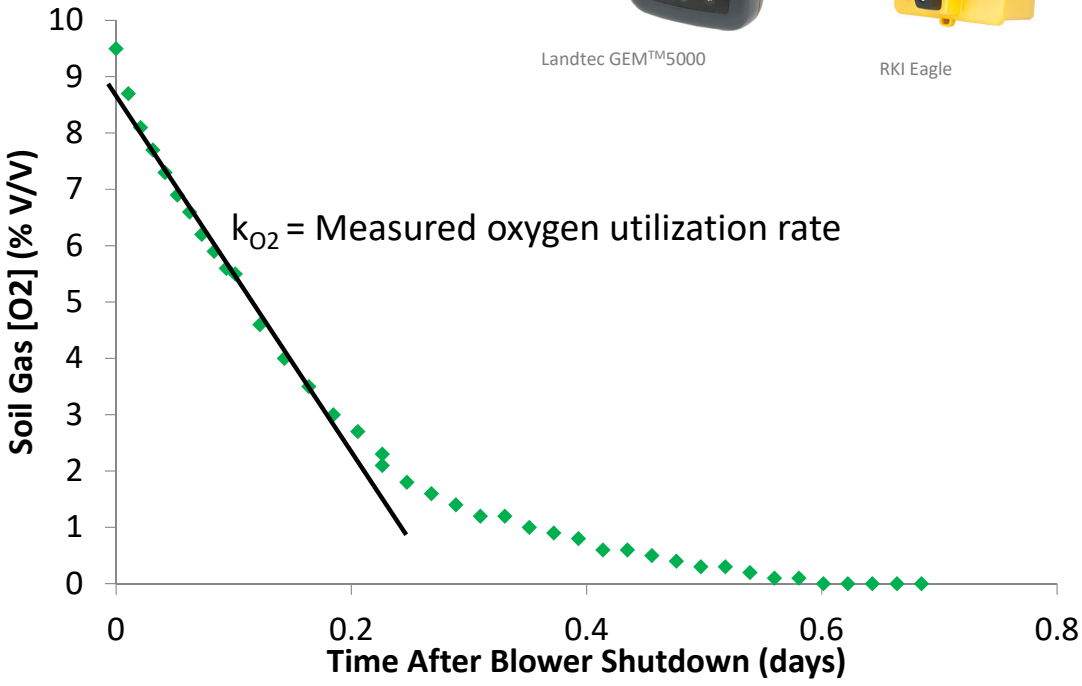
$$k_B = \frac{-k_{O_2}/100 \cdot \theta_g \cdot \rho_{O_2} \cdot S_{O_2}}{\rho_{bulk}}$$

(Leeson and Hinchee 1995)

- k_B = Rate of aerobic biodegradation (mg-HC/kg-soil/day)
- k_{O2} = Measured oxygen utilization rate (vol%-O_2/day)
- θ_g = Gas-filled soil pore space
- S_{O2} = Stoichiometric mass ratio of HC to O_2
- ρ_{O2} = Density of oxygen gas
- ρ_{bulk} = Soil bulk density

Landtec GEM™5000

RKI Eagle



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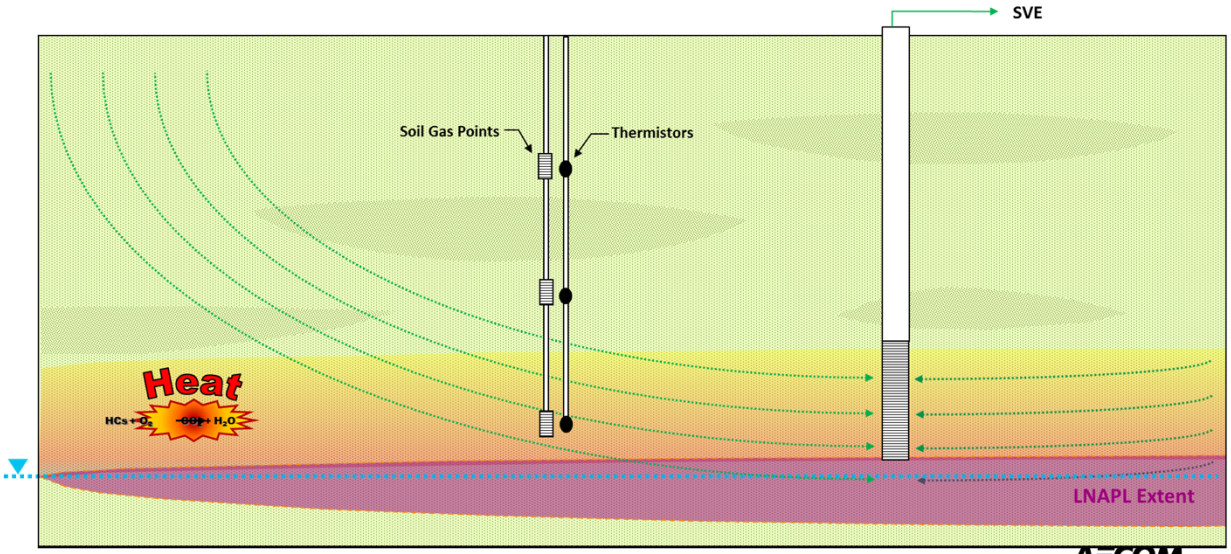
Biodegradation Rates while Operating
Steady State

- Extraction
  - At intake, measure
    - Flowrate
    - O_2, CO_2, and CH_4 concentrations
- Injection
  - Measure
    - Flowrate of system
    - O_2, concentrations at soil gas monitoring points

Mass of hydrocarbons degraded per day using O_2

$$HC_{bio} = \left(\frac{C_{V,bkgd} - C_{V,O_2}}{100}\right) \times Q \times C \times \rho_{O_2} \times MW_{O_2} \times \frac{kg}{1{,}000\ g} \times \frac{1{,}440\ min}{day} \qquad \text{(Eq. 3-2)}$$

USEPA, 1995



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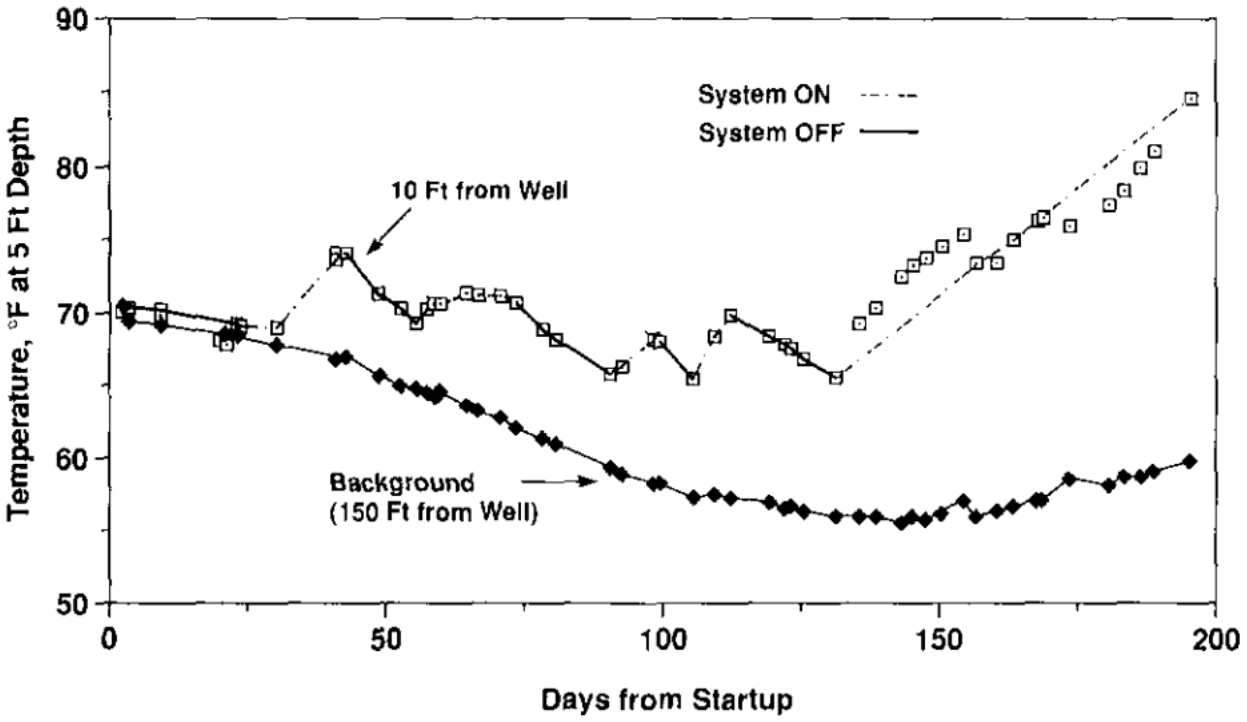
Heat Generation from Biodegradation



Mohr and Merz 1995

Quantifying bioremediation rates
Mohr and Merz 1995
Subramanian et al. 2012
Sweeney et al. 2013

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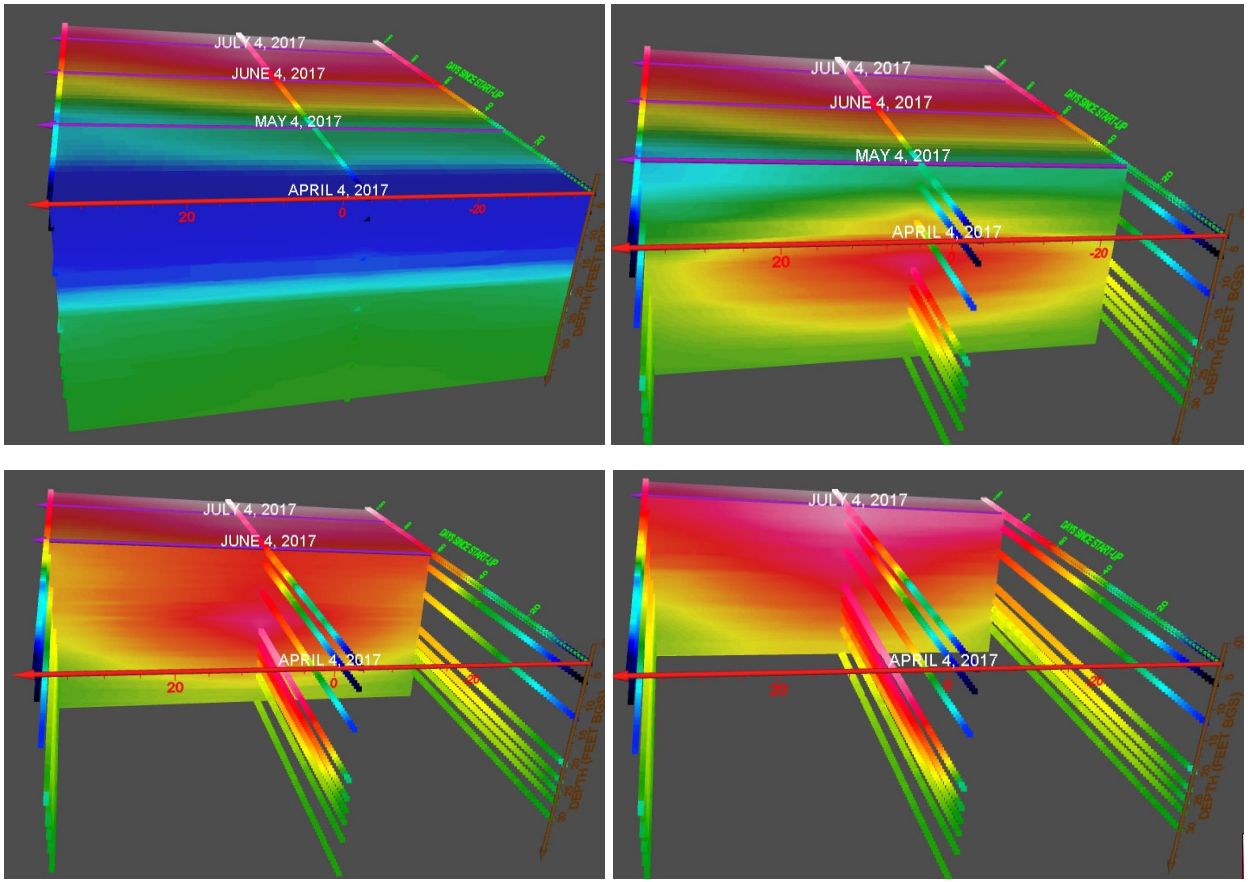
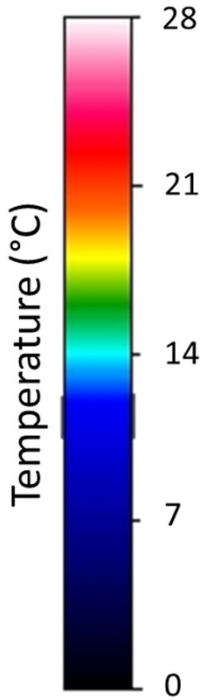
Subsurface Temperature During Bioventing





Created by and provided courtesy of Andrew Kirkman

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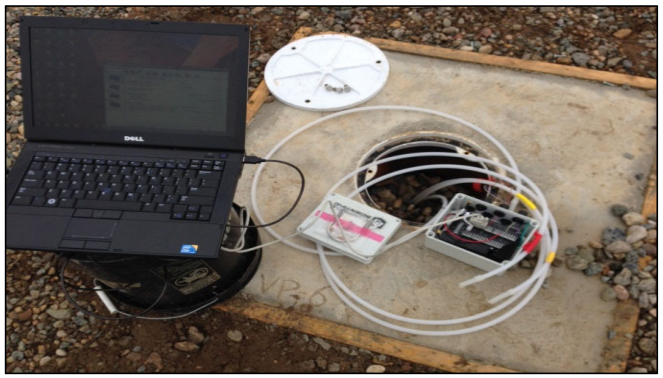
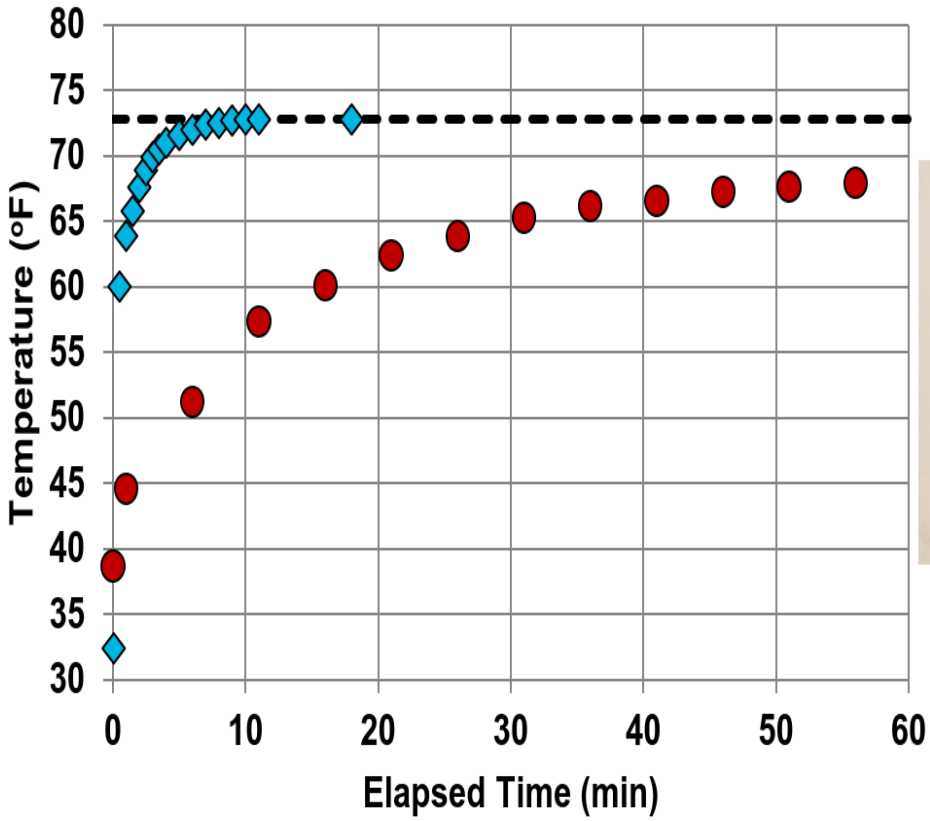
Soil Temperature Measurement Devices



MadgeTec Thermocouple

Campbell Scientific Data Logger



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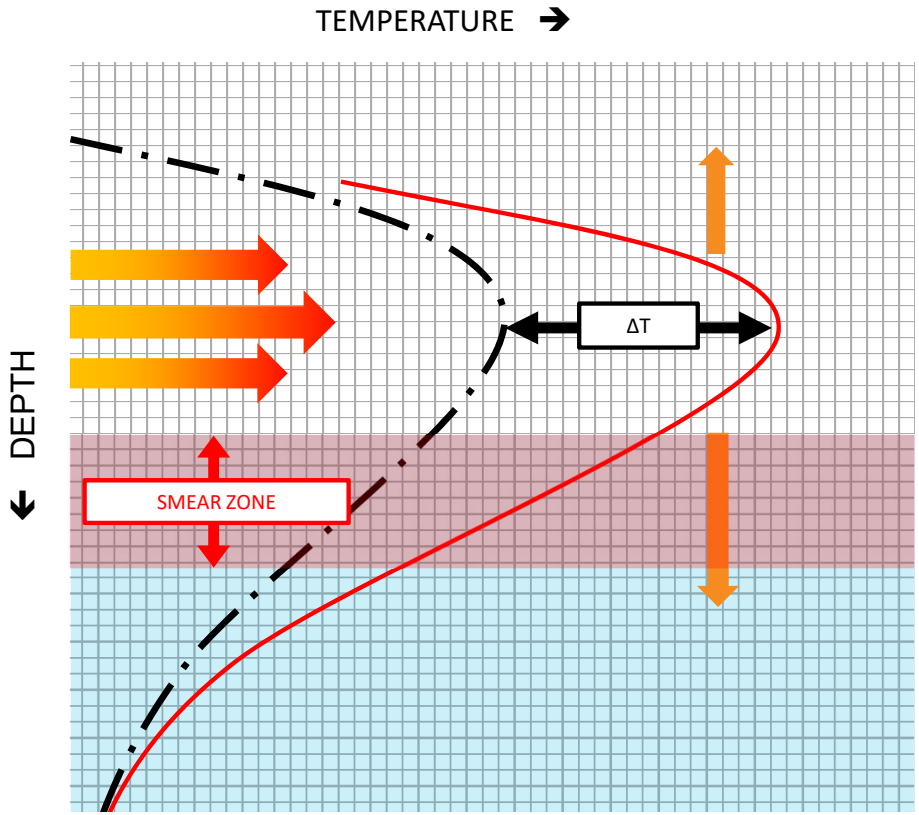
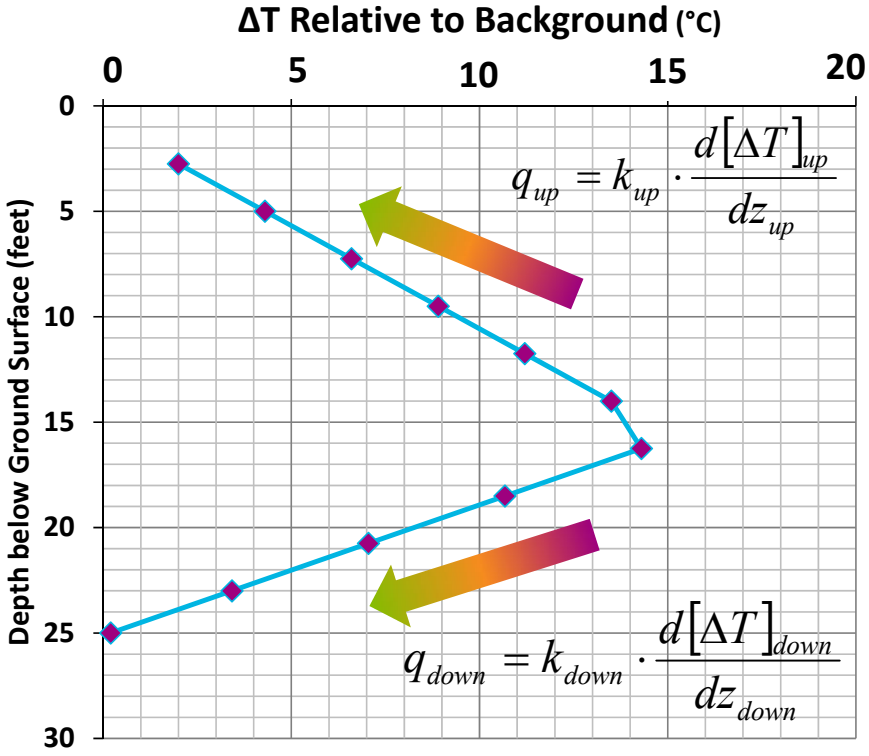
Heat Flux Model





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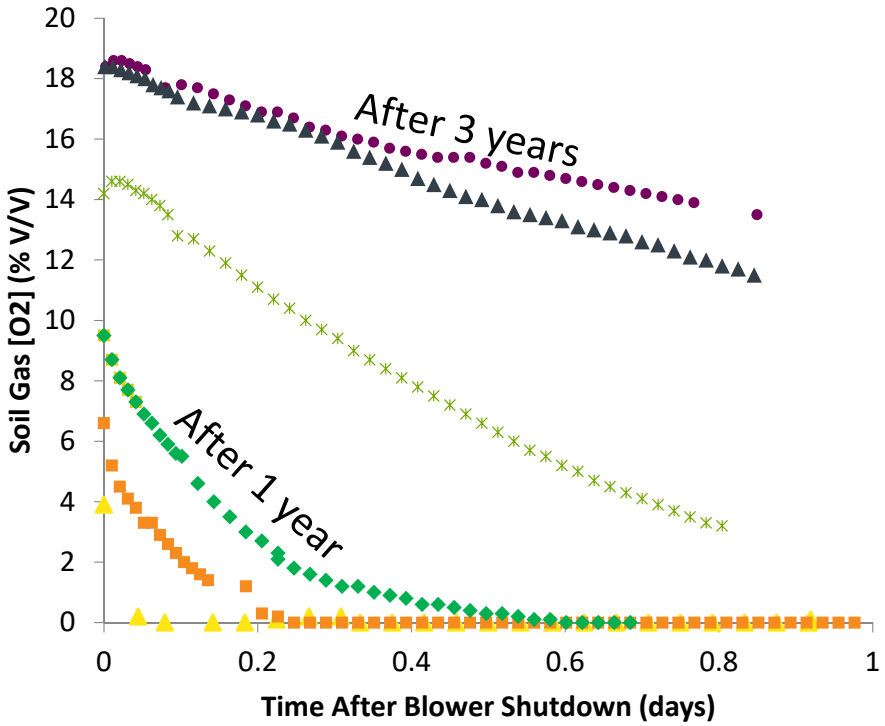
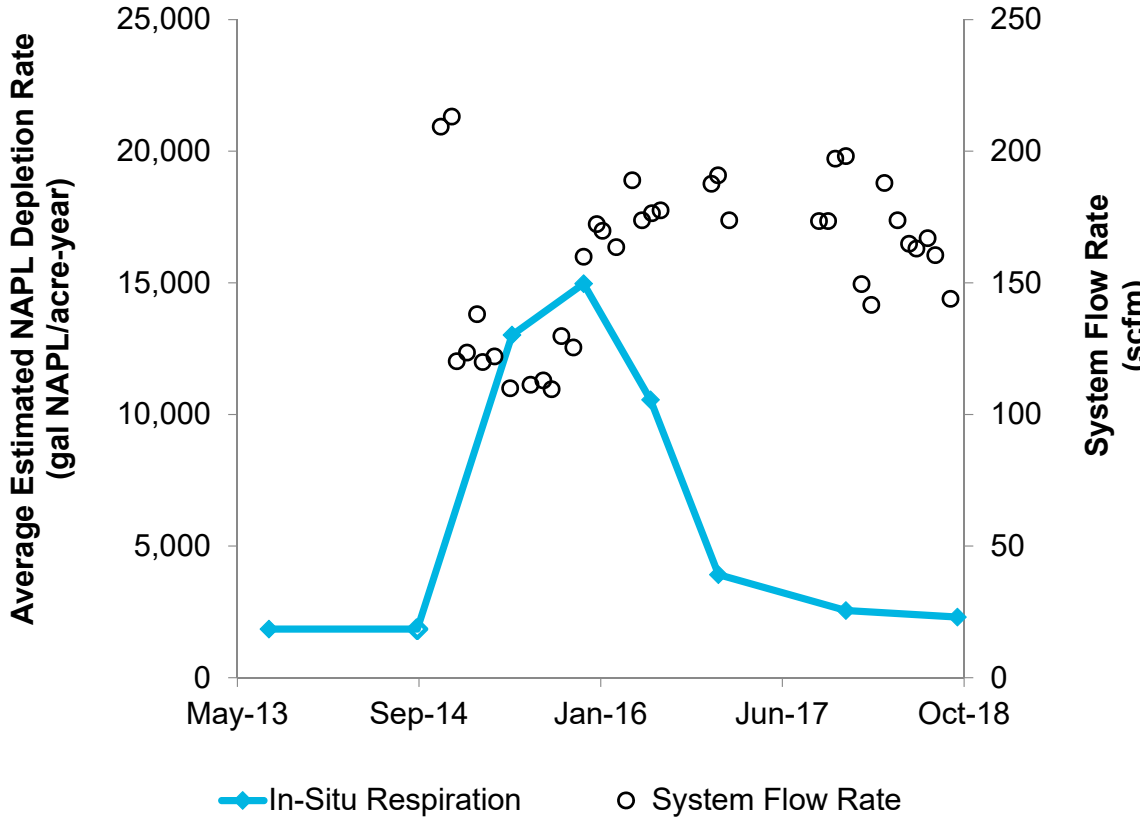
Insitu Respiration Tests





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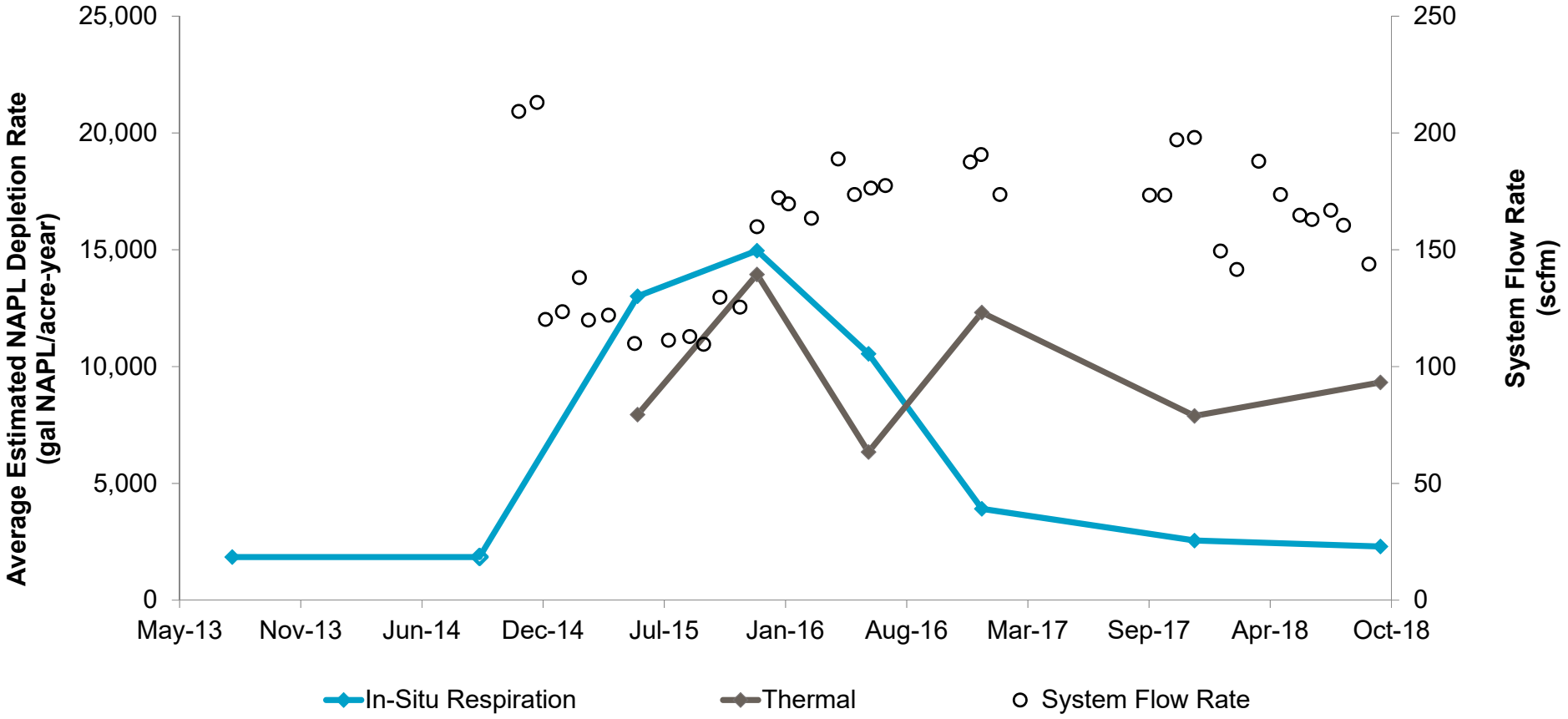
In-situ Respiration vs. Thermal



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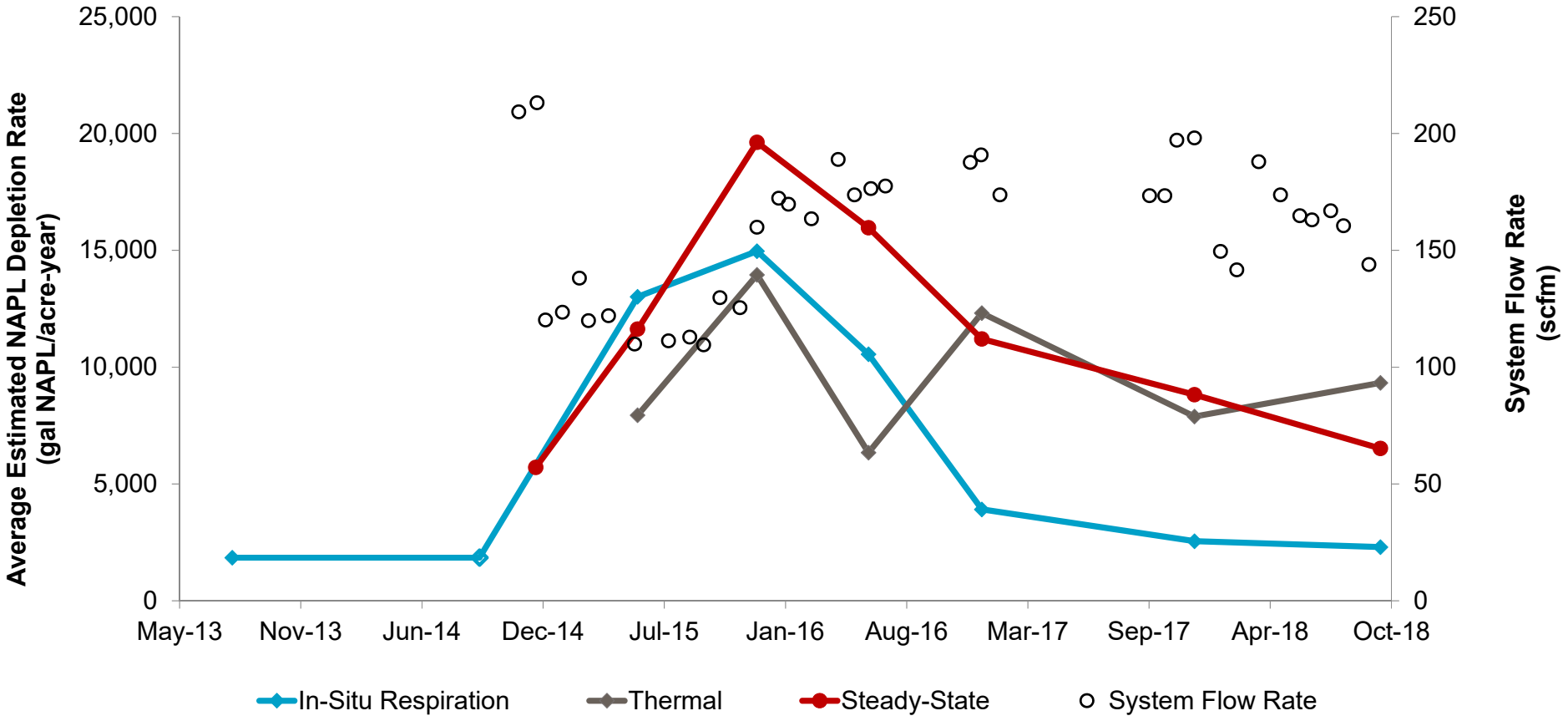
In-situ Respiration vs. Thermal vs. Steady State



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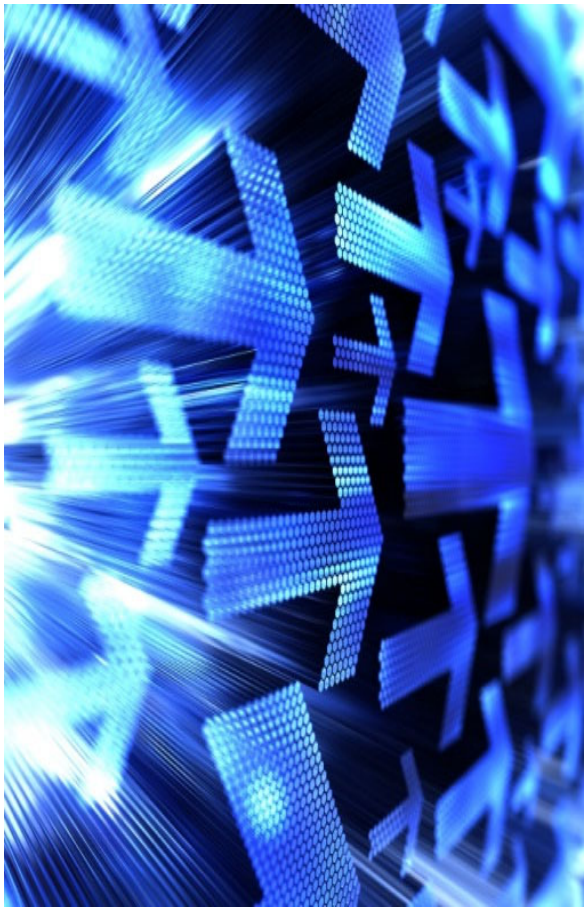
Conclusions

- Bioventing enhances natural biodegradation
- Bioventing often outperforms hydraulic LNAPL recovery
  - Accessible smear zone is a key consideration
- Bioventing is a viable remedy for addressing mobile LNAPL (if needed)
  - Not satisfactory to control imminent migration or dissolved phase concerns
- New performance monitoring techniques for injection systems improve understanding



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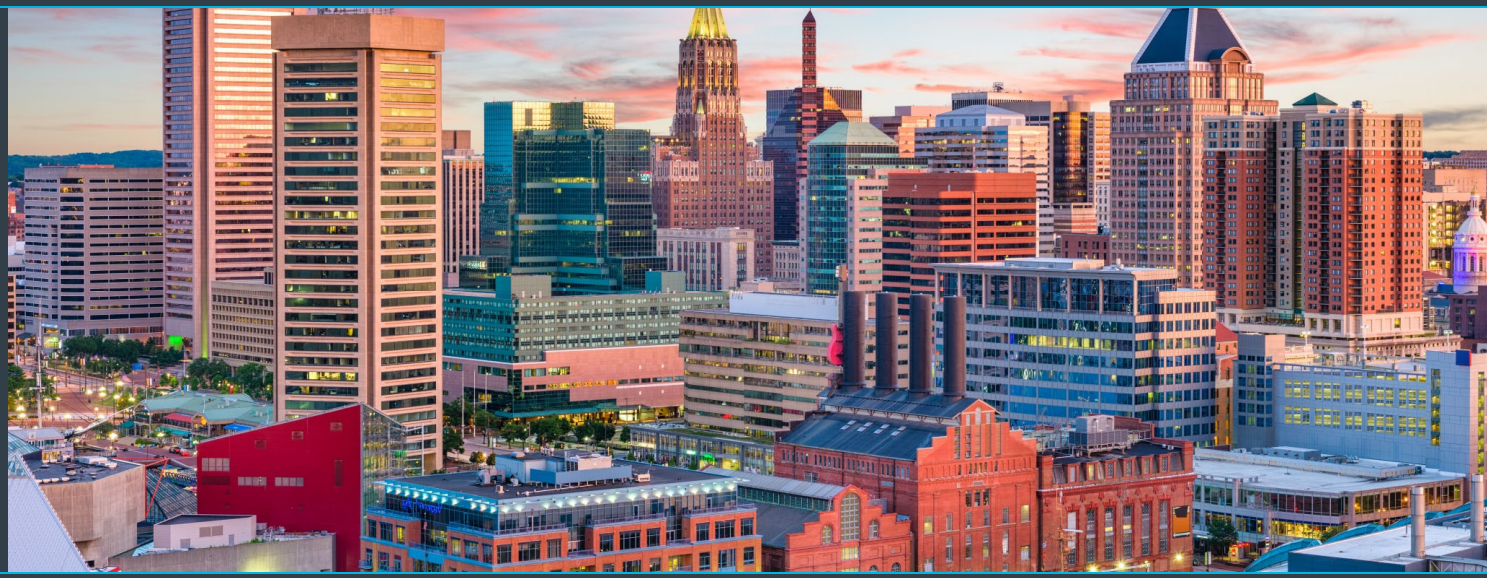

Thank You!

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