Enhancing Biodegradation of LNAPL with Bioventing

National Tanks Conference

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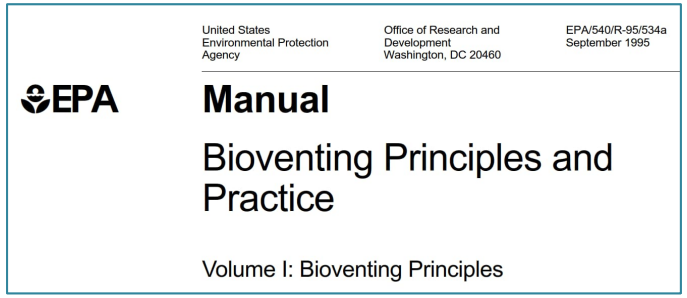
Introduction

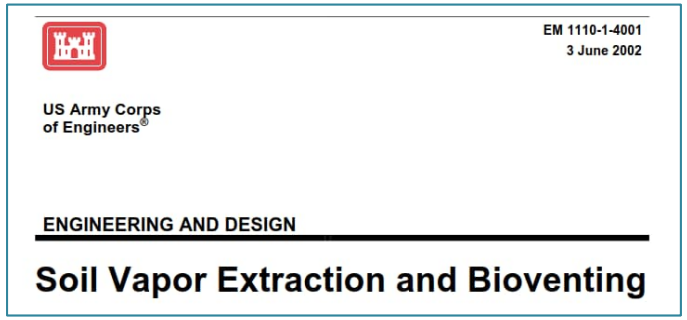

United States Environmental Protection Agency | Office of Research and Development Washington, DC 20460 | EPA/540/R-95/534a September 1995

EPA

Manual

Bioventing Principles and Practice

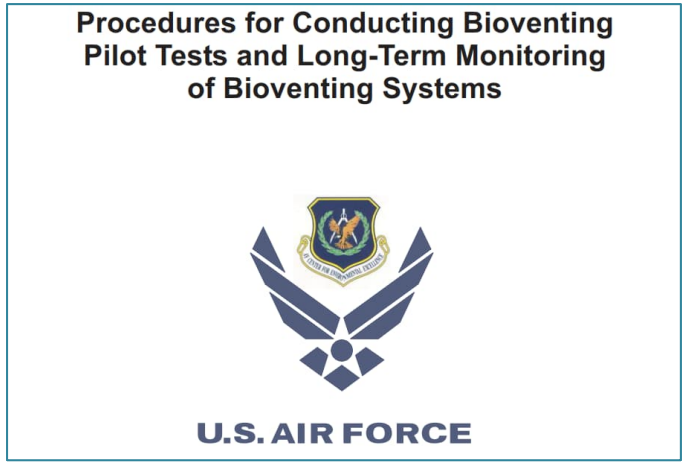
Volume I: Bioventing Principles


EM 1110-1-4001
3 June 2002

US Army Corps of Engineers®

ENGINEERING AND DESIGN

Soil Vapor Extraction and Bioventing


Procedures for Conducting Bioventing Pilot Tests and Long-Term Monitoring of Bioventing Systems

U.S. AIR FORCE

Bioventing

Aeration of unsaturated zone soils to stimulate in situ biodegradation of hydrocarbons.

Several Possible Configurations

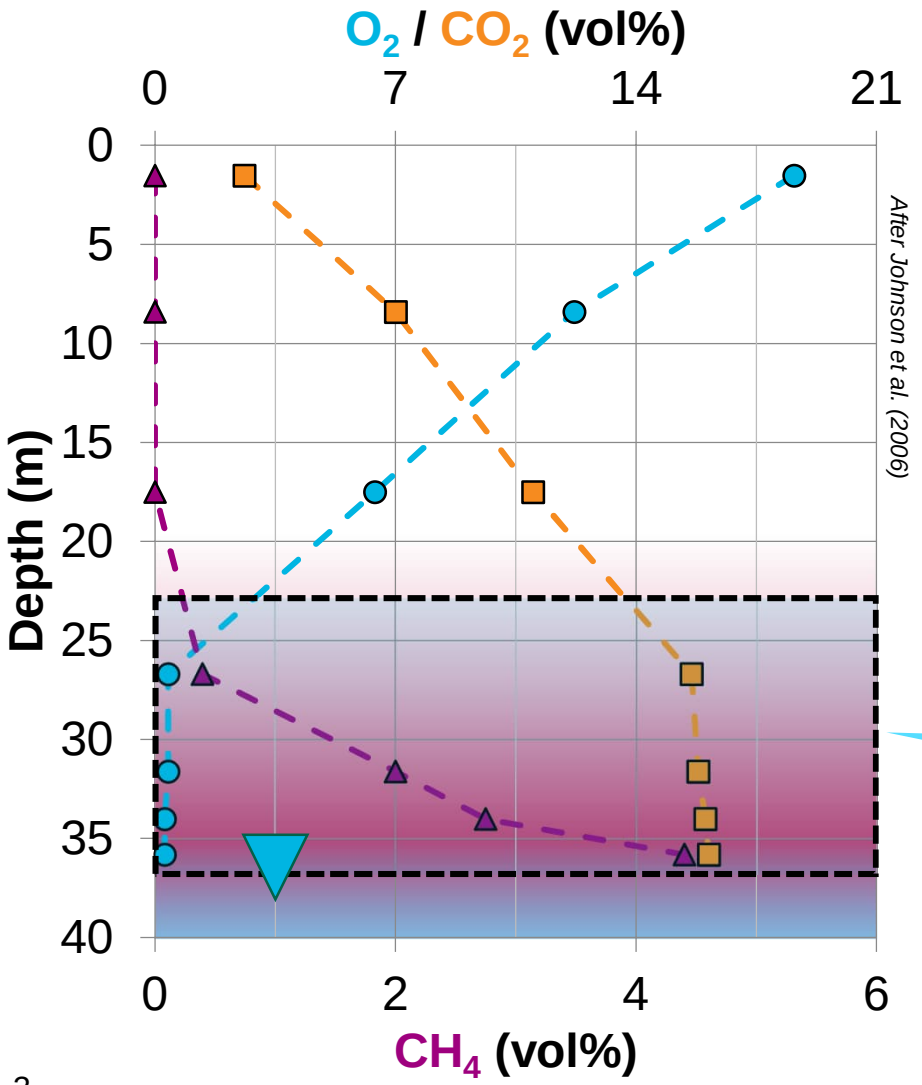
- Air injection or extraction (or combination)
- Passive/natural pressure-driven (ESTCP, 2006)

Potential Remedial Goals

- Depletion of LNAPL (saturation reduction)
- Reduce fraction of specific constituents (composition change)
- Enhanced Biodegradation of VOCs for PVI protection.

Application to mobile and residual LNAPL is a more recent concept (ITRC, 2018)

Bioventing as Enhanced NSZD?



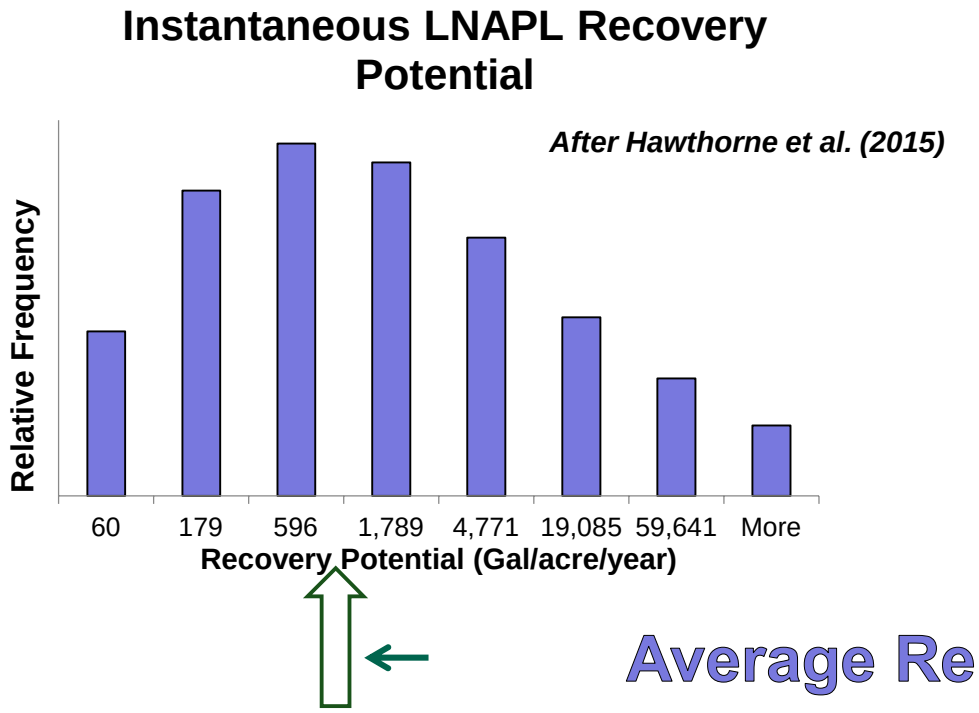
- A basic check for bioventing effectiveness is to determine if the system is oxygen limited
- Oxygen depletion is a result of NSZD
- Oxygen is consumed by petroleum degraders and methanotrophs
- Bioventing supports both microbial communities

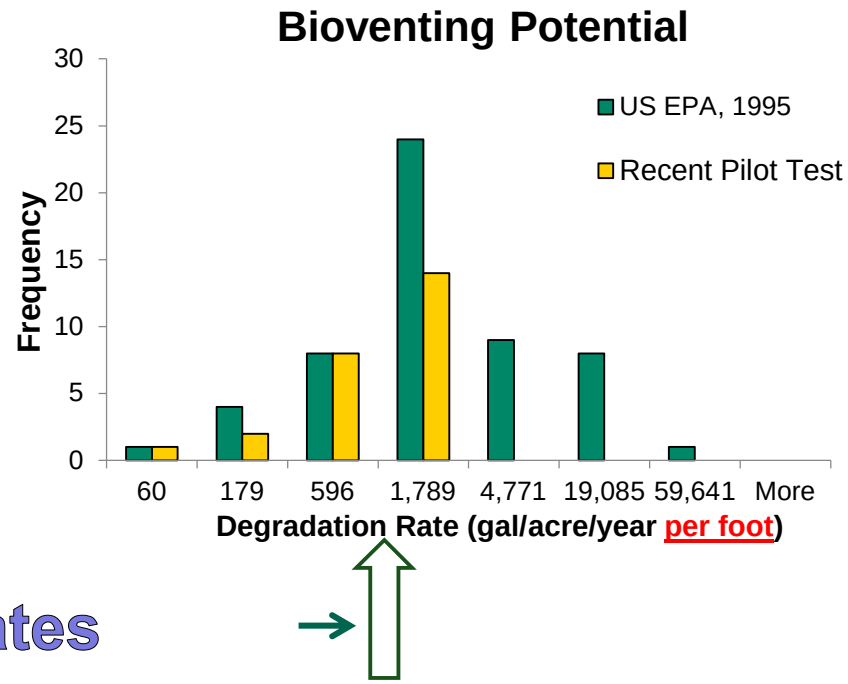
Oxygen Limited Zone

Historical Bioventing Literature

- 1995 EPA Bioventing Manual
- Presented information on US Air Force bioventing initiative
- Bioventing respiration rates at 48 facilities were tabulated
- Several sites included initial, 6-month and 1-year respiration data

Comparison to Hydraulic Recovery Potential





Average Removal Rates

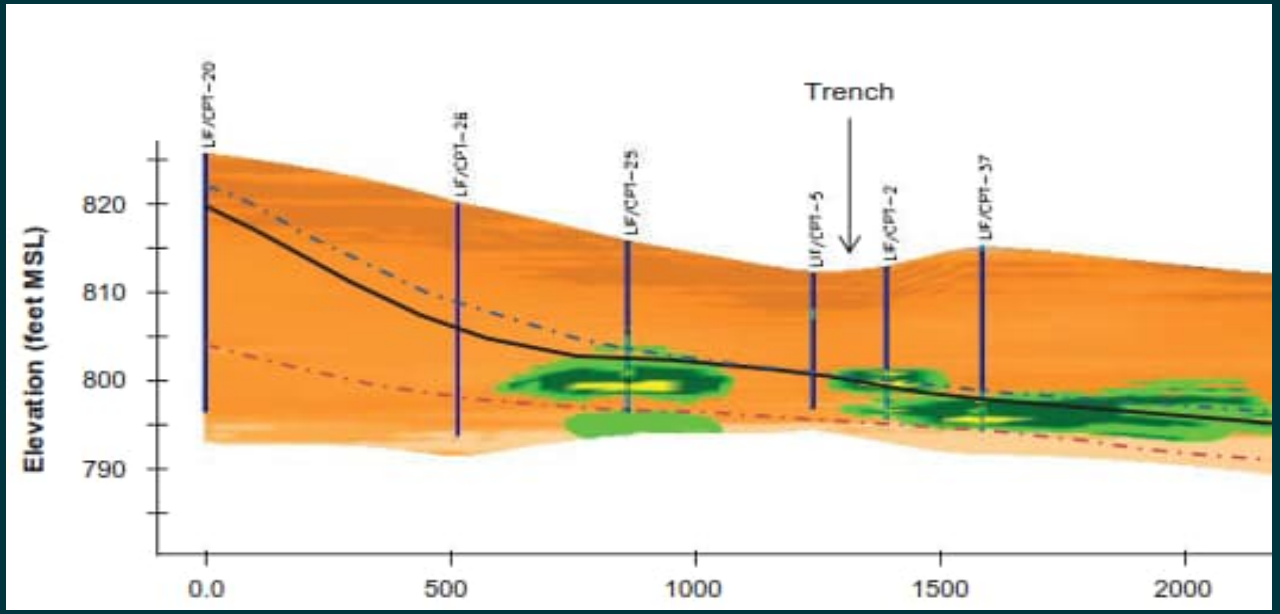
- Average **INITIAL** LNAPL recovery rate ~ Average Bioventing rate **FOR 1 FOOT OF SOIL TREATMENT**
- Microbes are not limited by concentration of LNAPL (i.e., too toxic)
- Limited by nutrients, water content, composition of LNAPL

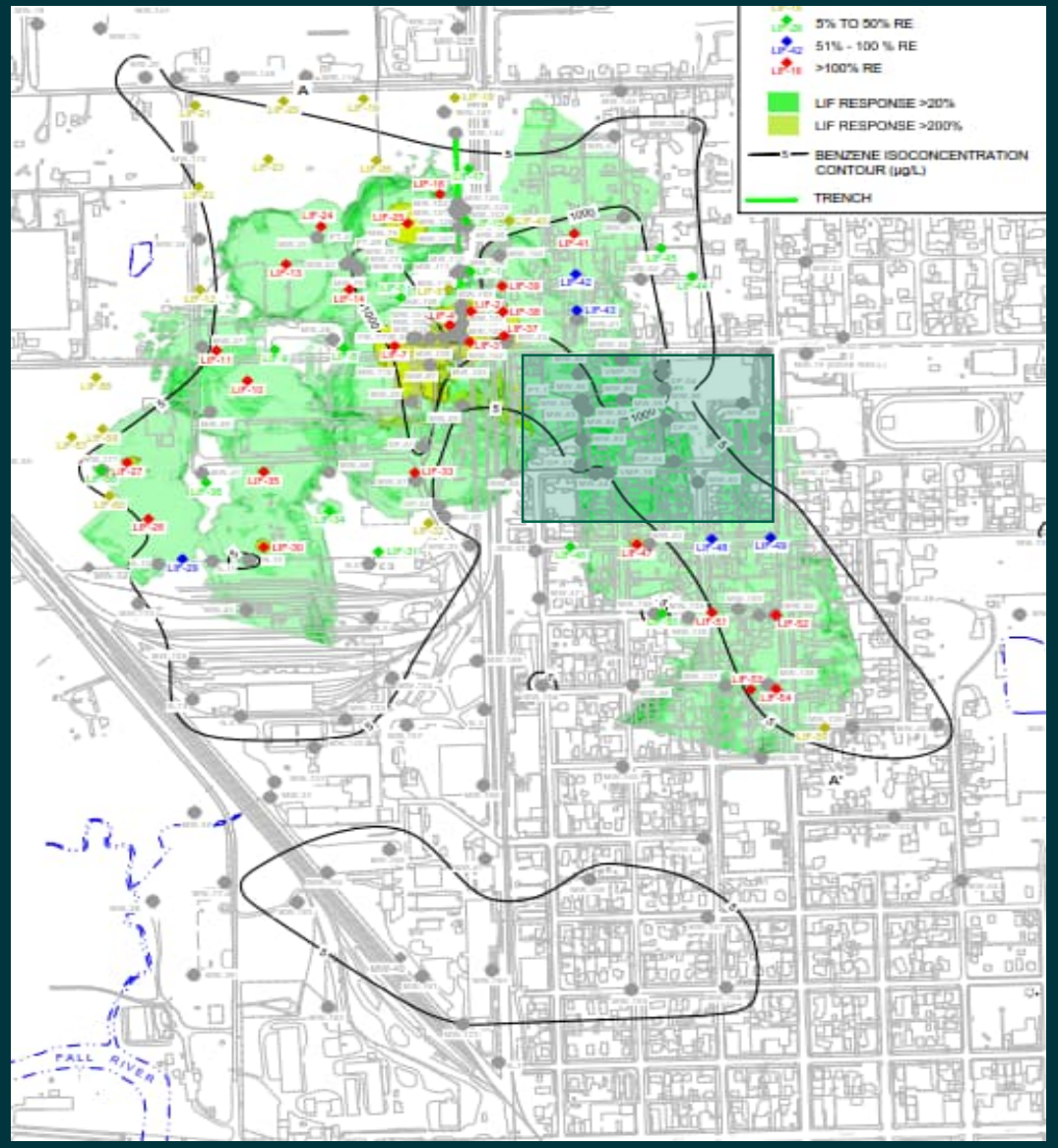
Data Sources Represent API Tn Database & AFCEE Bioventing Database

Bioventing with Mobile LNAPL?

MPE System Operated at Former Refinery

- Gasoline in channel deposits
- 6.5-acre remediation system operated 13 years
  - Groundwater, LNAPL, and soil gas extracted:
  - 8 recovery wells and a trench





Bioventing with Mobile LNAPL?

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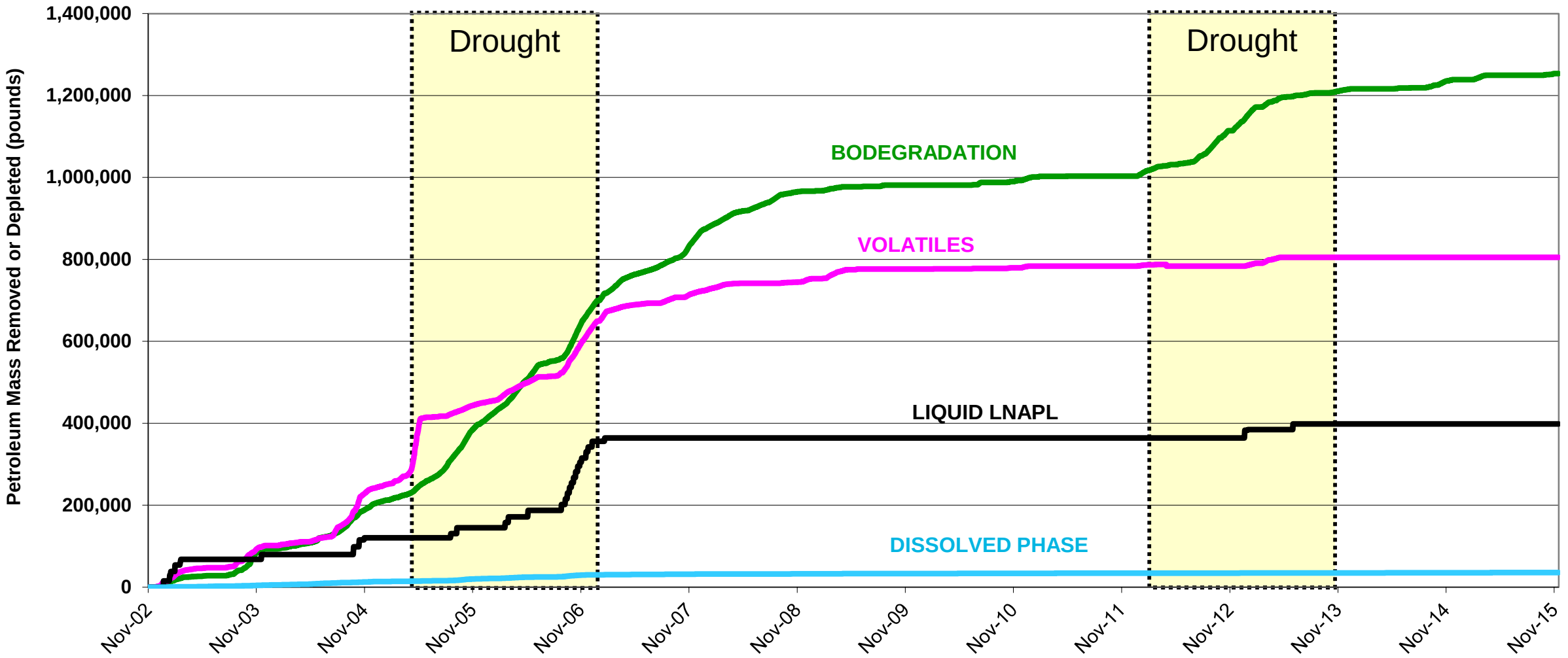
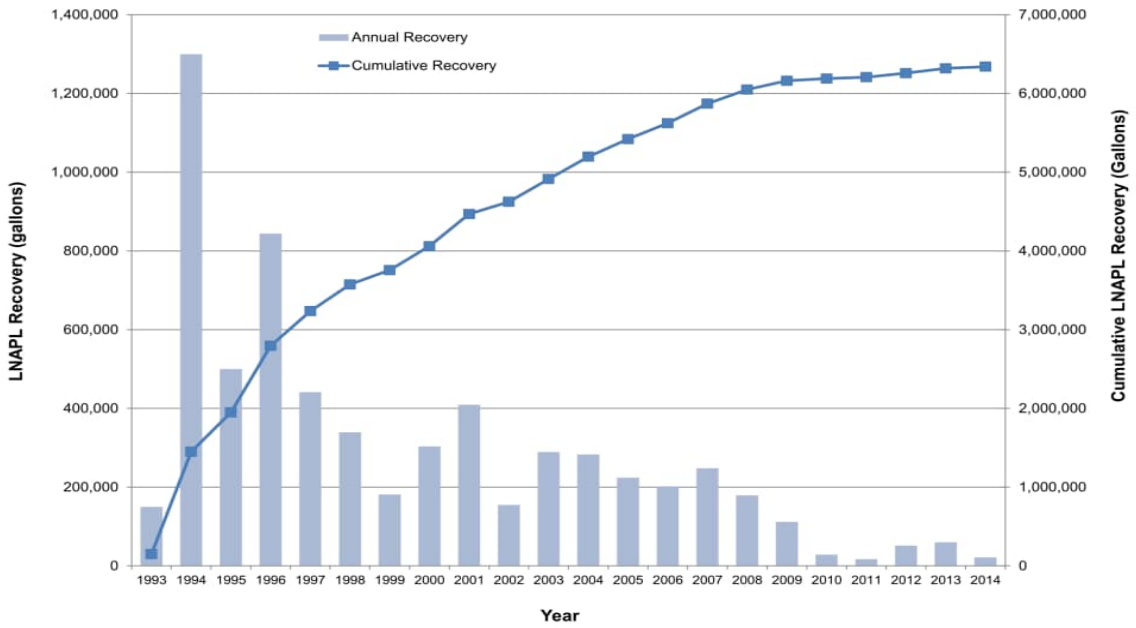
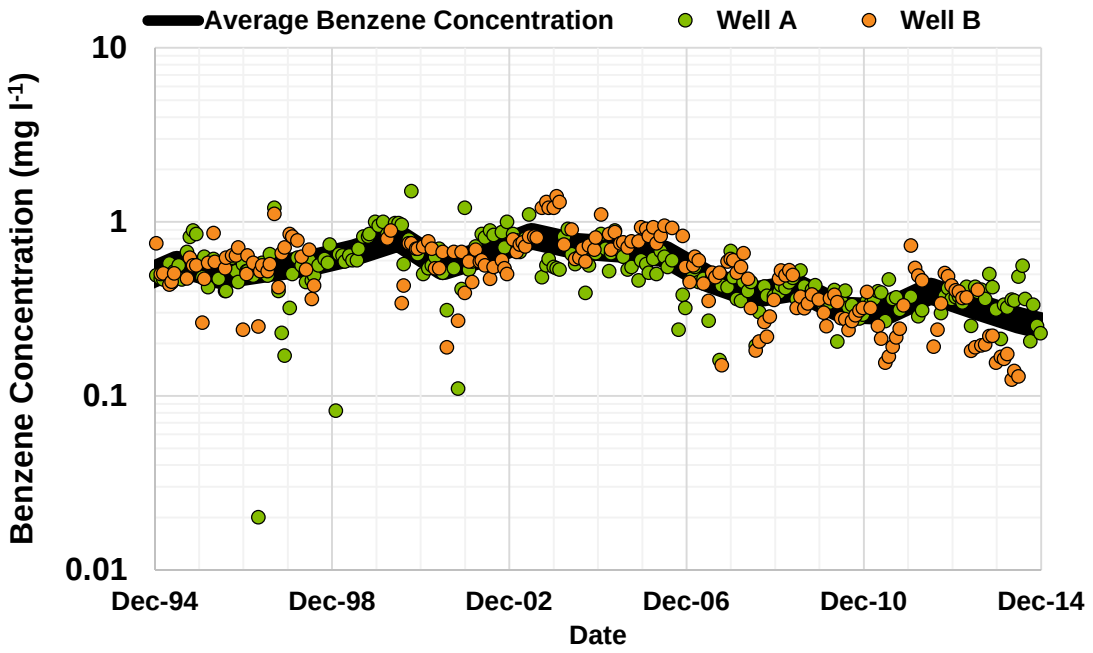


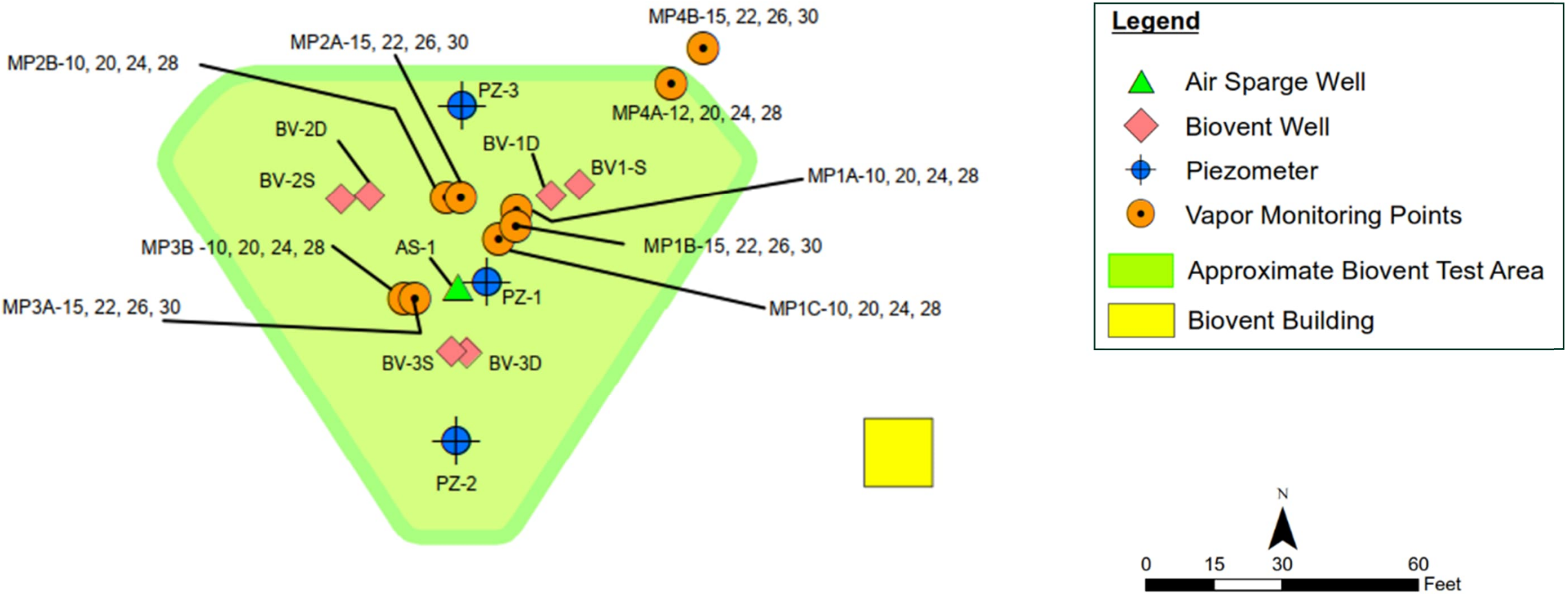
Case Study

- Site Conditions
  - Fine-grained soils overlying sand
  - Water table ~ 30 ft bgs
    - Fluctuates from 24 to 31 ft bgs
  - LNAPL Smear Zone extends 10 to 20 feet above water table
- Historical Remedial Actions
  - LNAPL Recovery
  - Groundwater Pumping
- Remedial Goals
  - Recover LNAPL to MEP
  - Reduce Benzene in Groundwater
- Challenges
  - Asymptotic LNAPL recovery
  - Benzene persistent in GW

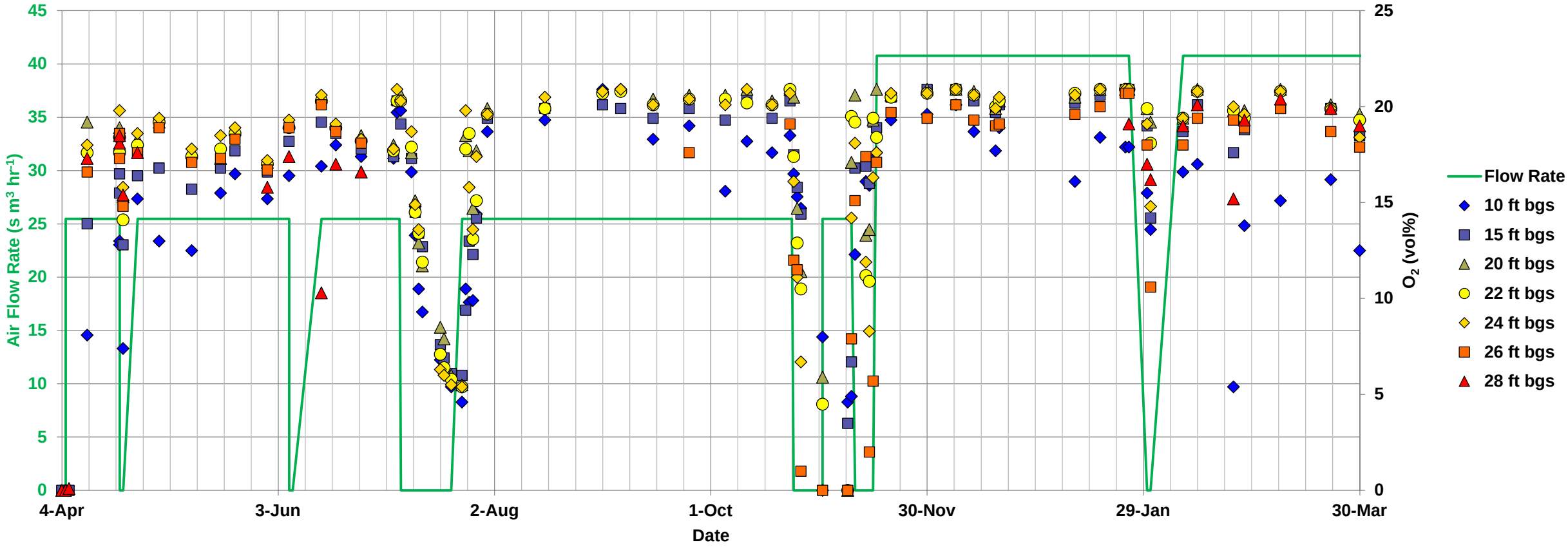




Bioventing Test Layout



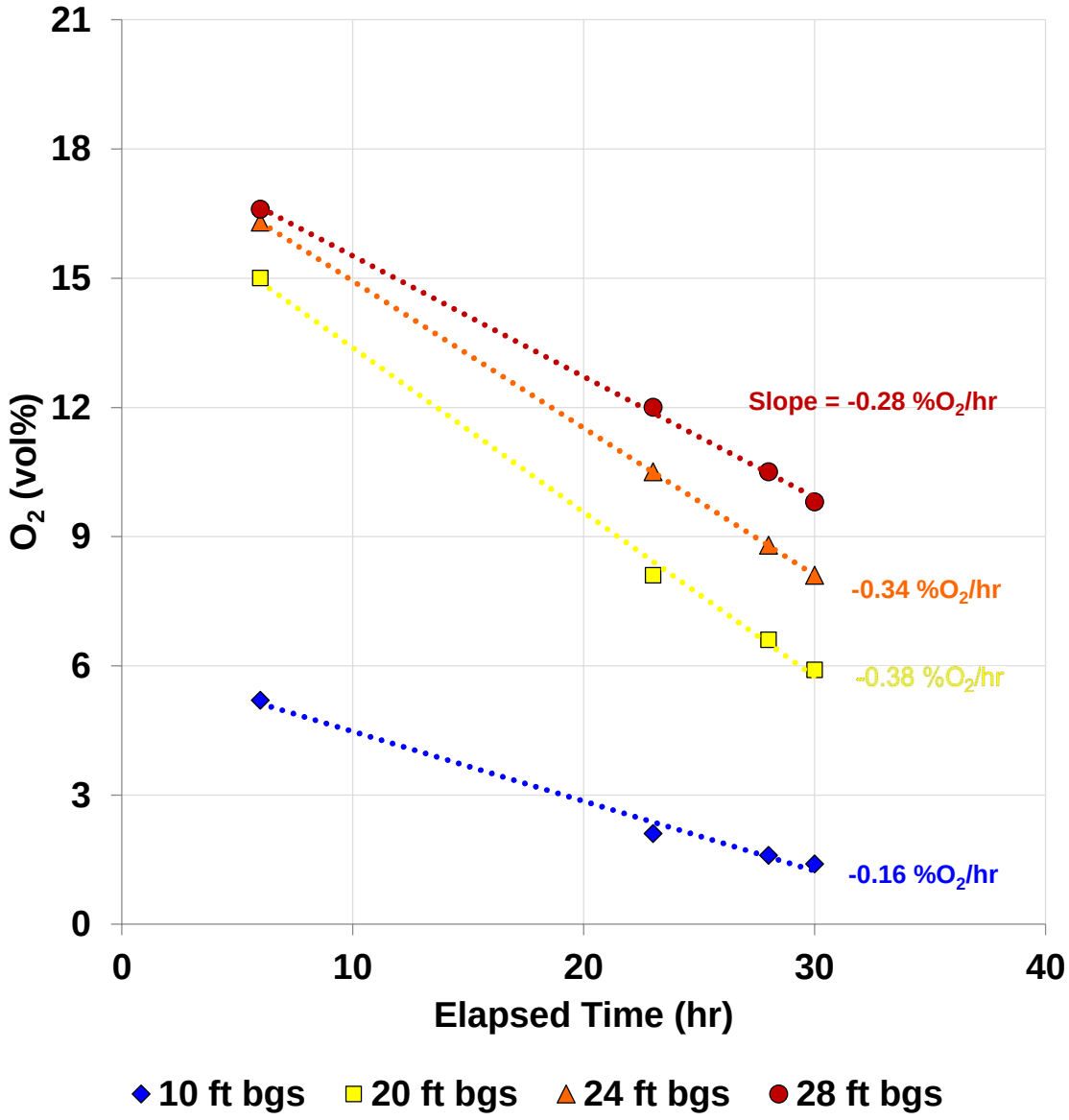
Performance Monitoring – Oxygen Distribution



- Routine monitoring during system operation
  - Verify adequate O_2 throughout target ZOI
  - Increased O_2 during air injection
  - O_2 declines during down-time

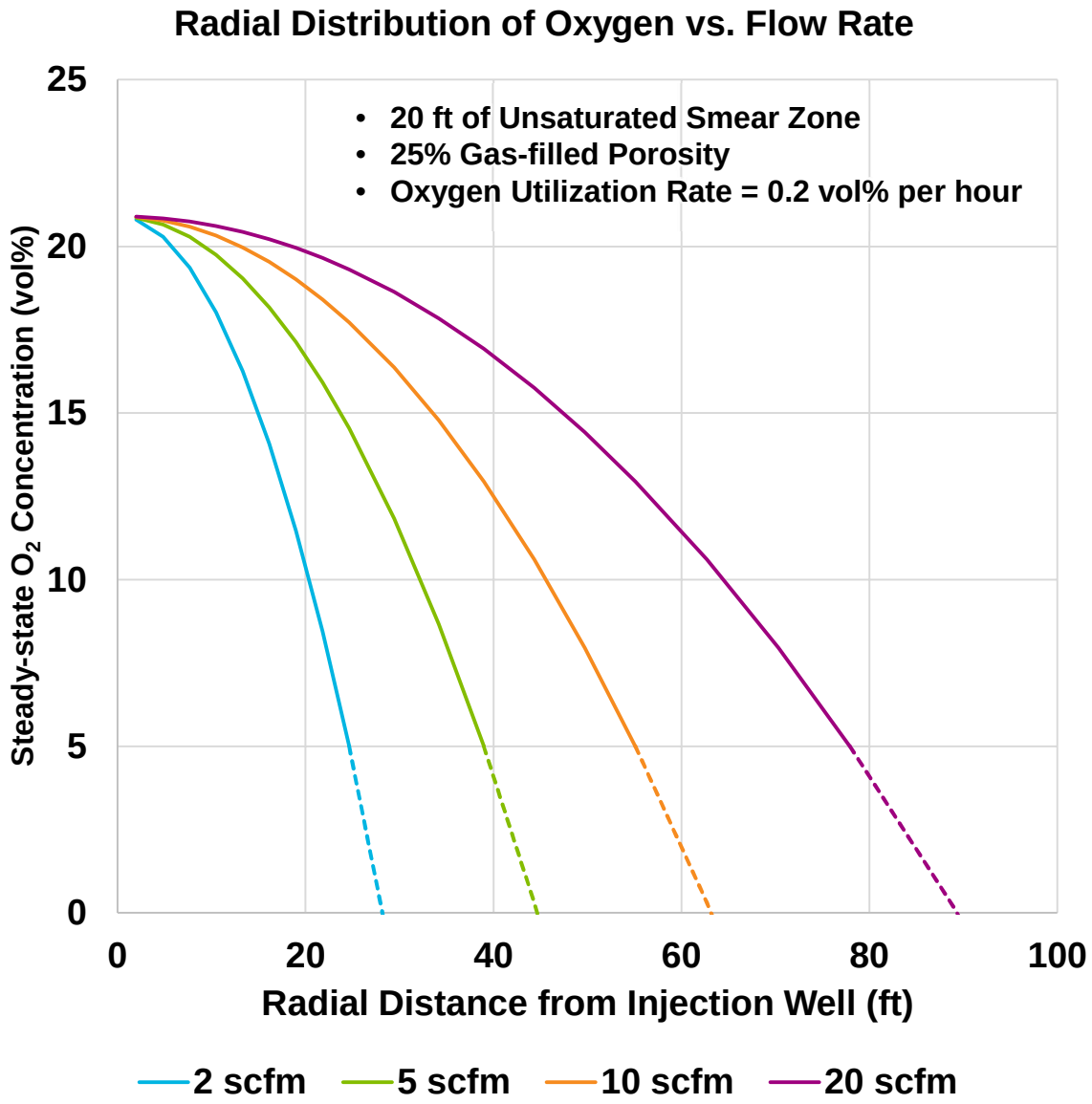
$$HCs + O_2 \longrightarrow CO_2 + H_2O$$

Performance Monitoring – Respiration Testing



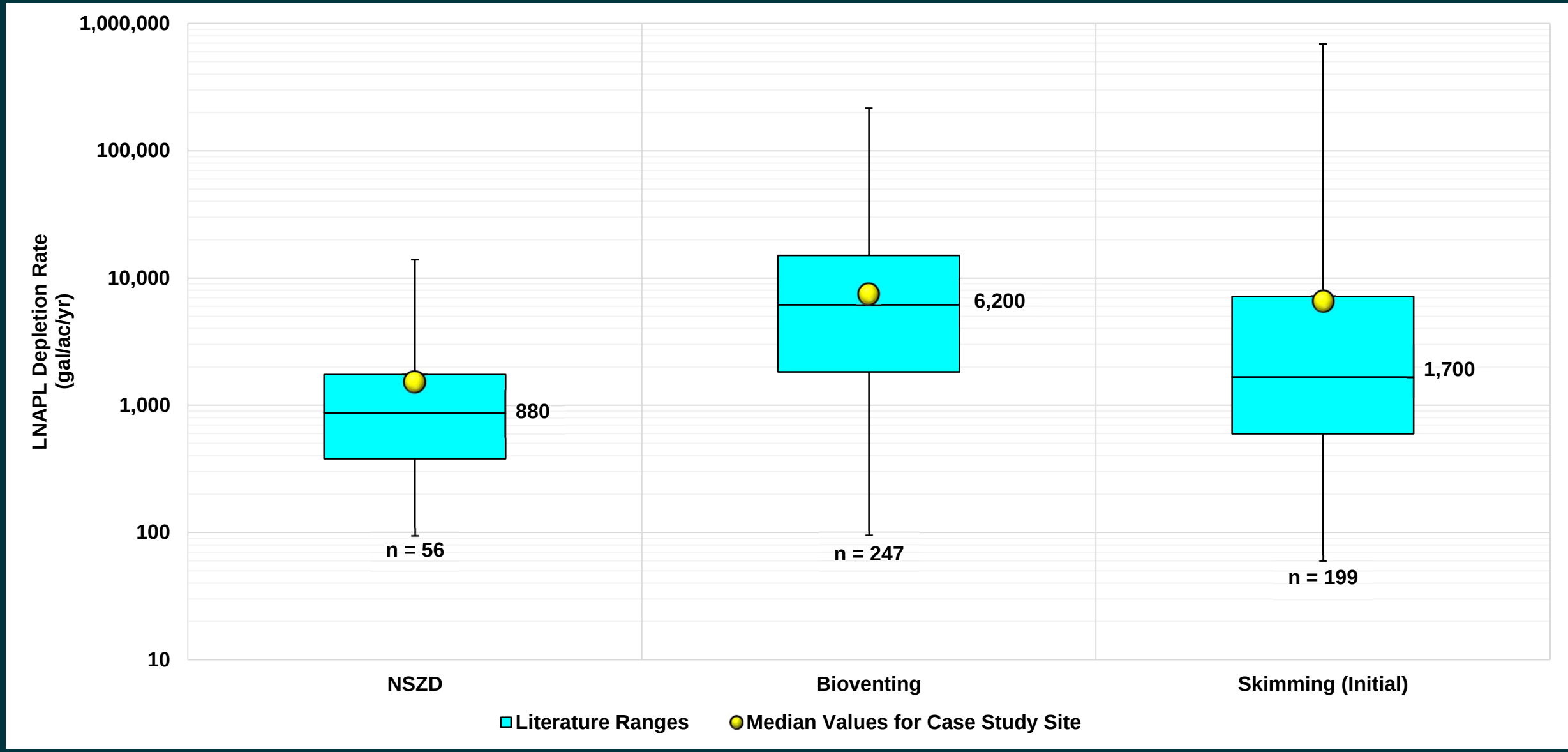
- Stop air injection (time = 0)
- Monitor decline in O_2 concentrations
  - O_2 consumed in aerobic oxidation of hydrocarbons
- Oxygen utilization rate is the slope of the oxygen concentration versus time data.
- Biodegradation rate is proportional to oxygen utilization rate
  - See EPA (1995) for stoichiometric relationships and calculation procedures

Performance Monitoring – Steady State



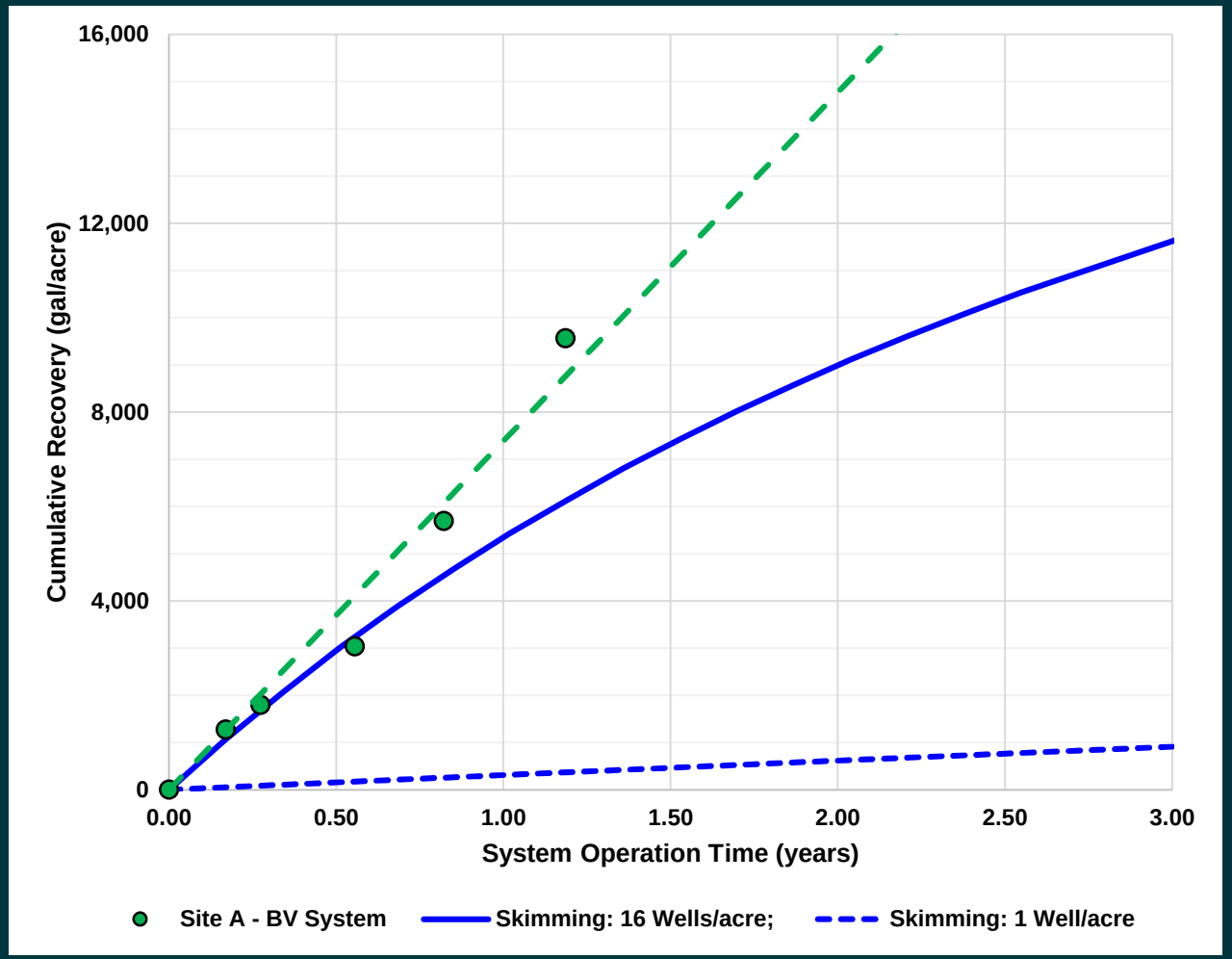
- System design flow rates to maintain adequate oxygen
  - Ideally, O_2 is not rate-limiting (typically > 5 vol%)
  - Replenish O_2 at rate that matches/exceeds utilization rate
- Routine Performance Monitoring
  - Verify adequate O_2 throughout target ZOI,
  - Estimate O_2 utilization rates from steady state distribution
  - Reduce System Down Time
- More Complex Flow Geometry
  - Residence Time Distribution from Tracer Tests
  - Air Flow Modeling (Kirkman et al., 2023)

LNAPL Depletion Rates

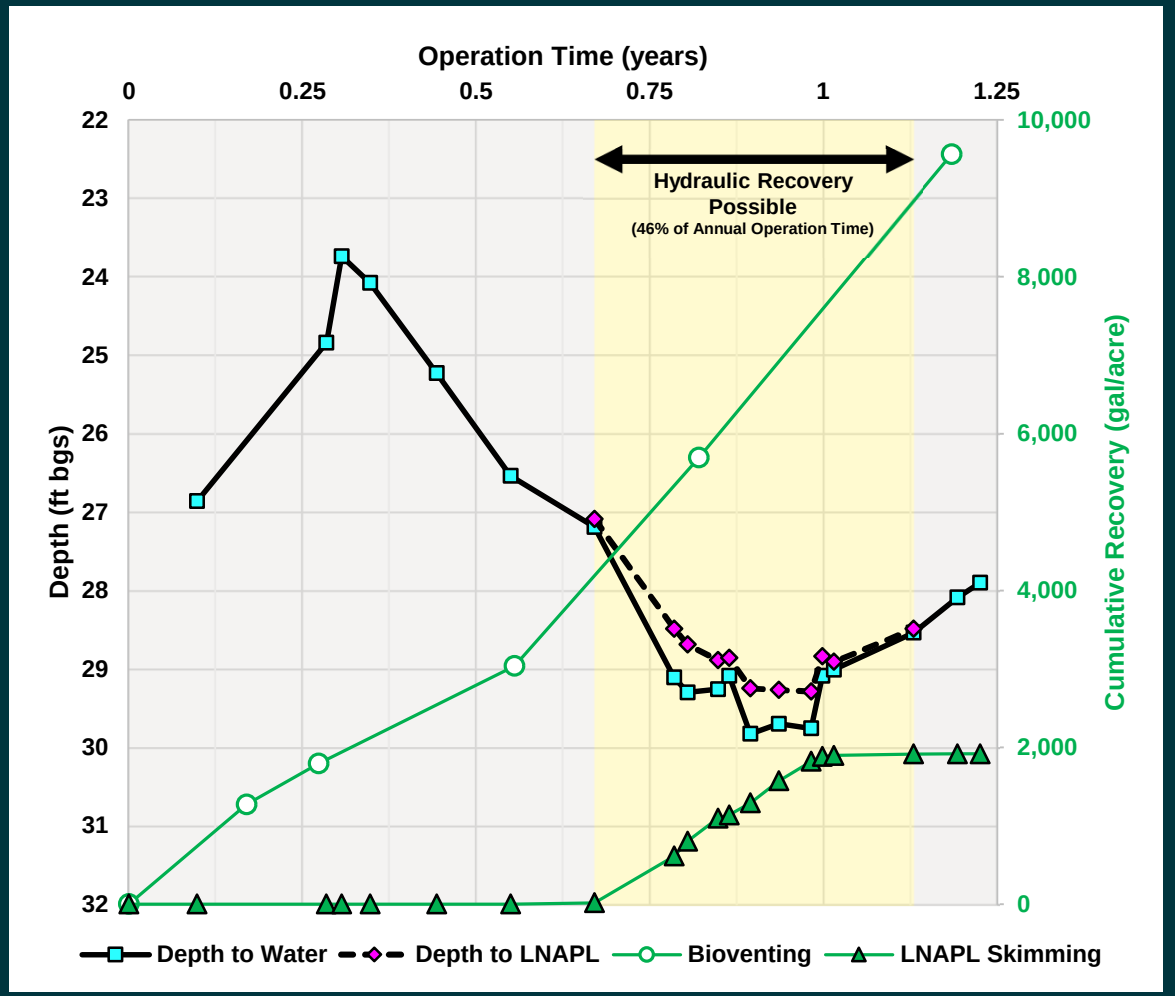


LNAPL Depletion
Skimming vs. Bioventing

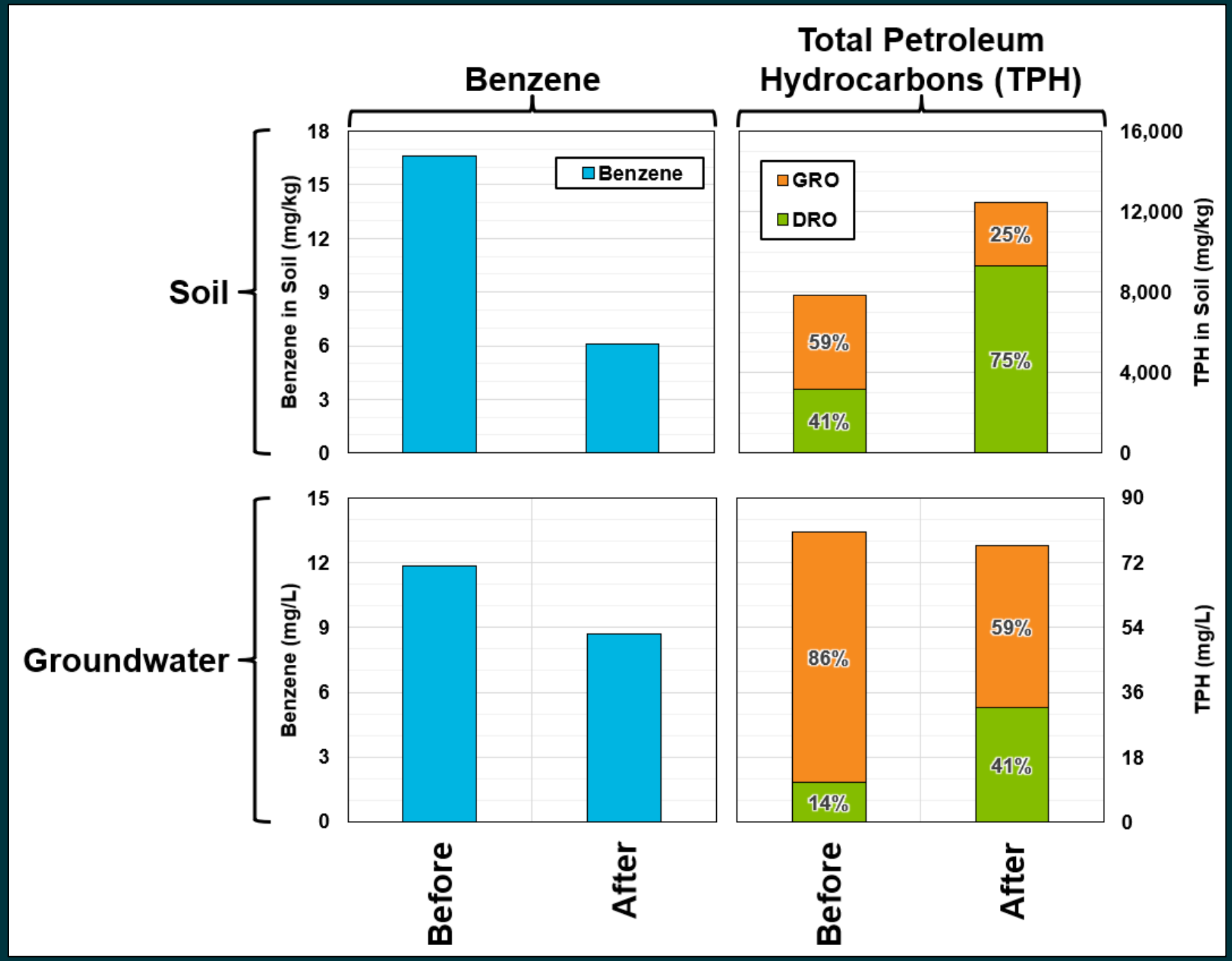
Bioventing Site Data vs. Modeled Skimming



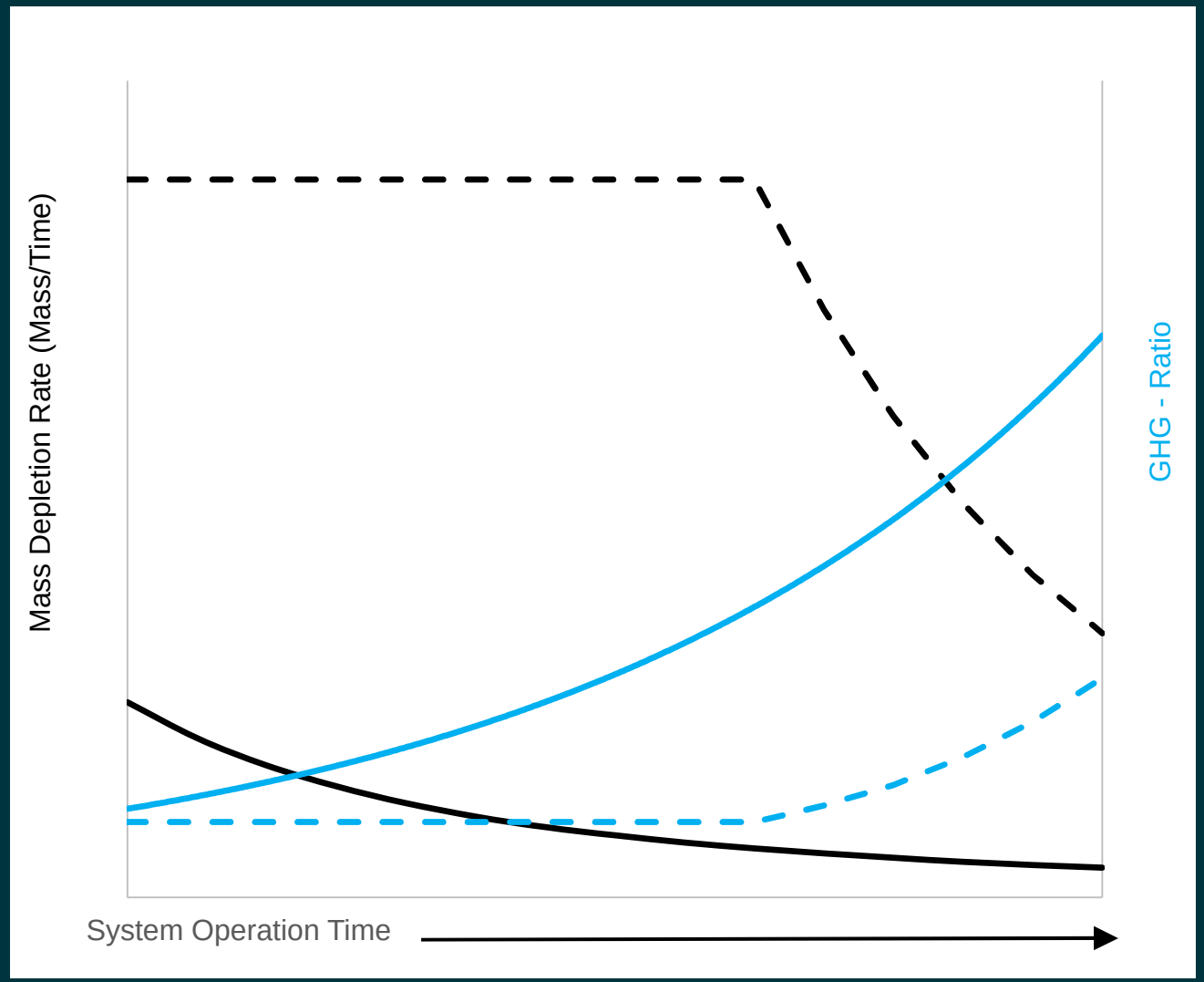
Bioventing Site Data vs. Realistic Skimming



Evidence of Composition Change



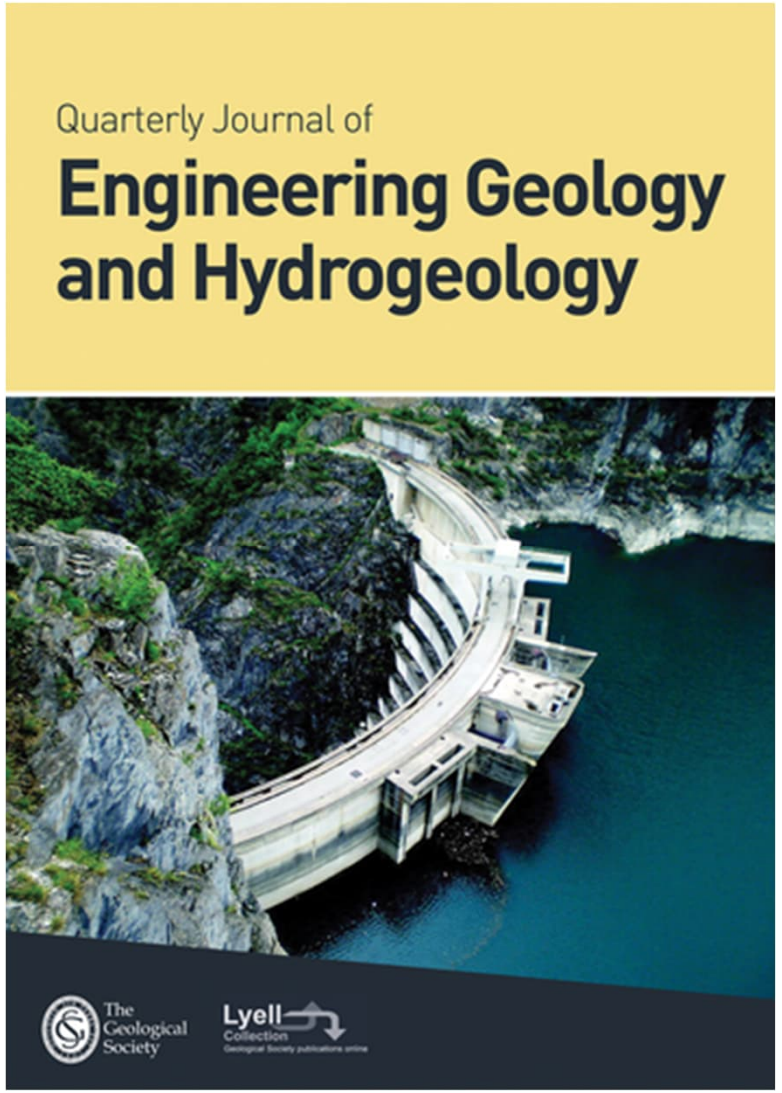
Nature Based Remediation



- Greenhouse Gas Emissions (GHG) Estimated using SiteWise™ Environmental Footprint Tool
- 16 Wells per acre for both technologies
- Bioventing assumes continuous operation of 10 HP blower
- Skimming using 16 x 280 W pumps, operating 46% of the time.
- Assume constant GHG emissions
  - GHG ratio (right axis) is ratio of emissions to depletion rate.

Conclusions

- Bioventing often outperforms hydraulic LNAPL recovery
  - Addresses mobile and residual LNAPL
  - Not likely to be adequate for controlling imminent migration or dissolved phase concerns
- Beneficial Composition Change
  - Preferential removal of benzene and lighter end compounds.
- Environmental Footprint
  - Less infrastructure, maintenance and waste handling
  - Sustained performance over time



Bioventing Revisited: Efficacy of Enhanced Biodegradation for Sites with Mobile LNAPL

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References

Leeson, A., and Hinchee, R. 1995. *Principles and Practices of Bioventing, Volume I: Bioventing Principles.* Report Prepared for US EPA and US Air Force: EPA 540 R-95 534a. https://clu-in.org/download/techfocus/bio/540R95534a.pdf

Leeson, A., and Hinchee, R. 1995. *Principles and Practices of Bioventing, Volume II: Bioventing Design.* Report Prepared for US EPA and US Air Force: EPA/625/XXX/001. https://clu-in.org/download/techfocus/bio/540R95534b.pdf

US ACE 2002. Soil Vapor Extraction and Bioventing. Report EM 1110-1-4001. US Army Corps of Engineers, Washington, DC. www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-1-4001.pdf

AFCEE 2004. *Procedures for Conducting Bioventing Pilot Tests and Long-Term Monitoring of Bioventing Systems*. Air Force Center for Environmental Excellence (AFCEE), US Air Force, Sand Antonio, TX. https://apps.dtic.mil/ dtic/tr/fulltext/u2/a423587.pdf

ESTCP 2004. *Natural Pressure-Driven Passive Bioventing,* ESTCP Cost and Performance Report CU-9715. Environmental Security Technology Certification Program (ESTCP), Alexandria, VA.

Johnson, P., P. Lundegard, and Z. Liu. 2006. *Source Zone Natural Attenuation at Petroleum Hydrocarbon Spill Sites, Volume I: Site-specific Assessment Approach,* Groundwater Monitoring and Remediation, 26, no. 4: 82-92.

Lundegard, P., and P. Johnson. 2006. *Source Zone Natural Attenuation at Petroleum Hydrocarbon Spill Sites, Volume II: Application to a Former Oil Field.* Groundwater Monitoring and Remediation, 26, no. 4: 93-106.

Hawthorne, M.J. 2015. Nationwide Statistical Analysis of LNAPL Transmissivity. Platform Presentation at the Third International Symposium on Bioremediation and Sustainable Environmental Technologies, Miami, FL.

ITRC. 2018. *LNAPL Site Management: LCSM Evolution, Decision Process, and Remedial Technologies.* Washington, DC: Interstate Technology & Regulatory Council. https://lnapl-3.itrcweb.org

Kirkman, A.J., J. Montoy, A. McCormick. 2023. *Application of Analytical Element Model to Bioventing*. Platform Presentation at the Sixth International Symposium on Bioremediation and Environmental Biotechnology, Boston, MA.

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