An Evaluation of Natural Source Zone Depletion Versus Active Remediation Rates

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Drivers and Objective

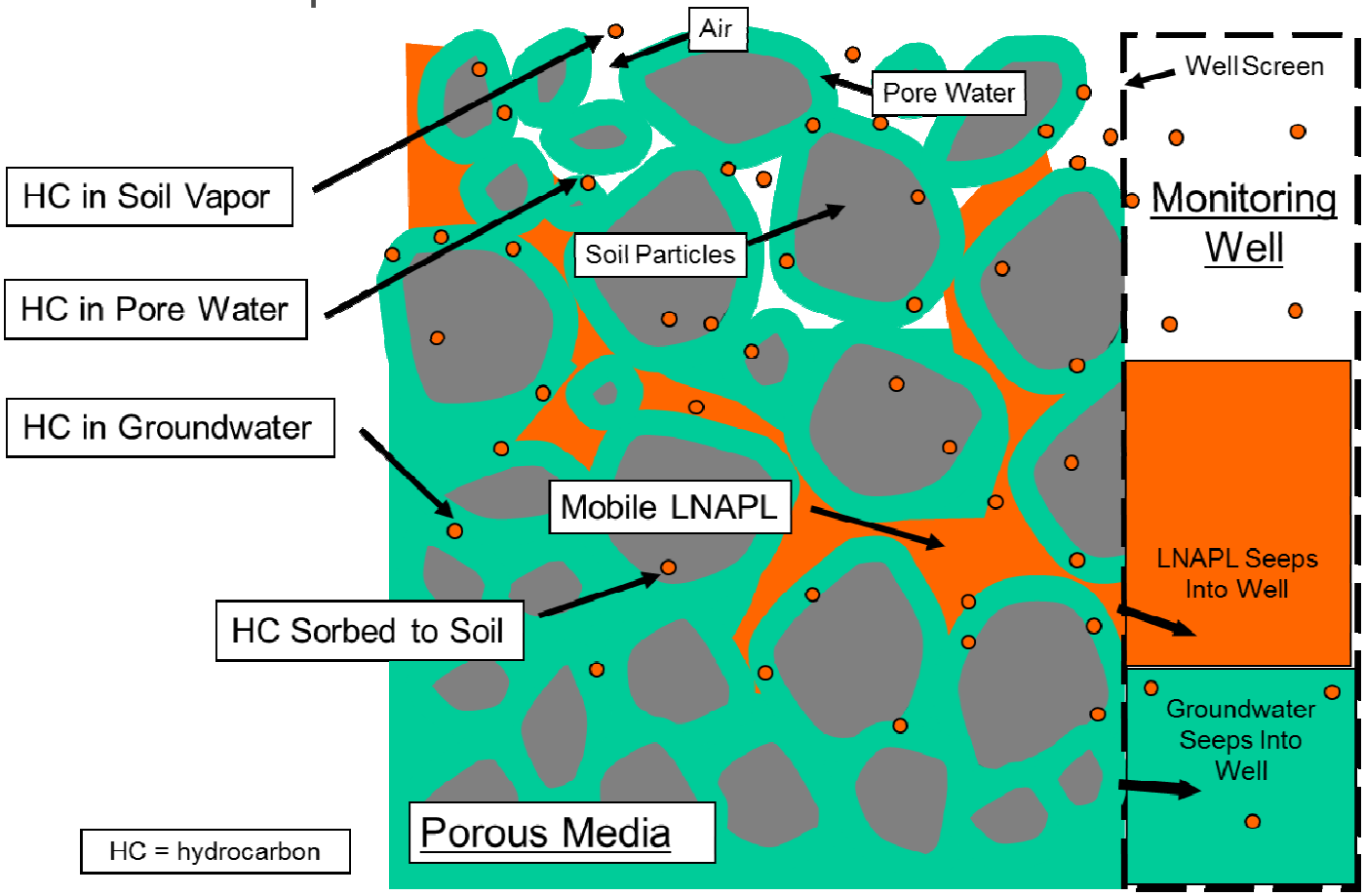
- Measurement of natural source zone depletion (NSZD) rates (aka loss rates) of petroleum hydrocarbon LNAPL is an emerging science
  - To receive broader support, it is important to ground-truth the results
- To provide perspective, a survey consisting of 51 diverse sites/systems was performed to improve understanding of rates of remediation (in consistent units) for various petroleum remediation approaches
- This presentation will compare NSZD remediation rates to active remediation systems, and show that measurements of NSZD rates are comparable

Agenda

- Conceptualization of LNAPL in Subsurface
- Overview of NSZD
- Rates of NSZD as Measured by CO_2 Efflux
- Rates of Active Remediation
- NSZD vs Active Remediation Rates
- Conclusions

LNAPL Setting

- LNAPL exists in 4-phases



- Pore fluid profile often at <30% pore volume

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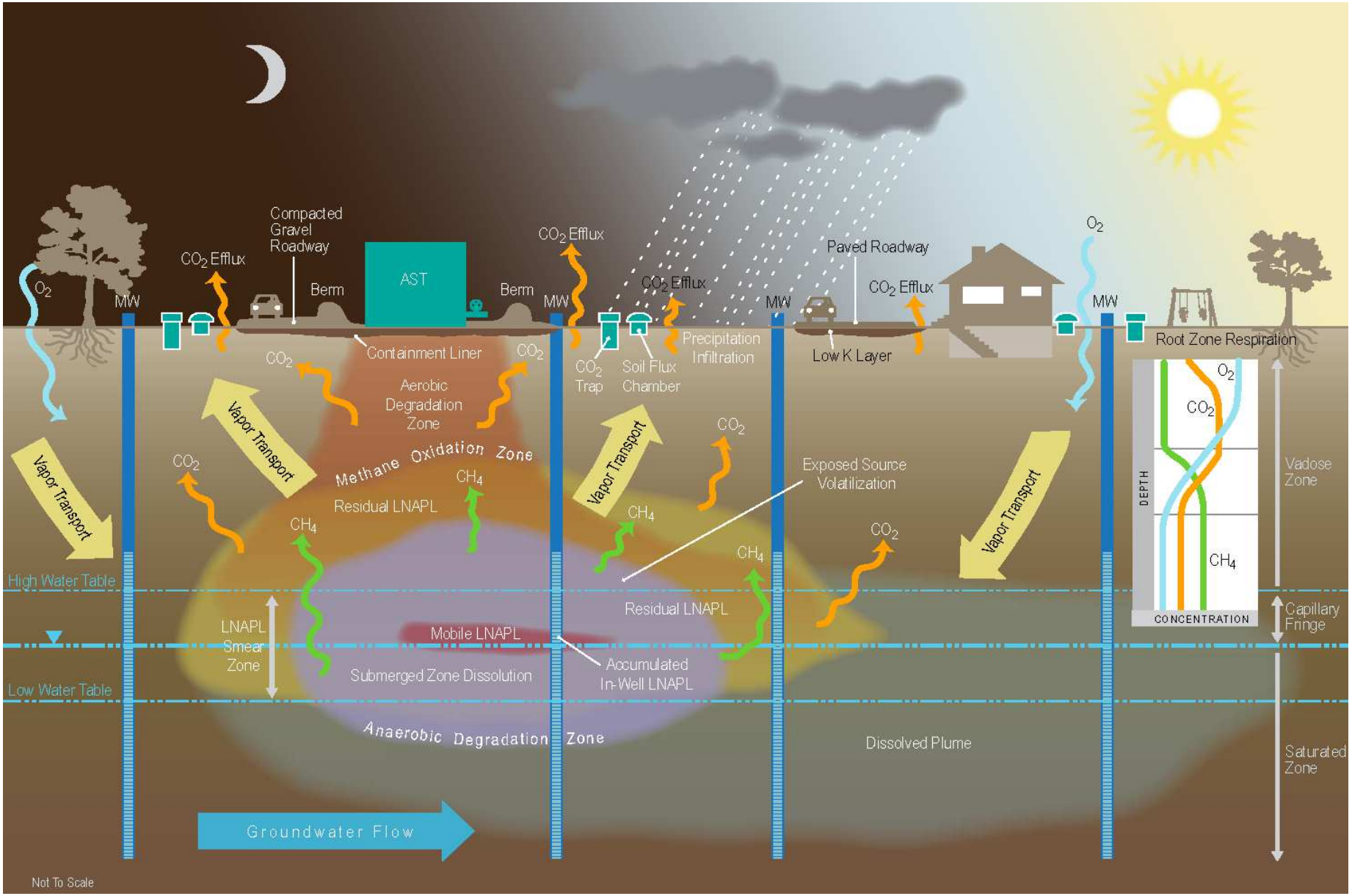
LNAPL Quantification

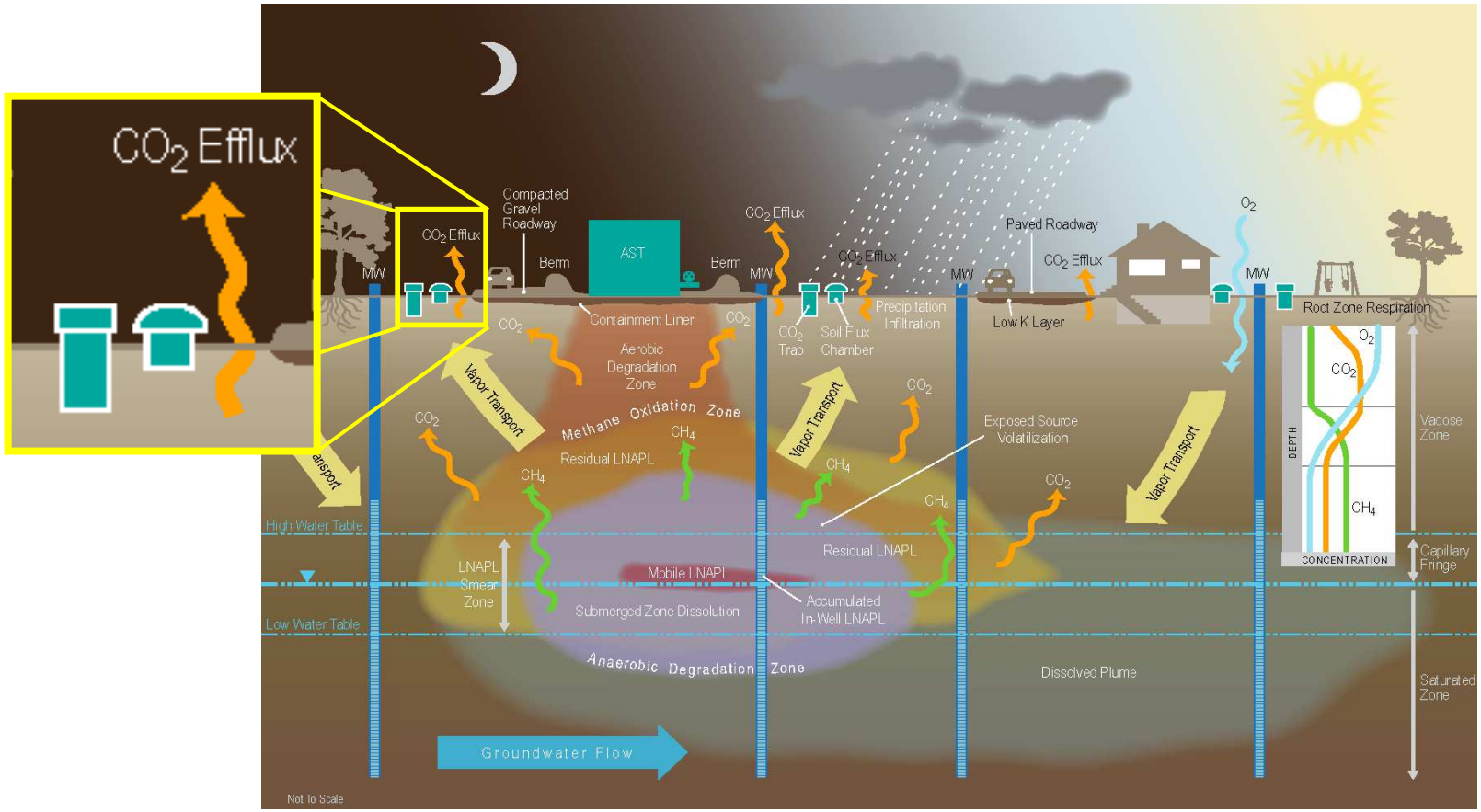
- Integrating specific volume over an area provides an estimate of the volume of LNAPL in the subsurface
  - A 1-ft mobile LNAPL smear zone profile with specific volume of 0.05 ft^3/ft^2 roughly equates to 16,000 gallons of LNAPL per acre (gal/ac)
- Removal of 5,000 gallons from this area, reduces the in situ LNAPL volume by 30%
  - Reduces in situ LNAPL pore fluid saturations in smear zone profile to a maximum equal to the residual LNAPL saturation
  - Non-recoverable, immobile fraction will remain in situ

Natural Source Zone Depletion - Petroleum



Natural Source Zone Depletion - Petroleum

- LNAPL is degraded by the intrinsic processes of volatilization, dissolution, and biodegradation
- Results in significant and measurable losses of source material



Carbon Dioxide (CO_2) Efflux Measurements

- Estimated NSZD (aka LNAPL loss) rates based on stoichiometric conversion of sitewide CO_2 efflux measurements
- 8 diverse sites (E-Flux CO_2 Traps – 3 sites and LI-COR® 8100A soil flux system – 6 sites)
  - Total of 86 CO_2 trap and 290 LI-COR® event-locations
- Site conditions included:
  - Natural gas well site
  - Operating gas plant and compressor station
  - Pipeline
  - Terminal
  - Railyard
  - Remote maintenance camp
- Urban and rural areas with predominantly pervious, but variable ground cover
- Consolidated and unconsolidated subsurface soil

E-Flux CO_2 Trap

LI-COR® 8100A Soil Flux System

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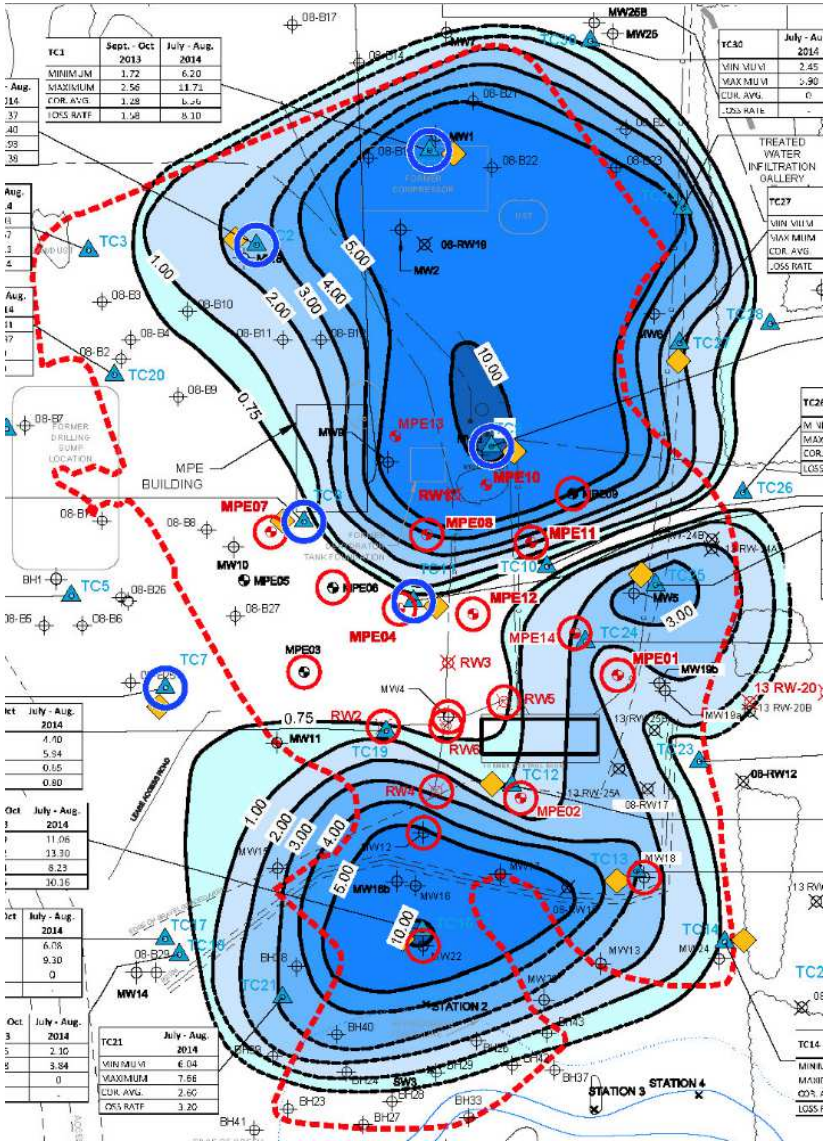
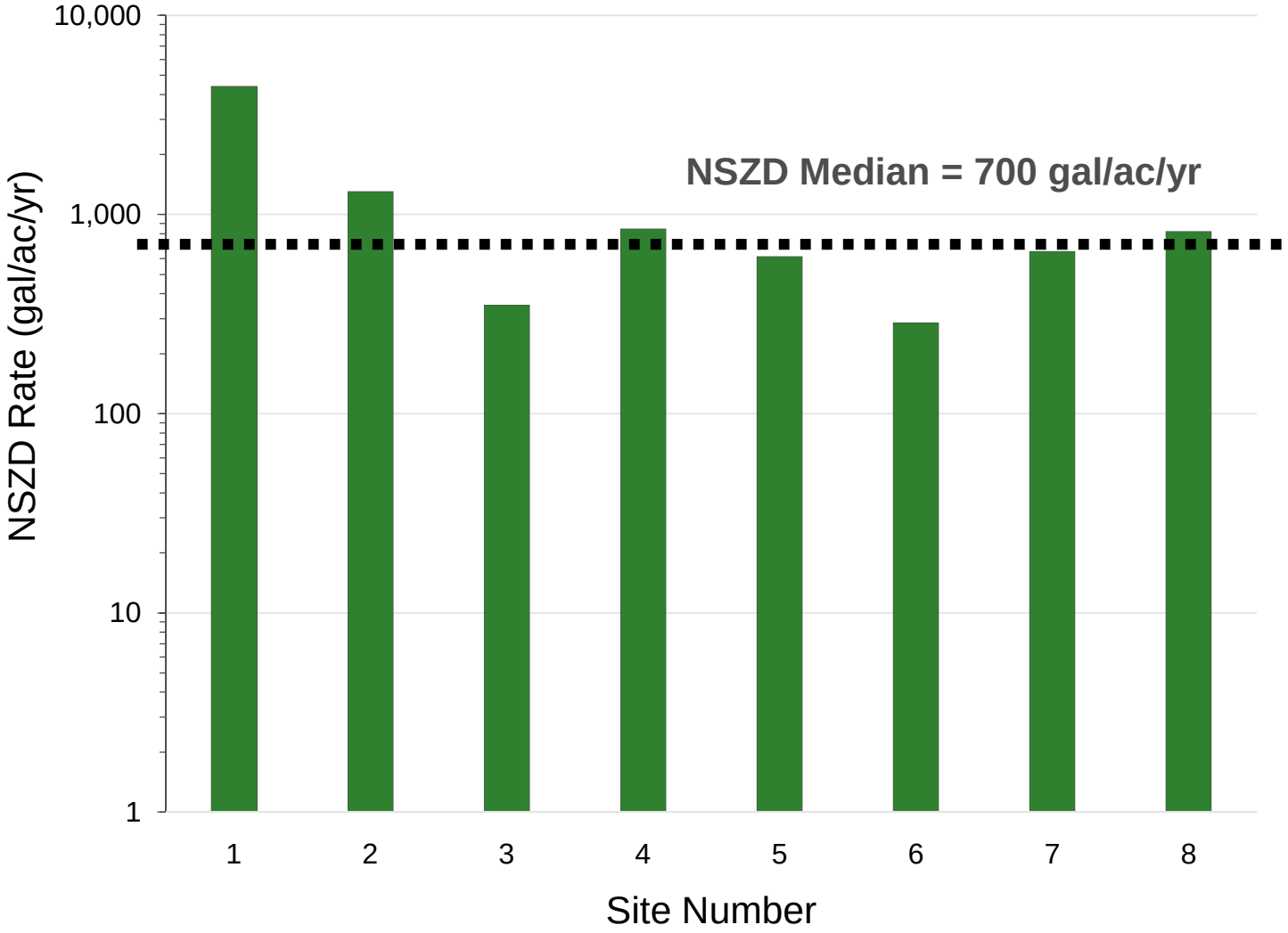
Example Results from a NSZD Evaluation

- Collected CO_2 efflux measurements
- Corrected for background
- Performed stoichiometric conversion
- Plotted NSZD rates
- Integrated the results to estimate a sitewide NSZD rate
- Sites with multiple rounds of measurements were seasonally adjusted to estimate an annual rate



Summary of NSZD Rates



★ Note: Recall a site with LNAPL specific volume of 0.05 ft^3/ft^2 contains 16,000 gals/ac.

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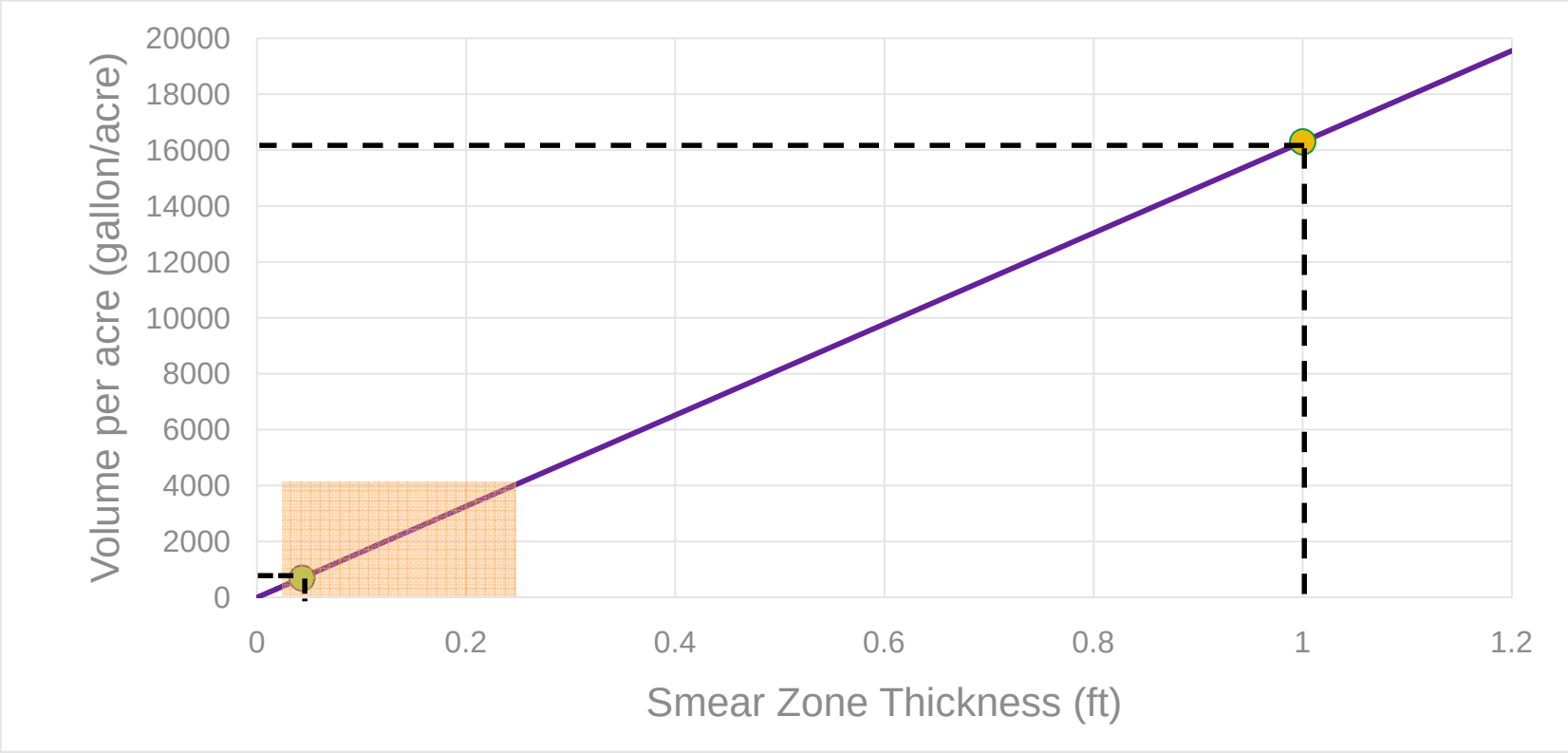
Summary of NSZD Rates

- Recall: 1-ft mobile LNAPL smear zone profile with specific volume of 0.05 ft^3/ft^2 roughly equates to 16,000 gallons of LNAPL per acre (gal/ac)



- Removal of 700 gallons per acre equates to less than an inch removal, with the same assumptions

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Assessment of Comparable Rates of Remediation

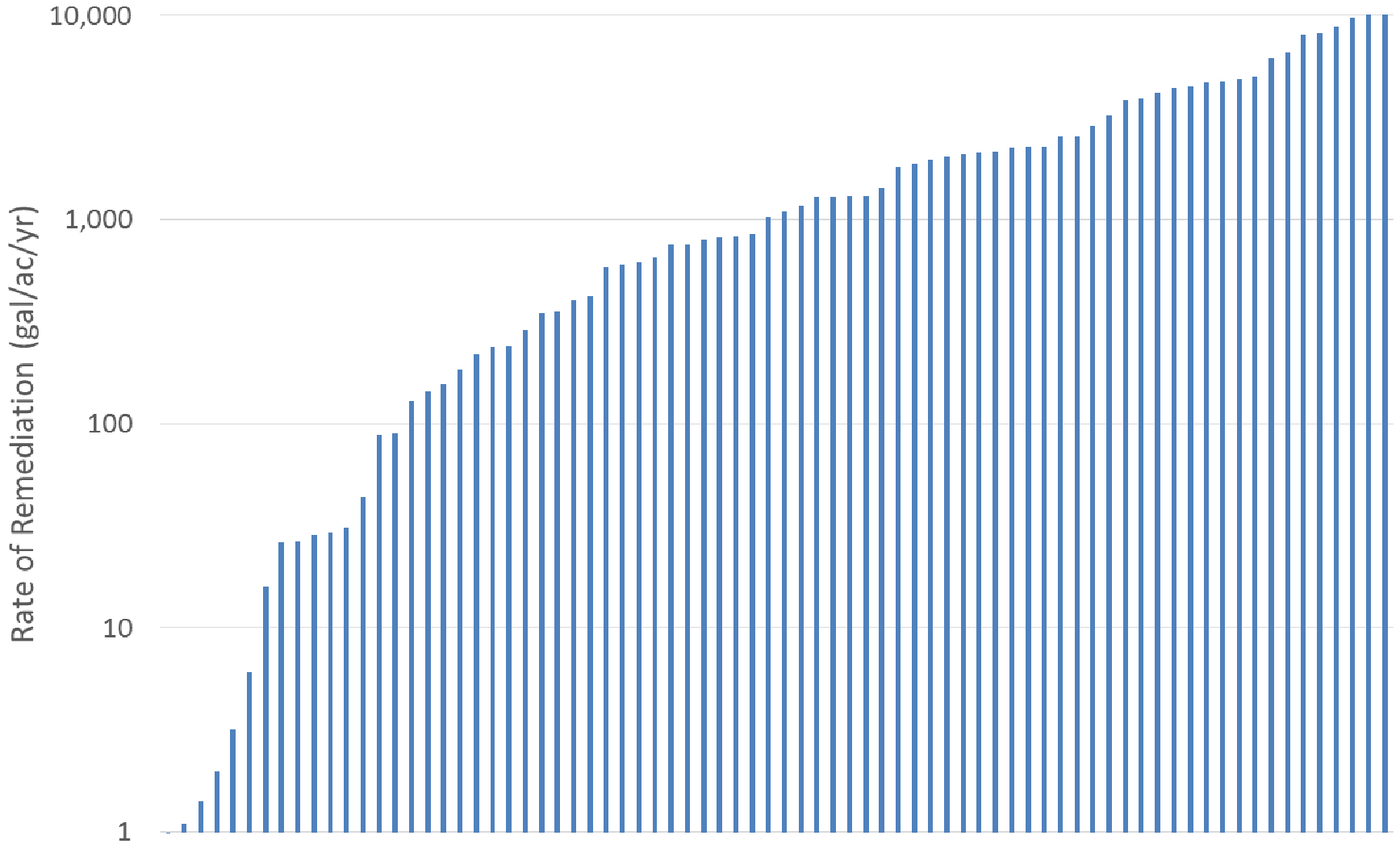
- Surveyed projects to compile real site monitoring data
- 43 systems

LNAPL Skimming	6
Groundwater drawdown-enhanced Skimming	5
Bioventing/Biosparging	4
Soil Vapor Extraction	5
Air Sparging/Soil Vapor Extraction	10
Multiphase Extraction	13
Total Number of Active Systems in Survey =	43

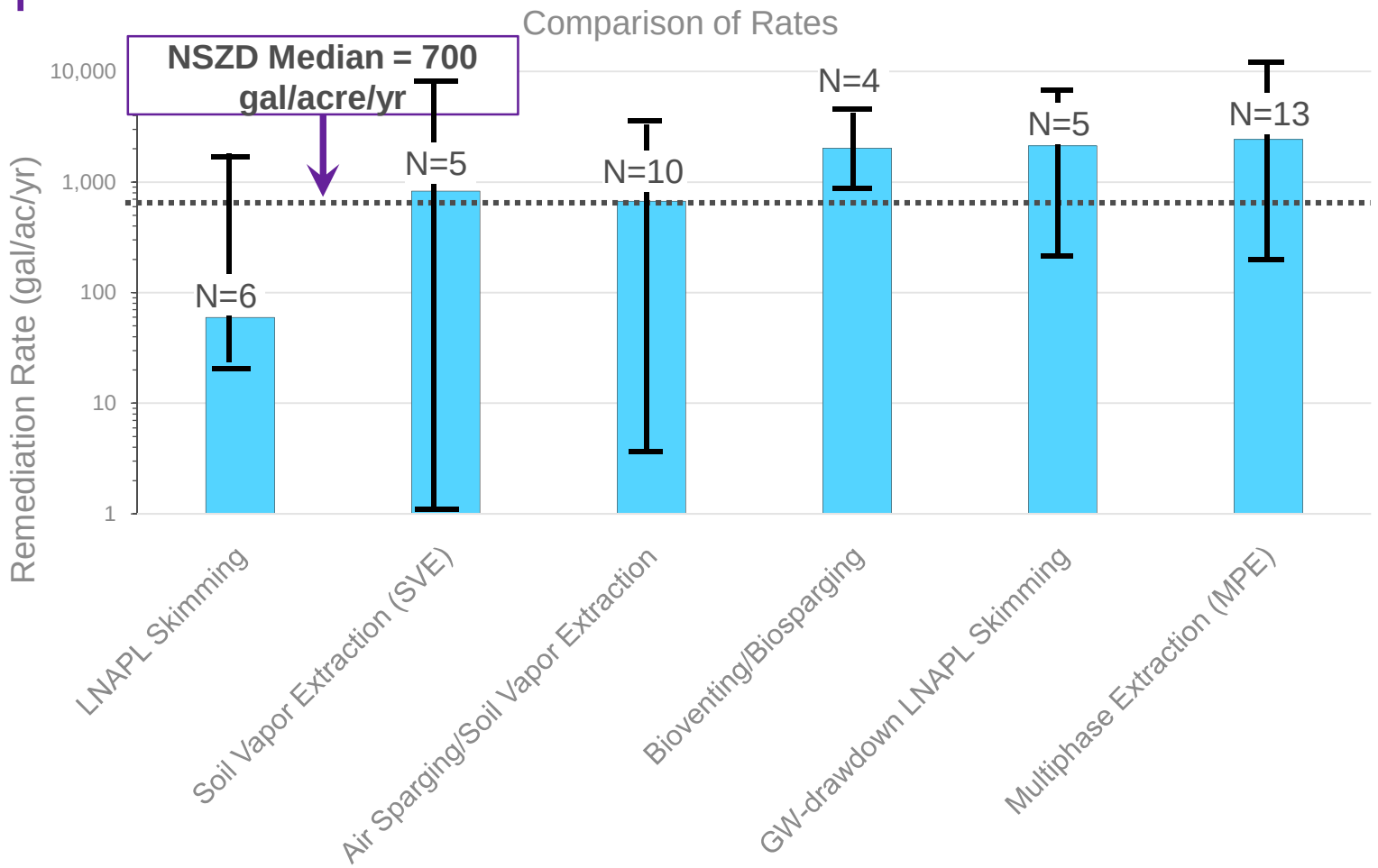
- Sites in survey include a variety of:
  - petroleum products
  - source zone dimensions
  - remedial design bases
  - operation and maintenance routines (i.e., zones, pulsing, etc.)

	Median	Range
Treatment Area Size (acres)	2.0	0.1 - 108
Total Volume Removed (gallons)	4,500	18 - 6,000,000
Mass Removal Rate (pounds/year)	7,339	4 - 5,000,000
Years of Operation (years)	5.0	0.6 - 24
Remediation Rates (gallons/acre/year)	1,057	0.1 - 11,790

Active Remediation Rate Survey Results



Comparison of Median Rates of Remediation



- Survey indicates that NSZD rates fall within the range of other remedial approaches

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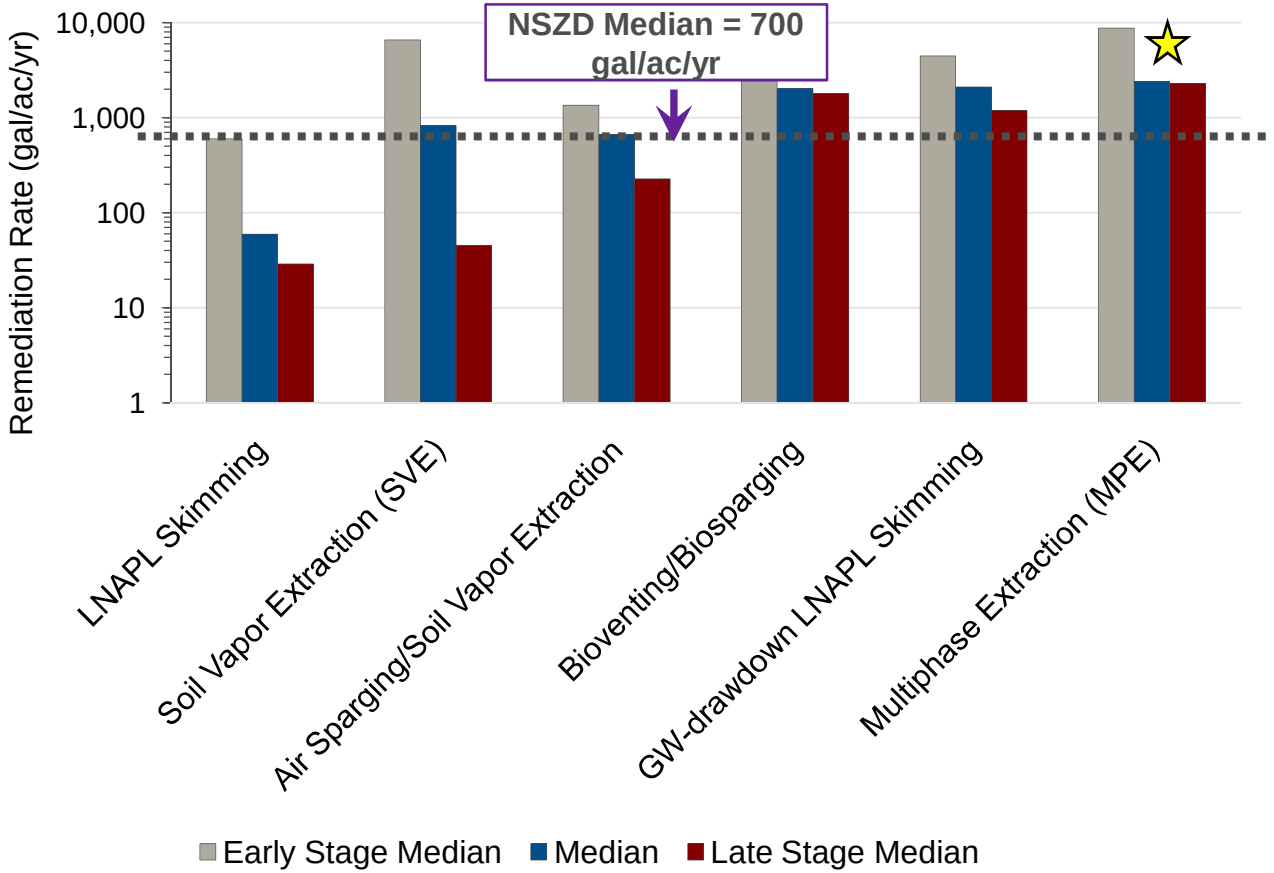
Evaluation of Early and Late Stage Rates



- Midway into remediation, NSZD may become stronger than some remedies

- Note: 10 of the 13 MPE systems had no difference in early and late remediation rates, thus were excluded from this early/late data sets

Approximate Efflux Monitoring Costs

- LI-COR soil flux system
  - Rental ~$1,700/month for the first month and ~$900/month for subsequent months
  - 20 beveled 8” PVC collars ~$300
  - Mobilization, 8 hrs onsite/visit, 2 field technicians – install collars and perform four rounds of daily measurements
  - ~$500/location
- E-Flux CO_2 traps
  - Field components (~$320/location)
  - CO_2 and ^{14}C analysis of traps ~$1,700/location
  - Two site visits, start and end of 2 week deployment period (install and retrieve/ship traps, 4 hrs onsite, 1 field technician)
  - ~$2,000/location

Conclusions

- In general NSZD rates measured using CO_2 efflux methods are reasonable
  - They fall within the spectrum of the surveyed remedial systems (~200-4,000 gal/ac/yr)
  - Are consistent with plausible rates of remediation for sites with >10,000 gal/ac present in the subsurface
- NSZD rates are significant and are competitive with remediation rates of some active systems
- There appears to be a point during remediation when the effectiveness of active remediation may fall below NSZD
  - The NSZD rate is a useful metric for optimization of active remediation

Thank You

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