Reevaluating Mass Removal Efficiency Metrics Using Environmental Footprint Data

Battelle 2024 Chlorinated Conference
Denver, Colorado

5 June 2024

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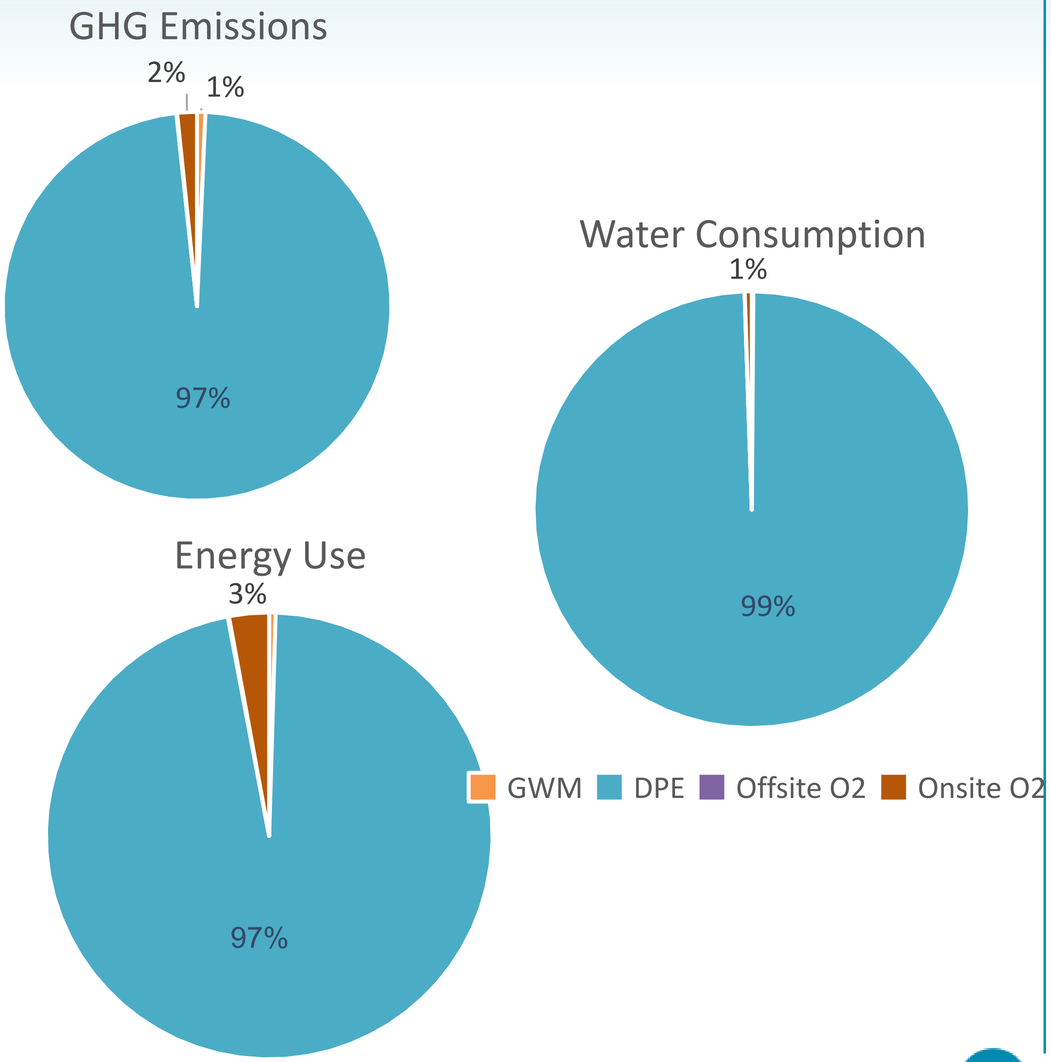
Introduction

Initial Site Driver

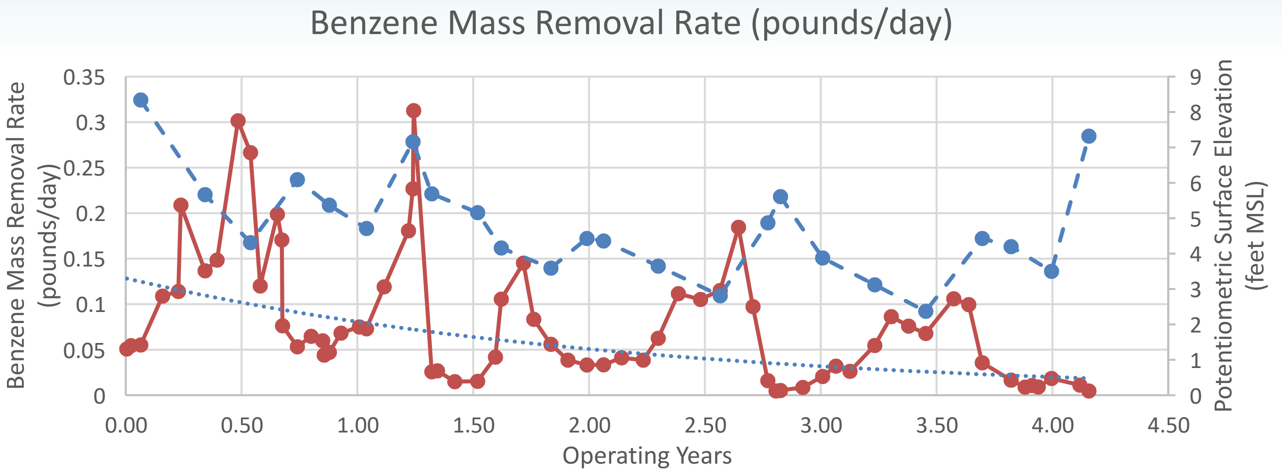
- Preliminary environmental footprint analysis for a site in 2016
  - DPE and two oxygen systems in operation
- DPE system responsible for vast majority of emissions & consumption
- Efforts to improve sustainability were focused on DPE system

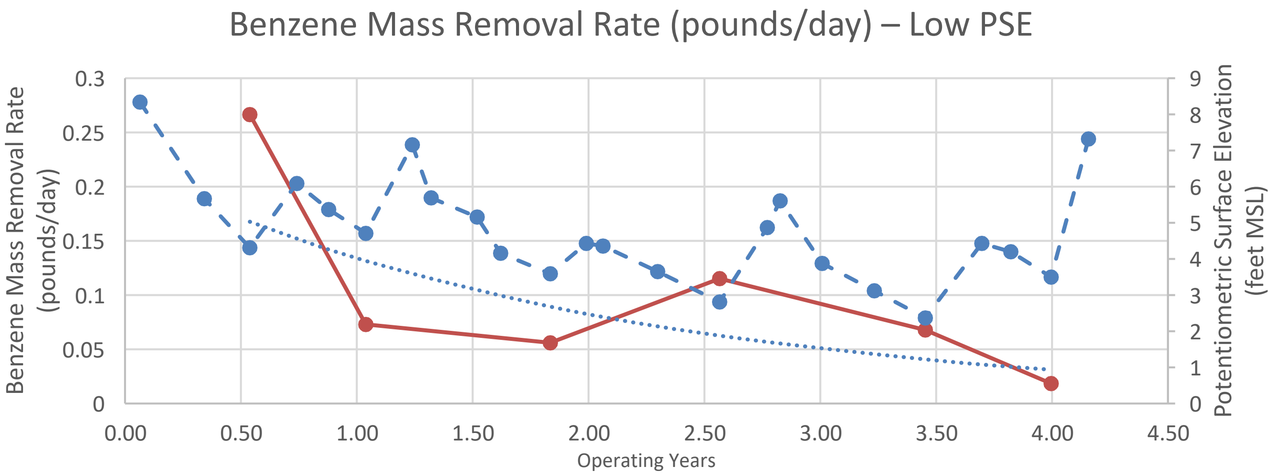


Introduction

Initial Site Driver

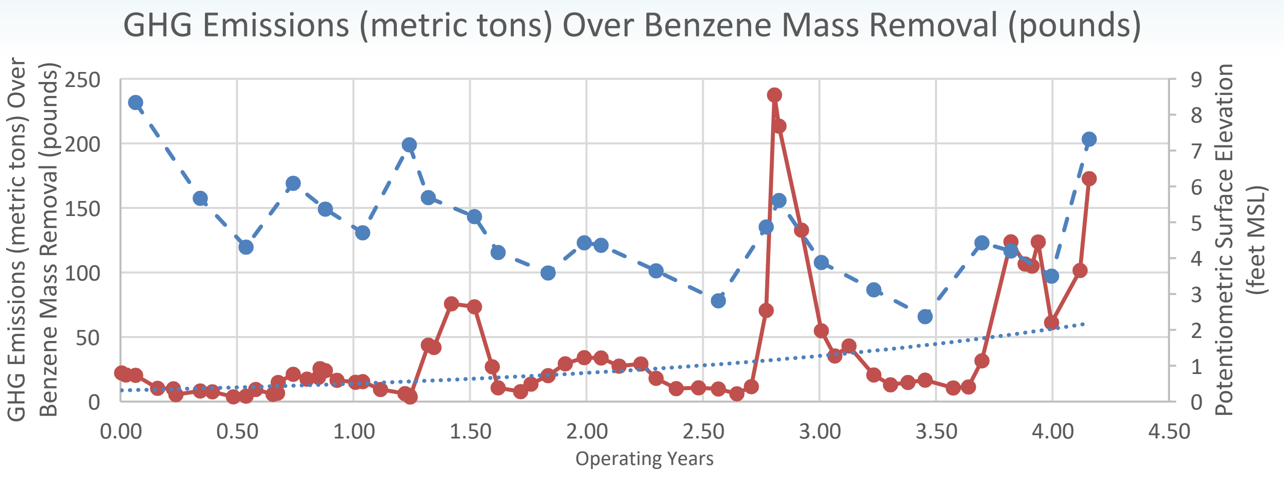
- ❑ Traditional efficiency metric
- ❑ SVE benzene mass removal rate declining over time
- ❑ Mass removal only effective during low groundwater periods

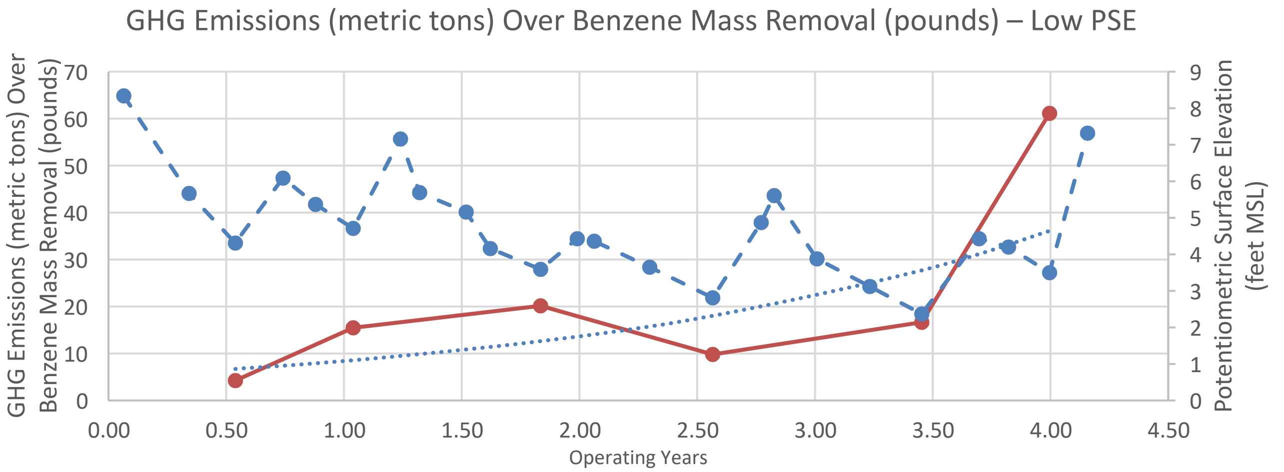




Introduction
Initial Site Driver

- ❑ Alternate efficiency metric
- ❑ GHG emissions required to remove a pound of mass were increasing over time
  - ▫ Including during more efficient low GW periods
- ❑ 14x increase in emission to mass removal ratio





Study Objectives

- Reevaluate current or past systems to determine the remediation footprint per unit of COC mass removal
  - In addition to pounds/day or dollars/pound, evaluate efficiency based on GHG emissions/pound
  - Metric for the **environmental/social cost** of removing COC mass
- Include a range of remediation technologies
- Look for trends or indicators for applying this metric to decision-making

Sites and Technologies

Petroleum Release Site	No. in Evaluation
Gas station	6
Terminal	3
Refinery	1
TOTAL	*10*

Remedial Technology	No. in Evaluation
SVE	7
O2/AS	5
ISCO	4
TOTAL	*16*

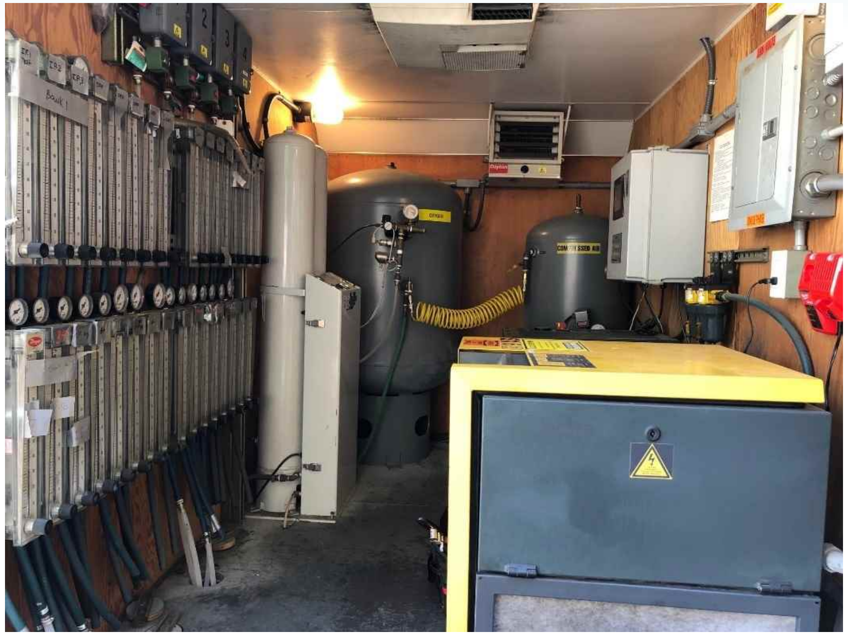
Methods

- Contaminant mass removal
  - SVE = Vapor-phase TPHg removal calculations
  - O2/AS = GW benzene plume mass change using Ricker Method plume analytics
  - ISCO = Stoichiometric calculation of TPHg destruction
  - MNA/NSZD = Plume mass change and LNAPL degradation calculations
- Environmental footprint analysis
  - SiteWise
  - Annual O&M (SVE & O2) or complete event (ISCO)
  - Excludes infrastructure/installation

Oxygen Injection

Initial Footprint Observations

- Minimal variation and relatively low remediation footprint
- Consistent system components and O&M schedules
- Footprint/mass removal ratio is driven by groundwater plume mass change over time



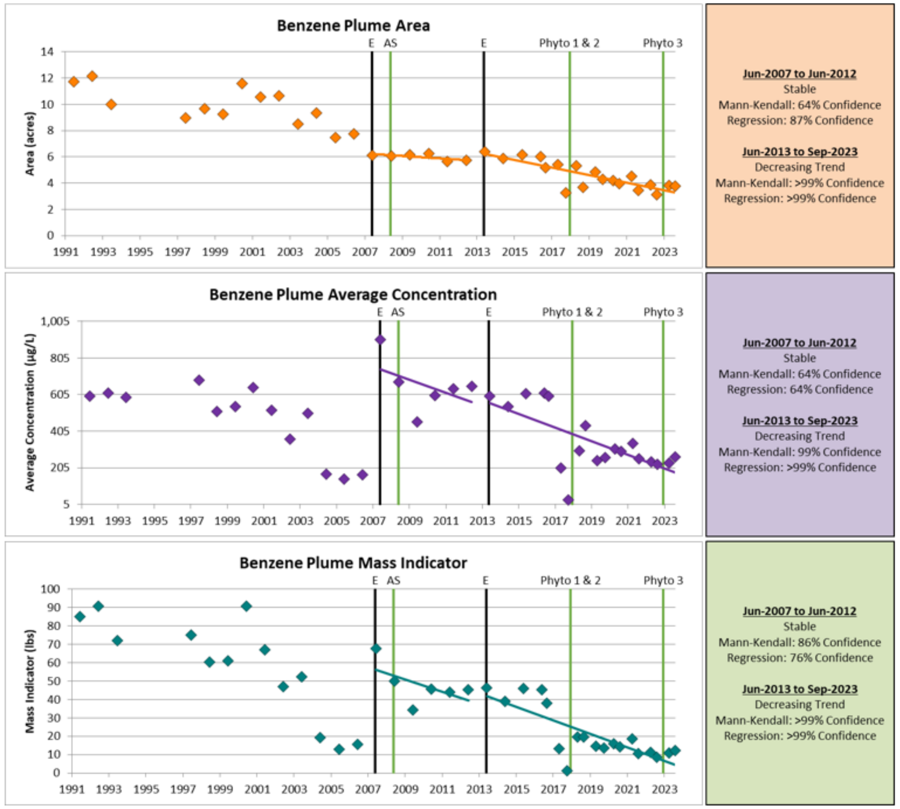
Site	Annual O&M GHG Emissions (metric tons)
1	11.6
2	15.2
3	12.9
4	13.2

Oxygen Injection

Ricker Method Overview

- Stoichiometric calculations of mass removal based on volume of oxygen delivery are likely overestimates and generally remain constant year to year

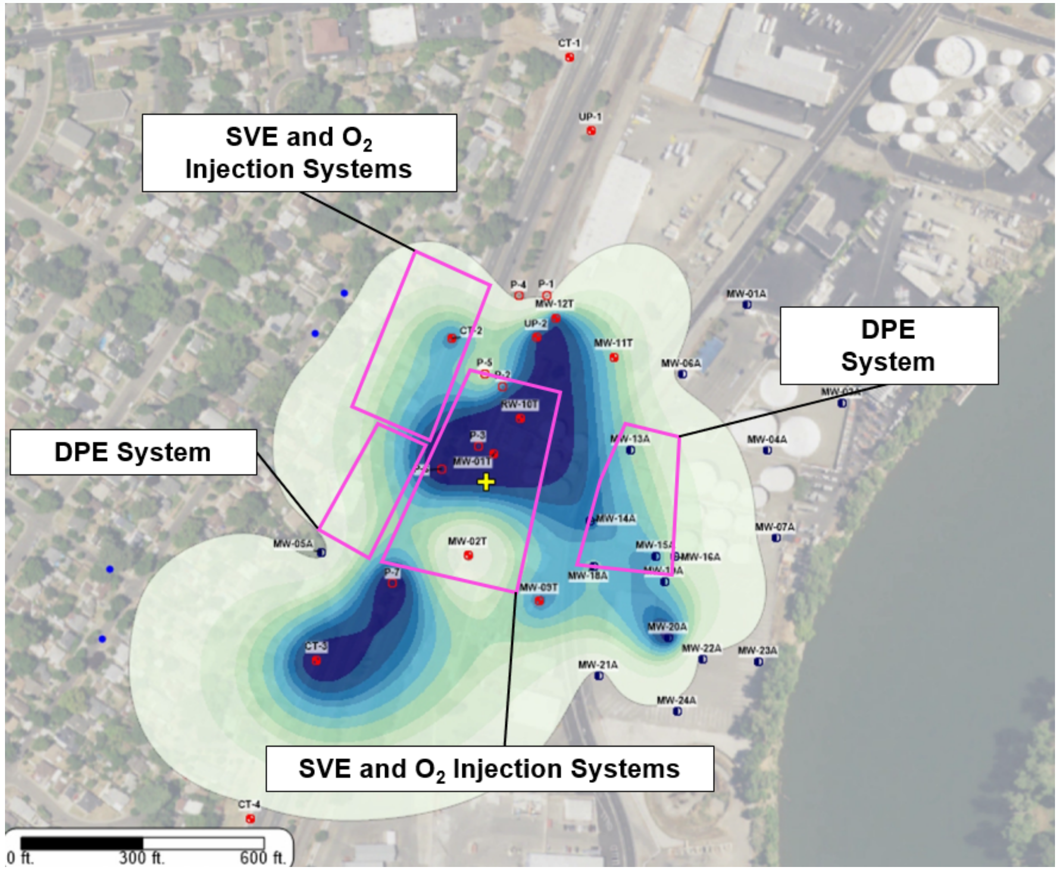
- Ricker Plume Analytics used to calculate change in groundwater COC plume mass
  - Dissolved phase only (ignoring soil or other media)



Plume Analytics® Services

Oxygen Injection
Ricker Method Overview

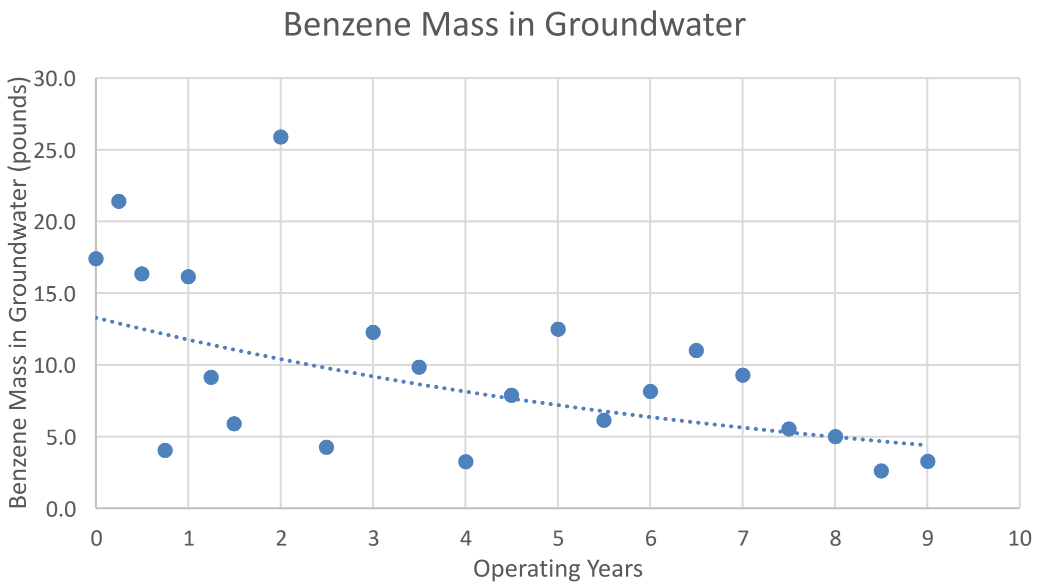
- Remediation Window tool used for sites with multiple systems
- Plume mass change calculated only within treatment area of each system

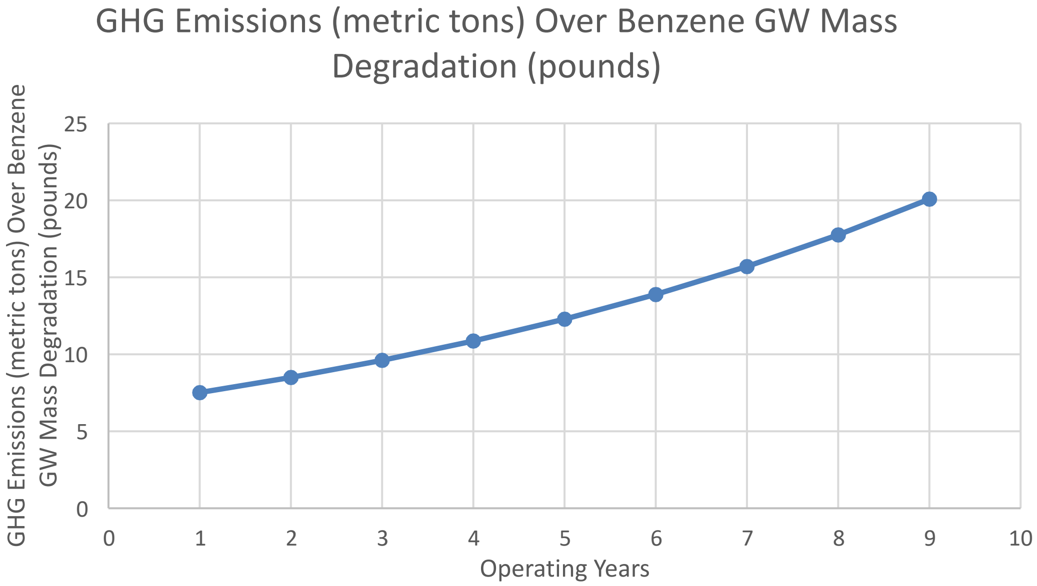


Oxygen Injection

Site 1 Results

- GW plume mass fluctuates event to event
- Footprint/mass removal ratio calculated using plume mass trendline

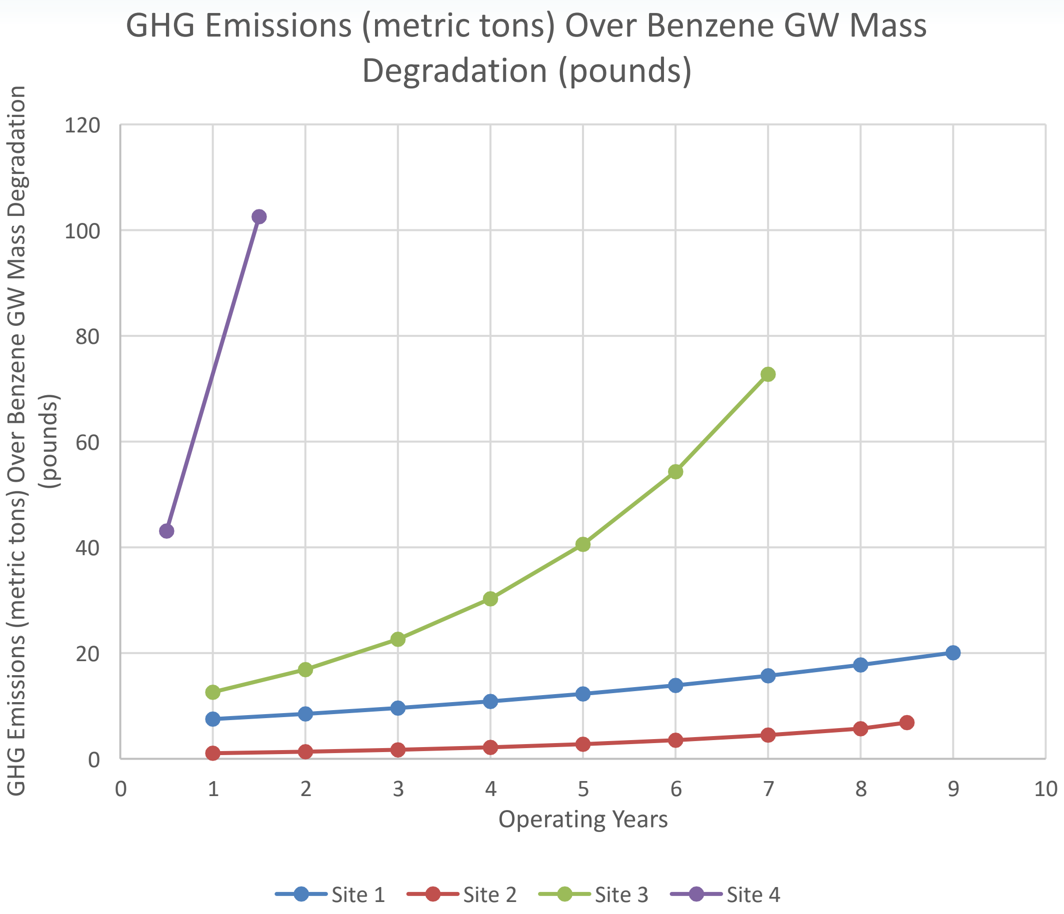




Oxygen Injection

Footprint/Mass Removal Ratio Changes

- Site 1 = 3x after 9 years
  - Efficient system
- Site 2 = 7x after 8.5 years
  - ROI limited by fine-grained lithology (~5 feet)
  - COC reductions largely a result of natural attenuation and O2 injection likely ran too long
- Site 3 = 6x after 7 years
  - Based on limited effectiveness, transitioned to ISCO for more aggressive source removal
- Site 4 = 2x after 1.5 years
  - Low GW mass but contentious stakeholder situation requiring ongoing active remediation



ISCO
Site Summary

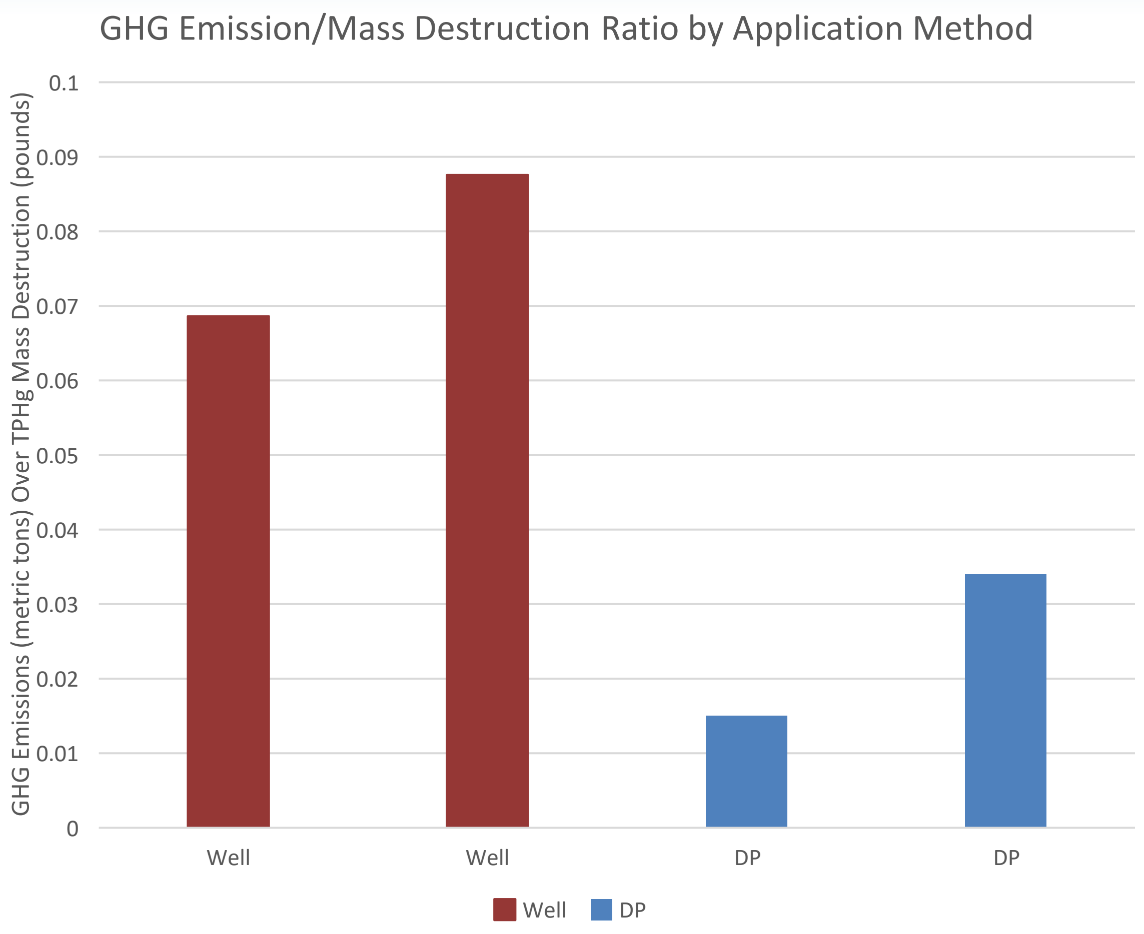
- Four similar events at UST sites in evaluation
  - Two injections using existing wells
  - Two injections using direct push rig and injection trailer
  - Sodium persulfate and sodium percarbonate oxidants

- TPHg mass destruction calculated based on stoichiometry

Site	Application Method	TPHg Mass Destruction (pounds)	GHG Emissions (metric tons)
1	Well	134	9.2
2	Well	730	63.9
3	Direct Push	684	10.3
4	Direct Push	310	10.5

Footprint/Mass Removal Ratio Results

- GHG emissions affected by application method
  - Higher footprint for well injections
  - Lower footprint for direct push injections
- Faster pace reduces overall emissions & consumption
  - Reduction in use of generators, pumps, mixing tanks, commutes to/from site



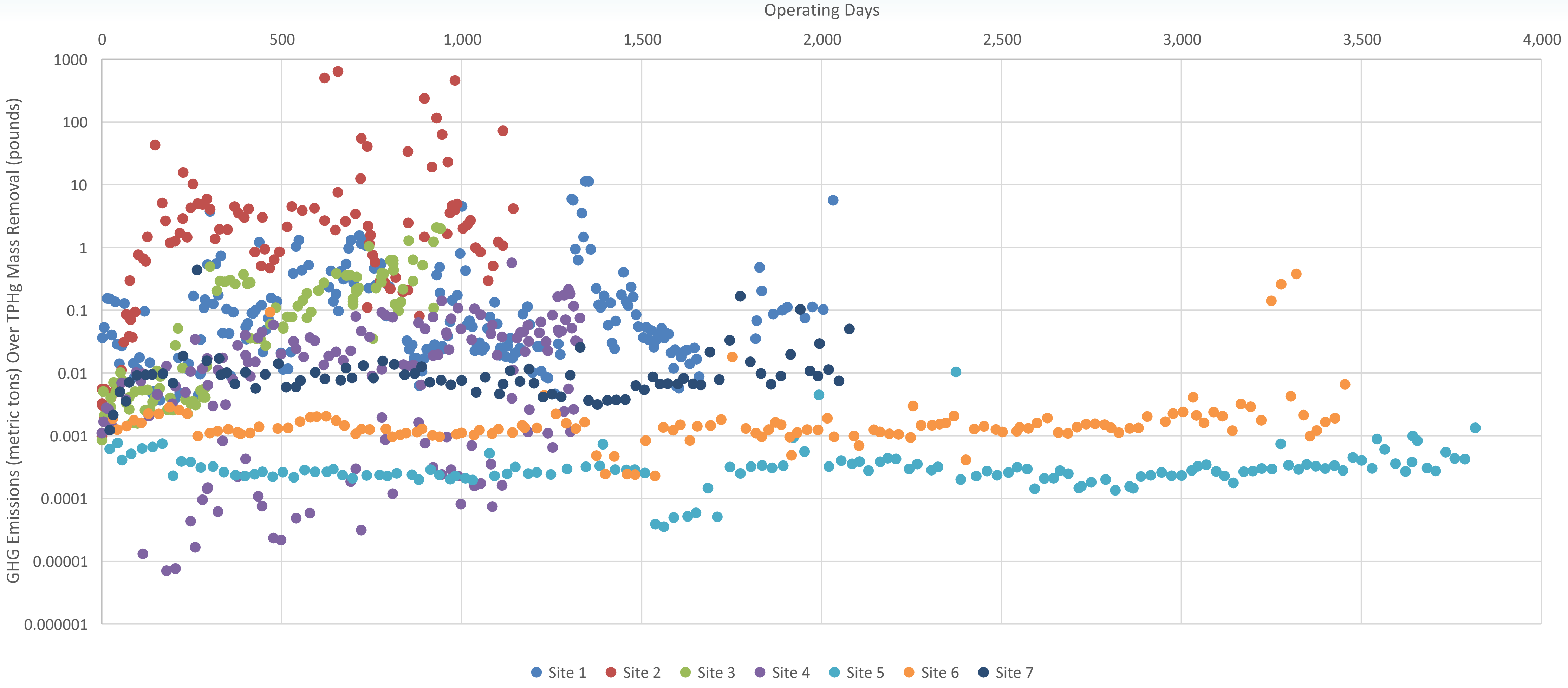
Soil Vapor Extraction
Site Summary

- Significant variability in system sizes, mass removal rates, and GHG emissions
- High frequency of mass removal calculations

Site	Blower Motor	Oxidizer	Operating Years	Total TPHg Mass Removal (pounds)	Total GHG Emissions (metric tons)
1	20 hp	Thermal Ox	5.6	63,428	2,296
2	5 hp	Electric Catox	3.1	13,530	139
3	5 hp	Thermal Ox	2.6	41,121	489
4	8.5 hp	Electric Catox	3.6	57,085	552
5	15 hp	Thermal Ox	10.5	3,528,346	829
6	15 hp	Thermal Ox	9.5	2,554,330	3,018
7	15 hp	Thermal Ox	5.7	538,357	4,012

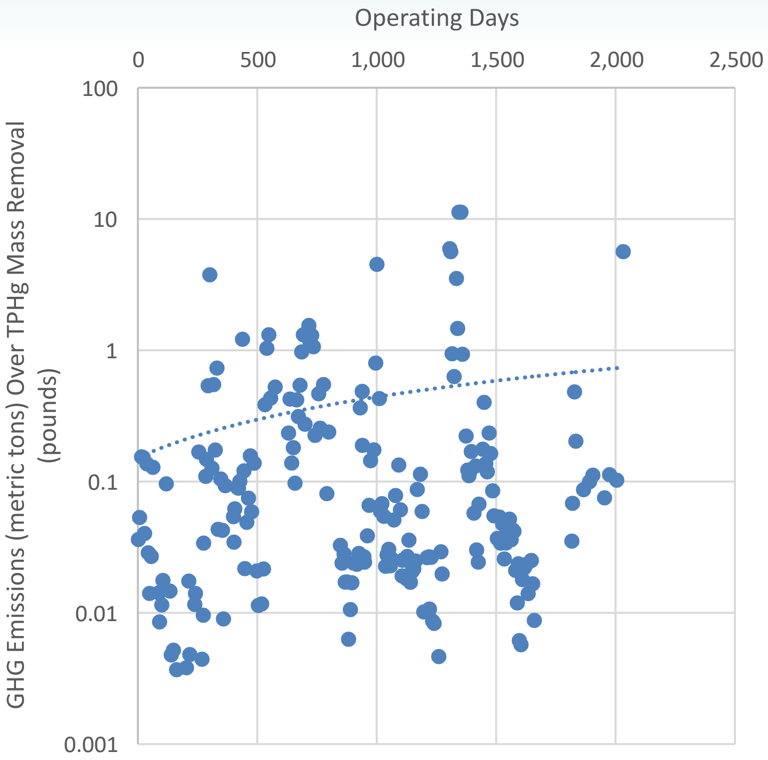
Soil Vapor Extraction

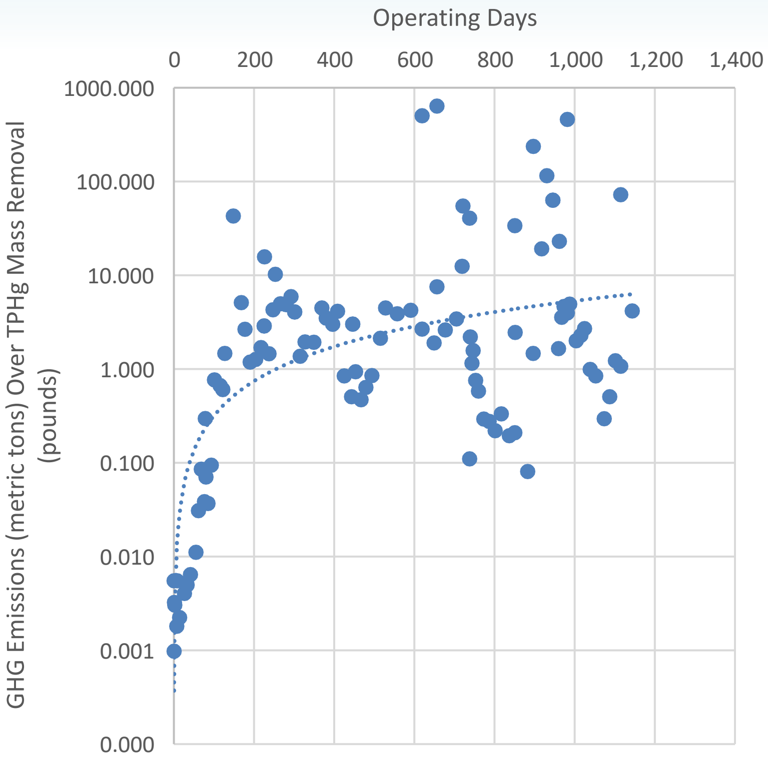
Range of Results

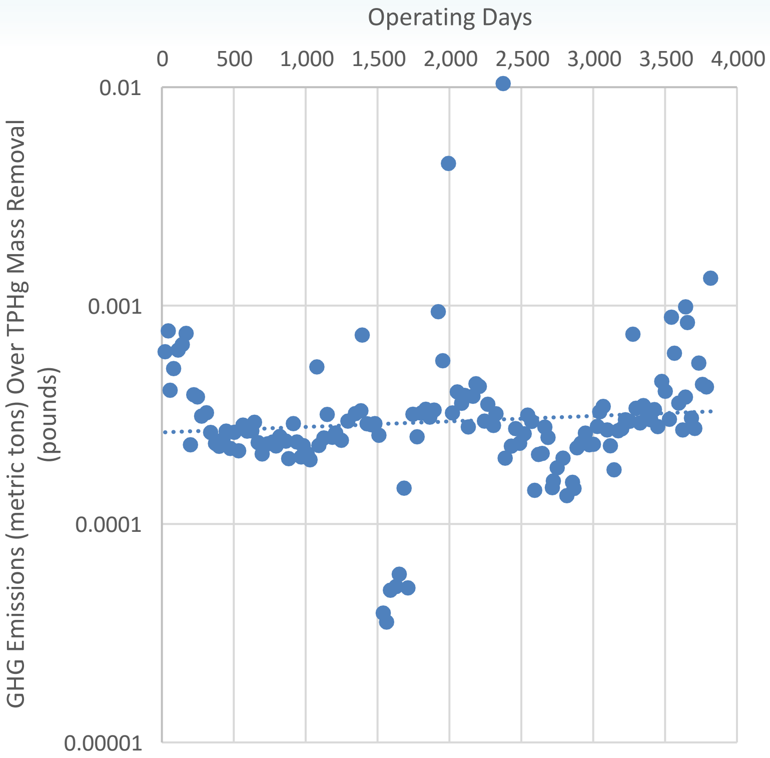


Soil Vapor Extraction

Selected Results







- 5x increase
- High variability in efficiency due to WL changes

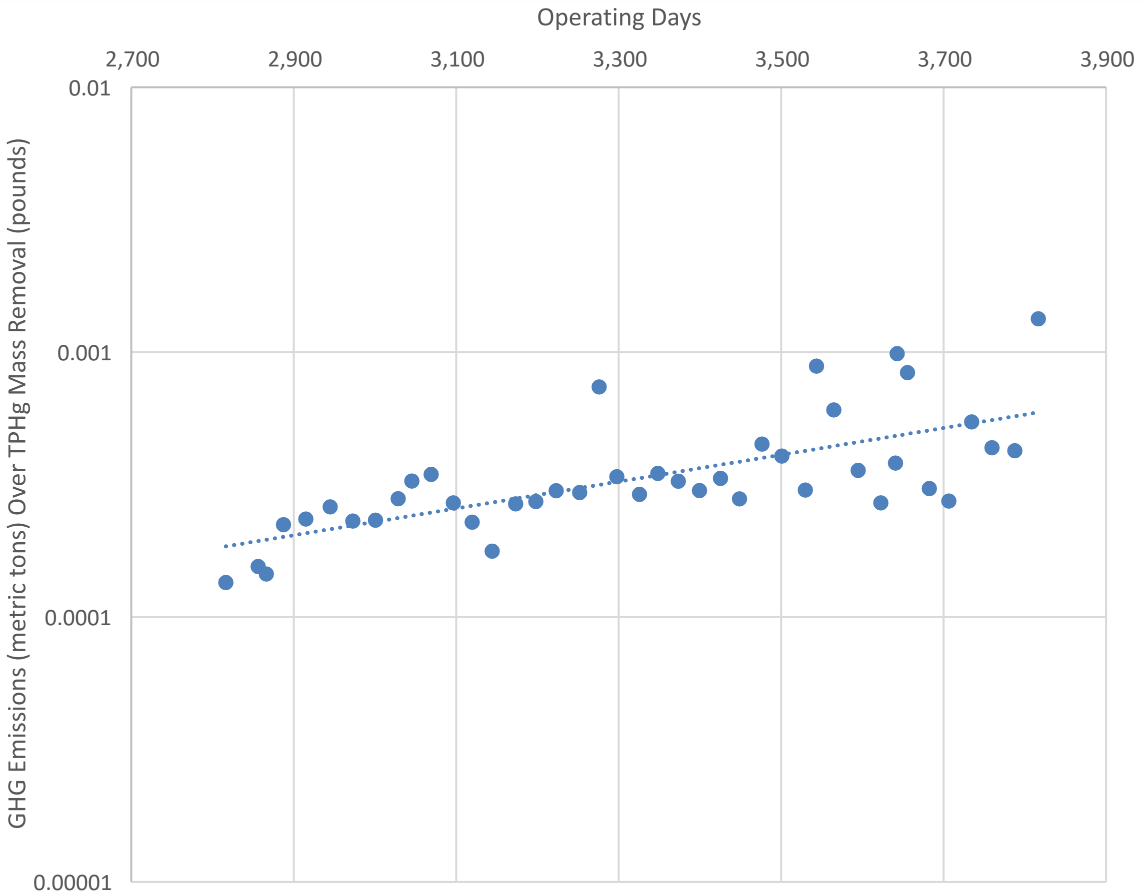
- >5,000x increase (20x from day 100)
- Regulator required SVE with O2 injection

- 1.3x increase
- Appears to be operating efficiently…

Soil Vapor Extraction

Site 5 Recent Results

- Focus on recent few years of operation
- Footprint/mass removal ratio increasing
  - Range = 0.0002 to 0.0007
  - 3.3x increase
- Early recognition of decreasing efficiency can be opportunity to optimize or evaluate alternatives such as bioventing



Soil Vapor Extraction

Overall Observations

- Site-specific conditions greatly affect the range of footprint/mass removal ratio
  - Understanding of CSM & goals is important for interpretations
- Comparing the rate of increase in the ratio at a site over time is valuable as a LOE to communicate **GHG emission cost** of continued operation

Site	GHG Emissions/Mass Removal		
	Initial	Final	Increase
1	0.2	0.8	5x
2	0.001	6.1	>5,000x
3	0.003	1.1	380x
4	0.001	0.02	19x
5	0.0003	0.0004	1.3x
6	0.001	0.002	2x
7	0.007	0.01	2x

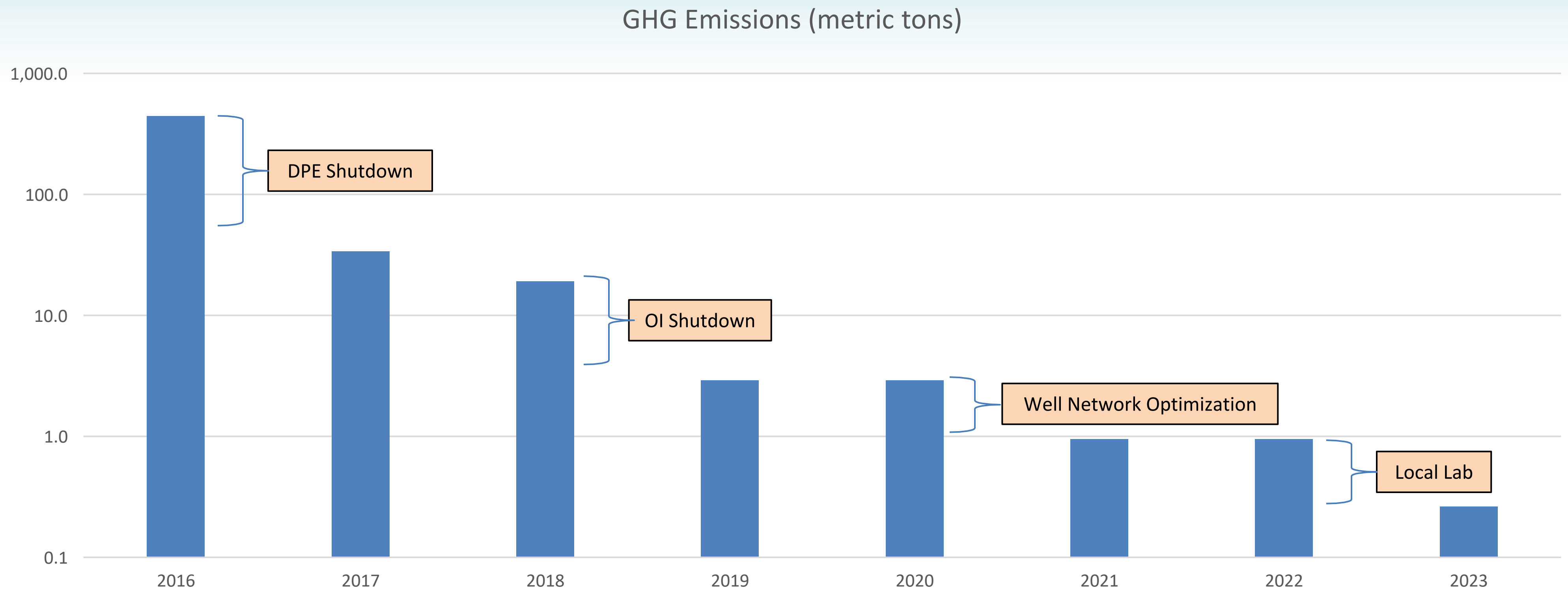
Case Studies

Two example sites that demonstrate benefits of incorporating footprint analysis:

- Case Study Site 1: Over 99 percent reductions in footprint metrics through shutdowns and optimizations
- Case Study Site 2: Remedy change that greatly decreased the footprint/mass removal ratio

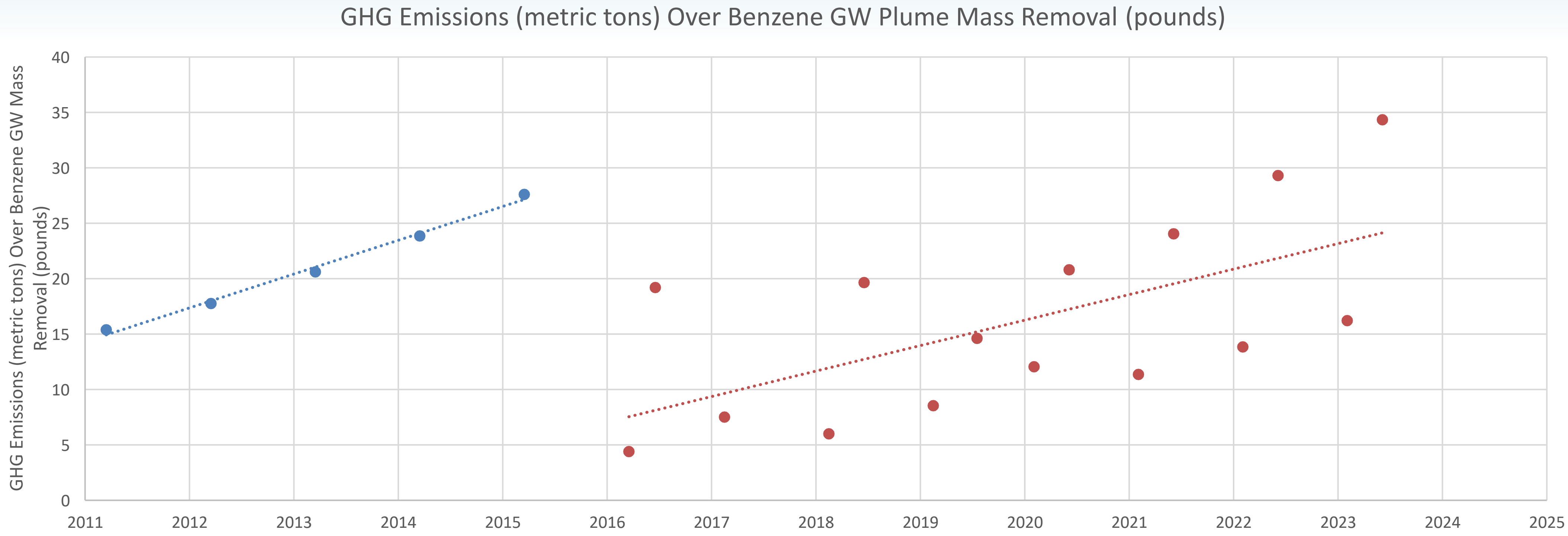
ORION

Case Study Site 1



- Accelerated shutdown of remediation systems driven by effort to improve footprint with agency communication/involvement
- Continued optimizations in GWM program
- Drastic improvement in total GHG emissions and other sustainability metrics

Case Study Site 2



- ❑ Increasing footprint ratio under previous remediation systems (P&T and AS)
- ❑ Remedy transition (P&T to phytoremediation) reset the footprint ratio to a lower baseline
- ❑ Recent increase in footprint ratio is due to significant reductions in plume mass

Future Research

- Baseline footprint/mass removal ratios are heavily influenced by plume size/mass; attempt to normalize the ratio to account for these factors for more direct comparisons across sites

- Metric captures the GHG cost of continued system operation; convert to an actual dollar cost based on social cost of carbon

- Incorporate MNA/NSZD data sets

Questions