Remediation Exit Strategy - Defining When to Turn Off an Engineered System*

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Abstract

It is a “given” that remedial action objectives should be clearly defined before constructing an engineered remediation system. However, there is a difference between regulatory cleanup goals and defining when an engineered system will cease to be effective. Even the most innovative remediation technology has limits due to the natural complexity of subsurface geologic and hydrogeologic conditions. A final phase of monitored natural attenuation (MNA) after active remediation will typically be required before cleanup goals are ultimately achieved. The best approach to achieving a site closure is to define the exit strategy before implementing engineered remediation. The remediation exit strategy should be site-specific and explain how the engineered system will change subsurface chemistry or characteristics to address the remedial objectives. It should not only state the exit criteria, but also specify performance measures for system operation and decision points for transition if multiple technologies are planned. Scientific tools and processes that will be used to demonstrate that it is time to shut off a system should be described. The strategy should also allow for phasing out an engineered system over time, reducing the remediation ‘footprint’ to only those areas that may still exceed exit criteria. The regulatory agency needs to be engaged in developing the remediation exit strategy. Even under the most prescriptive regulatory framework, performance goals may be established for subsurface conditions that will trigger remediation system end points. Finally, the approved criteria should be revisited periodically, as new diagnostic tools become available for evaluating remediation progress. A case study is presented for a robust exit strategy developed for soil/groundwater remediation of petroleum hydrocarbons at a former oil refinery. Deep air sparging with soil vapor extraction (SVE) began operating in 2003, following successful pilot testing. Dialog with the lead agency during implementation culminated in regulatory approval of an engineered remediation exit strategy. The remedial

objective is to employ deep air sparging to reduce dissolved concentrations until monitored natural attenuation (MNA) is more effective than an engineered remedy. Performance measures include system reliability (uptime), operational parameters (flow rates, pressure), and monitoring parameters (hydrocarbon mass removal rate, concentration decline, composition change). Exit criteria include multiple lines of evidence to demonstrate that contamination is diminishing and that a technology has reached its effective limit, such as nonlinear regression analysis of SVE mass removal rate. Rebound monitoring criteria are also incorporated. The approved exit strategy envisioned that SVE would eventually be discontinued, transitioning to a 'bio-sparging' operation (air sparging without SVE) as part of the remediation lifecycle. In 2011, compositional changes in extracted hydrocarbon vapors and declining concentrations demonstrated that it was time to change technology. The dominant hydrocarbon mass removal mechanism had changed from air stripping (volatilization) to in situ aerobic biodegradation. The regulatory agency was reluctant to discontinue engineered vadose zone remediation completely, but continued SVE operation at the site would not be cost-effective from an energy and carbon footprint perspective. Therefore, an alternative technology, in situ bioventing, was proposed. Bioventing involves injection of ambient air into the vadose zone at low flow rates to enhance in situ aerobic biodegradation of residual petroleum hydrocarbons. An in situ respiration field test was successfully performed to demonstrate that bioventing can destroy significantly greater petroleum hydrocarbon mass than SVE can remove at this stage in the site's remediation lifecycle, and the agency approved the alternative technology. The robust remediation exit strategy, developed with and approved by the regulatory agency years before, was the foundation for transition from SVE to in situ bioventing technology. The exit strategy was revised in 2012 to replace SVE performance measures and exit criteria with bioventing components. The criteria were also updated to incorporate better scientific methods available today, such as compound-specific stable isotopic analysis, to validate remediation progress and determine when system operation should end. The exit strategy will continue to guide decision makers for this site throughout the remaining active remediation.

Remediation Exit Strategy – Defining When to Turn Off an Engineered System

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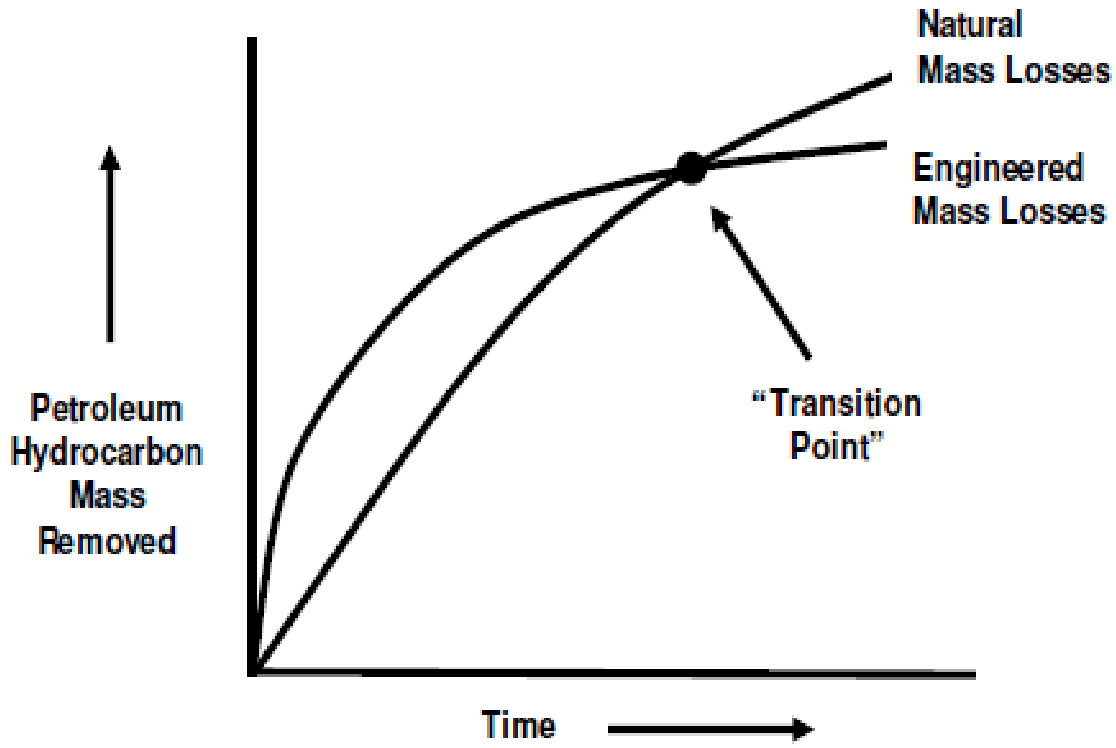
Outline

- Why do you need a Remediation Exit Strategy?
- Developing a robust Remediation Exit Strategy
  - best practices
  - components
- Petroleum Hydrocarbon Remediation Case Study
- Summary

Why do you need a Remediation Exit Strategy?

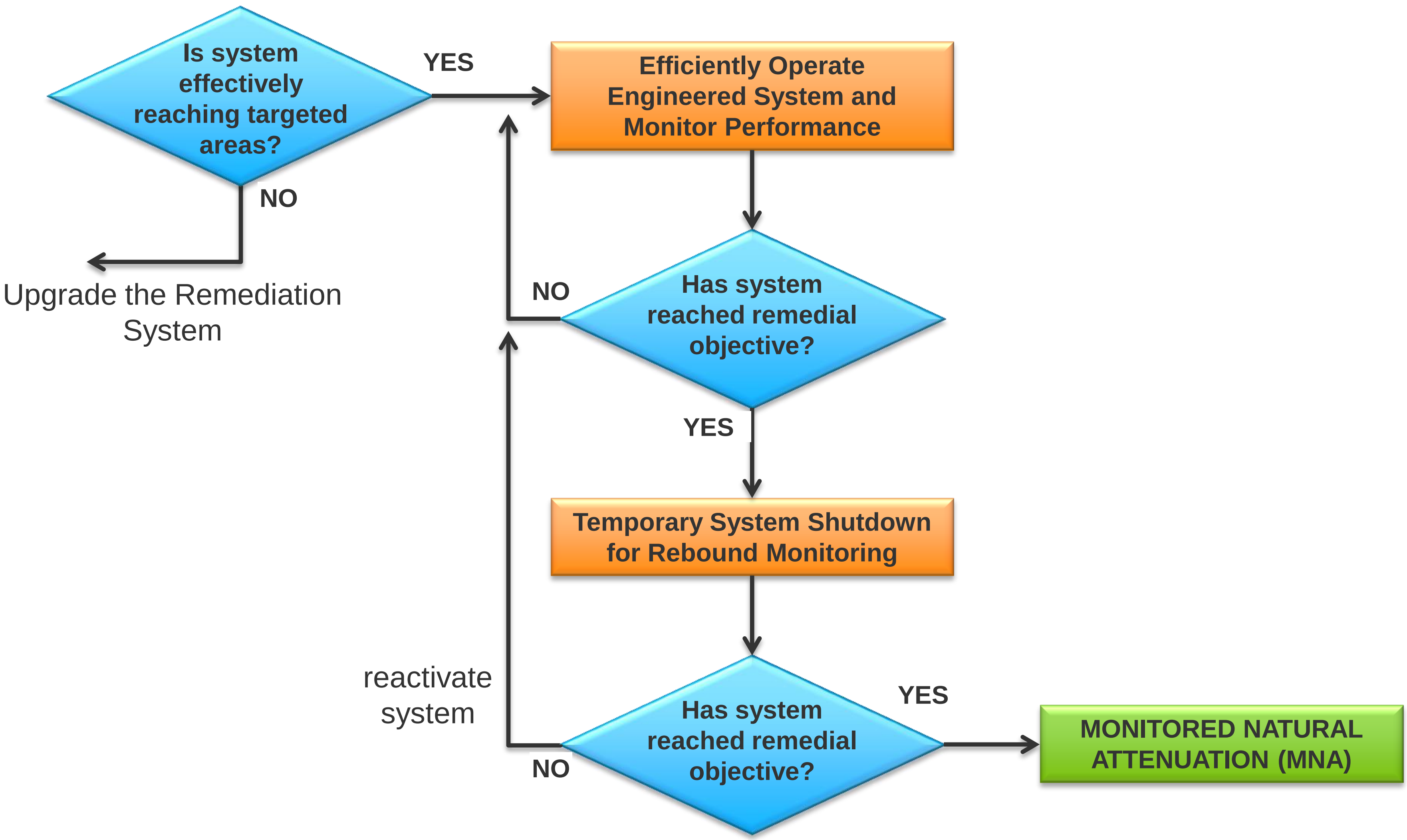


There is a difference between regulatory cleanup goals and the point when an engineered system will cease to be effective.

Developing a robust Remediation Exit Strategy

- **Best Practices:**
  - Engage regulator early
  - Define clear decision points (flow chart)
  - Include multiple lines of evidence
  - Incorporate “footprint” reduction
  - Recognize technology advances over time
  - Cite references for scientific methods

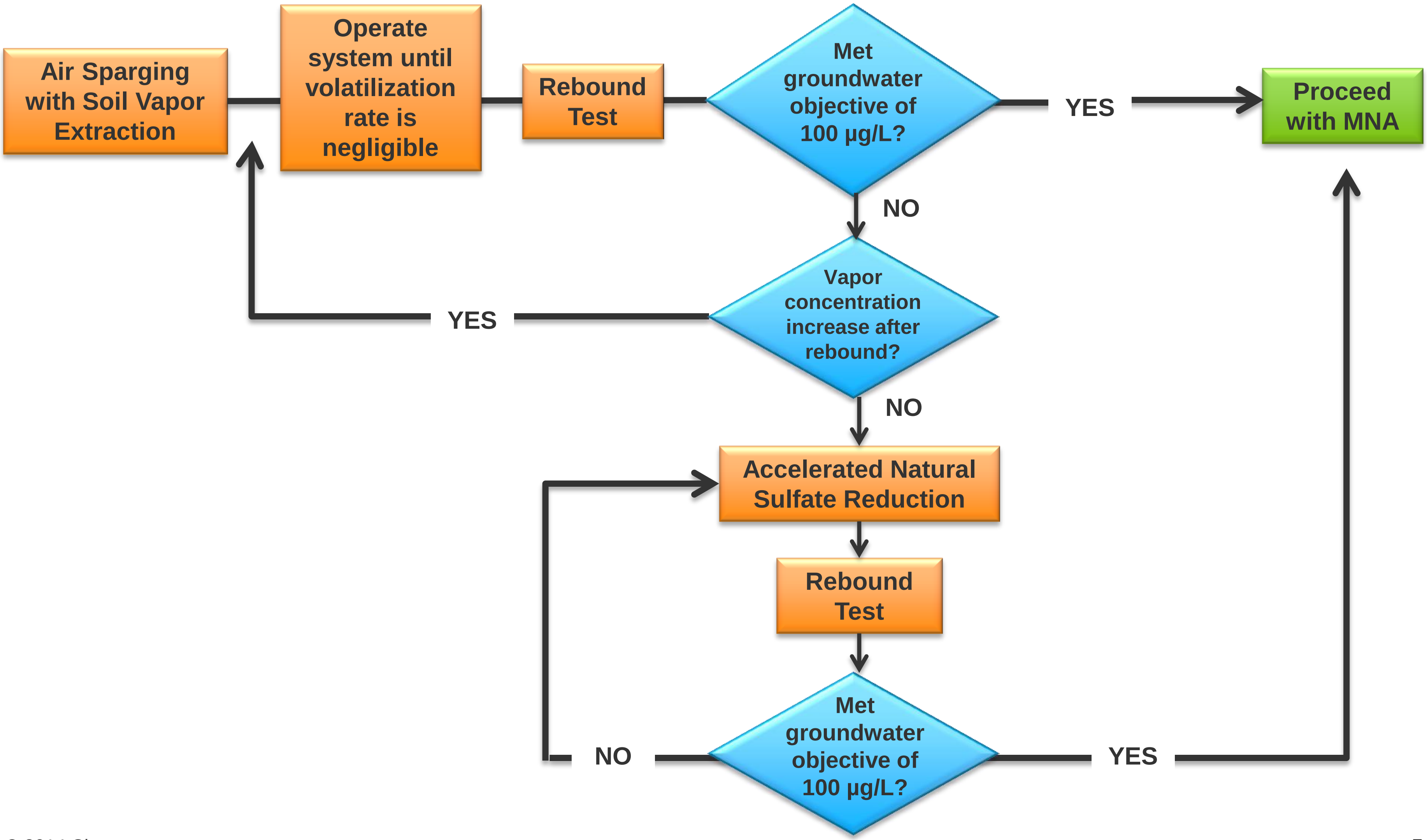
Remedial Strategy Decision Tree



Remediation Exit Strategy components

- Remedial objectives of engineered system
- Performance measures for system operations
- Diagnostic tools to demonstrate remediation effectiveness
- Decision points / performance goals
- Exit criteria for engineered system
- Literature references

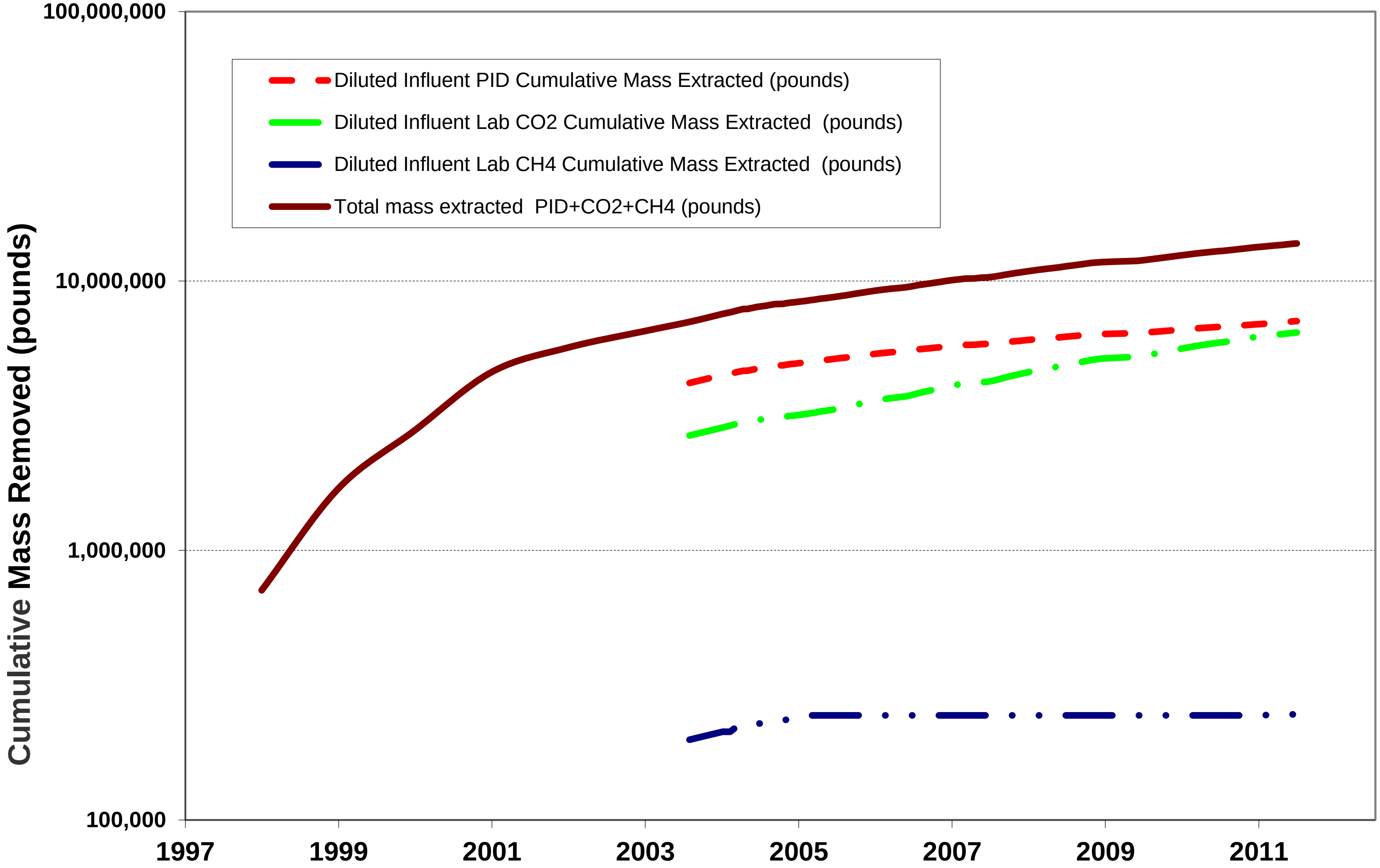
Performance Goals



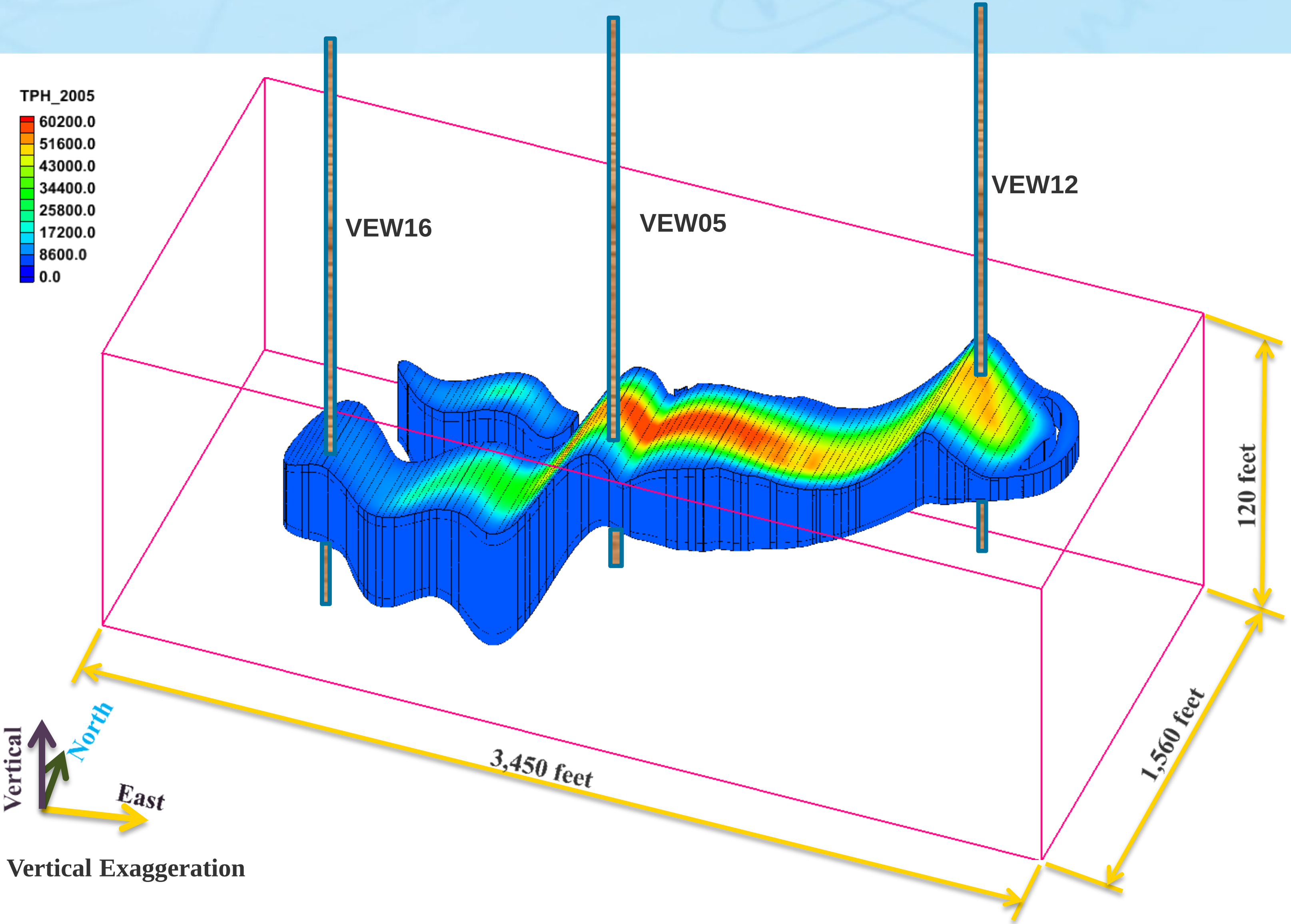
Petroleum Hydrocarbon Remediation Case Study

- Deep air sparging with soil vapor extraction (SVE)
  - Early agency engagement and approval of the site remediation exit strategy
- Performance measures
  - System reliability (uptime)
  - Operational parameters (flow rates, pressures)
  - Monitoring parameters (hydrocarbon mass removal rate, concentration decline, composition change)
- Exit criteria
  - Multiple lines of evidence (mass calculations, time series plots)
  - Rebound calculation and time period

Vadose Zone Remediation Progress

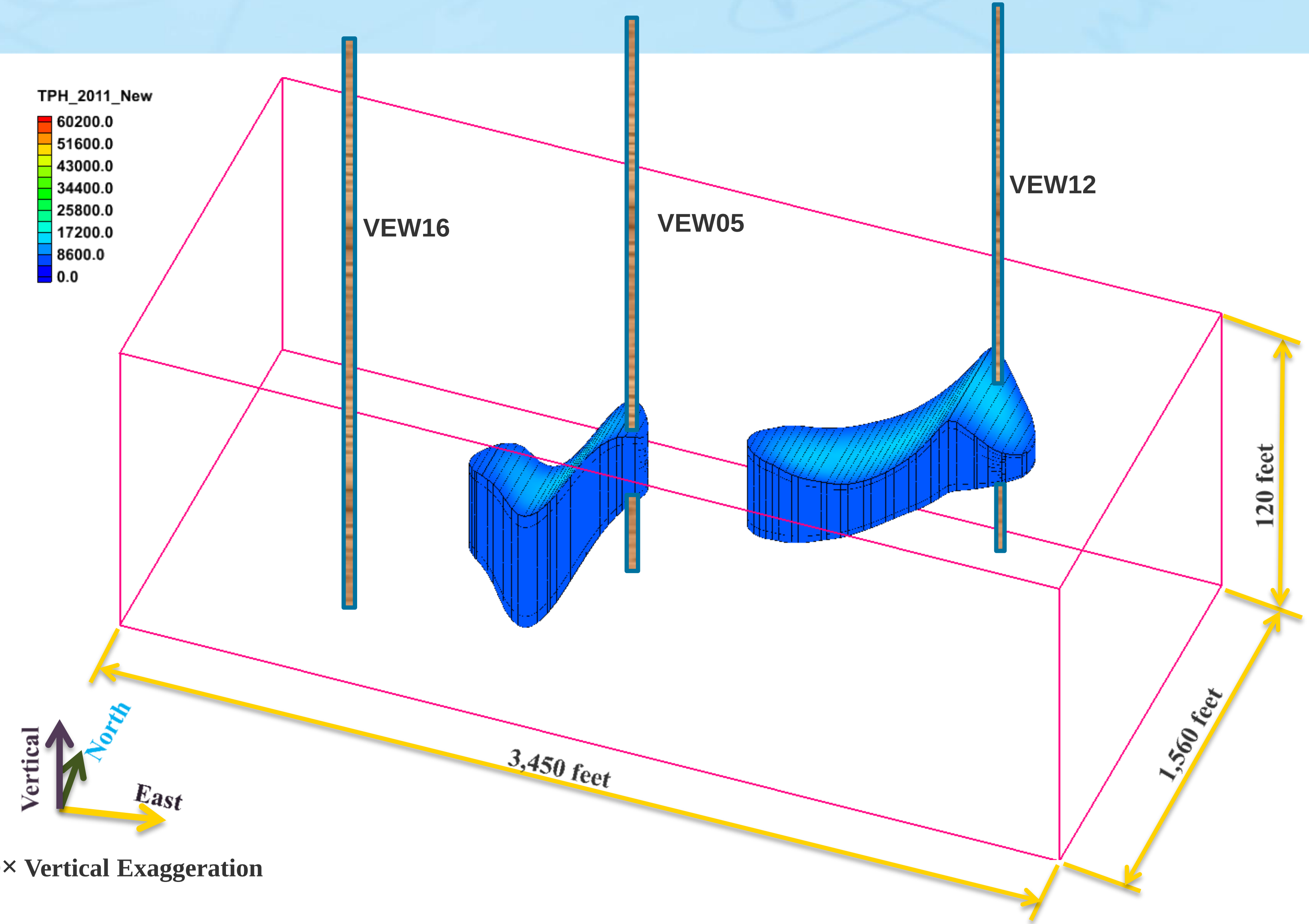


2005 Soil Gas TPHg Concentrations (> 5,000 ppmv)



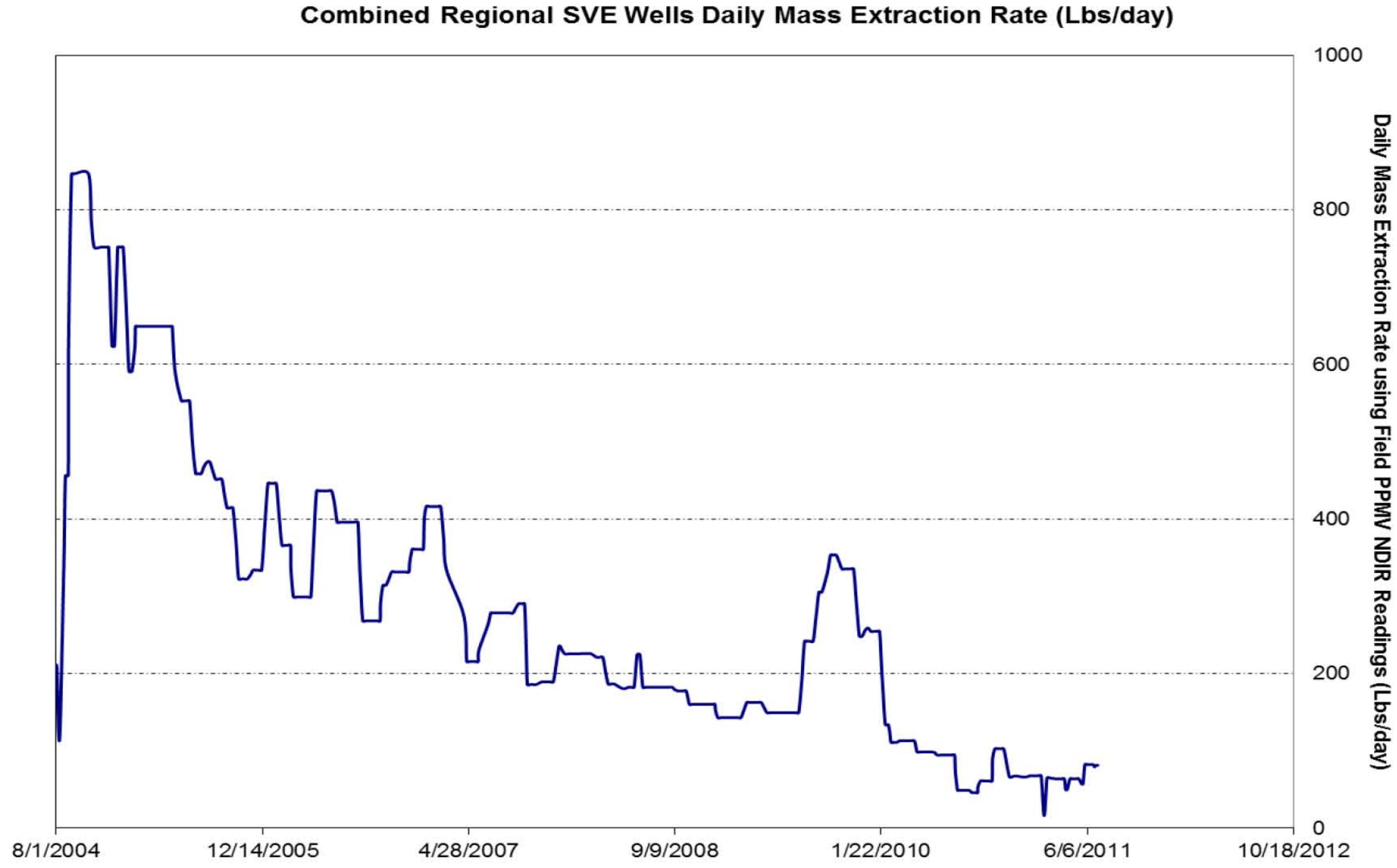
10× Vertical Exaggeration

2011 Soil Gas TPHg Concentrations (> 5,000 ppmv)



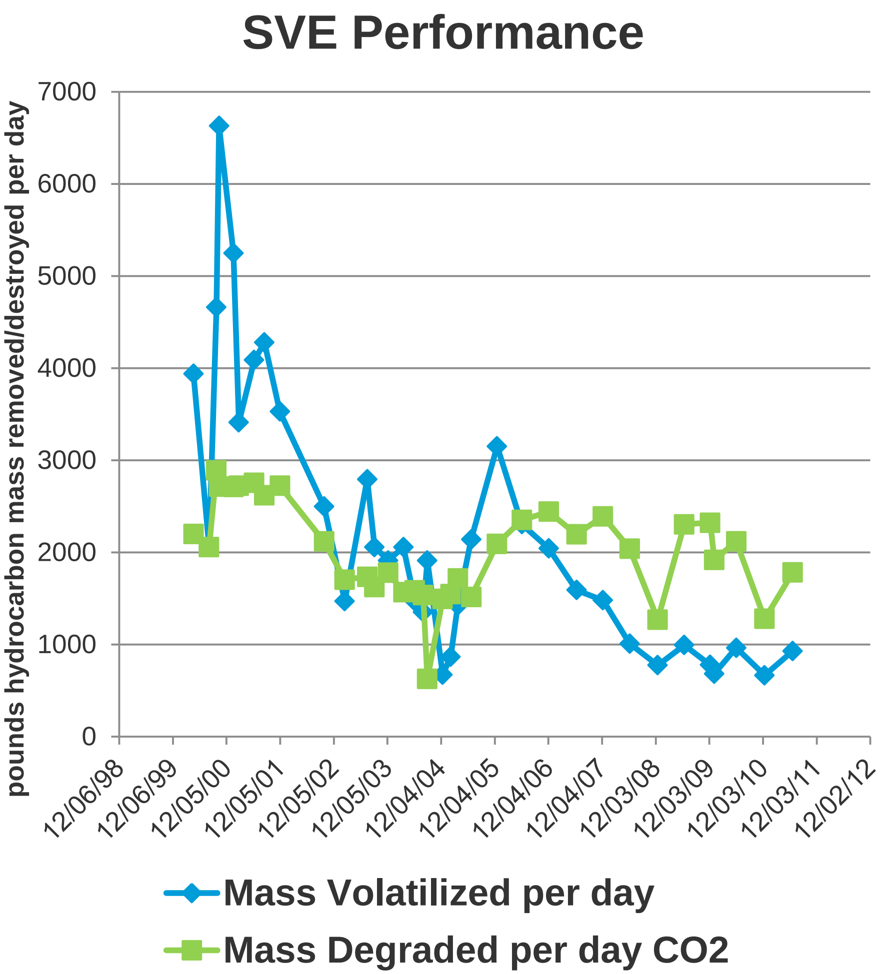
10× Vertical Exaggeration

SVE Daily Mass Extraction Rate Over Time



Demonstrating Transition Point

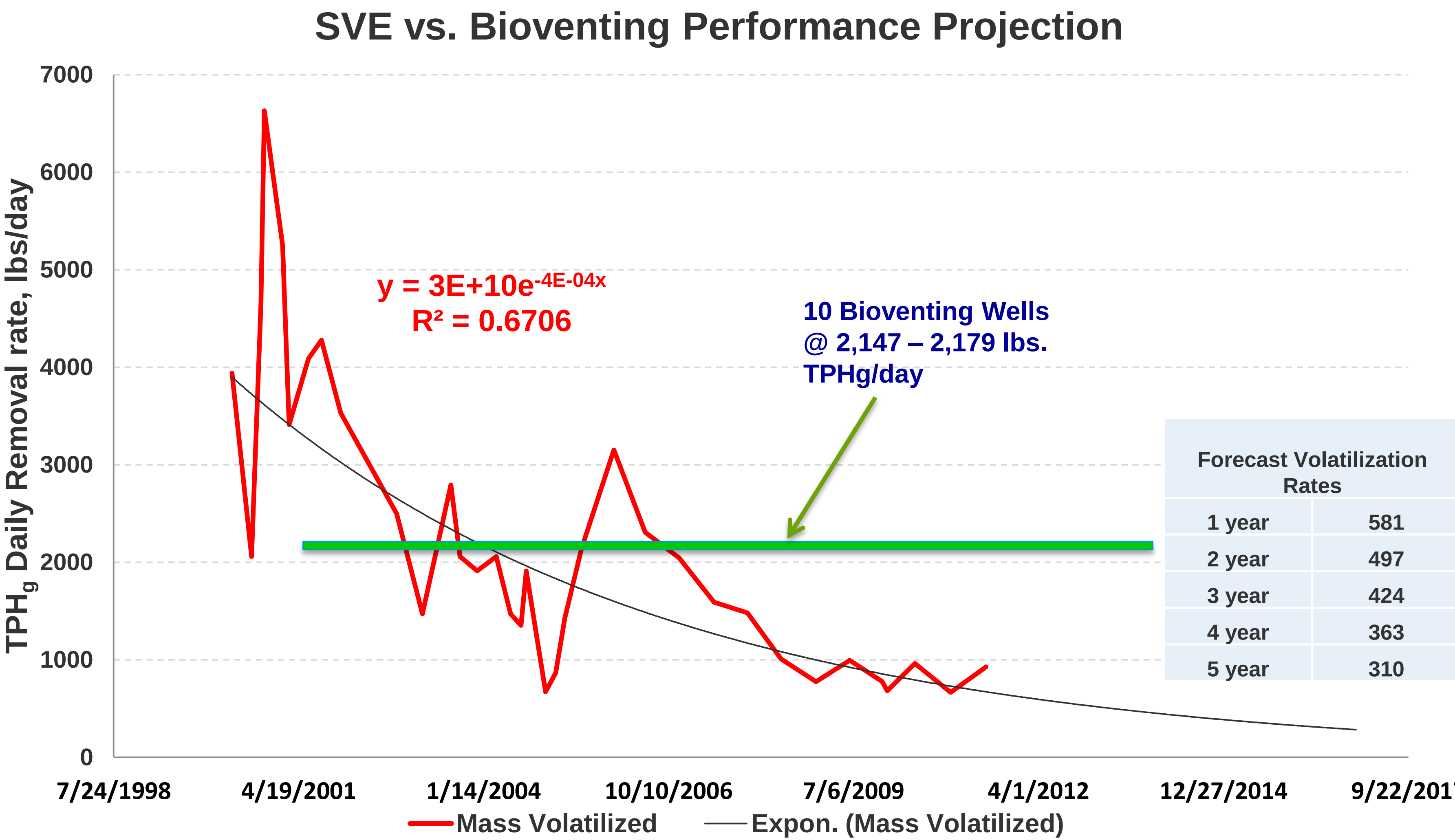
- After years of SVE coupled with deep air sparging, much of the volatile hydrocarbons has been removed. Biodegradation has become the dominant mass removal mechanism.
- Bioventing is a “greener” technology than SVE and can deliver larger volumes of oxygen more efficiently to the vadose zone for biodegradation.



In Situ Respiration Field Test Objectives

- Respiration rates are used to estimate mass destruction rates through aerobic biodegradation in units of mg TPH_g/Kg soil-day
- Aerobic biodegradation mass destruction rates determine operational requirements for a full-scale bioventing system.

Projected Daily TPH_g Biodegradation Rates Based on an In Situ Field Respiration Test



Forecast Volatilization Rates	
1 year	581
2 year	497
3 year	424
4 year	363
5 year	310

Remediation Exit Strategy Revision

- Replaced SVE criteria with bioventing components.
- Added molecular diagnostic tools (compound specific stable isotope analysis).
- Retained similar performance measures and exit criteria.
- Retained rebound definition.
- Retained option for footprint reduction.

Summary

- **A robust remediation exit strategy can …**
  - guide decision makers throughout active remediation
  - be the foundation for transition between multiple technologies and engineering end points