Jacobs Challenging today. Reinventing tomorrow.

Lessons Learned Thermally Treating 18 Source Areas on the Velsicol Chemical Superfund Site, Michigan

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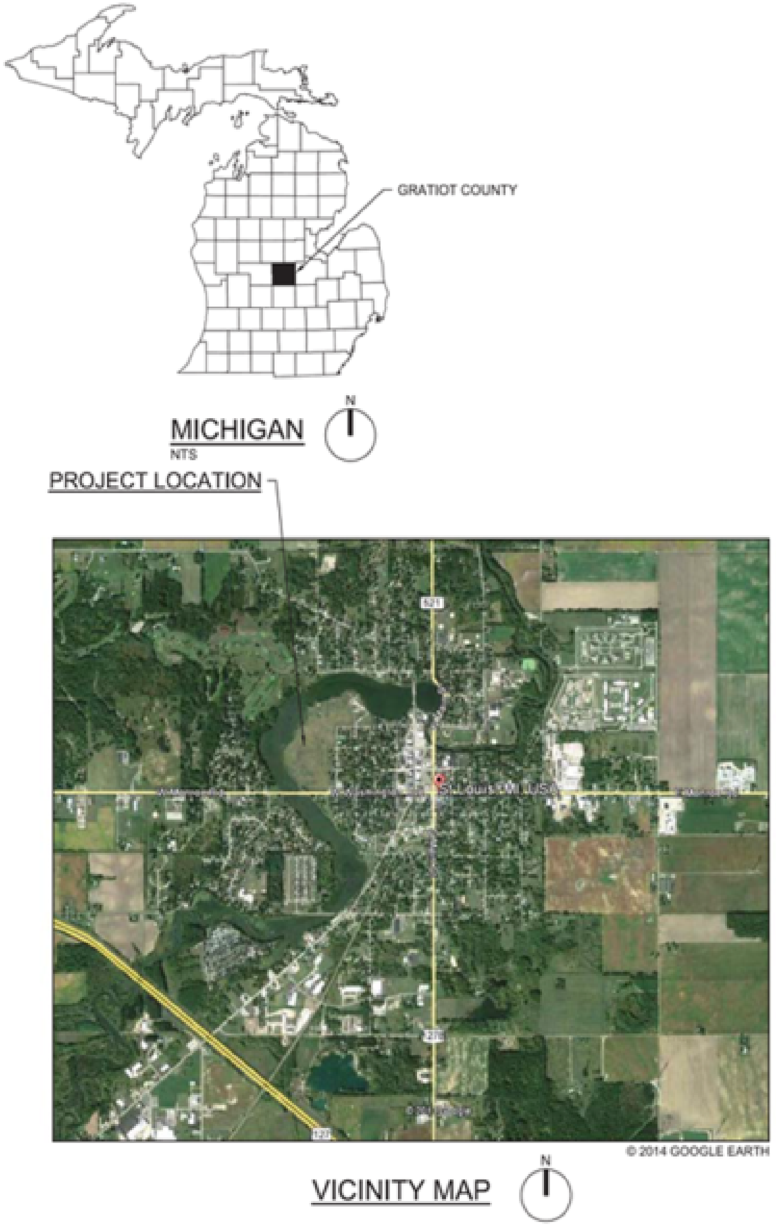
Velsicol Superfund Site



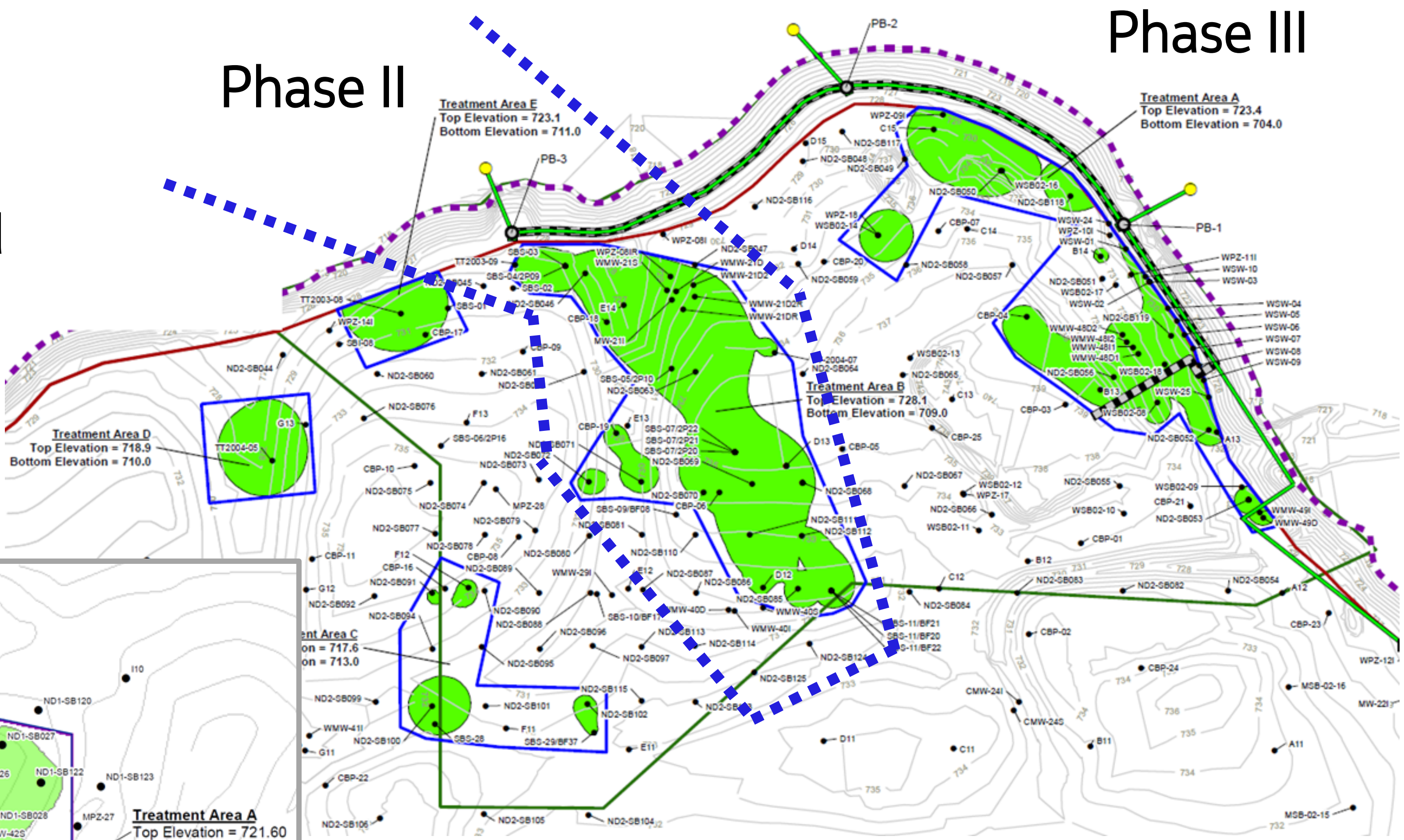
- 52 Acre former chemical manufacturing area along the Pine River in St. Louis, Michigan
- Between 2017 and 2022 in-situ thermal treatment (ISTT) was applied in 18 discrete source areas

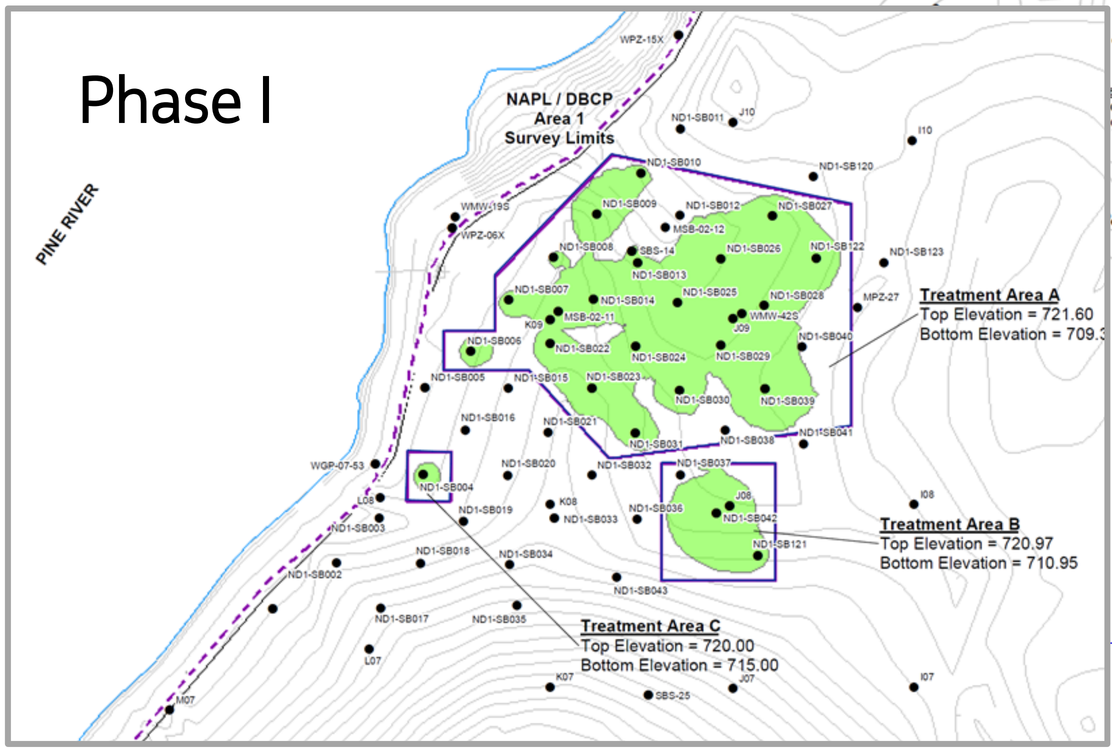
Treatment Area Summary

Parameter	Phase I	Phase II	Phase III	Total
Area (sq ft)	43,658	39,920	38,890	**122,000**
Volume (yards)	16,361	19,220	21,863	**57,445**
Discrete Source Areas	5	3	10	**18**
Heaters	276	242	325	**843**
Shallow Extractors	0	52	70	**122**
Multiphase Extraction Wells	59	52	70	**181**
Total Operating Days	226	302	274	
Days to Target Temperature	135	156	117	
Days at Target Temperature	91	146	157	
Mass Removed (pounds)	55,700	183,000	142,000	**380,700**

Source Area Overview

- Phased delivery provided unique opportunity to implement change as project progressed



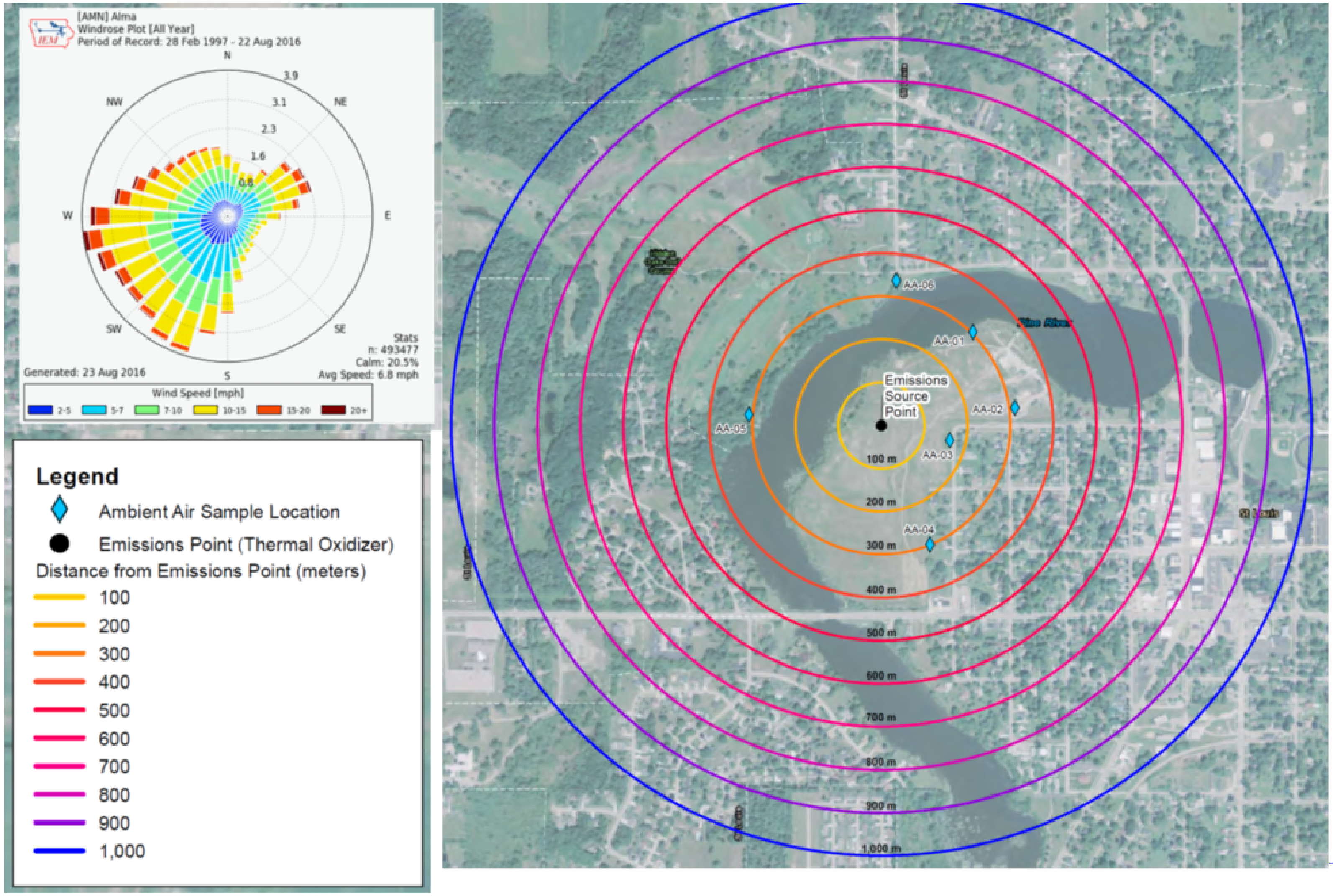


- Lessons learned directly integrated to subsequent phases

The Importance of Ambient Air Monitoring

Integrate adaptive design strategies when operating conditions require

Laboratory Data Drives Decisions



- Document the thermal remedy is functioning in a way that is protective of public health.
- Ensure health and safety of site or operations personnel

Field Monitoring Tools Lack Specificity

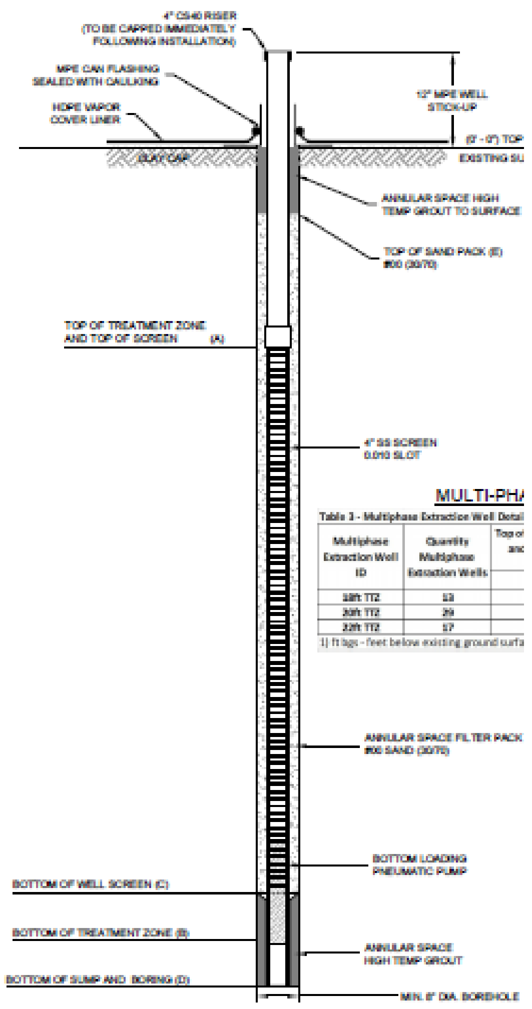
Photoionization Detectors (PID)

- Realtime measurements
- Simple operation
- Screening quality data
- High variability in sensing capabilities

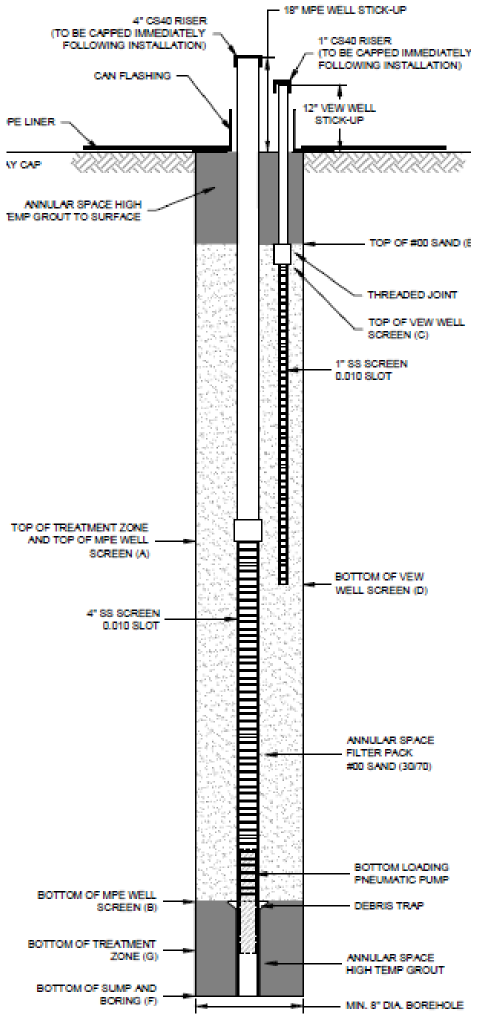
Optimal Applications

- Process vapor screening
- Air monitoring for properly trained workers

Enhanced Vapor Extraction Through Adaptive Design



Phase I

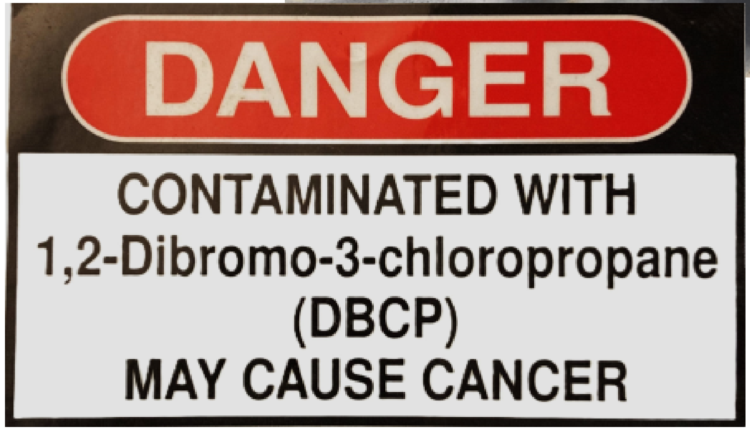


Phase II

- Recovery well design modified to provide independent shallow and deep vapor extraction capabilities.
- Supplemental dedicated shallow extraction points also integrated to Phase II design
- Design change eliminates nuisance well field odor

An Unwelcomed Guest Arrives

- 1,2-Dibromo-3-chloropropane (DBCP)
  - Confirmed male sterility agent and known carcinogen
  - Permissible exposure limit (PEL): <u>9.67 µg/m^3</u>
  - No reliable tools for real time measurement
  - Self-contained breathing apparatus (SCBA) is required
- Detected off-site in ambient air sample above project specific action limit (0.1 µg/m^3) during Phase II startup
- Immediate actions
  - Enhanced engineering controls
  - Elevated personal protection levels (SCBA)
  - Increased ambient air monitoring
  - Enclosure of liquid handling operations

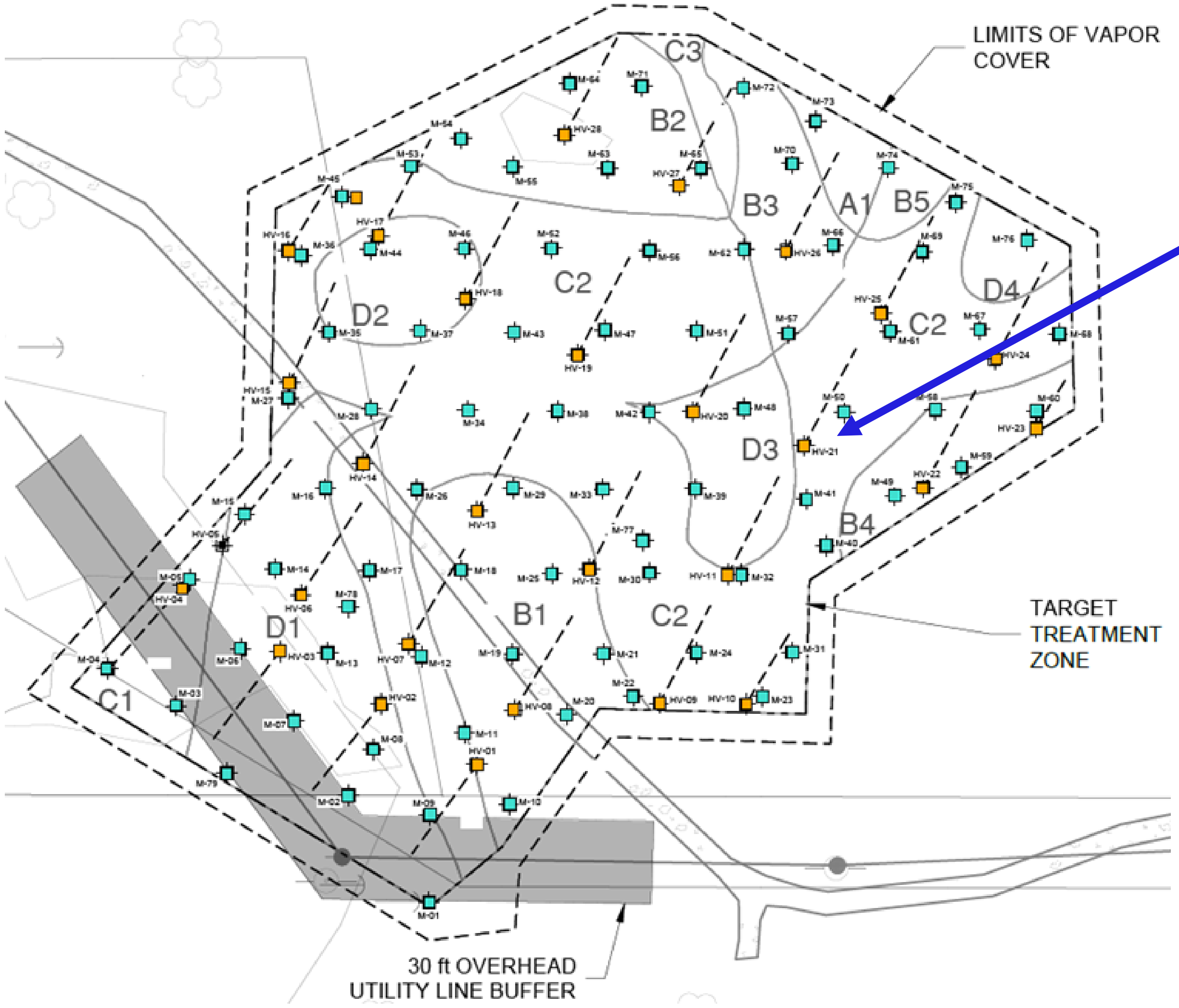


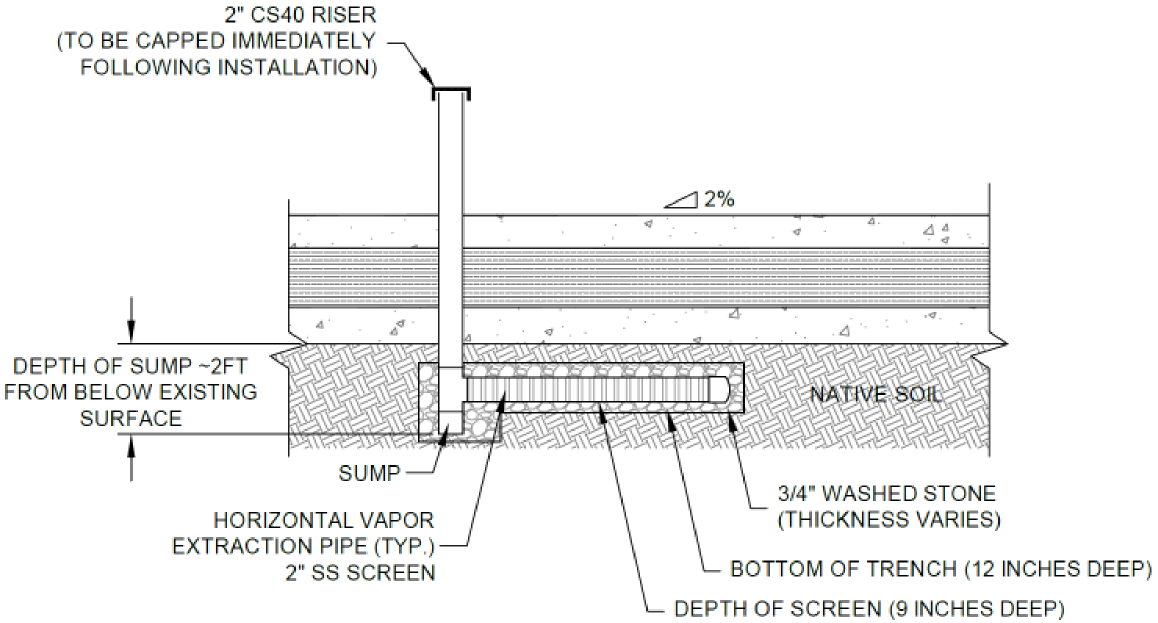
Engineering Controls Improve Vapor Capture

- Process vessel vapor extraction enhanced
- Secondary seals for inspection doors

Liquid storage vessels specified with sealed inspection ports to provide a more robust vapor seal

Vapor Extraction Design Evolves Again





- A final phase of thermal treatment at a satellite disposal area incorporates shallow horizontal vapor collection beneath an insulated vapor cover

Velsicol Burn Pit (Phase IV)

Conceptual Site Models

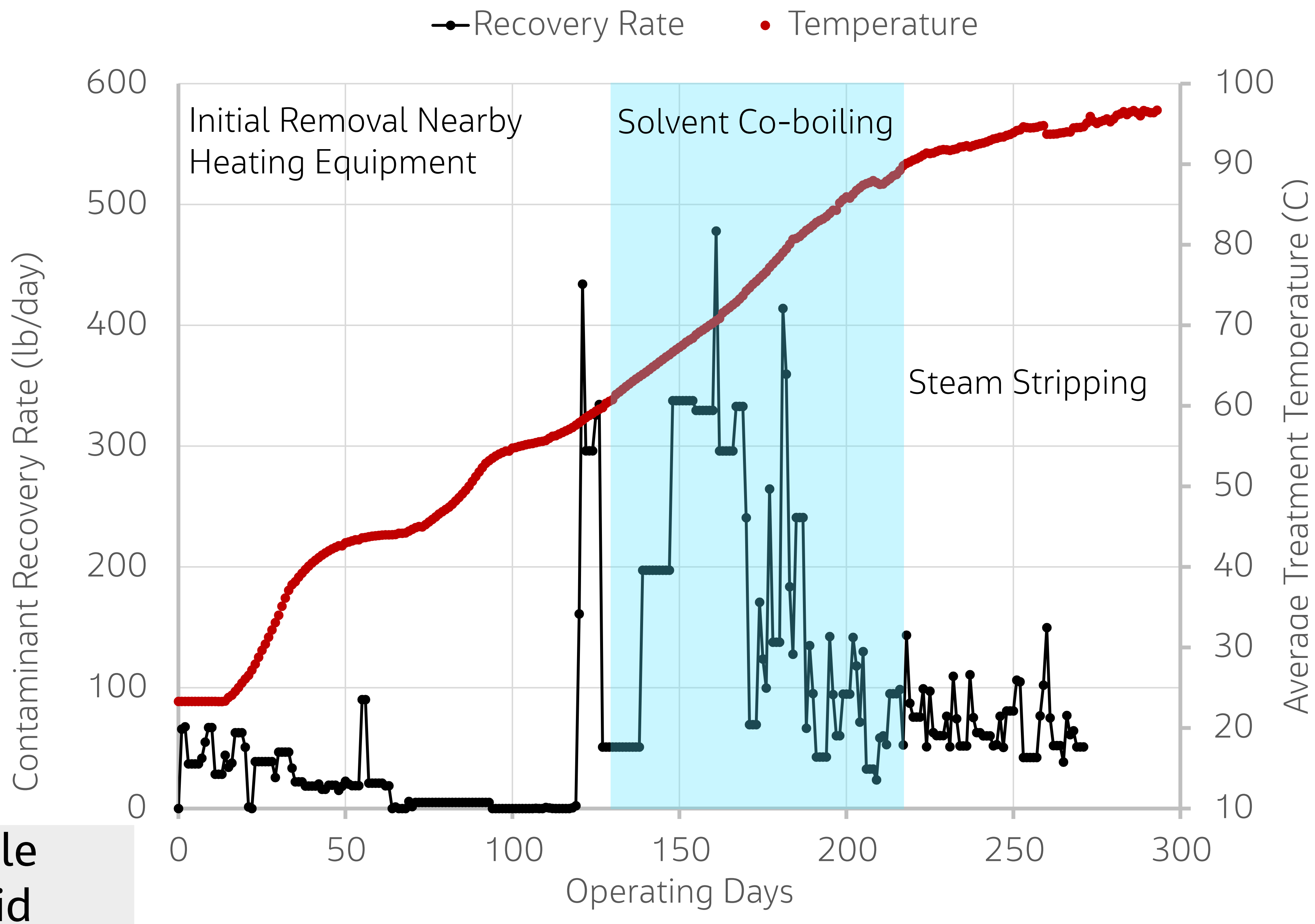
Even the best can lead you astray

Solvent Encountered During Sediment Excavation

- Dense product found in sand seams incised in the glacial till
- More than 4,000 gallons of product recovered directly from the till surface
- Product composed of chlorinated volatile organic compounds

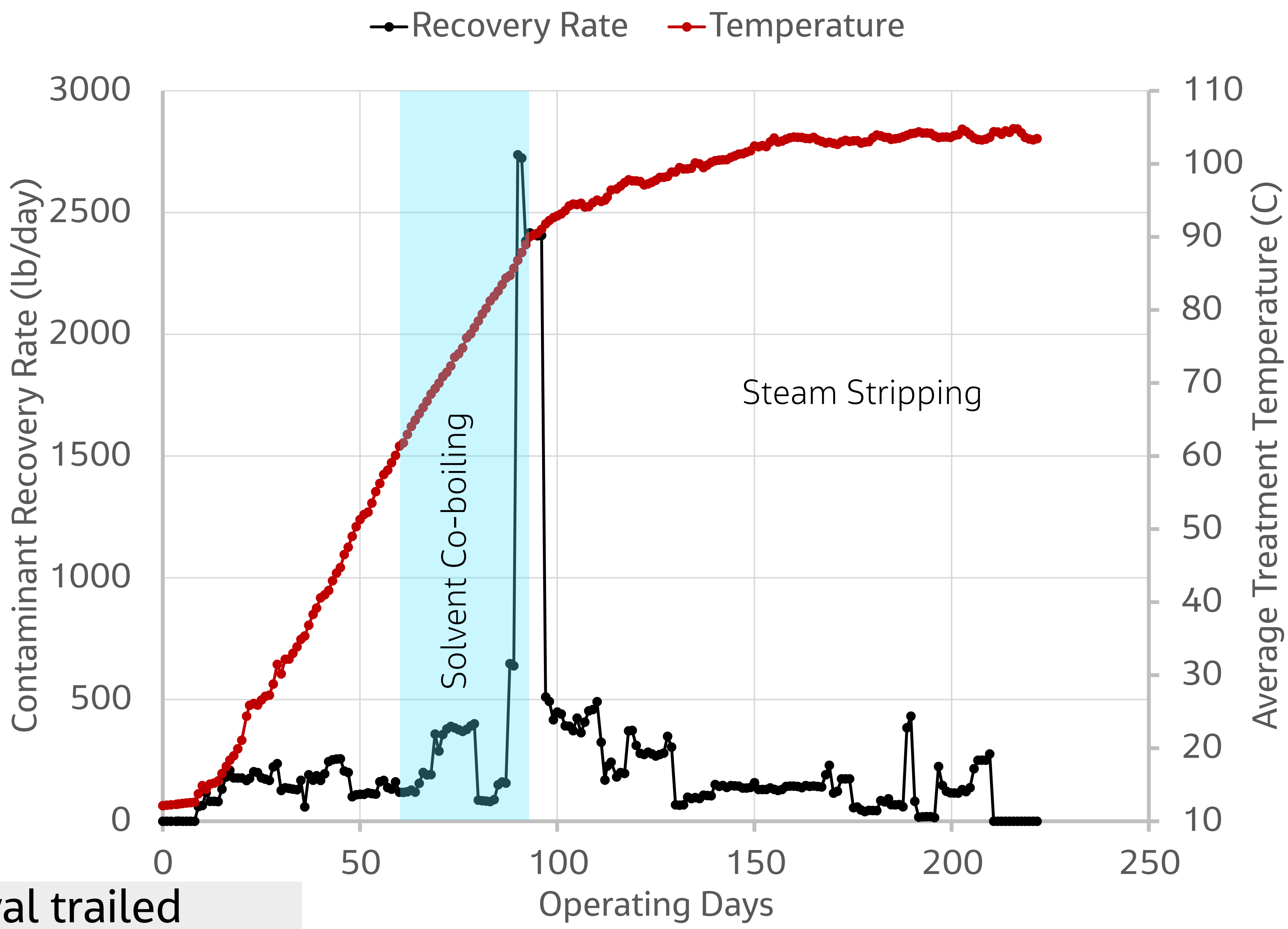
- Upland thermal treatment areas included observed locations of solvent seeps to the pine river.

Expected Response



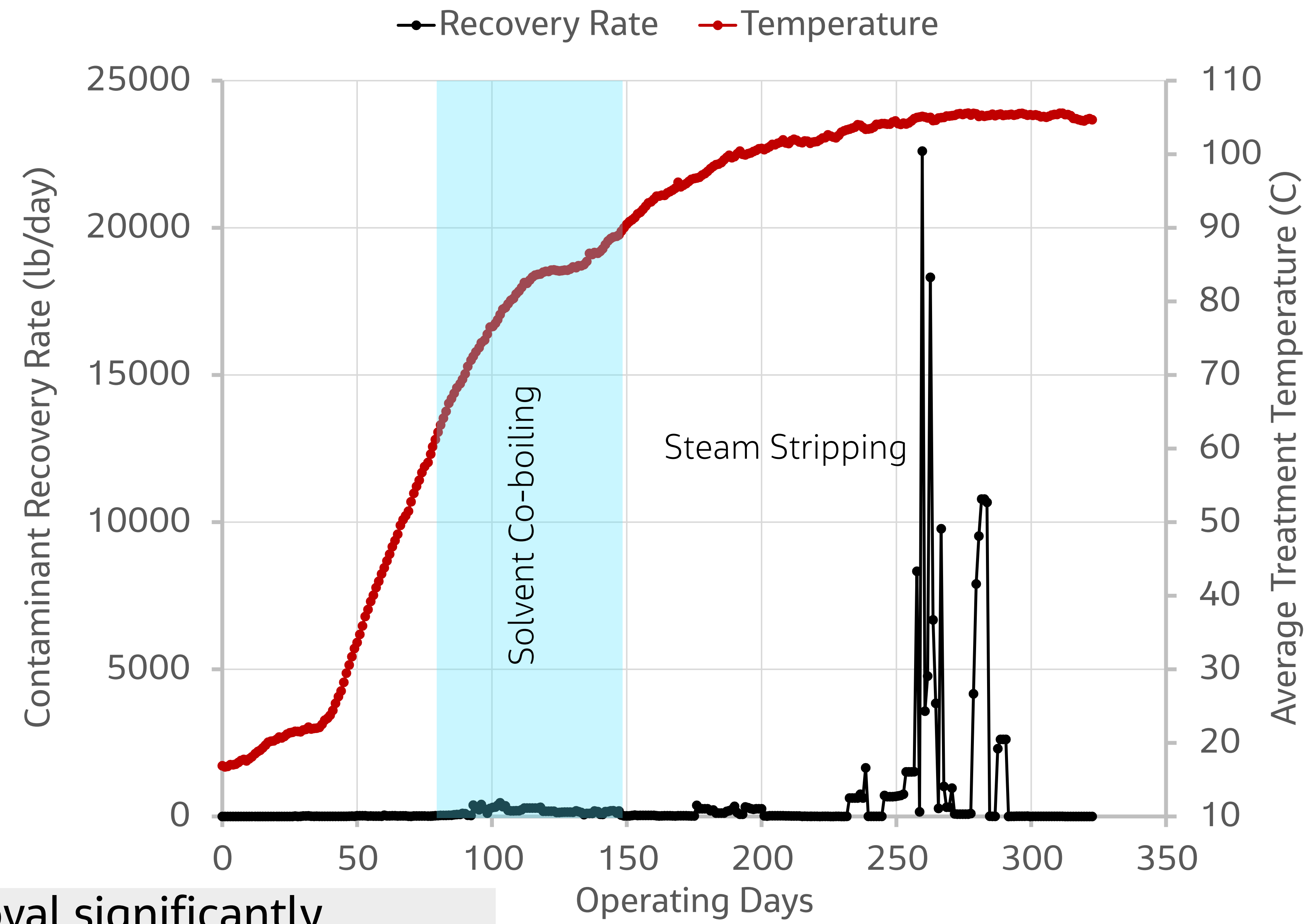
Typical removal of volatile non-aqueous phase liquid during subsurface heating

Phase I Response



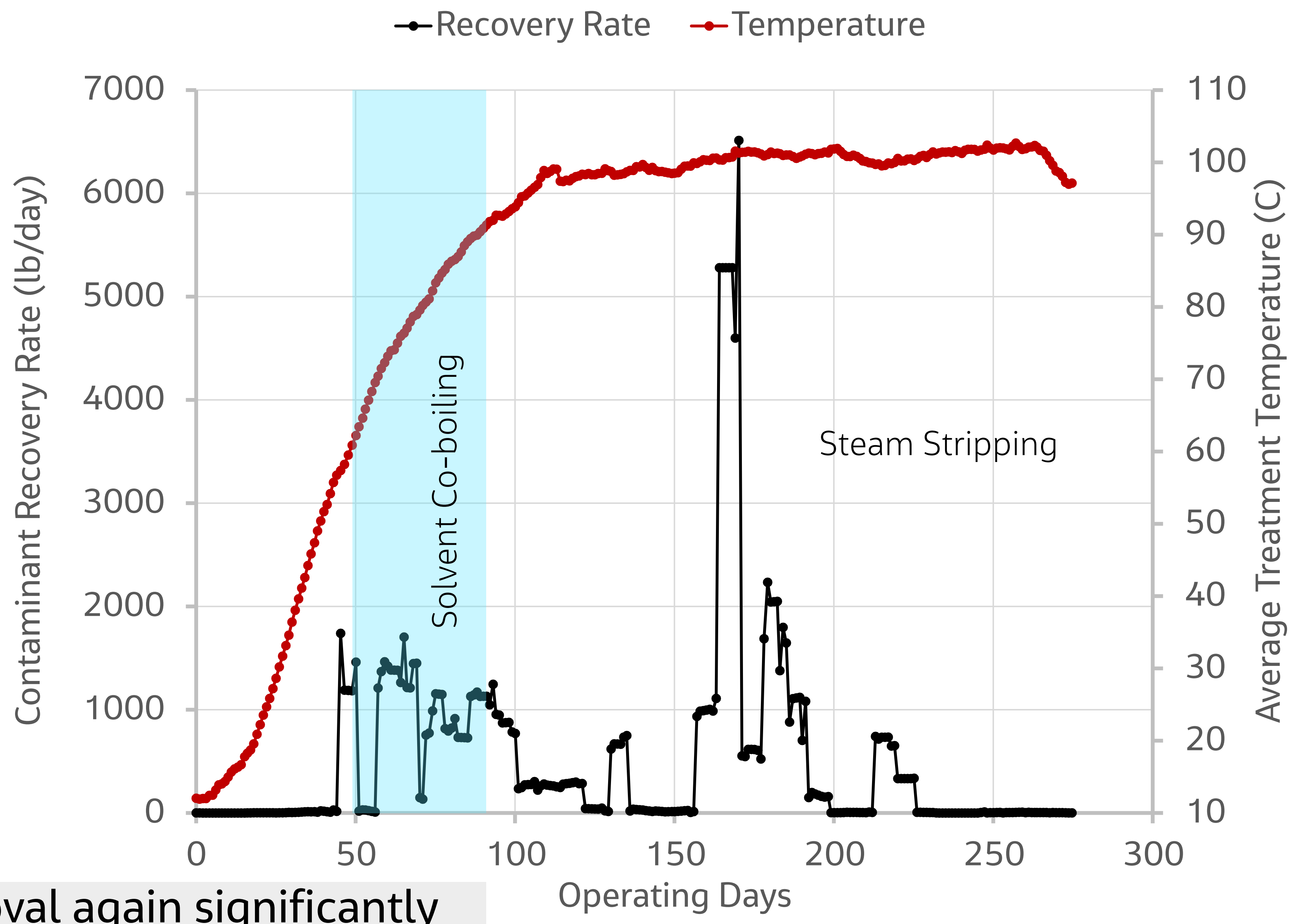
Peak contaminant removal trailed solvent co-boiling temperature range

Phase II Response



Peak contaminant removal significantly trailed solvent co-boiling temperature range

Phase III Response



Peak contaminant removal again significantly trailed solvent co-boiling temperature range

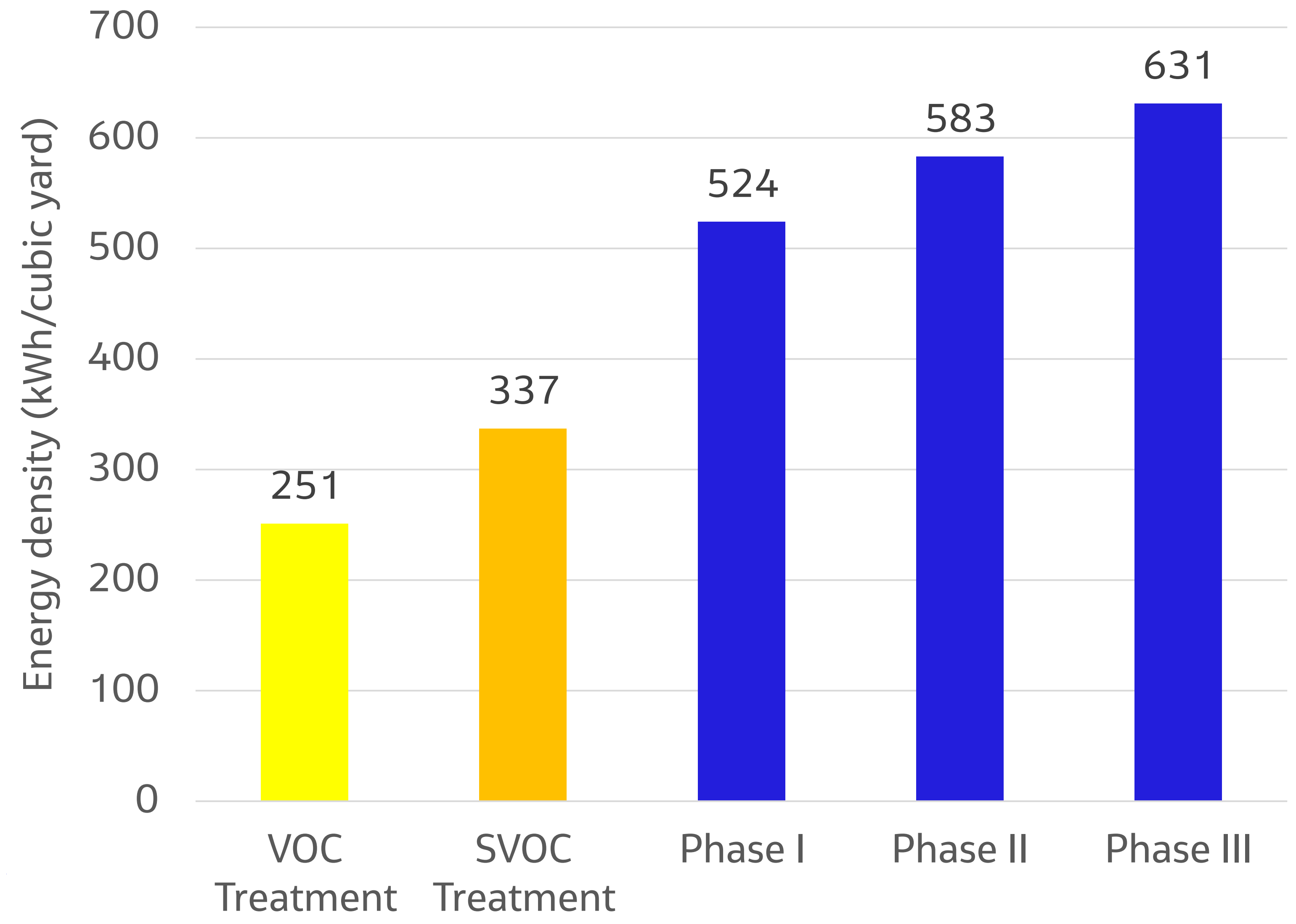
Liquid Phase Contaminant Recovery Dominated all Treatment Phases

- Site investigation and monitoring data suggested presence of dense chlorinated solvents in discrete upland source areas
  - Vapor treatment premised on thermal oxidation
- Significant volumes of low volatility NAPL were recovered during treatment
  - Vapor treatment by activated carbon likely sufficient
- Product disposal logistics proved challenging
  - System had limited storage; fast turnover needed

Energy input can be used to identify a thermal treatment system endpoint

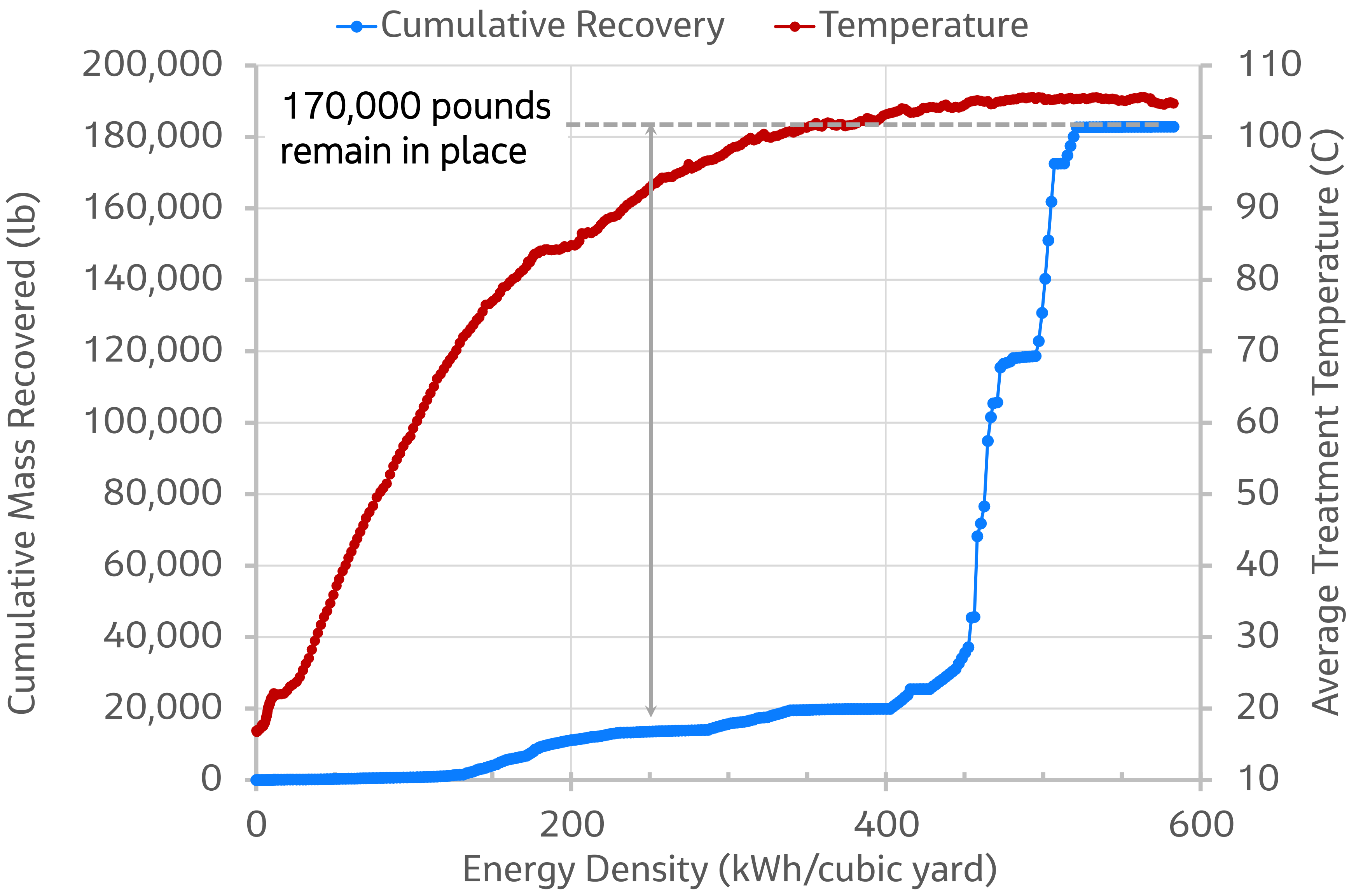
Remember that energy is only one part of the story

Approach Shutdown Conditions Premised on Energy Cautiously



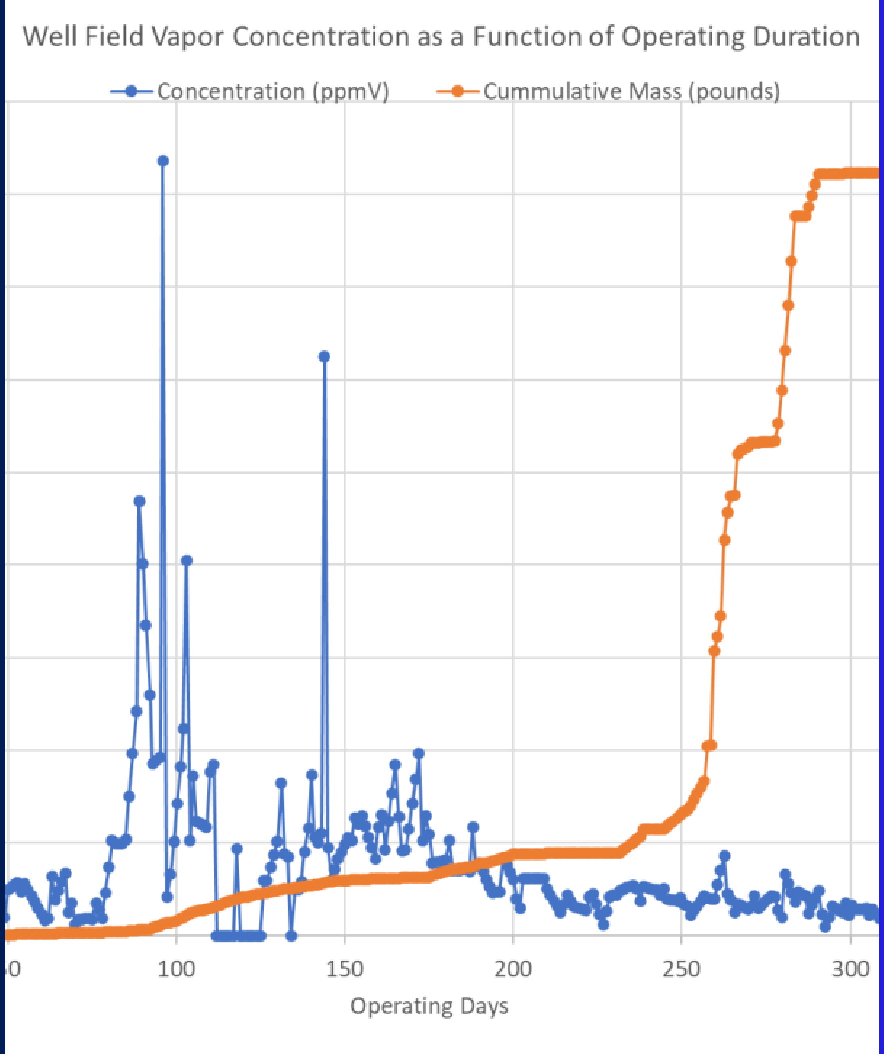
- Must be considered in parallel with subsurface temperature and mass removal rates to guide system shutdown
- Shutdown approaches which factor multiple lines of evidence may offer much greater certainty

Phase II Energy Input Example



If industry experience energy endpoints were applied significant mass would have remained after shutdown

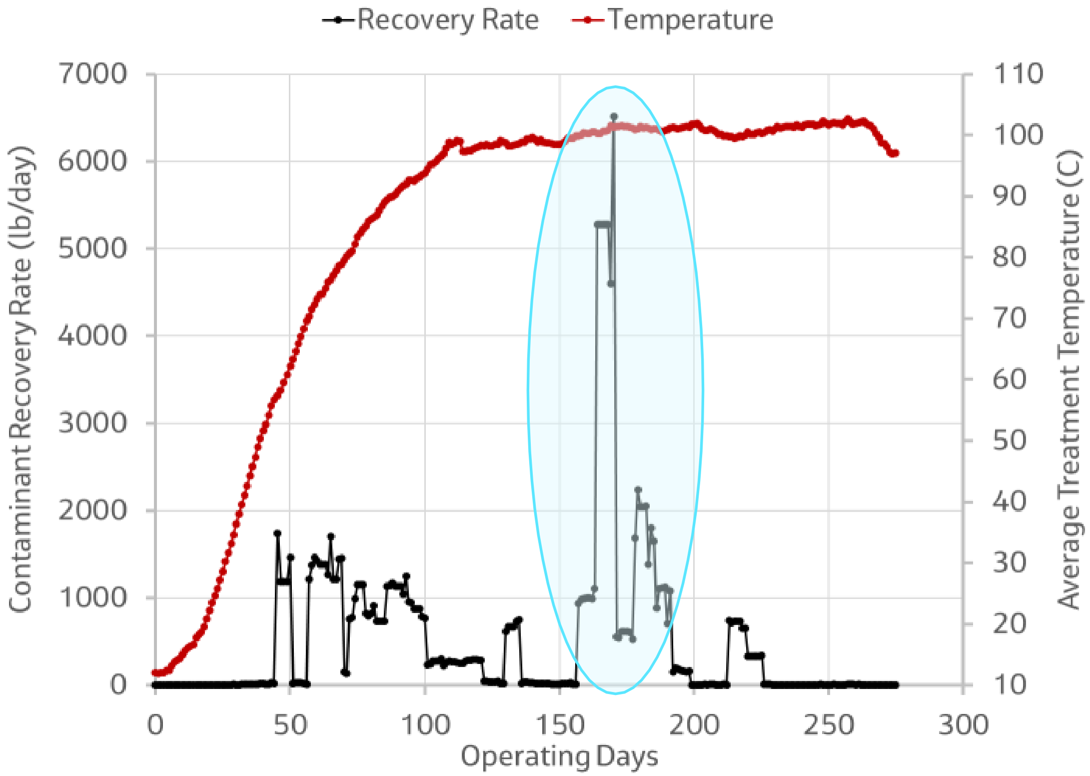
Apply Diminishing Returns Strategies for Shutdown



- Multiple lines of evidence using measurements of contaminant recovery, subsurface temperature and energy input over time to:
  - Demonstrate that the practical (and technical) endpoint for subsurface contaminant removal has been reached
  - Demonstrate that additional thermal energy input or extended system operation will not yield a significant reduction in soil and groundwater contaminants

Molten Contaminant Recovery Observed

- Phase III peak mass recovery occurred <u>after</u> exceeding an energy density of 425 kWh/yard
- Liquefied DDT was extracted in several locations which immediately solidified when cooled



Closing Thoughts

- Air Monitoring
  - Use non-selective air sampling devices wisely; remember they can provide screening level results at best
  - Many other tools are available to provide more meaningful air monitoring data
- Conceptual Models
  - Plan for contingences in ISTT system design and operations timeline
  - Build contractual flexibility around contaminant mass removal
  - Expect the unexpected
- System Shutdown
  - Energy density is important but there is much more to the story
  - Compile multiple lines of evidence for diminishing returns demonstration

✓ When considering your own ISTT applications its never too early to establish framework for endpoint determination and system shutdown

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