

## **Thermally Enhanced Biodegradation of Dissolved TCE in LNAPL Under Active Building Using Horizontal Wells**

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# Project Team



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# Presentation Overview



1. Project Objective
2. Background
3. SVE Results
4. LNAPL Evaluation
5. Next Generation Sequencing
6. Implications for Future
7. Summary of Results/Lessons Learned

# 1.0 Project Objective



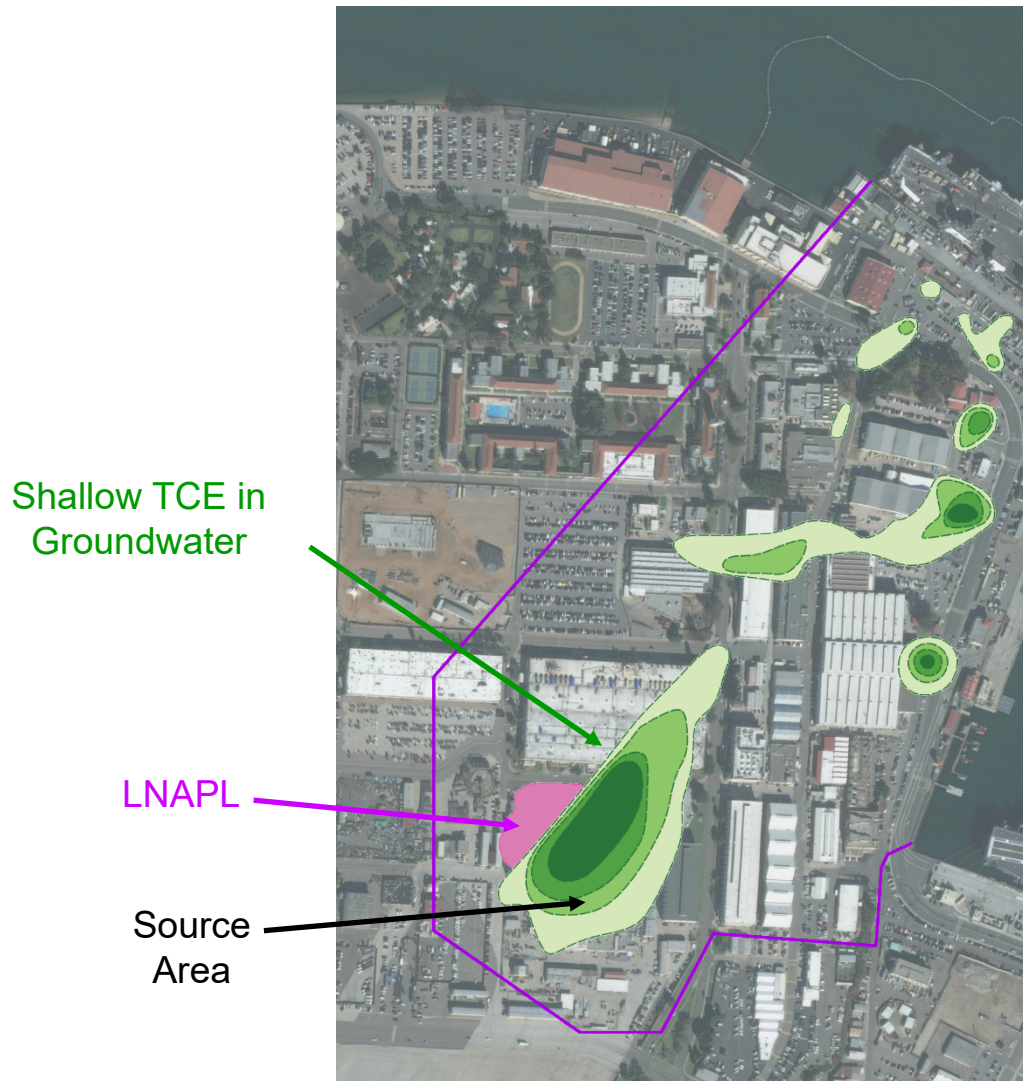
- *Concerns:*

- Highly used building, critical to mission operations, occupants exposed to elevated cVOC levels in indoor air
- cVOCs (2% to 5%) were dissolved in ~ 1 million gallons of petroleum hydrocarbon LNAPL
- cVOCs were volatilizing (exacerbated by LNAPL temperatures > 140°F due to nearby steam line)

- *Challenges:*

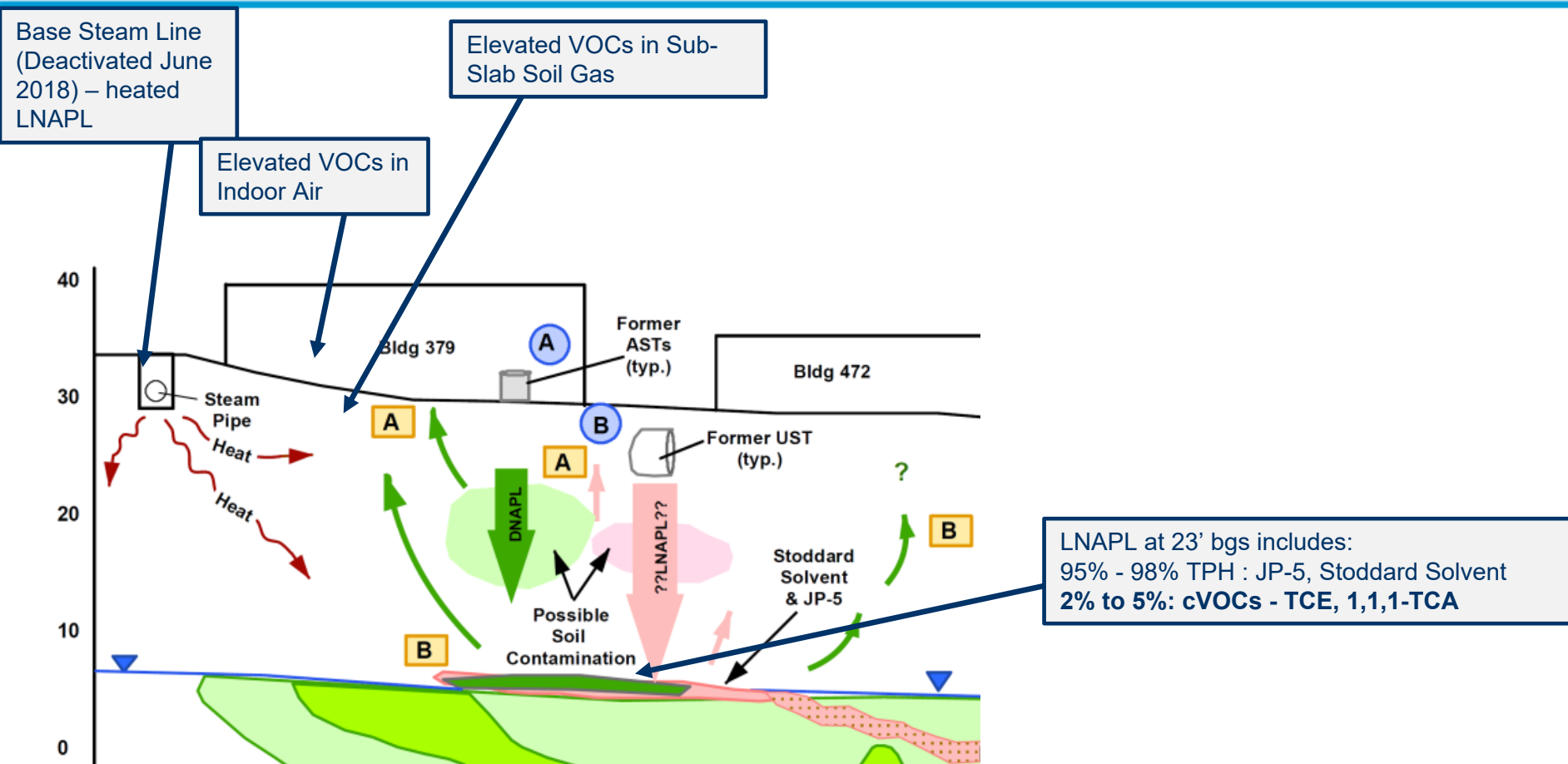
- Reducing cVOCs within LNAPL while protecting building occupants, using a combination of SVE and steam injection
- Demonstrate reduction of source, based on cVOC analyses of LNAPL and other lines of evidence
- **Demonstrate anaerobic biodegradation of cVOCs in LNAPL to allow (future) cessation of steam injection**

## 2.1 Site Location



- 172,000 SF Building (Source Area) has a ~ million-gallon LNAPL plume at 23 ' bgs (petroleum hydrocarbons) with dissolved cVOCs (TCE and 1,1,1-TCA)
- Vapor Investigations in 2014 indicated elevated levels of cVOCs in indoor air and very elevated levels (TPH+cVOCs) in soil gas ( $>20,000,000 \mu\text{g}/\text{m}^3$ )
- A Time Critical Removal Action (TCRA) was initiated for Vapor Intrusion (VI) in 2015

## 2.2 Conceptual Site Model



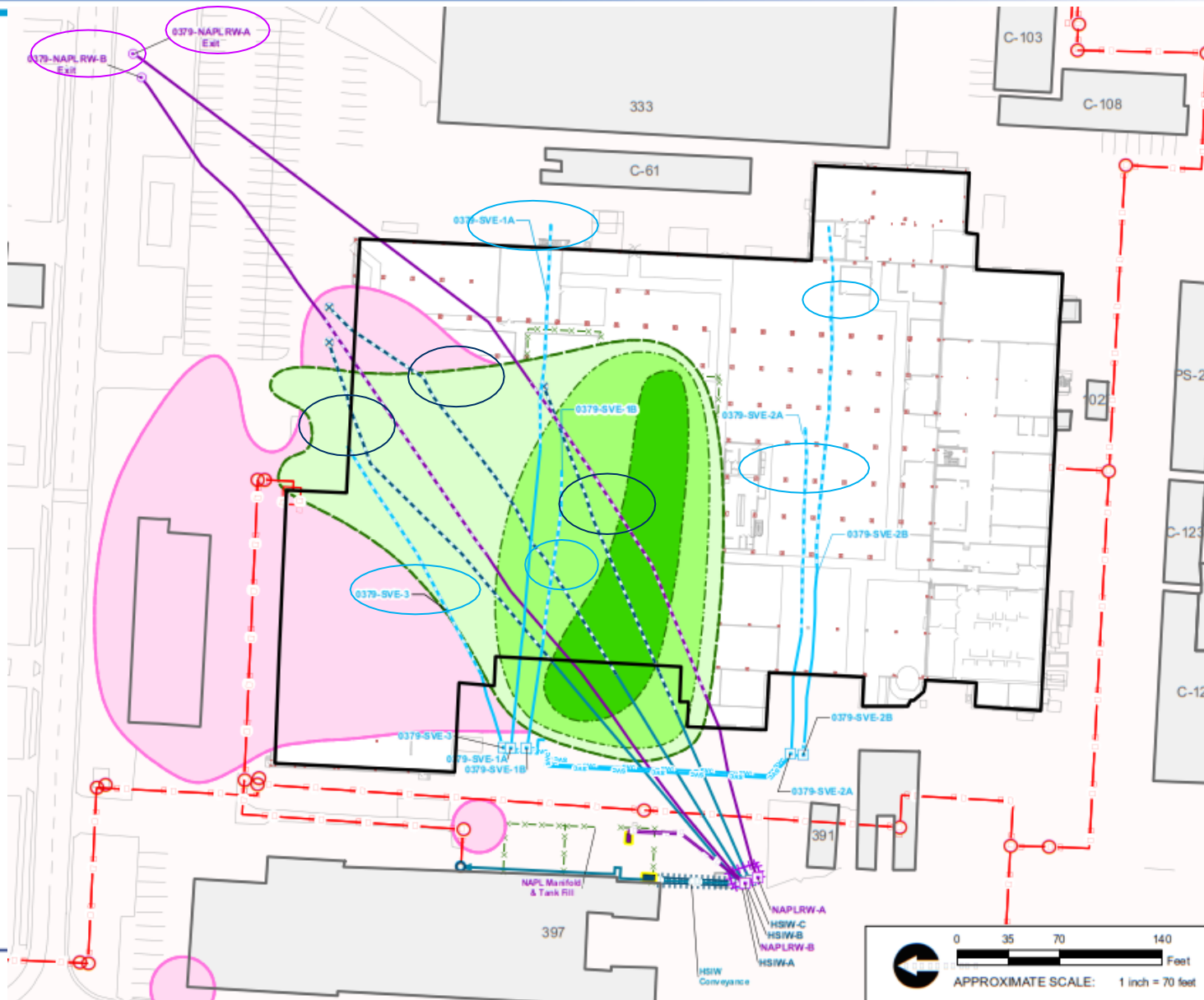
**Time Critical Removal Action initiated 2015 to address VOCs in Indoor Air**

## 2.3 TCRA Timeline

- 2014: ~ 15,000 LF of cracks/joints in the floor were sealed
- 2016: SVE started with 2 horizontal SVE wells (10 ft bgs), with initial extraction rates > 100 lbs/day (sealing enhanced the ROI)
- 2017: it was observed that the LNAPL (23 ft bgs) had elevated temperatures (up to 140 °F), due to heat radiating from the Base steam line (6 ft bgs)
  - ❑ High temperature (and moisture content) of extracted vapor was impacting the performance of the treatment system (3C system from GEO)
  - ❑ Initial thought was to mitigate the effects of the steam line (such as vent wells) but instead Navy elected to use the steam to increase the volatilization of cVOCs; since a robust SVE system was already in place
- 2017: Steam injection wells (horizontal) were installed under the LNAPL, and plumbed into the Base steam:
- 2018 February: steam was injected from February to June 2018
- 2018 June: Base steam system was discontinued
- 2021: Steam injection resumed using a steam boiler



## 2.4 VI TCRA Well Layout



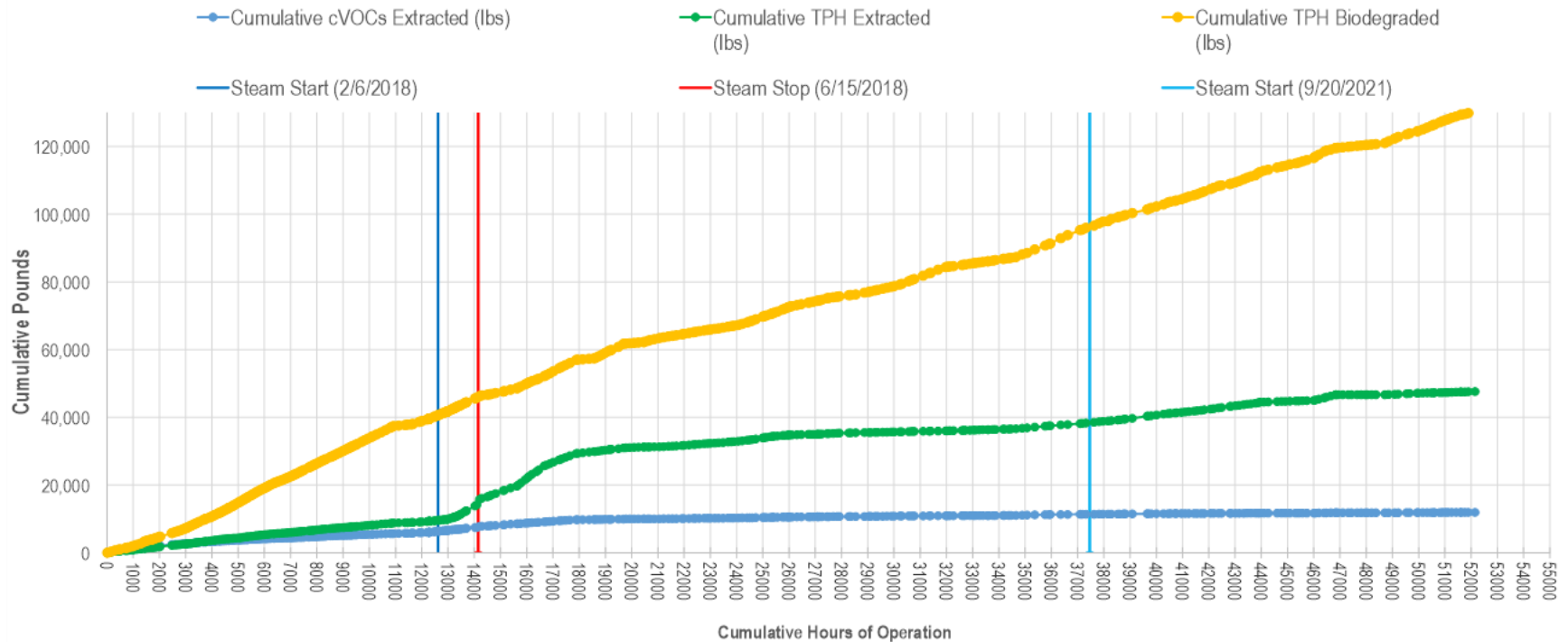


## 2.5 SVE System Details

- Vapors recovered and treated using C3 system from GEO
- Too rich to treat with GAC, ThOX, CatOX
- Extracted vapor is routed through vapor liquid separators
- Condenser condenses vapors into liquids:
  - Condensate filtration
  - Coil coalescing filtration
  - Two heat exchangers
  - Two 1,000-lb activated carbon vessels



## 3.1 SVE Results: Extraction Metrics



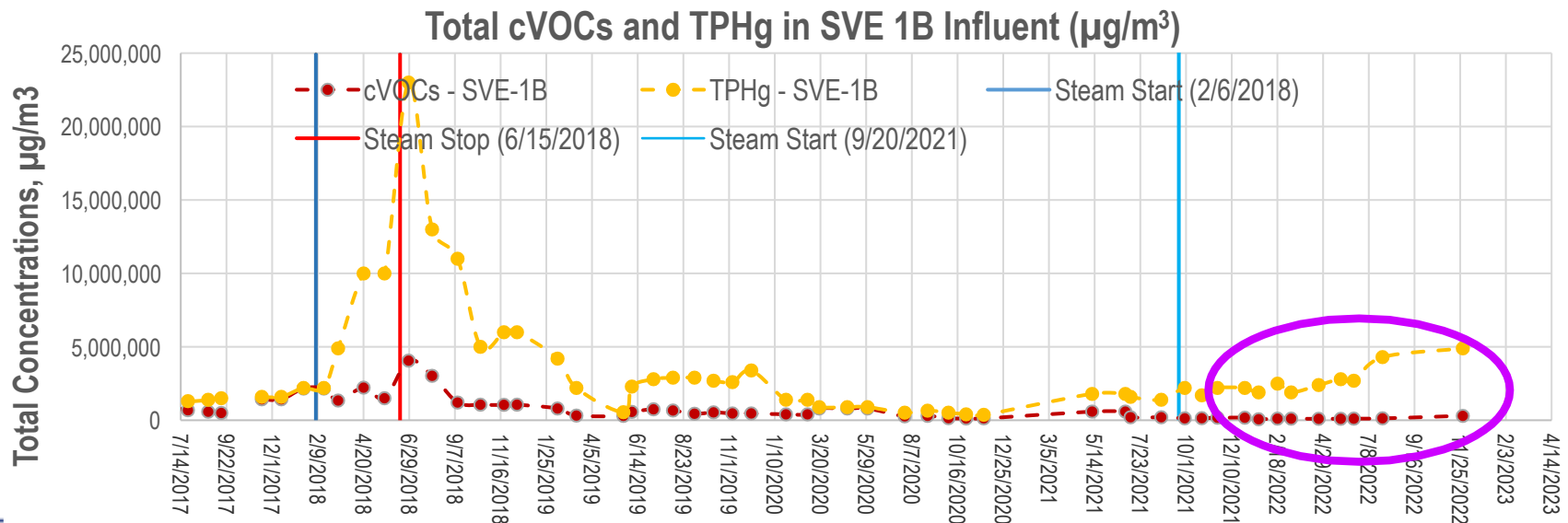
- ~ 60,000 lbs of TPH/cVOCs have been recovered and recycled by the SVE system
- ~125,000 lbs of TPH have been biodegraded aerobically
- Levels of cVOCs and TPH in extracted vapor have decreased by 1 OOM
- **Levels of cVOCs in indoor air were reduced to acceptable levels after SVE was initiated (and remain low to date)**

## 3.2 Transition from VI Mitigation to Source Reduction (2018)

- SVE was initially intended to mitigate VI (NAPL at 23 feet bgs, wells screened at 10 feet bgs) by keeping sub-slab under vacuum
- Injection of steam enhanced source reduction – volatilization of dissolved cVOCs was the main intent
- Steam injection was initially done for < 6 months in 2018 (using the same steam that exacerbated VI to begin with)
- Steam injection resumed in late 2021 (after 2 years of planning) with a new steam boiler (Base steam no longer present)

### 3.3 Effect of 2018 Steam Injection – Extracted Vapor

| No. | Parameter                                | Before     | After      |
|-----|------------------------------------------|------------|------------|
| 1   | VOC Reading (PID): SVE-1B Influent       | 1,500 ppm  | 4,200 ppm  |
| 2   | VOC Reading (PID): SVE-3 Influent        | 130 ppm    | 520 ppm    |
| 3   | Temperature of Extracted Vapor           | 70 °F      | 85 °F      |
| 4   | Liquids per day in Effluent of C3 System | 20 gallons | 40 gallons |









## 4.2 Vinyl Chloride in LNAPL over time (contd.)

1 Year after Steam Injection stopped



May 2019

NAPL Recovery Wells  
SVE Wells  
Steam Injection Wells

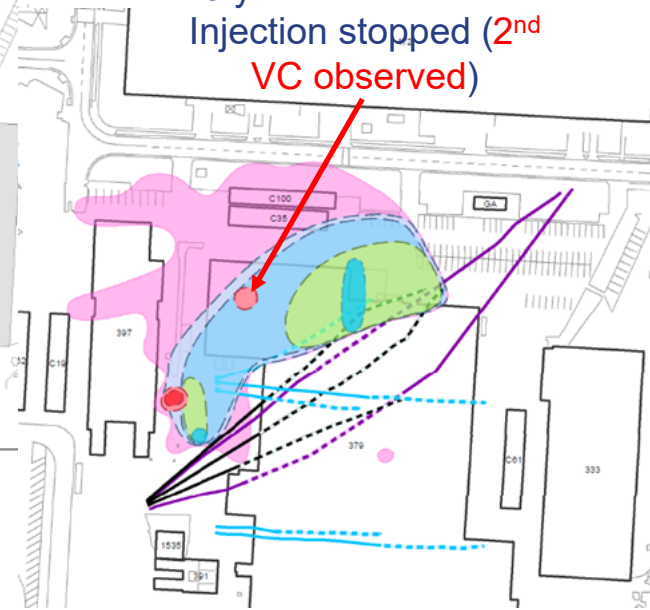
2 Years after Steam  
Injection stopped



May 2020

Pink = LNAPL Extent  
Green = TCE in LNAPL  
Blue = *cis*-1,2-DCE in LNAPL  
Red = VC in LNAPL

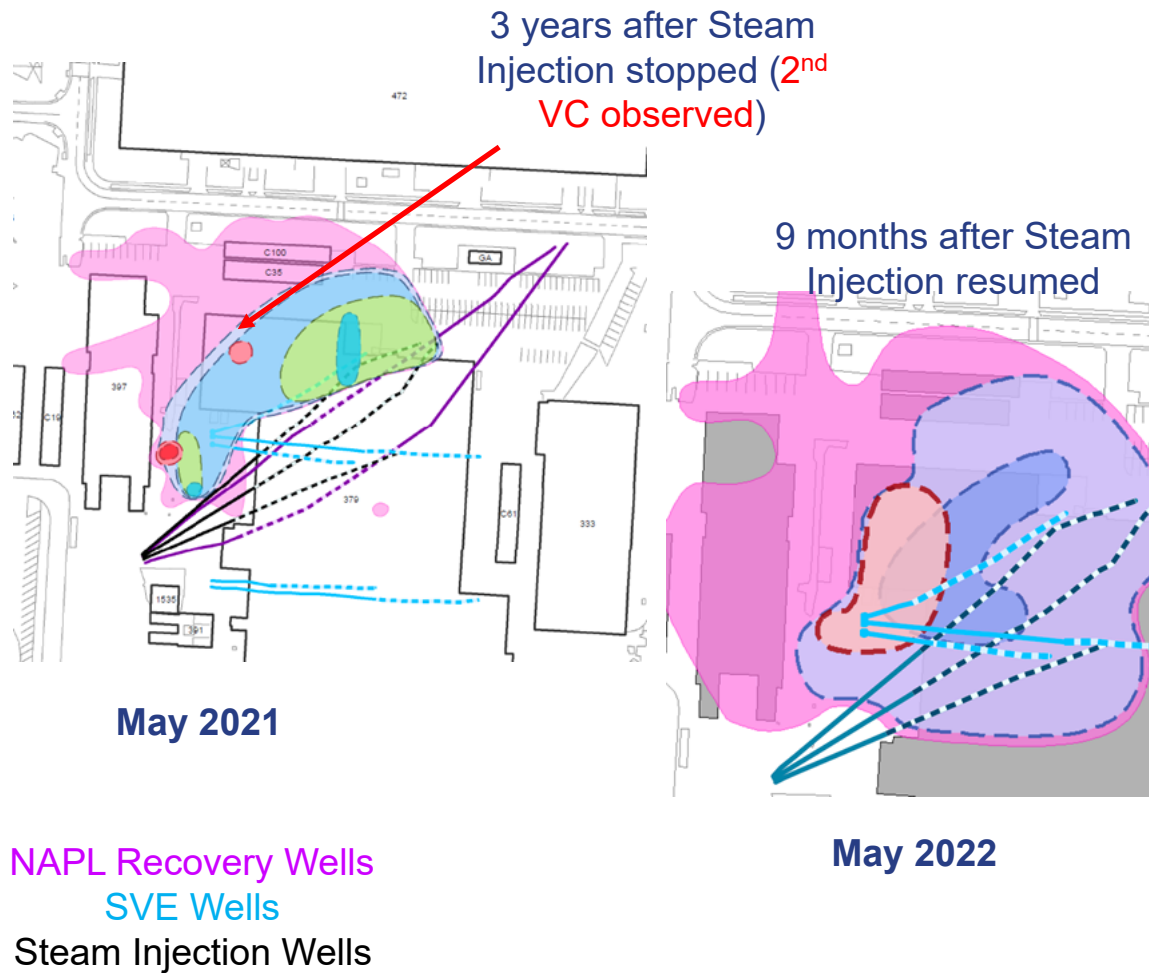
3 years after Steam  
Injection stopped (2<sup>nd</sup>  
VC observed)



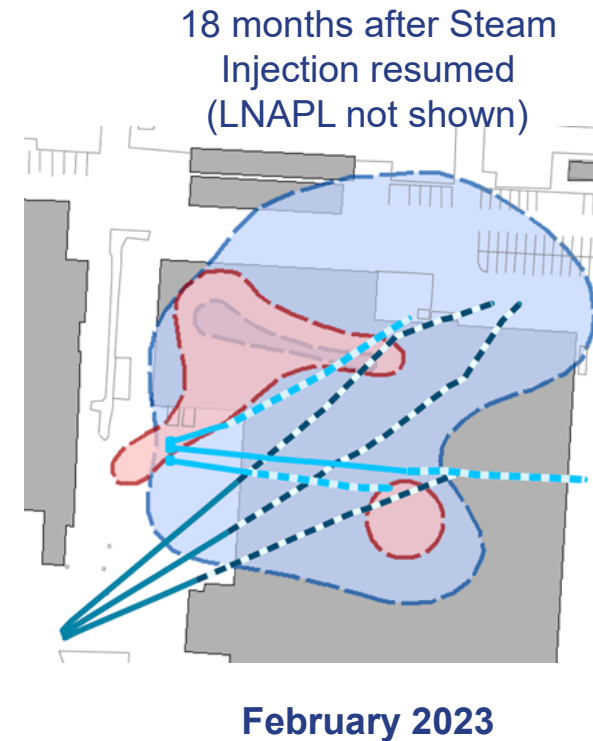
May 2021



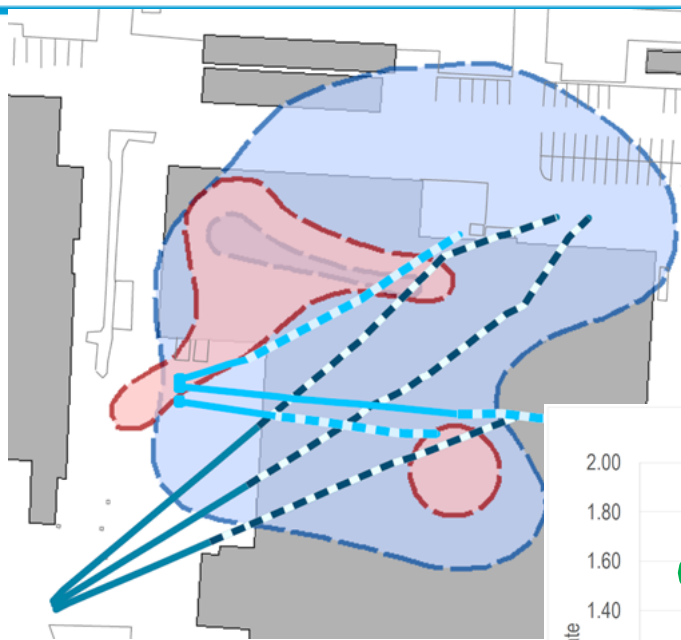
## 4.2 Vinyl Chloride in LNAPL over time (contd.)



Pink = LNAPL Extent  
Green = TCE in LNAPL  
Blue = *cis*-1,2-DCE in LNAPL  
Red = VC in LNAPL

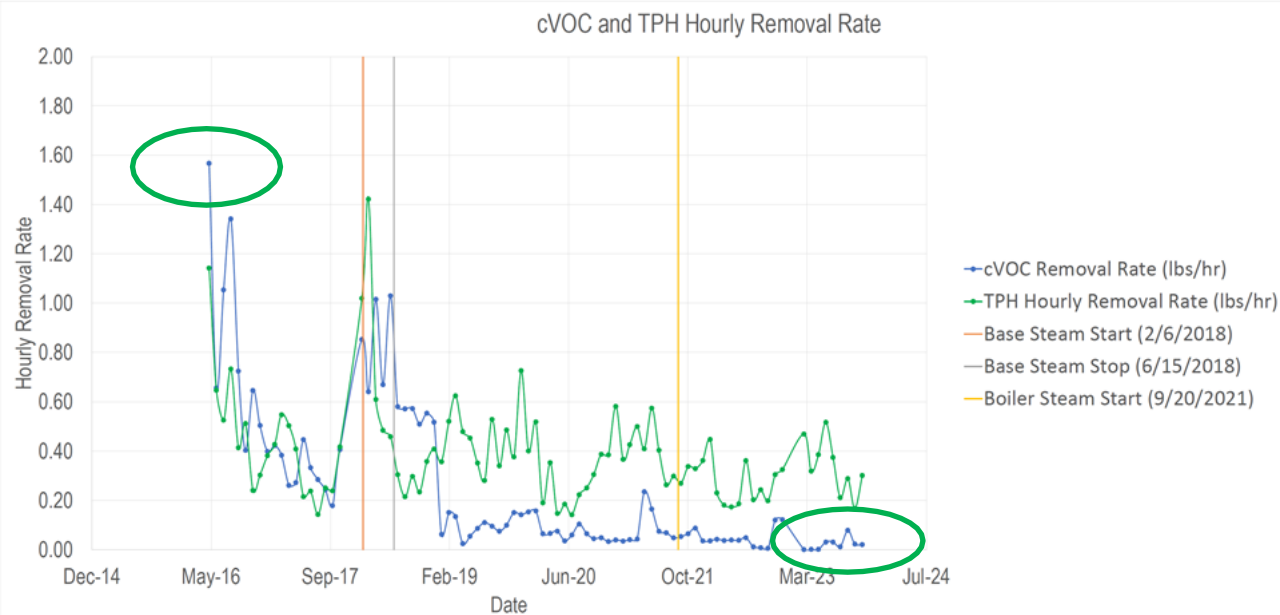


## 4.3 NAPL Conditions (2024) and SVE Influent Trends



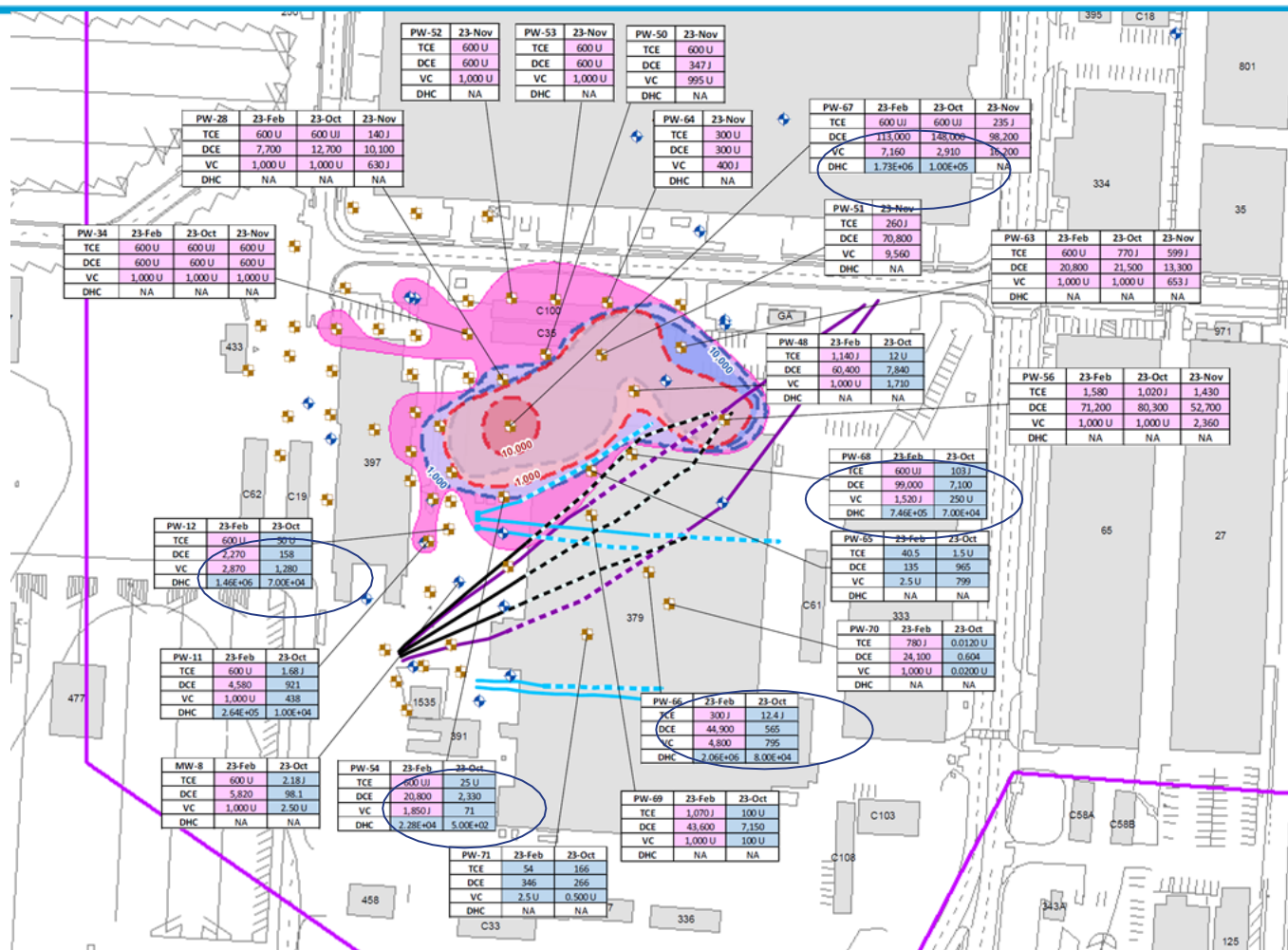
Green = TCE in LNAPL  
Blue = *cis*-1,2-DCE in LNAPL  
Red = VC in LNAPL

There is essentially no dissolved TCE in LNAPL



cVOCs in SVE Influent have  
decreased by over 1 OOM

## 4.4 Dissolved cVOCs in NAPL, DHC in NAPL-GW Interface



- Sampled 5 locations: GW just below LNAPL-GW interface
- Healthy DHC populations observed

## 4.5 Hypothesis re Decrease of TCE in LNAPL



- Dissolved cVOCs in LNAPL have decreased
- Healthy DHC in NAPL-GW interface (under the circumstances)
- Hypothesis:
  - ✓ Biodegradation occurring in GW just below NAPL
  - ✓ *Concentration gradients are causing dissolved cVOCs to decrease throughout LNAPL*
  - ✓ Biodegradation is **not** occurring in the NAPL

- Decided to look for DHC in the LNAPL – 2 locations selected





## 4.7 DHC + FGA – LNAPL Samples



| Target (Test ID)*                     | PW-54 Prod                 |                          | PW-67 Prod                 |                          |
|---------------------------------------|----------------------------|--------------------------|----------------------------|--------------------------|
|                                       | Gene Copies/L <sup>1</sup> | Percent (%) <sup>2</sup> | Gene Copies/L <sup>1</sup> | Percent (%) <sup>2</sup> |
| <i>Dehalococcoides (DHC)</i>          | 8.19 E+03 U                | NA                       | 1.58 E+06                  | 2.9                      |
| Run Date                              | 09-Apr-24                  |                          | 09-Apr-24                  |                          |
| <i>vcrA Reductase (FGA-VCRA)</i>      | 8.19 E+03 U                | NA                       | 8.19 E+03 U                | NA                       |
| Run Date                              | 09-Apr-24                  |                          | 09-Apr-24                  |                          |
| <i>bvcA Reductase (FGA-BVCA)</i>      | 8.19 E+03 U                | NA                       | 5.67 E+05                  | 1.0                      |
| Run Date                              | 09-Apr-24                  |                          | 09-Apr-24                  |                          |
| <i>tceA Reductase (FGA-TCEA)</i>      | 8.19 E+03 U                | NA                       | 4.09 E+05                  | 0.8                      |
| Run Date                              | 09-Apr-24                  |                          | 09-Apr-24                  |                          |
| Total Prokaryotes (PROK) <sup>3</sup> | 1.47 E+08                  | --                       | 5.44 E+07                  | --                       |
| Run Date                              | 09-Apr-24                  |                          | 09-Apr-24                  |                          |

- In GW the ratio of *tceA* to *bvcA* is 4:1, in LNAPL it is 0.8:1
- This suggests
  - Population in LNAPL is different from the GW
  - Growth is occurring in LNAPL

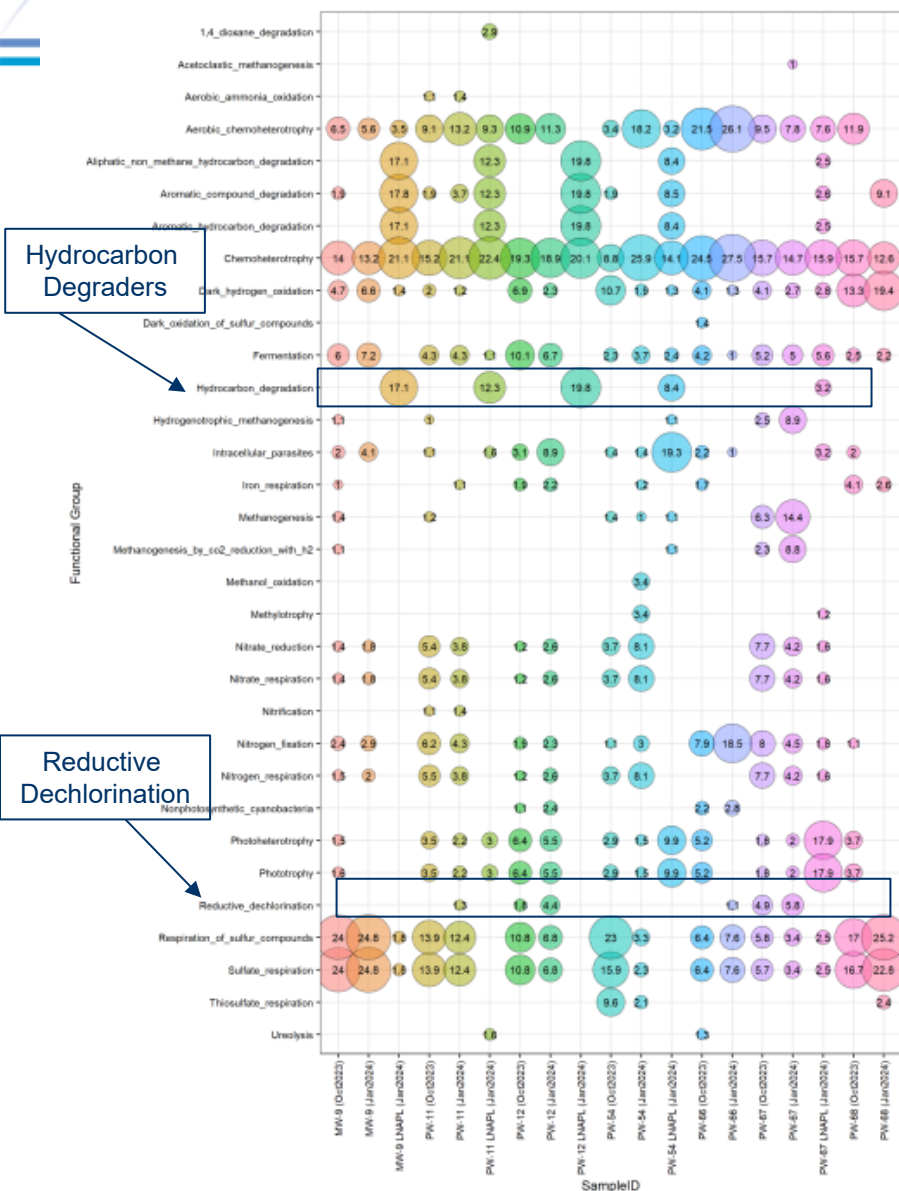
| Target (Test ID)*                     | PW-67                      |                          |
|---------------------------------------|----------------------------|--------------------------|
|                                       | Gene Copies/L <sup>1</sup> | Percent (%) <sup>2</sup> |
| <i>Dehalococcoides (DHC)</i>          | 4.20 E+08                  | 7.6                      |
| Run Date                              | 01-Apr-24                  |                          |
| <i>vcrA Reductase (FGA-VCRA)</i>      | 3.28 E+03 U                | NA                       |
| Run Date                              | 09-Apr-24                  |                          |
| <i>bvcA Reductase (FGA-BVCA)</i>      | 7.79 E+07                  | 1.4                      |
| Run Date                              | 09-Apr-24                  |                          |
| <i>tceA Reductase (FGA-TCEA)</i>      | 2.31 E+08                  | 4.2                      |
| Run Date                              | 09-Apr-24                  |                          |
| Total Prokaryotes (PROK) <sup>3</sup> | 5.50 E+09                  | --                       |
| Run Date                              | 01-Apr-24                  |                          |



## 4.8 Updated Hypothesis

- Dissolved cVOCs in LNAPL have decreased
- Healthy DHC in NAPL-GW interface (under the circumstances)
- **DHC present within LNAPL**
- Hypothesis:
  - ✓ Biodegradation occurring in GW just below NAPL
  - ✓ *Concentration gradients are causing dissolved cVOCs to decrease throughout LNAPL*
  - ✓ **Biodegradation also occurring within NAPL**

# 5.1 Next Generation Sequencing Results (GW and LNAPL)

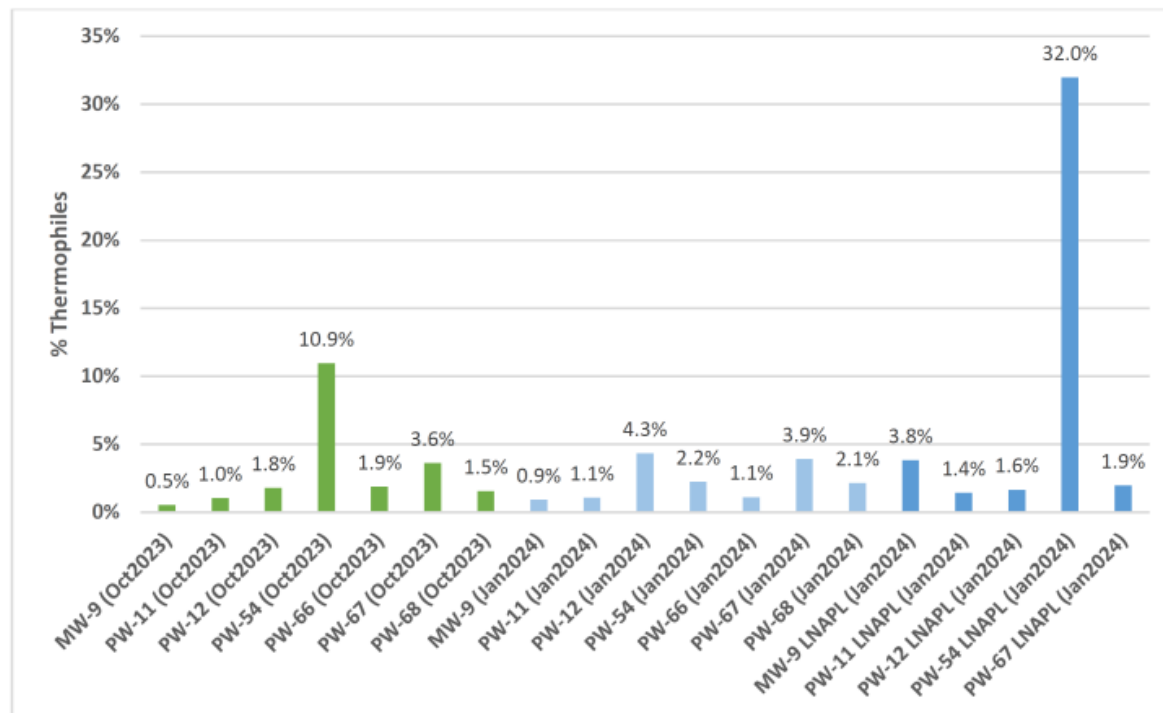


- Diverse microbial cultures are present in the LNAPL and groundwater just below the LNAPL

- Degraders of TPH as well as cVOCs

*Would continued steam injection detrimentally impact populations OR are there any thermophiles?*

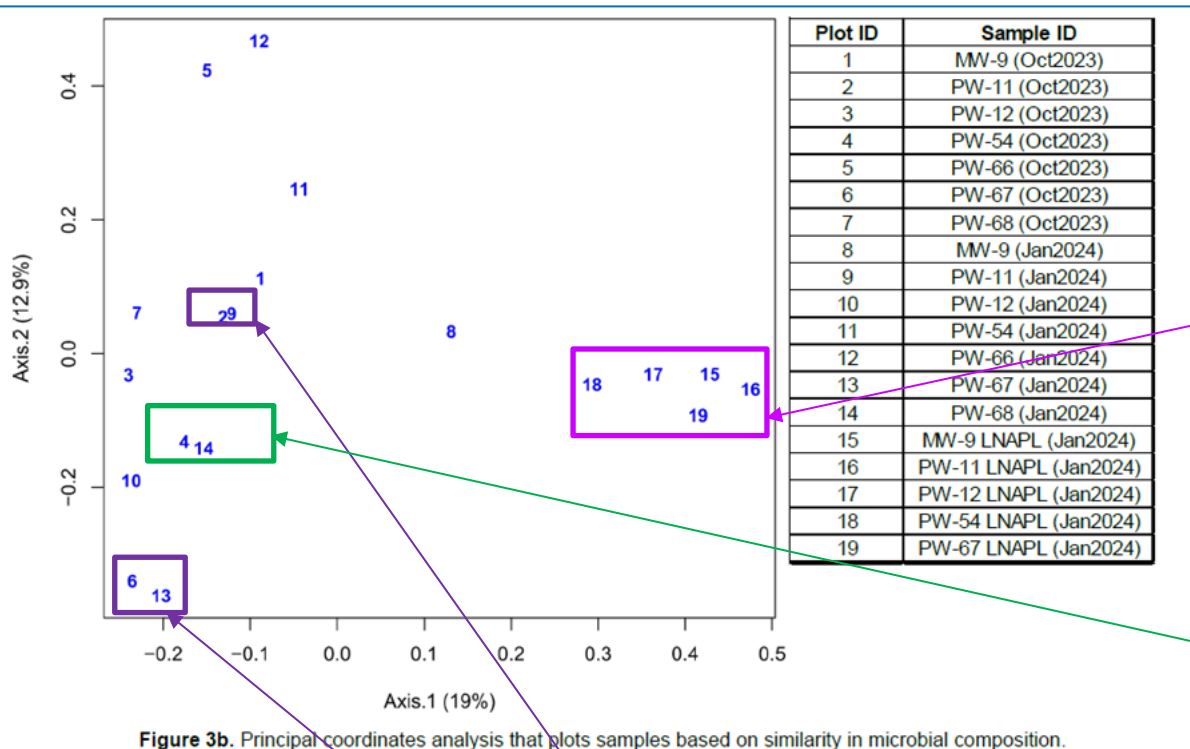
## 5.2 Thermophile Sequencing Results



Steam injection would likely not detrimentally impact populations (although it is not known which populations would survive)

**Figure 1.** Total percentage of identified thermophile sequencing reads in Site samples. Green bars represent samples from October 2023 and blue bars represent samples from January 2024. Light blue bars represent groundwater samples and dark blue represents LNAPL samples.

## 5.3 Microbial Composition



Different locations –  
same event

Different locations –  
separate events

Same location – 2  
separate events

Additional data to be  
collected: 2024-2025

## 6.0 Implications for Future Optimization



- |                                                                               |                                                                                                                    |
|-------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|
| 1. Levels of TCE in soil gas and extracted vapor have decreased substantially | 1. More cost effective to use VPGAC to treat extracted vapor                                                       |
| 2. Levels of TCE in LNAPL are or approaching ND                               | 2. Steam injection below LNAPL no longer necessary (but short-term injection directly into LNAPL being considered) |
| 3. Healthy population of DHC <b>in LNAPL</b> and GW below LNAPL               | 3. Dechlorination appears to be self-sustaining                                                                    |
| 4. Significant thermophilic population in GW and LNAPL                        | 4. Injection of steam will not be detrimental to microbes (in LNAPL and below)                                     |

## 7.0 Summary of Results/Lessons Learned

- SVE has recovered >60,000 lbs of TPH/cVOCs and an additional >125,000 lbs of TPH have been degraded (aerobically)
- VC detected in LNAPL (and soil gas) indicating anaerobic biodegradation of TCE within TPH-LNAPL
- Dissolved TCE within LNAPL is essentially ND
- DHC present in groundwater samples collected from just below LNAPL; **and also present within LNAPL**
- **Under the right conditions it is possible to biodegrade TCE dissolved in TPH-LNAPL**

***QUESTIONS?***