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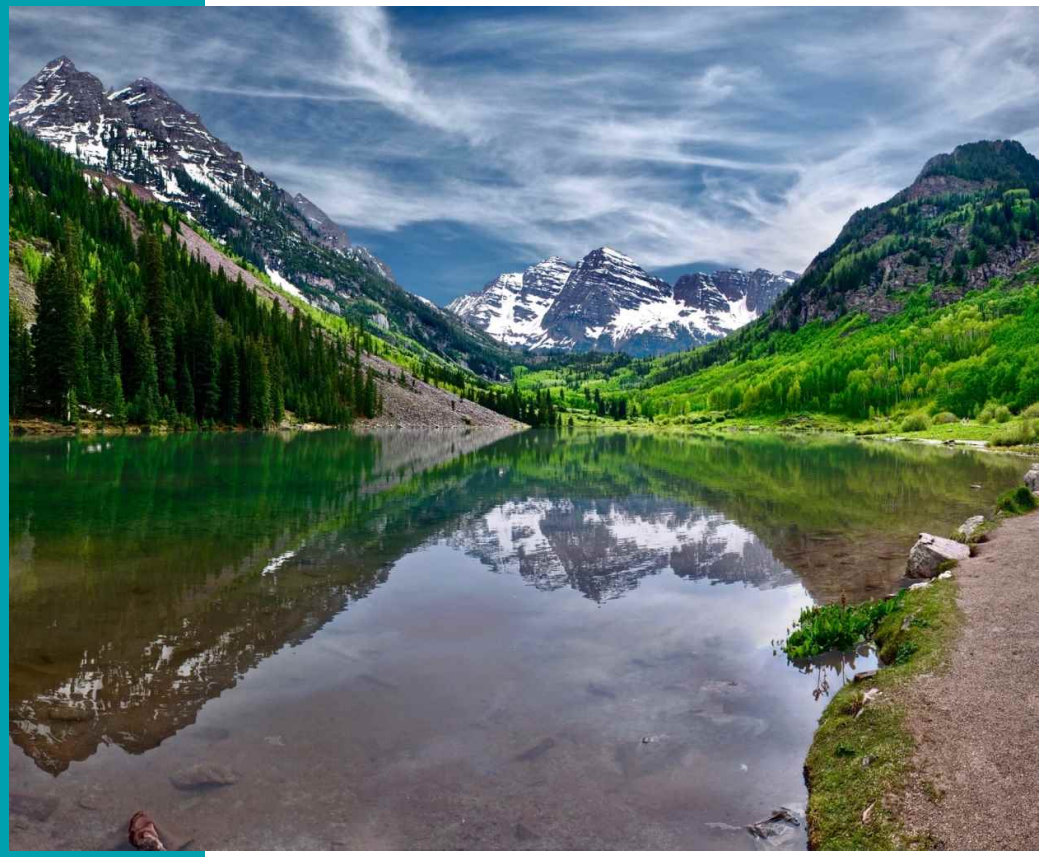
CREATIVE THINKING
EXCEPTIONAL SOLUTIONS



Natural Source Zone Depletion Study at a Former Central California Site: Evaluating the Influence of Vapor Extraction System and Air Sparging on NSZD Rate Determination and Study Duration

Thirteenth International Conference on Remediation of Chlorinated and Recalcitrant Compounds

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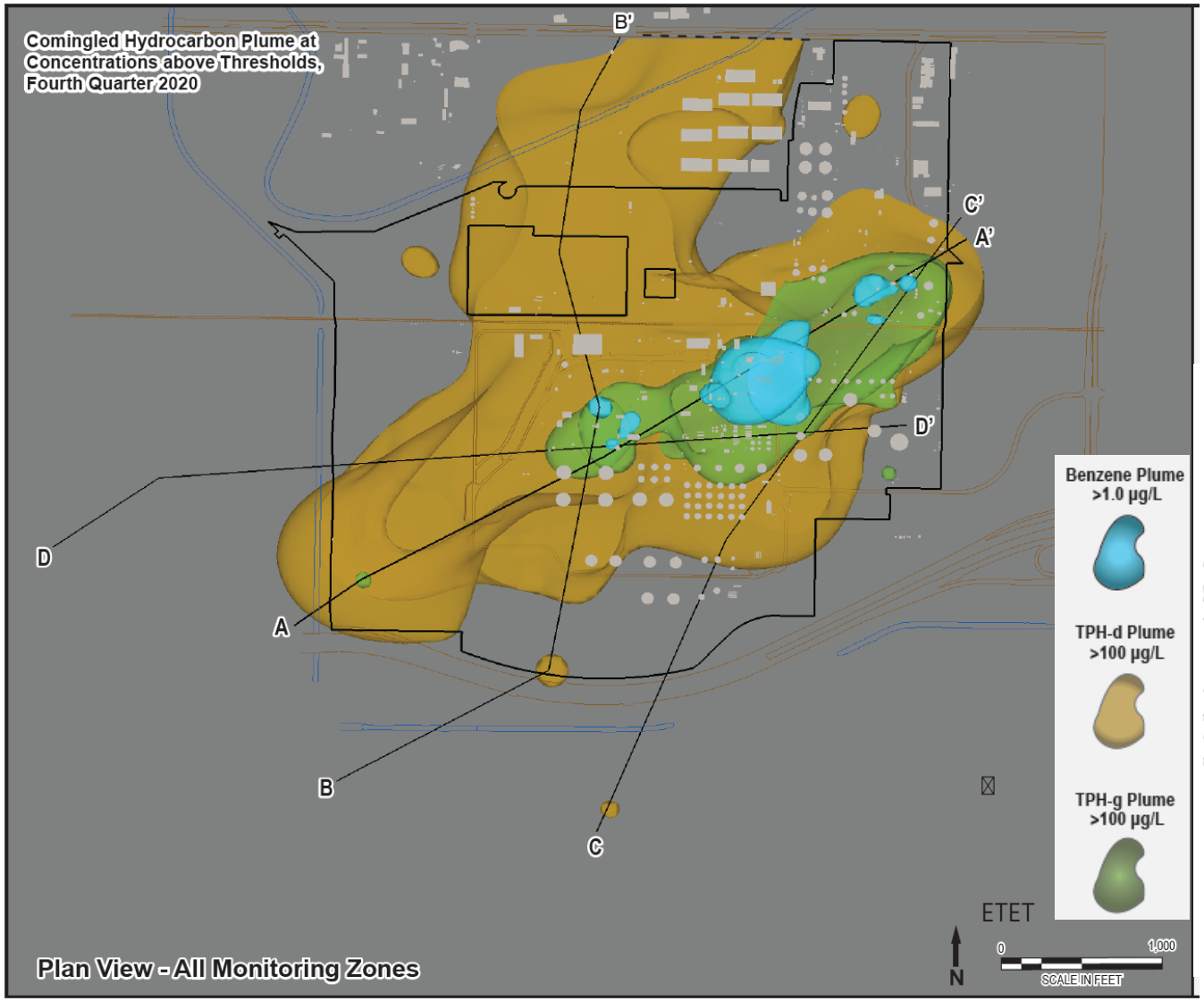
Presentation Overview

1. Site Background
   - Site Conditions
   - Remediation Systems

2. NSZD
   - NSZD Study and Processes
   - Methodology
   - Results

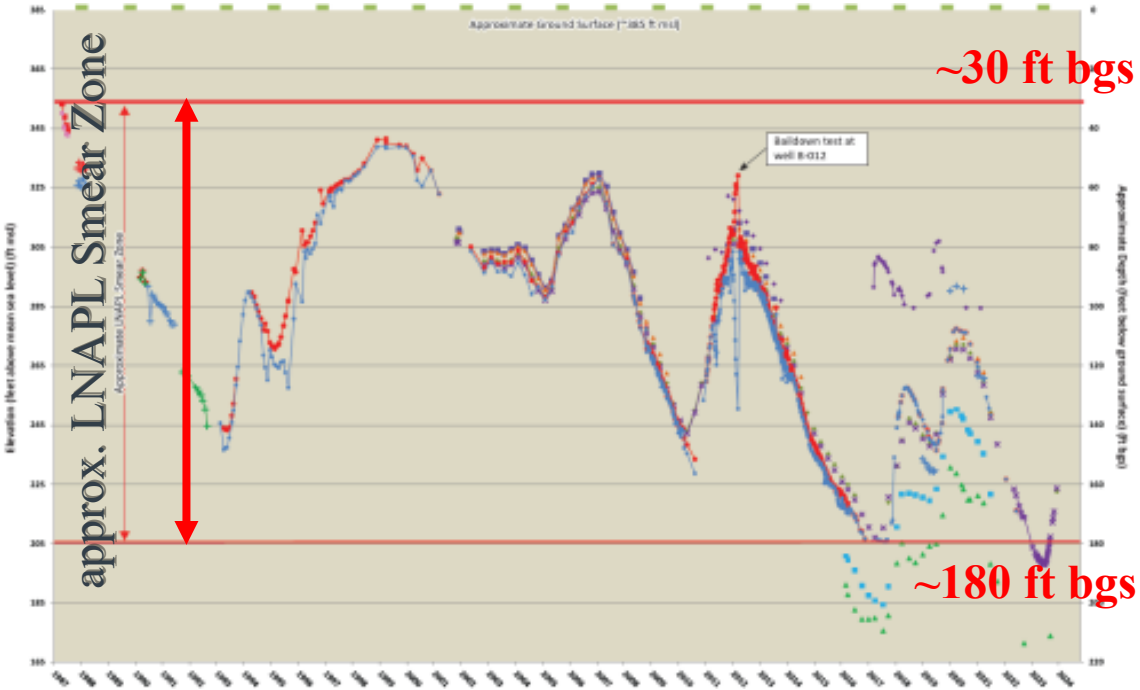
3. Thoughts on the Study

Site Conditions in 2020



Constituents of concern:

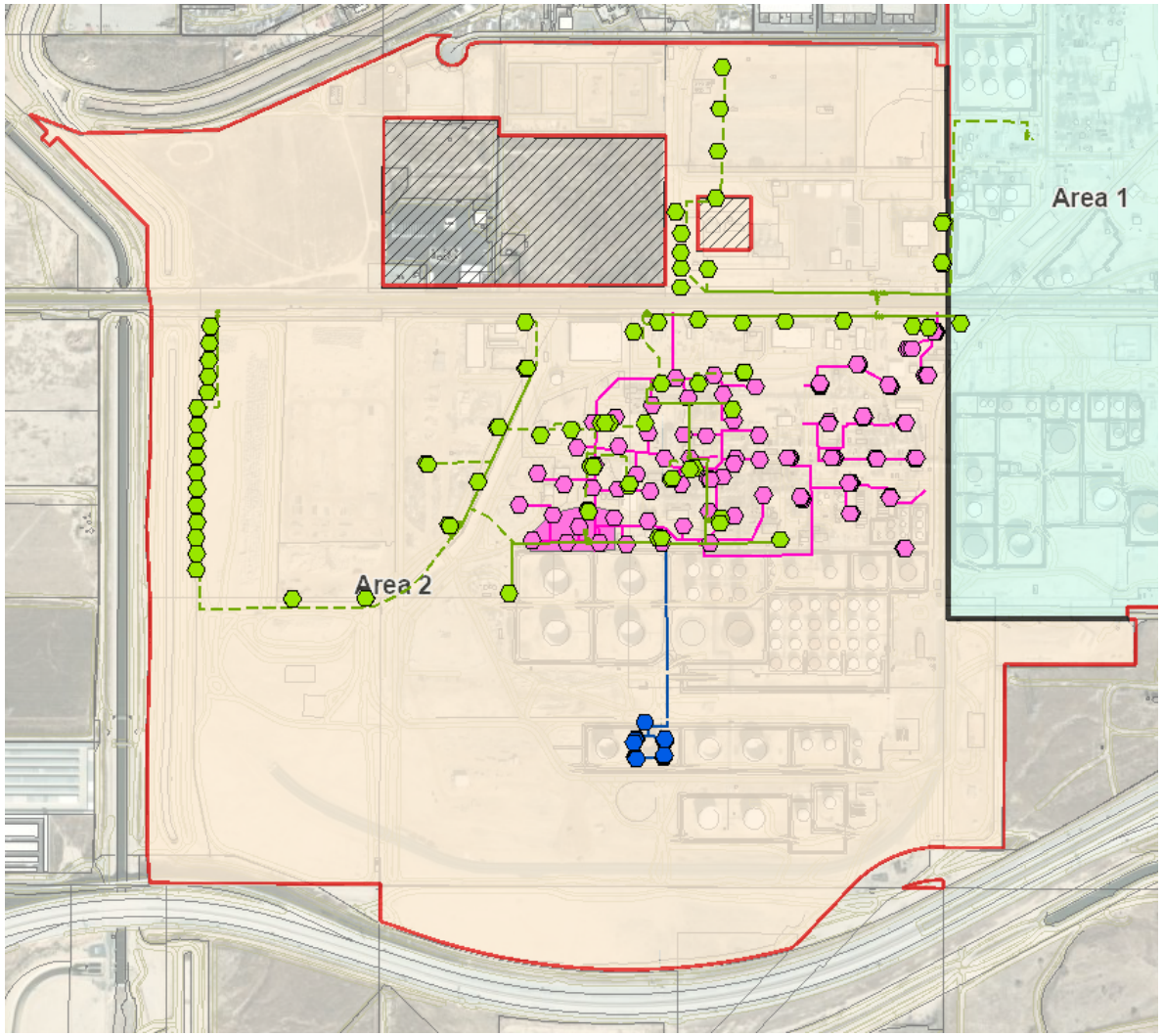
- TPH-g
- TPH-d
- Benzene
- MTBE



Remediation Systems

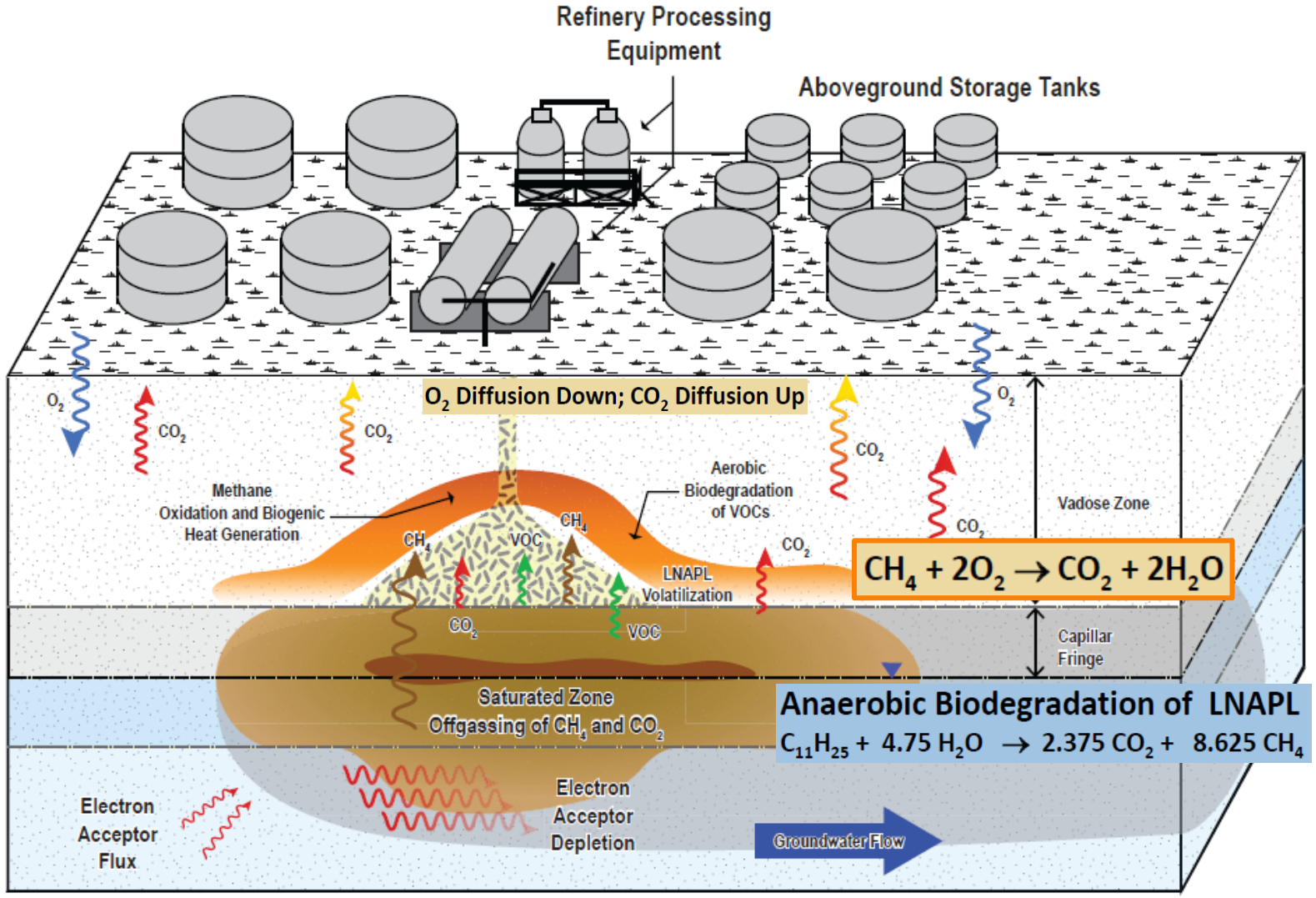
Ongoing Active Remediation in Area 2:

- Vapor Extraction System (VES; ⬢ & ⬢)
- Air Sparge System (AS; ⬢)



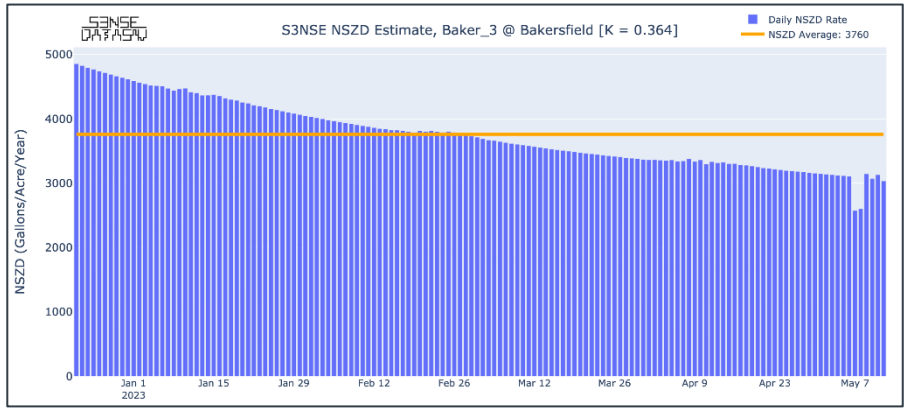
NSZD Study and Processes

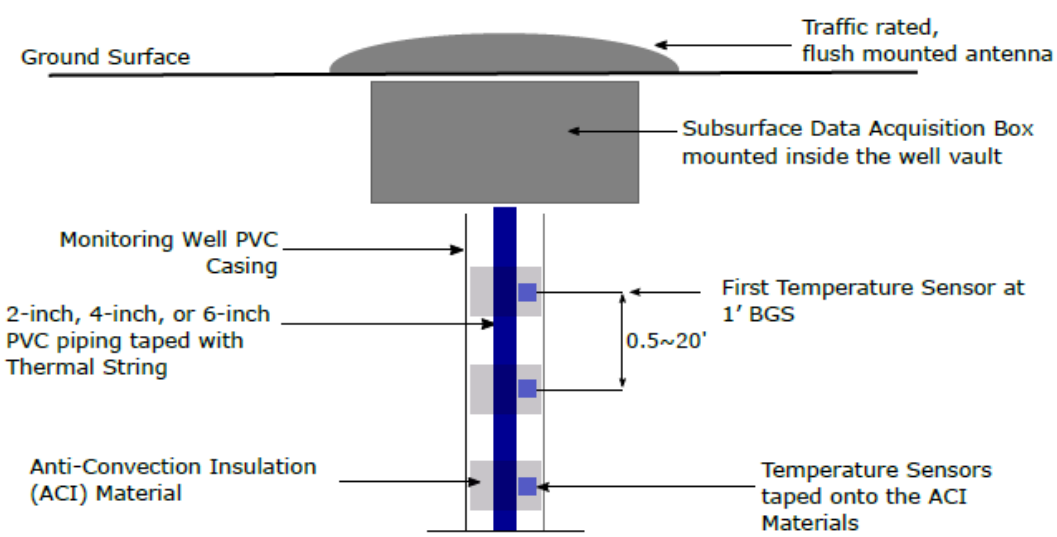
- Natural Source Zone Depletion (NSZD) refers to naturally-occurring processes that facilitate LNAPL attenuation.
- The dominant process is anaerobic methanogenesis in the deeper zones, which degrades LNAPL and produces CH_4 and CO_2.
- As CH_4 rises and O_2 diffuses down from the atmosphere, they meet to create an oxidation zone that produces CO_2 and heat.
- The heat signal is measured, and the heat flux is used to quantify a biodegradation rate.

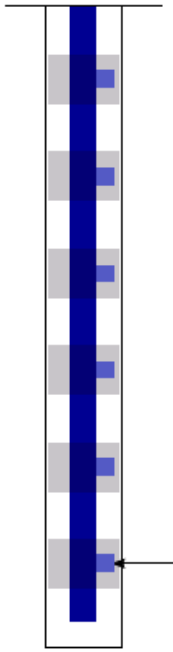


Methodology – Single Stick Method

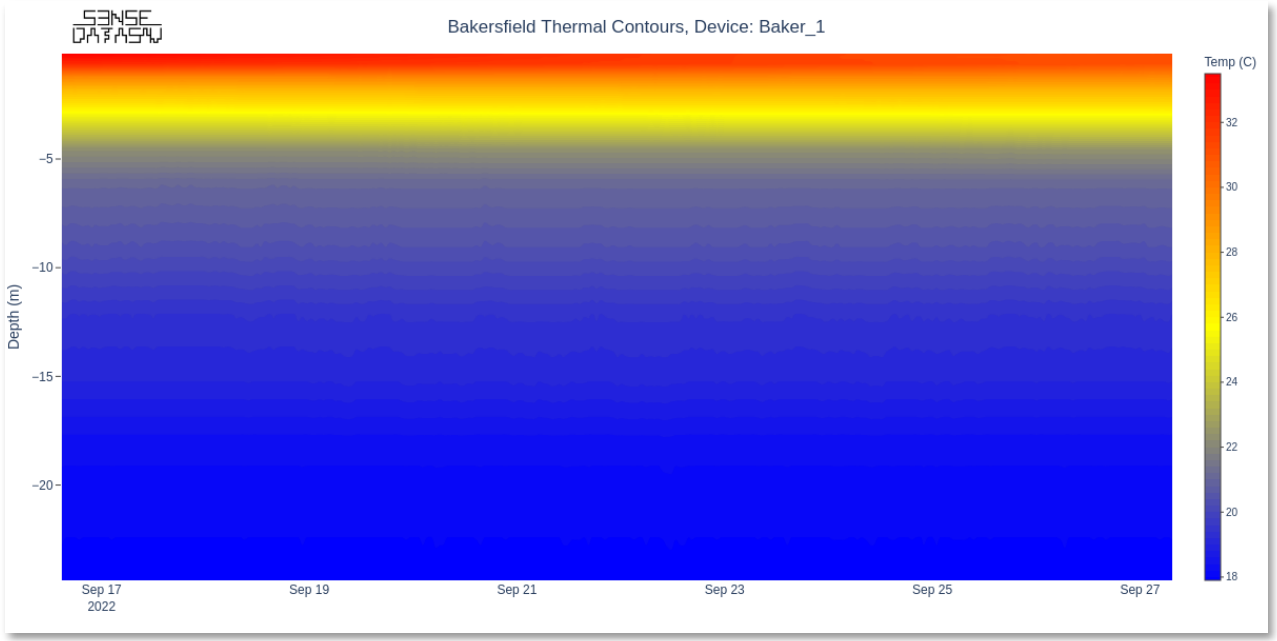
- NSZD Study was conducted between Sept 2022 and June 2023 (9 months).
- Available techniques:
  - Thermal Monitoring – ***Single Stick Method*** *developed by Kayvan Askarani & Thomas Sale (2020)*
  - Gradient Method
  - Carbon Traps
  - Dynamic Closed Chambers
- Measures the thermal flux and does not require a background location.
- Partnered with *S3NSE Technologies*



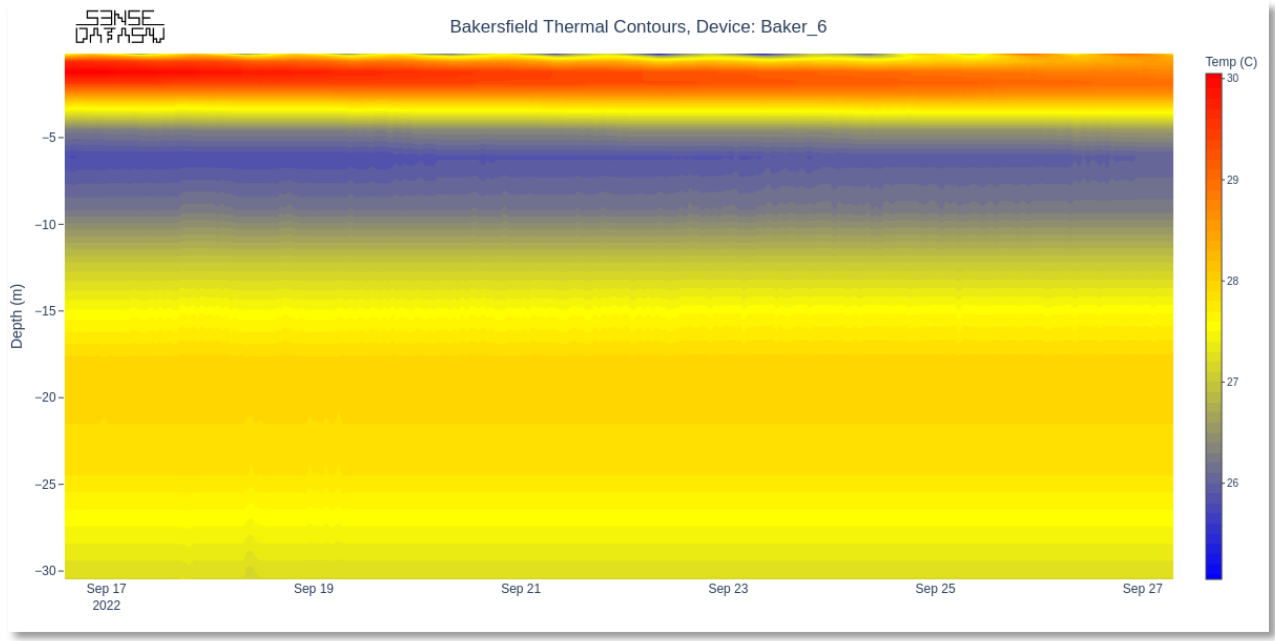




Thermal Graphs

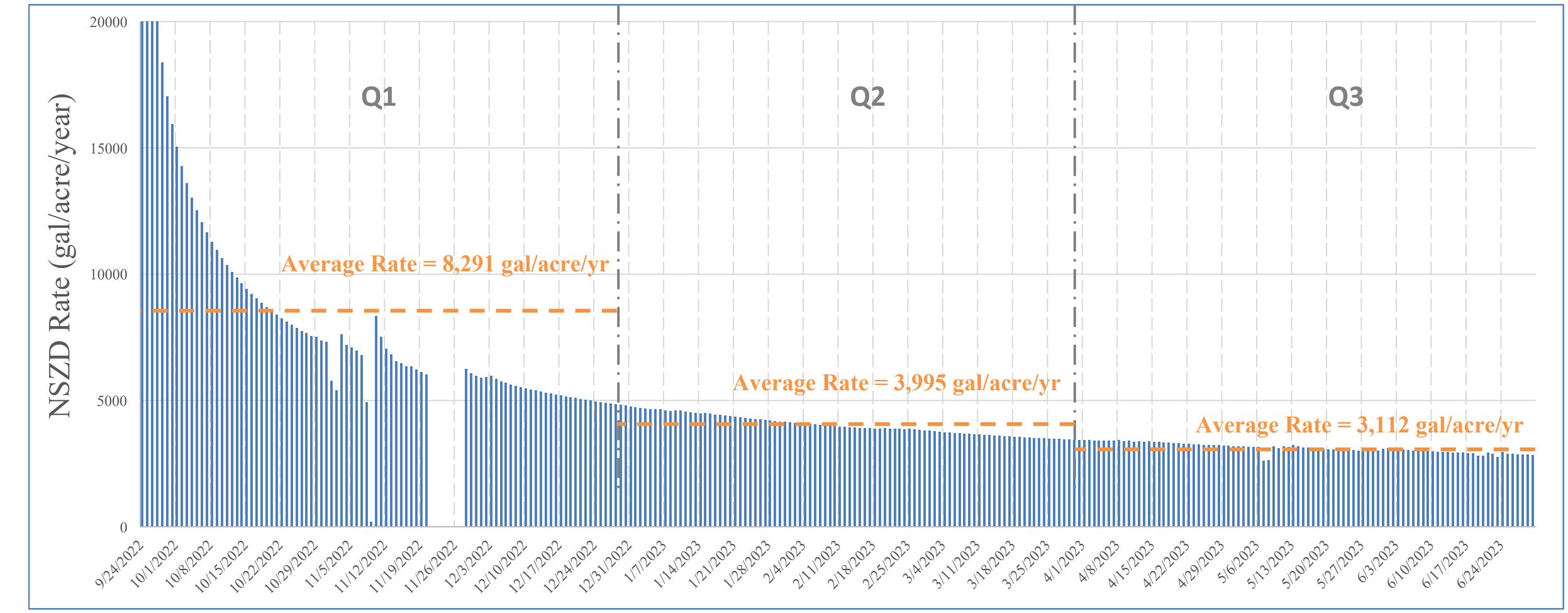


September 2022
Location 1 (Background; No Impact)

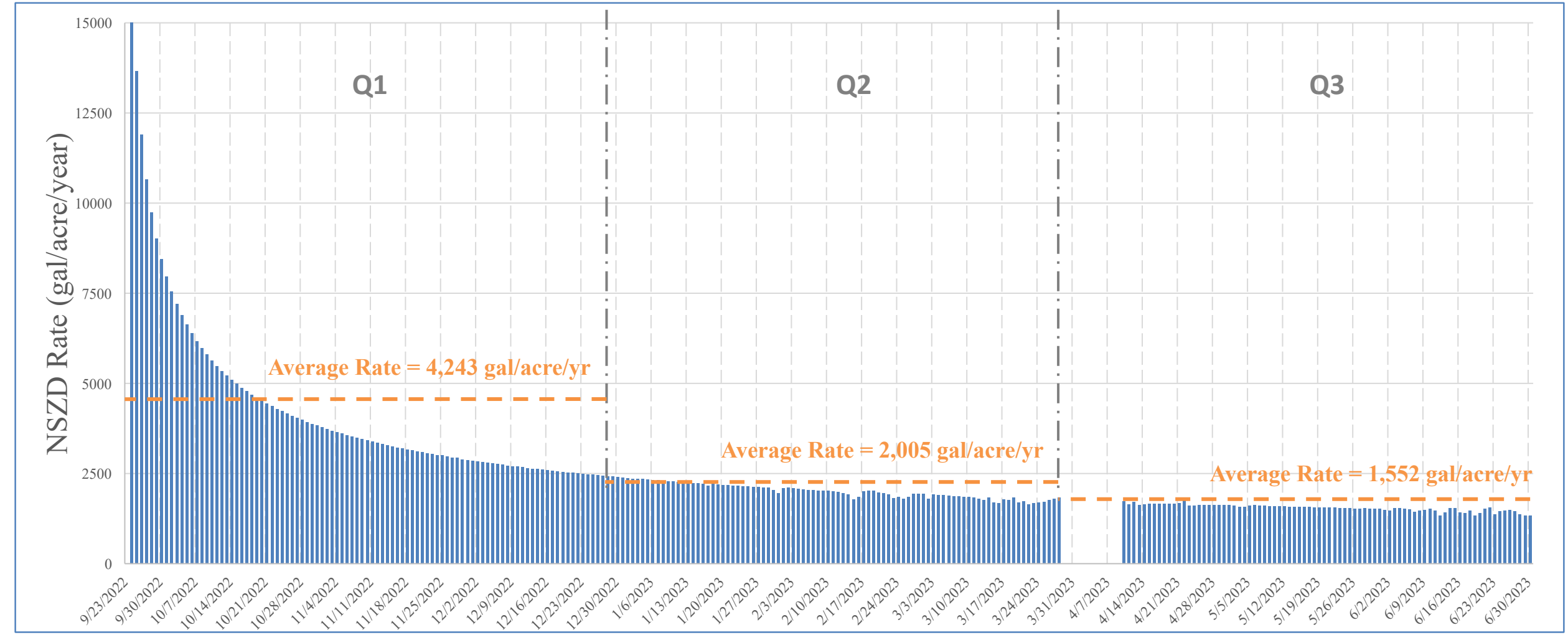


September 2022
Location 6

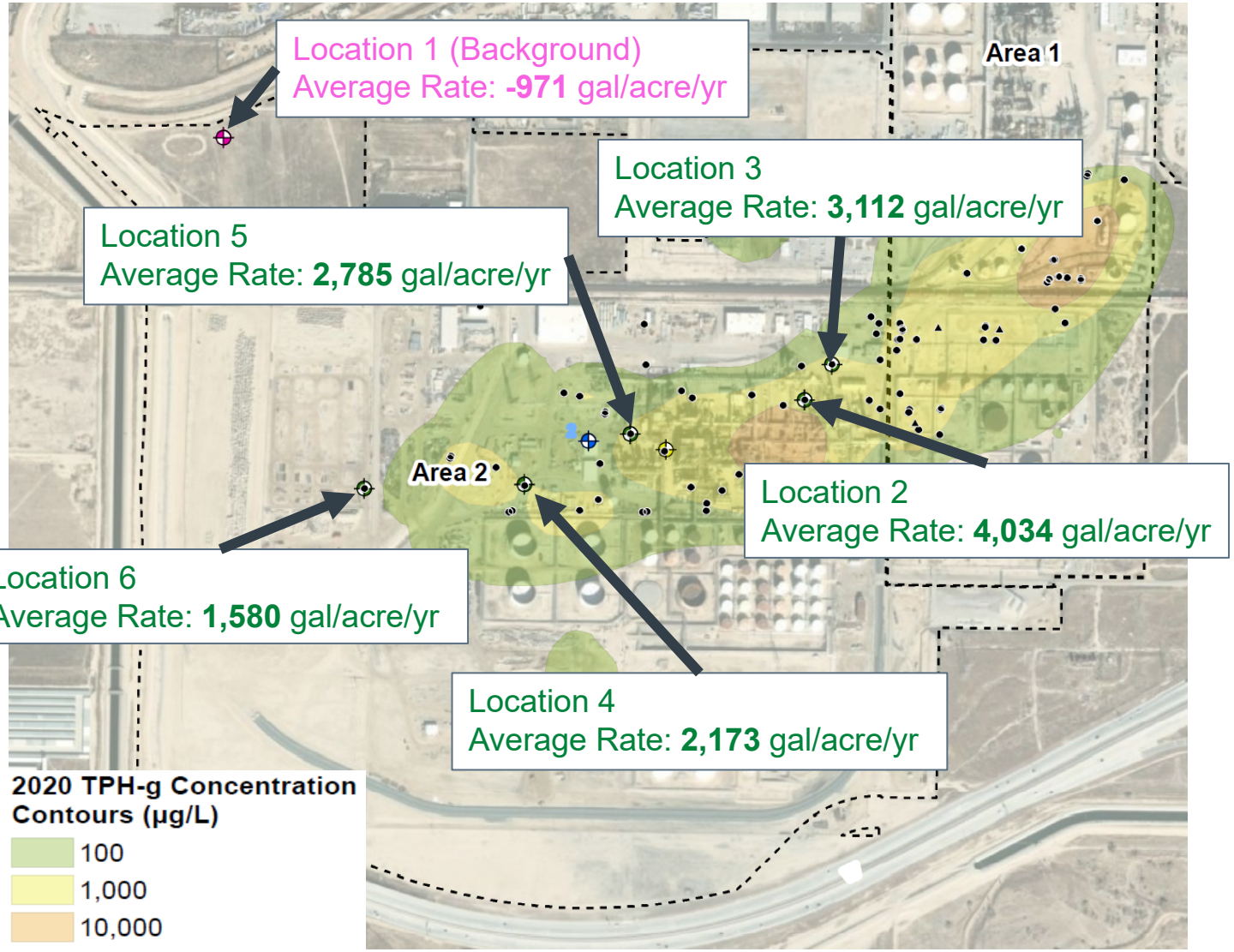
NSZD Rates: Location 3



NSZD Rates: Location 6



Calculated Rates



- Site Average (2023 Q2) = 2,731 gal/acre/yr
- Areas with higher concentrations of LNAPL in the saturated zone demonstrate higher rates of NSZD activity.
- NSZD is approximately 3x more efficient at degrading mass than the Area 2 VES:

Remediation System	Degradation Rate
NSZD	2,731 gal/acre/yr
Area 2 VES	1,000 gal/acre/yr

- NSZD is sustainable and has a significantly lower carbon footprint:

Remediation System Operation	Annual GHG Emissions (MT CO_2e)
NSZD	Essentially 0
Operation of Area 2 VES and Source Area AS	1,345

Thoughts on the Study

- The site required significant time to reach equilibrium in the vadose zone after the VES and AS system shutdown, observed by the rapidly decreasing NSZD rates over the first three to six months

- The high initial rates may come from:
  - Previous VES/AS operation → excess oxygen in the vadose zone → aerobic biodegradation of petroleum hydrocarbons resulting in large amount of heat being released from the subsurface;
  - Previous VES operation → pulled ambient heat into the subsurface during the summer months and led to an increase of temperature in the vadose zone;
  - Previous VES/AS operation → aerobic processing of petroleum hydrocarbons in the vadose zone, making some of the remaining hydrocarbon mass more amenable to methanogenesis → methanogenesis bloom and a temporary increase of NSZD → excess oxygen in the vadose zone for methane oxidation → larger heat signals

- When measuring NSZD at a site that is transitioning from active remediation to NSZD, the NSZD Study should be conducted for an extended period of time (ideally with real-time monitoring) to ensure the site reaches “NSZD equilibrium”.