SMART. SOIL. SCIENCE.

Shifting from Tradition: A Long Term NSZD Monitoring Approach for An Active Oil and Gas Facility in Saskatchewan

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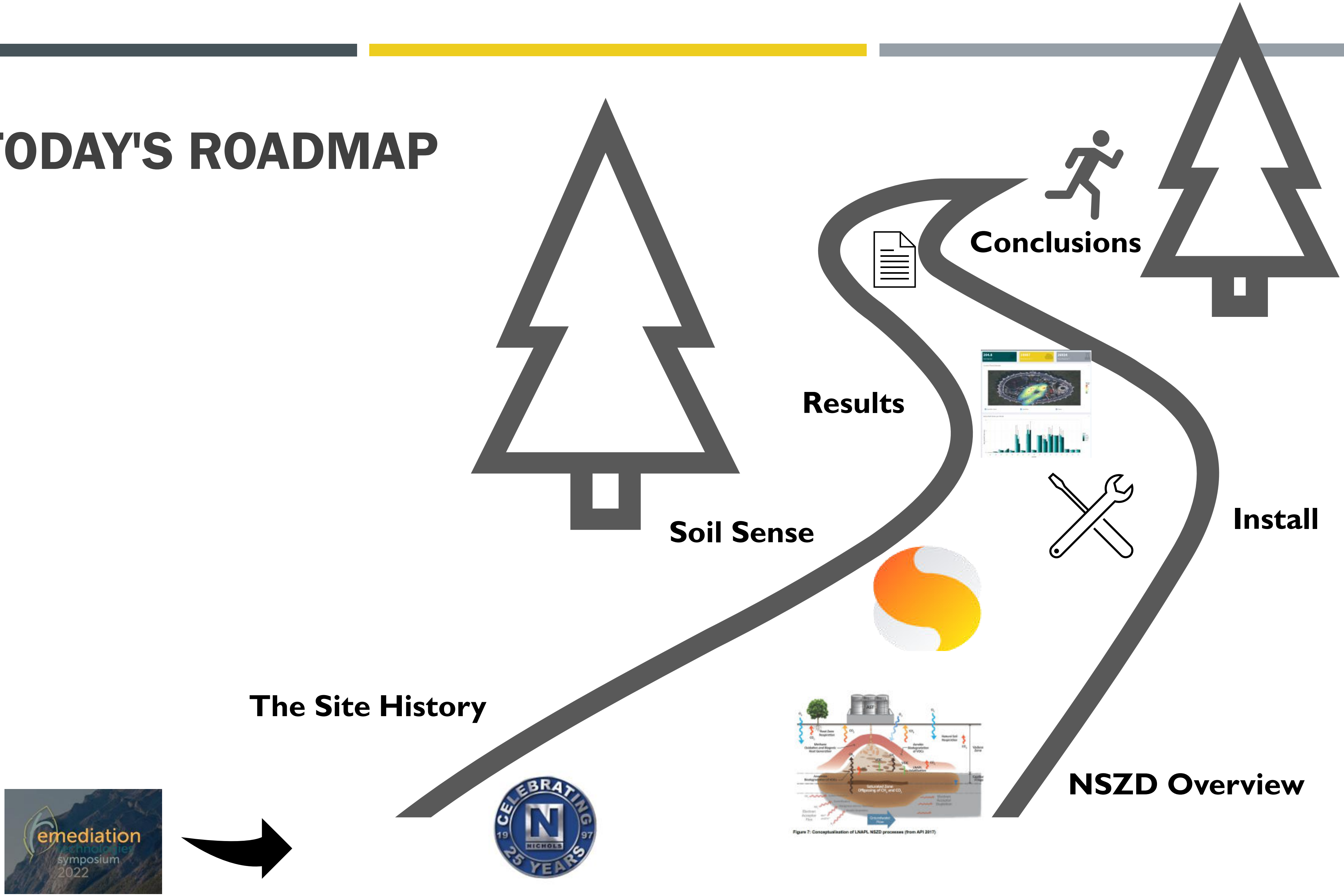
TODAY'S ROADMAP



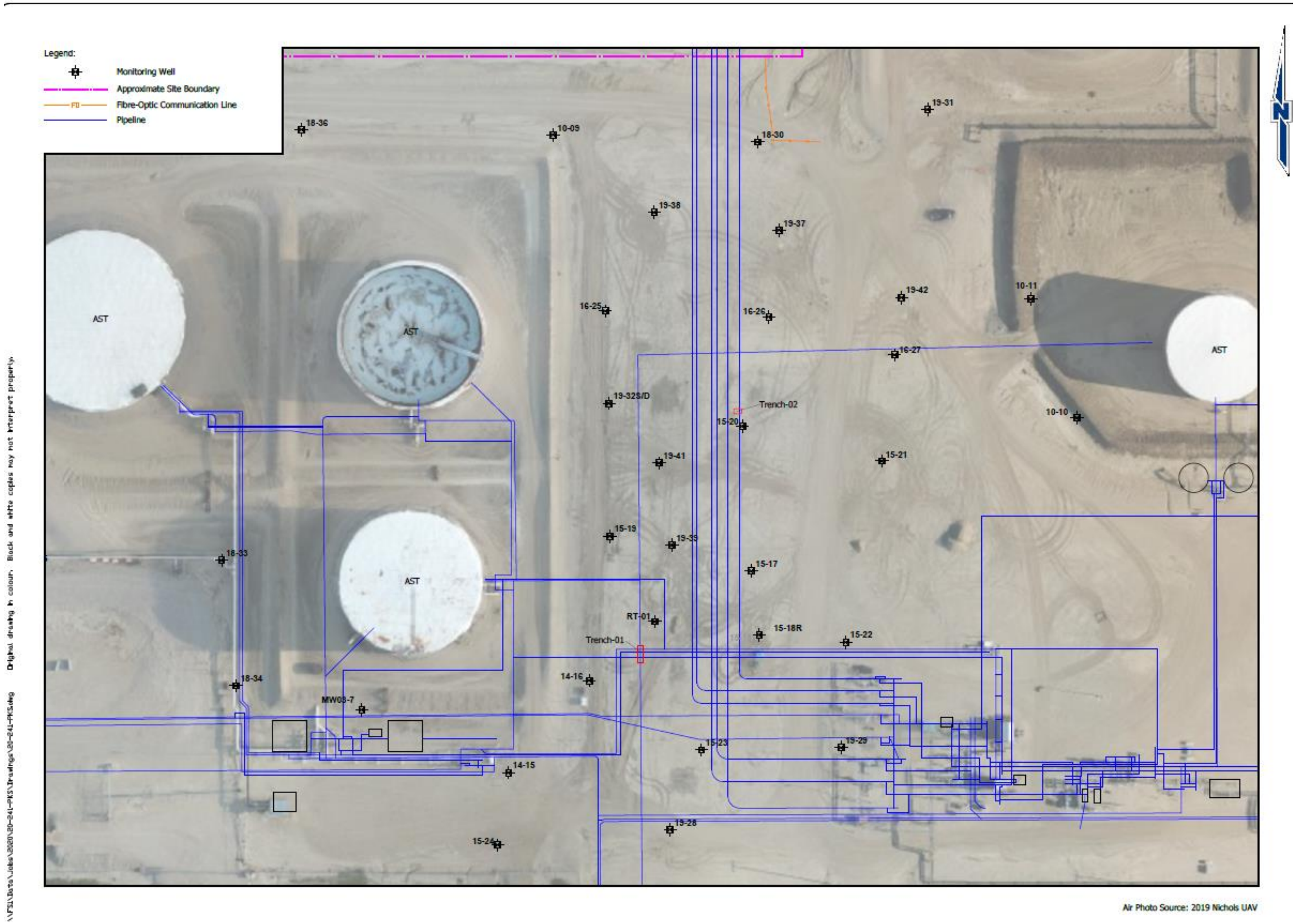
THE SITE

- **Active Facility**
  - Storage and Distribution of Crude Oil and Natural Gas Condensate
- **Site Infrastructure**
  - 14 ASTs
  - Above and below-ground pipelines
  - Truck loading/unloading terminal
  - Associated buildings

THE SITE

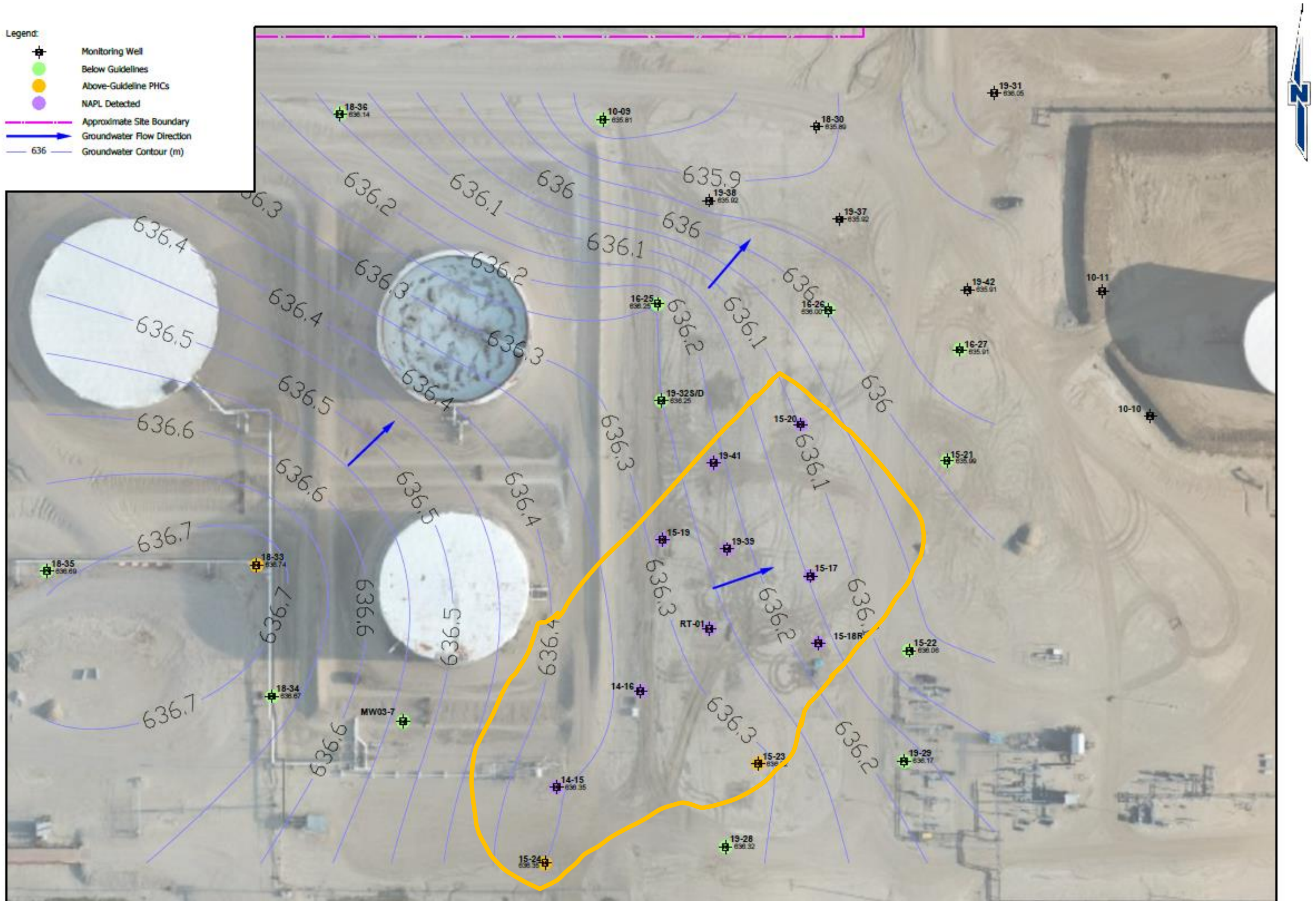
- **Numerous spills:**
  - 15 m^3 Crude Oil (2009)
  - 8 m^3 Crude Oil Blend (2010)
  - 2 m^3 Condensate (2013)
  - 0.1 m^3 Condensate (2015)
- **Primary COCs:** benzene, PHC F1

HISTORICAL INVESTIGATIONS



HISTORICAL INVESTIGATIONS – GROUNDWATER MONITORING

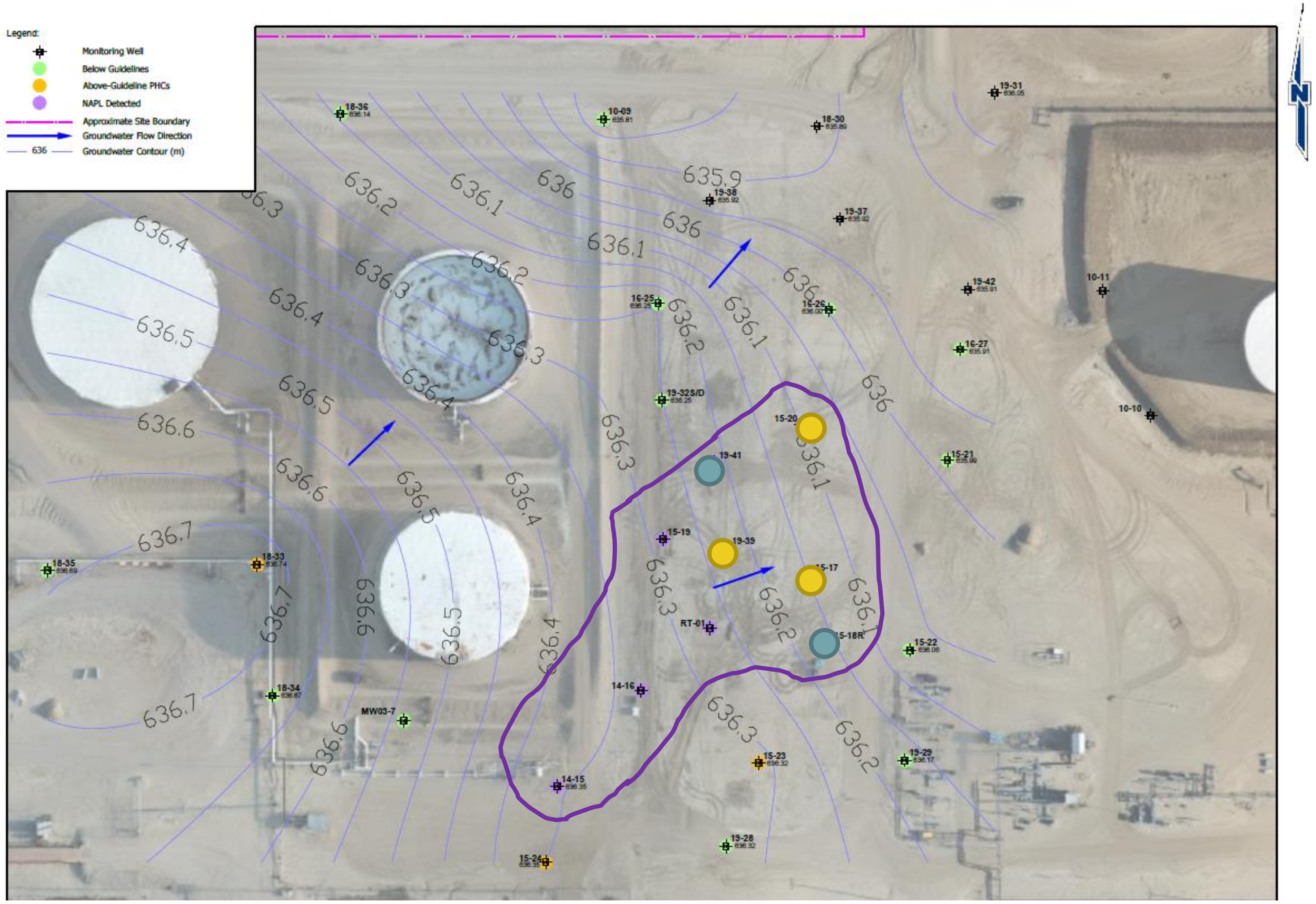
- Groundwater monitoring conducted biannually
- Dissolved benzene covers an area roughly 25, 000 m^2
- Depth to groundwater ranges from 1.87 to 4.94 m bgs,



HISTORICAL INVESTIGATIONS – LNAPL RECOVERY

2 Magnum Spill Busters & 3 Product Skimmers

- 2017-2020 = 8,100 L Removed
- LNAPL Transmissivity in 2019
- Mann Kendall
  - LNAPL Thickness either decreasing or stable at most locations



HISTORICAL INVESTIGATIONS – ESTIMATED IMPACTS

- Extent *(based on 2020 data)*
  - 62,000 m^3 benzene in soil
  - 11,000 m^3 LNAPL
    - Adsorbed
    - Mobile and residual

NATURAL SOURCE ZONE DEPLETION EXPLAINED

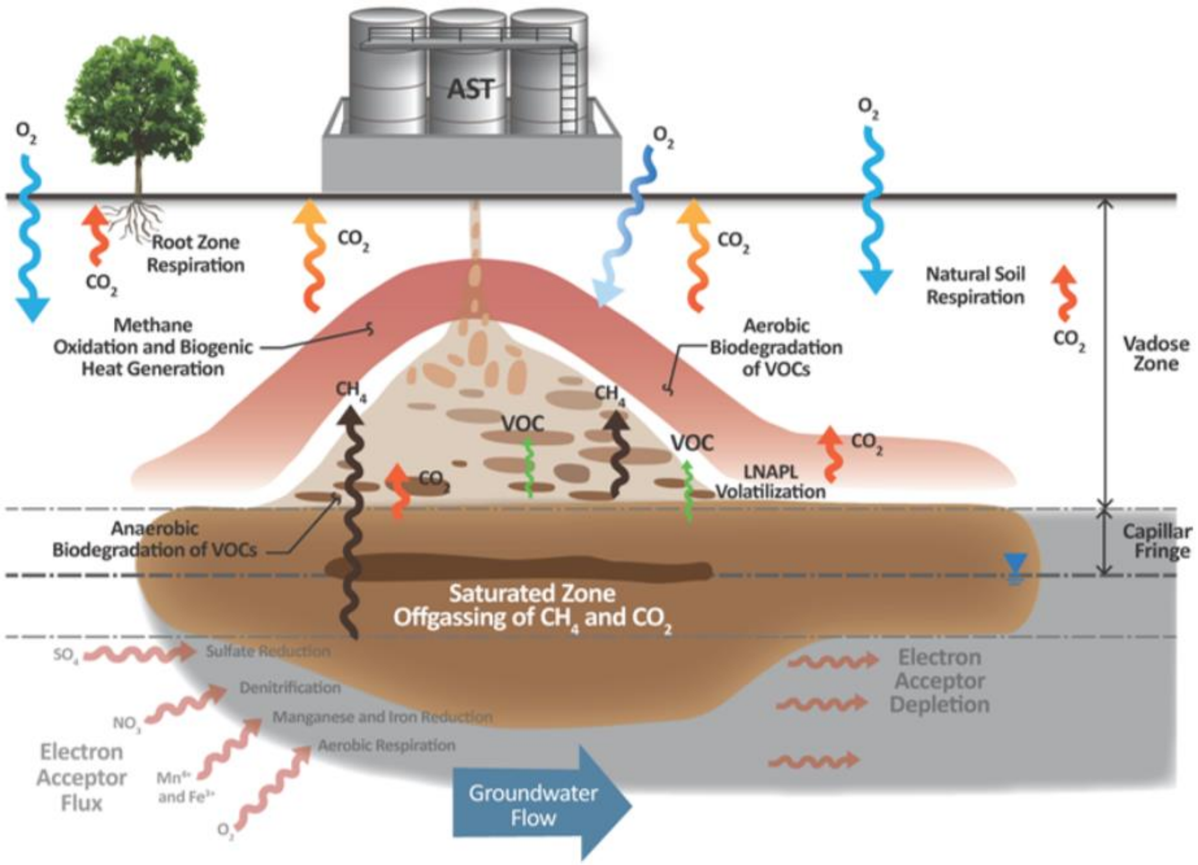


Figure 7: Conceptualisation of LNAPL NSZD processes (from API 2017)

CRC CARE Technical Report no. 46

The role of natural source zone depletion in the management of light non-aqueous phase liquid (LNAPL) contaminated sites

Aerobic Transport

Methane Oxidation

$$CH_4 + 2O_2 \rightarrow CO_{2\ (g)} + 2H_2O$$

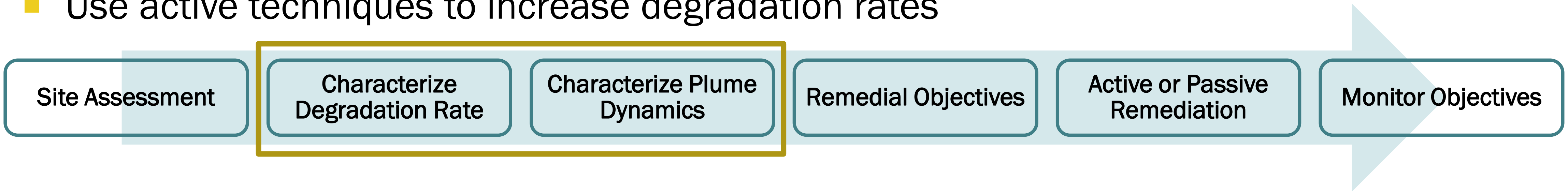
Methane Generation

$$4C_6H_6 + 18\ H_2O \rightarrow 15\ CH_{4\ (g)} + 9\ CO_{2\ (g)}$$

NATURAL SOURCE ZONE DEPLETION & SITE MANAGEMENT

Once natural rates established

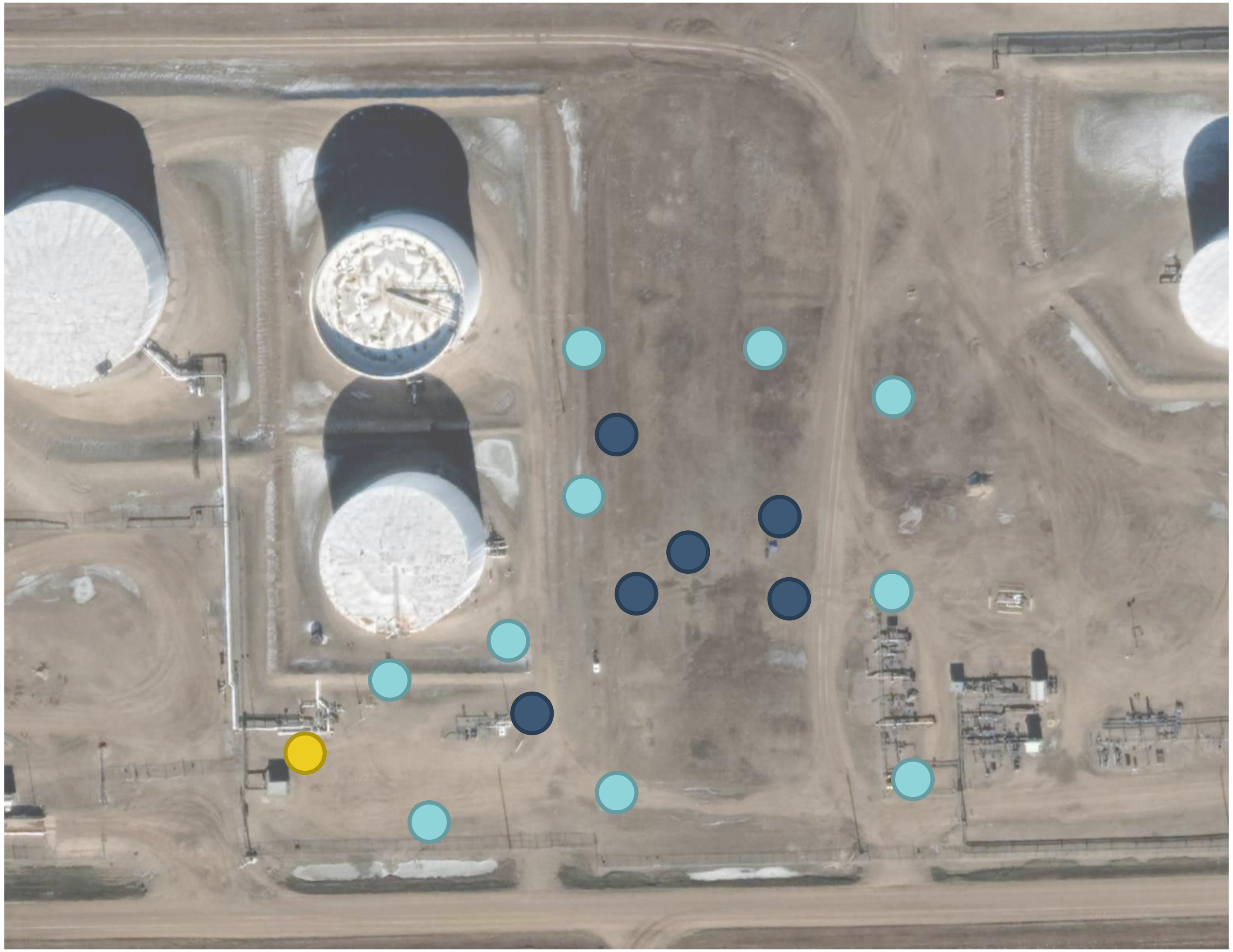
- Estimate mass removal rates & timeframes
- Estimate environmental and financial liability
- Use active techniques to increase degradation rates



PROJECT OBJECTIVES

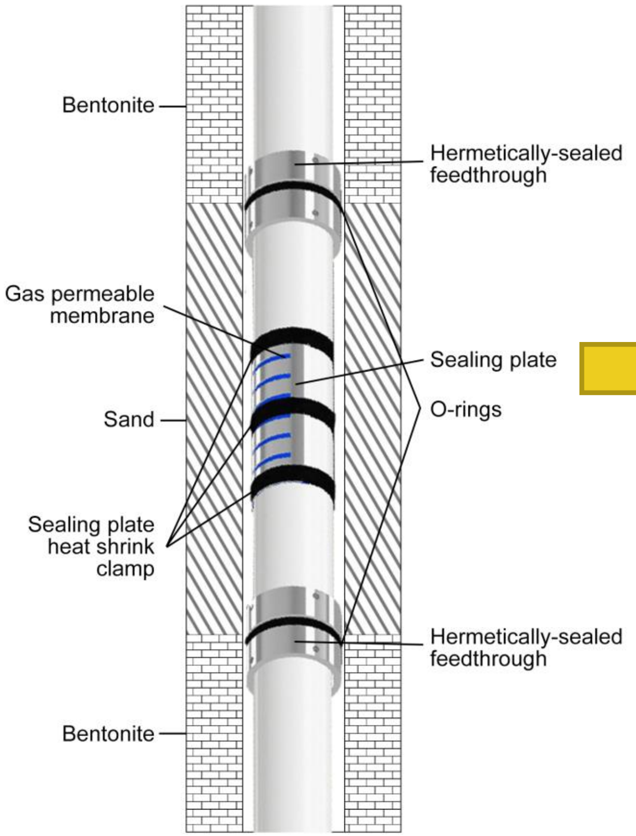
- Characterize Degradation Rate and Plume Dynamics
- Collect 365 days worth of Baseline Data
- *Reduce safety hazards, carbon footprint, and waste associated with collecting environmental samples*

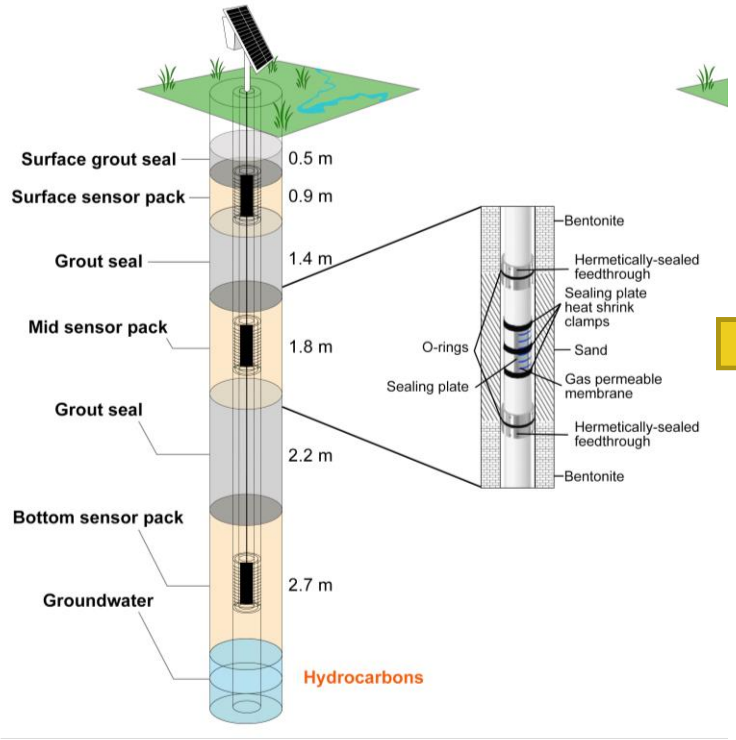
NSZD APPROACH



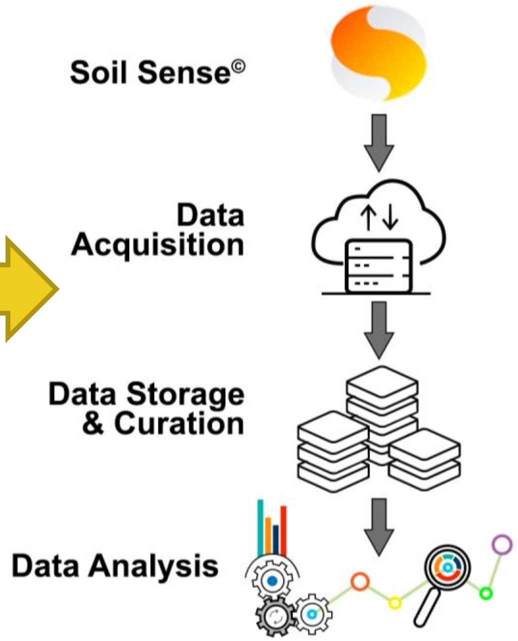
- 17 Soil Sense in October 2021
  - 1 Background
  - 6 In-plume
  - 10 Plume Fringe
- Sensors @ 1.5, 2, 2.5 m bgs

SOIL SENSE



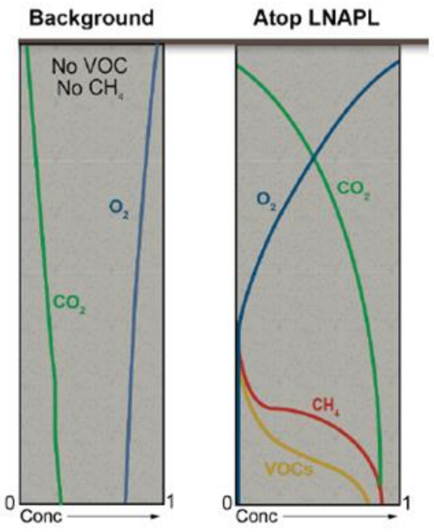


Sensors @ 1.5, 2, 2.5 m bgs



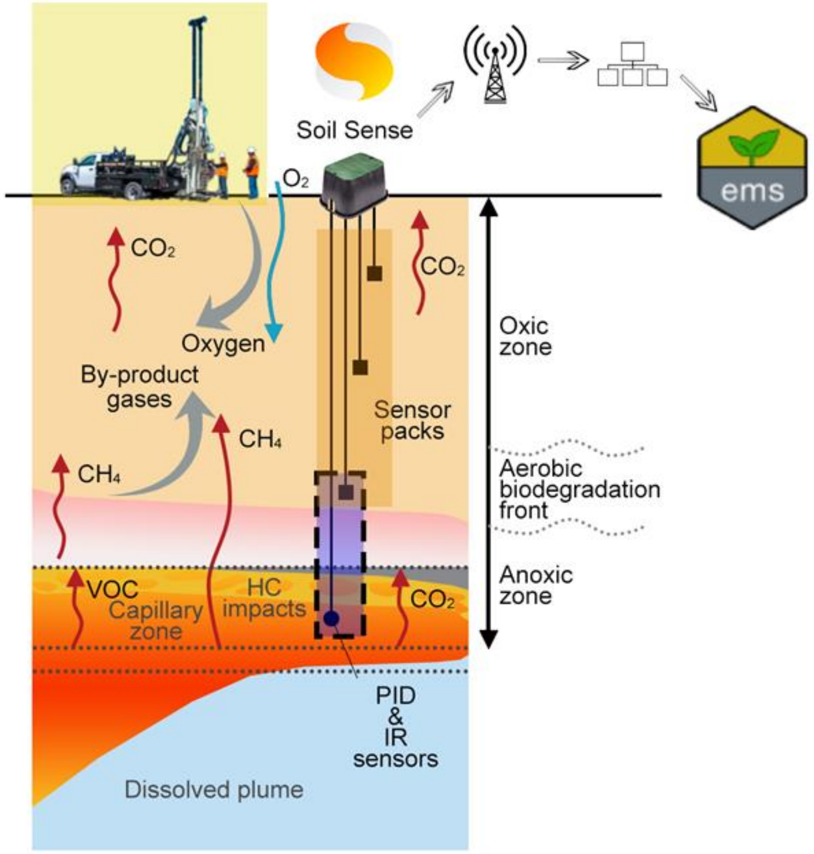
EVERY 30 MINUTES
365 DAYS/YEAR

SOIL SENSE AND CONCENTRATION GRADIENT



Site-Specific

Empirical stoichiometric conversion: benzene–CO_2



Persistent Measurements

Hydrocarbons (source) and CO_2 efflux (products)

Fick's First Law of Diffusion - rate of diffusion is proportional to the concentration and surface area

CRC Care 2018

1. $J = D_v^{eff}(\frac{dC}{dZ})$

J = steady state diffusive flux (g/m²-soil/s)
D_v^{eff} = effective vapour diffusion coefficient (m²/s)
$\frac{dC}{dZ}$ = soil gas concentration gradient (g/m³-m)

2. $J_{impacted} - J_{background} = J_{corrected}$

3. Theoretical stoichiometric conversion: benzene–CO_2

$2C_6H_6 + 15O_2 \rightarrow 12CO_2 + 6H_2O$
$2C_6H_6$: 2*(12.011 g/mol*6 + 1.008 g/mol*6) = 156.223 g/mol
$12CO_2$: 12*(12.011 g/mol + 15.999 g/mol*2) = 528.096 g/mol

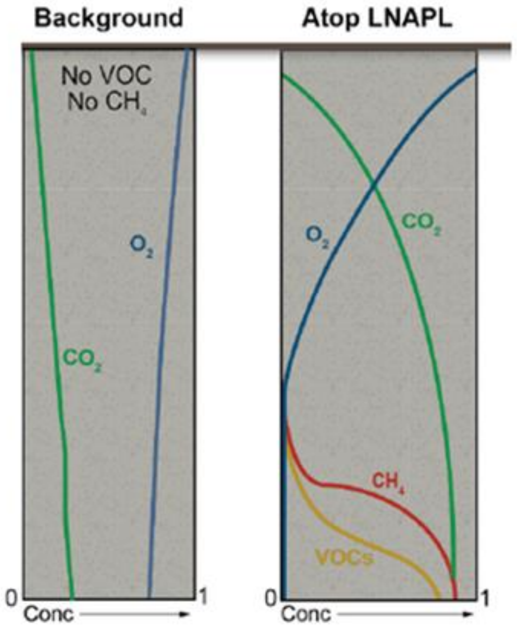
When 156 g of C_6H_6 are consumed, 528 g CO_2 are produced
$Stoich_{CO_2}$ = 156 / 528

4. Natural Source Zone Depletion

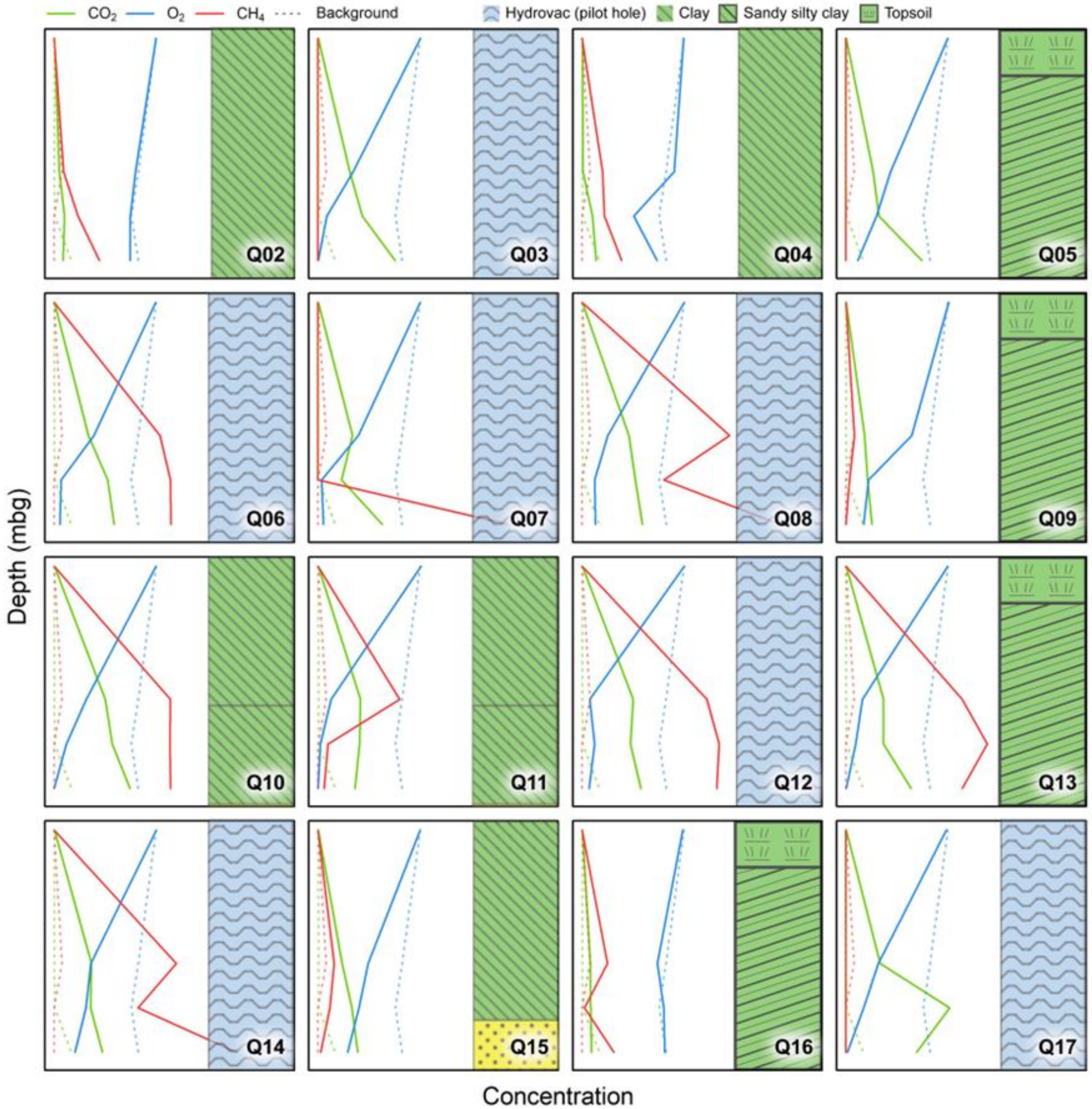
NSZD = $J_{corrected} * Stoich_{CO_2}$

RESULTS: GAS DIFFUSION

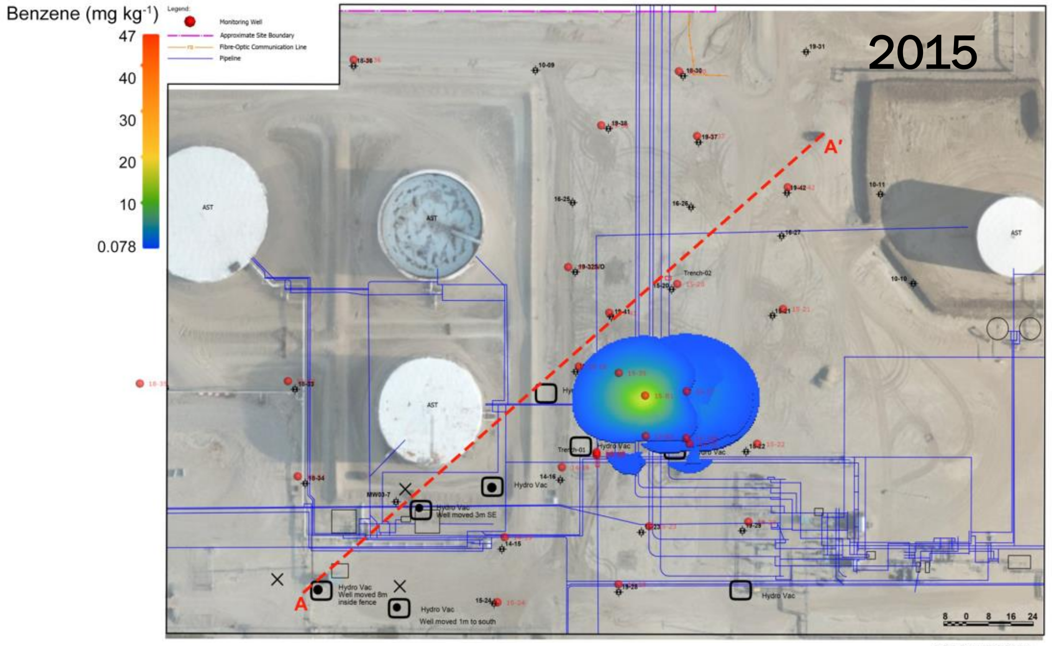
- CO_2, CH_4, O_2 Soil Gas Profiles
- Used Q01 to correct for natural soil respiration

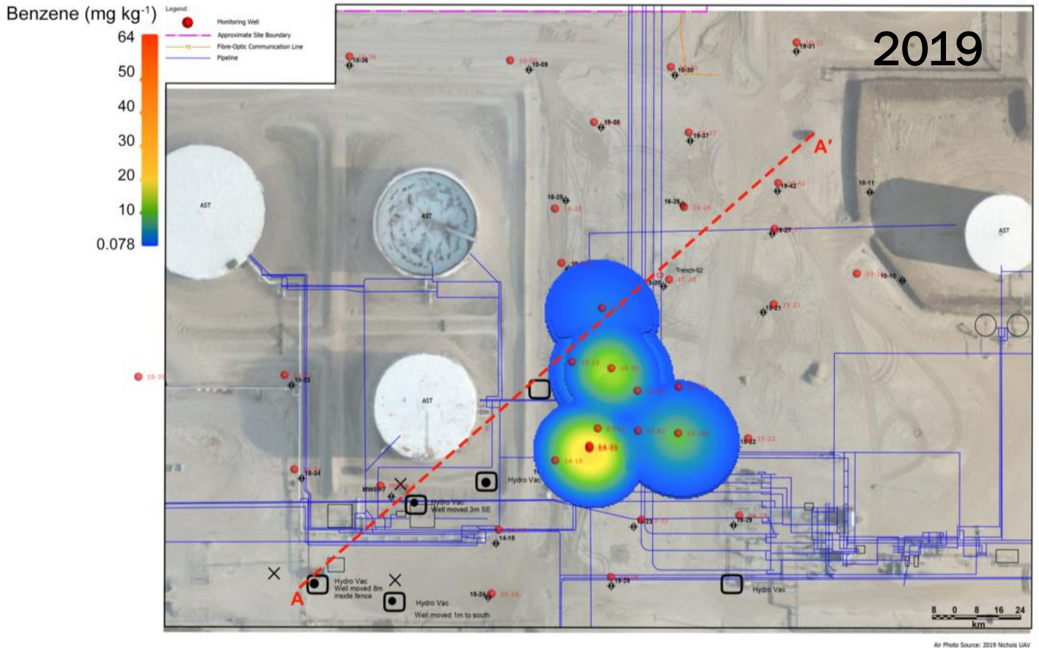


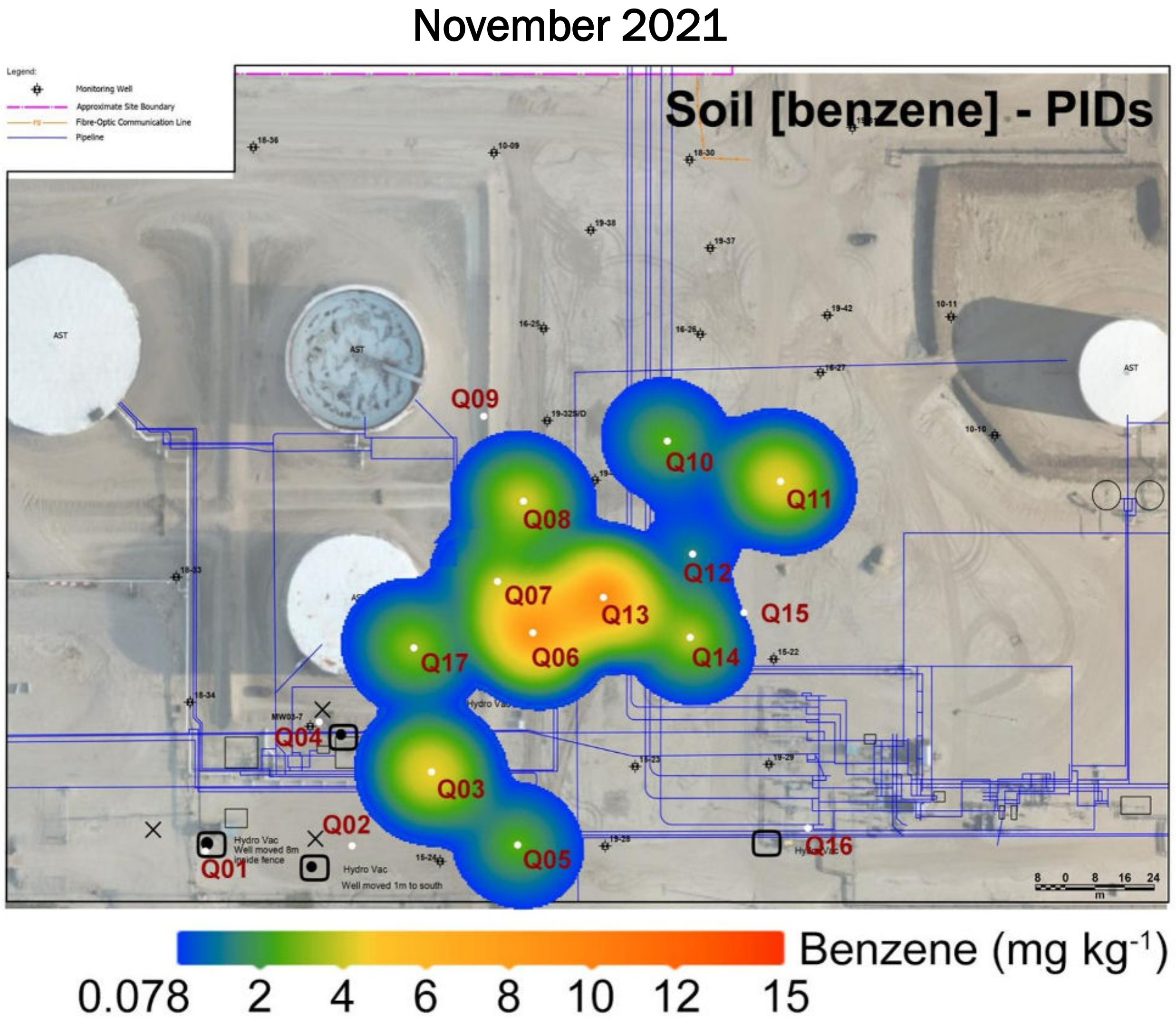
CRC CARE 2018



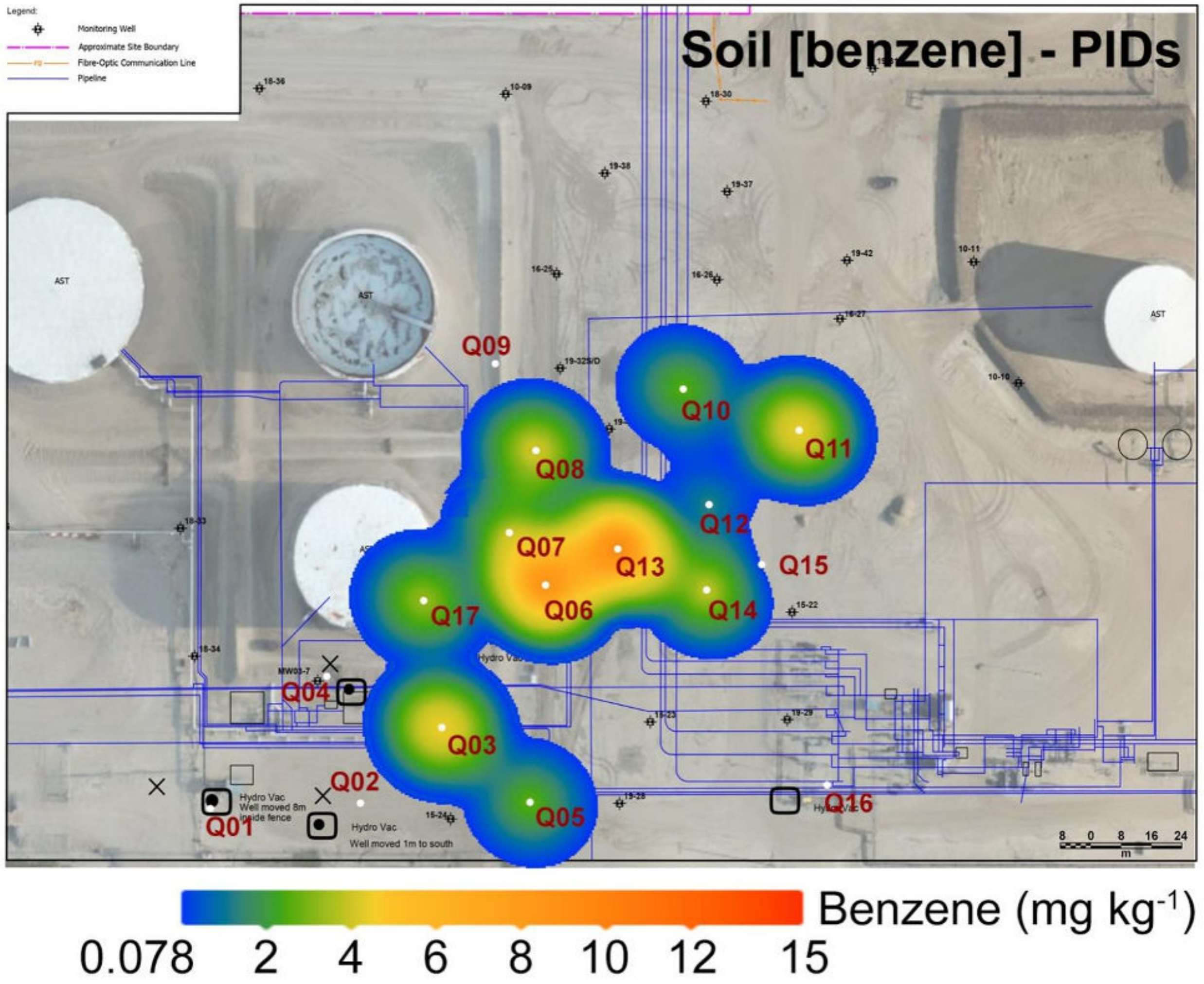
RESULTS: PLUME CHARACTERIZATION

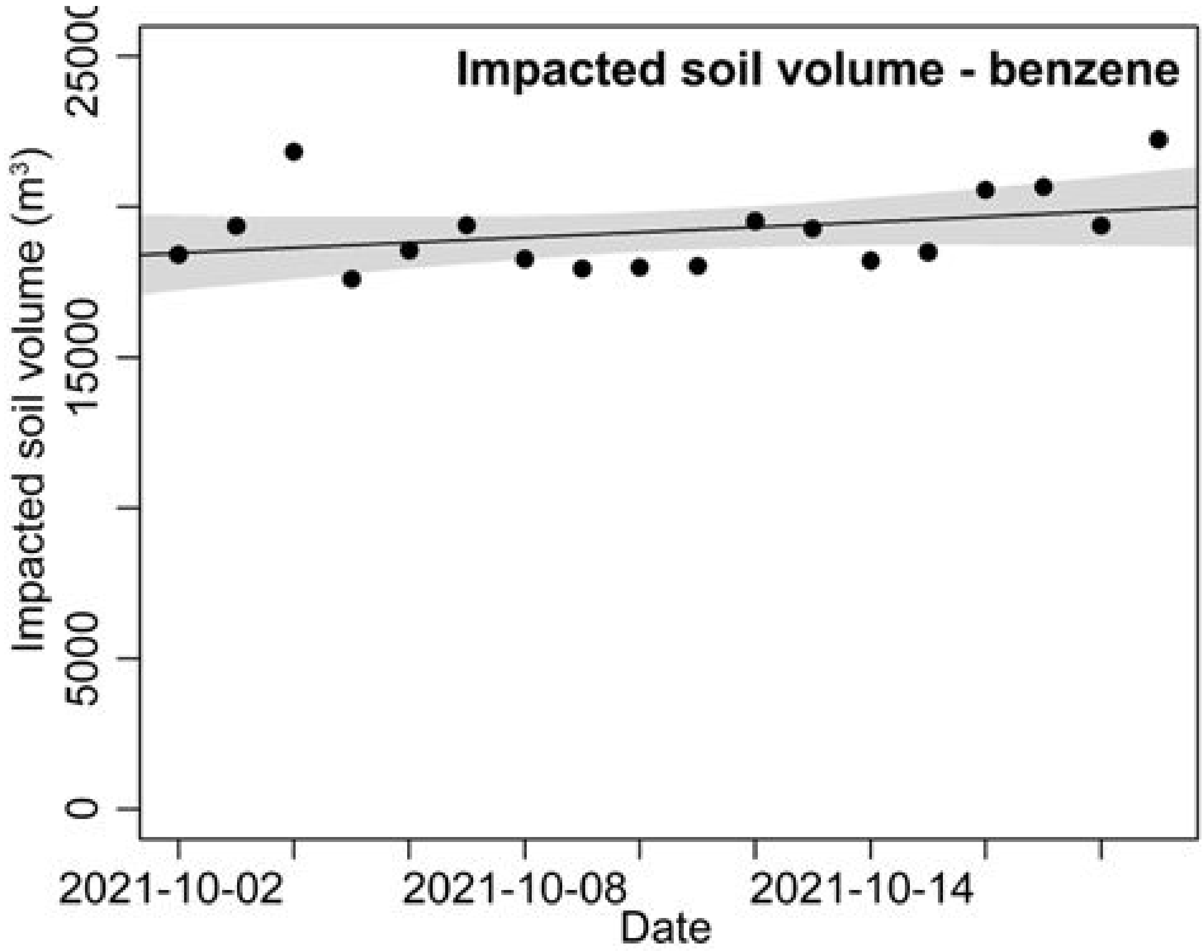




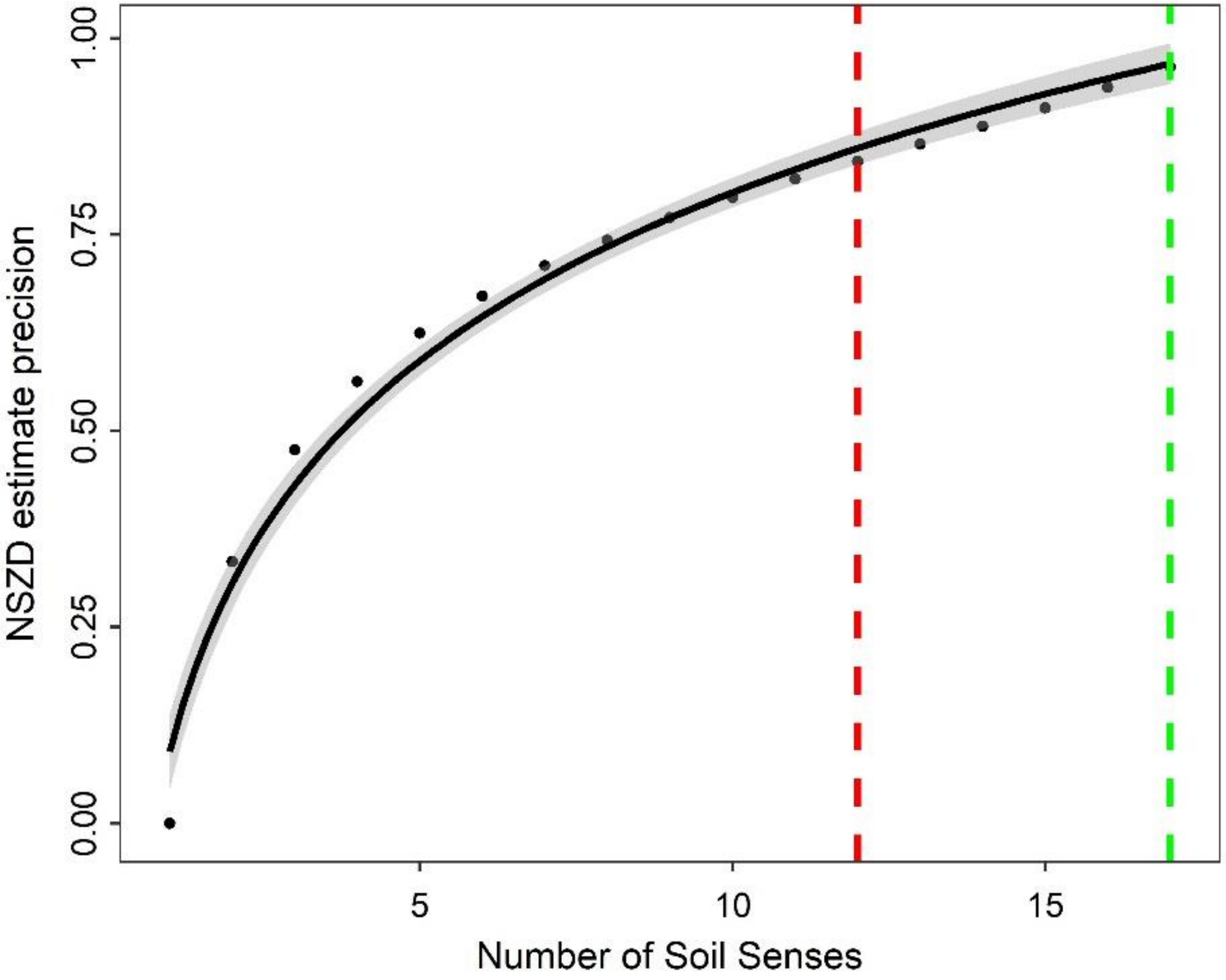


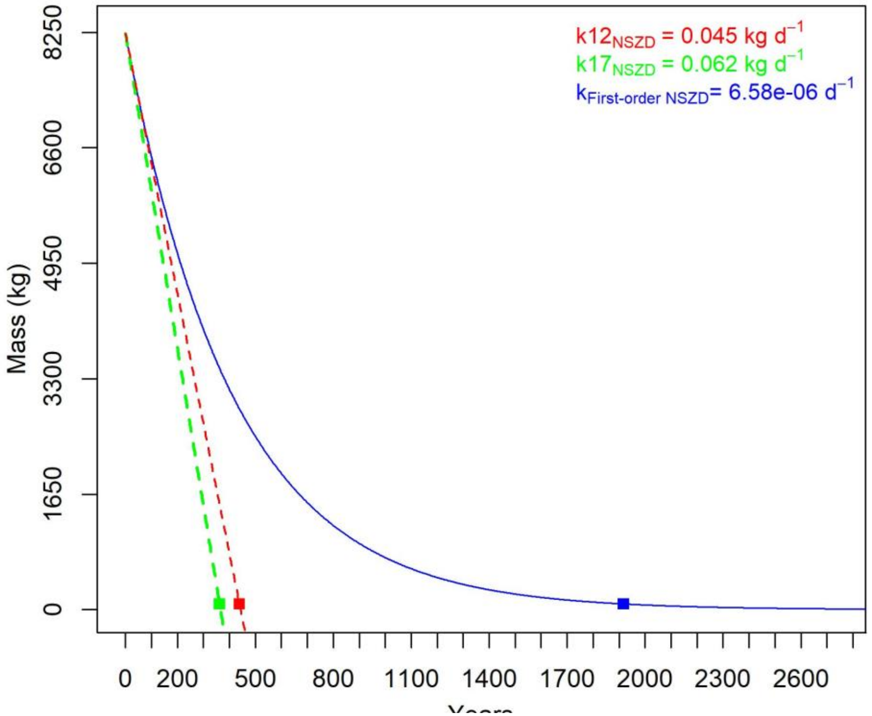
RESULTS: PLUME STABILITY

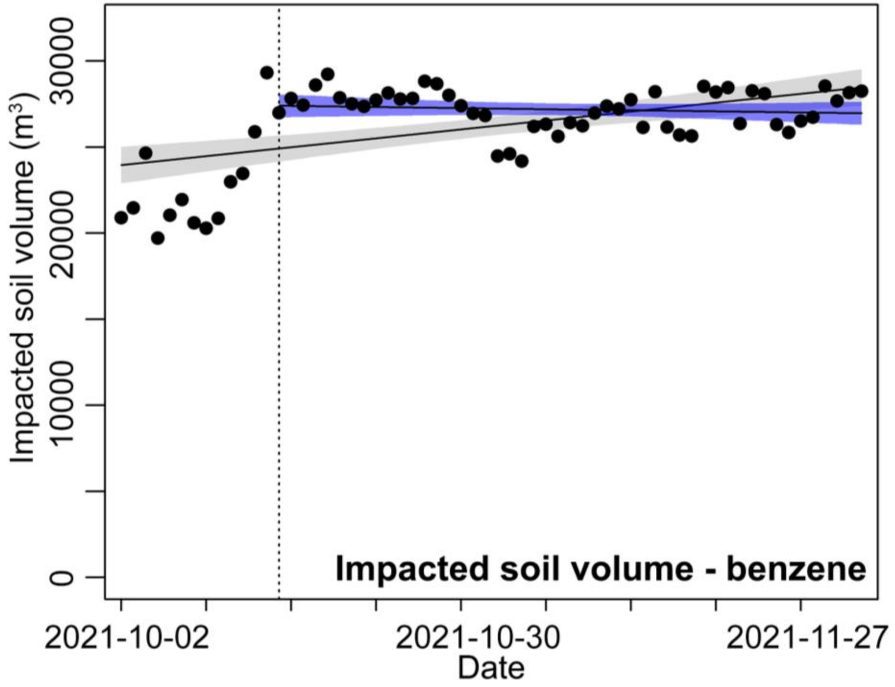




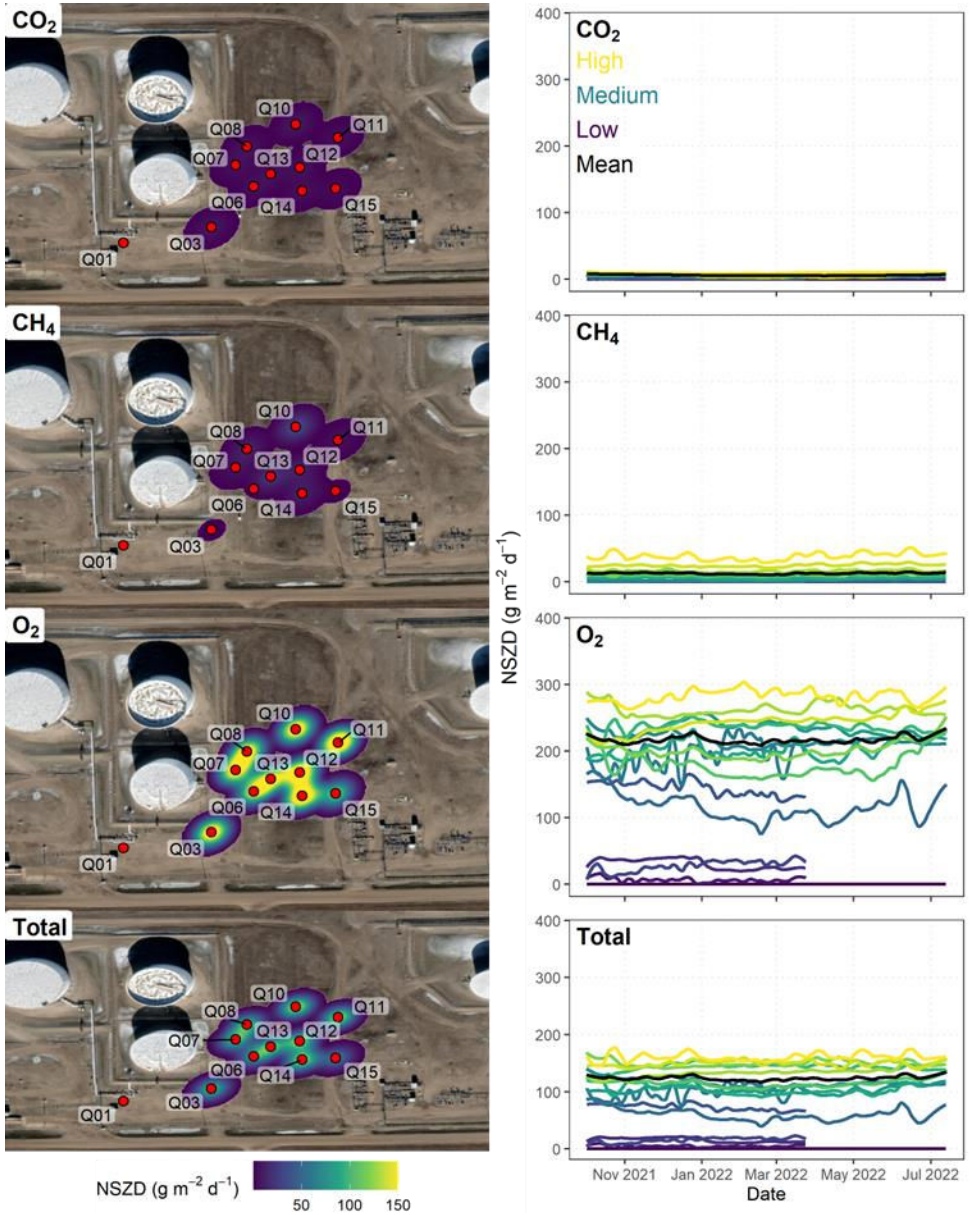
SENSOR OPTIMIZATION

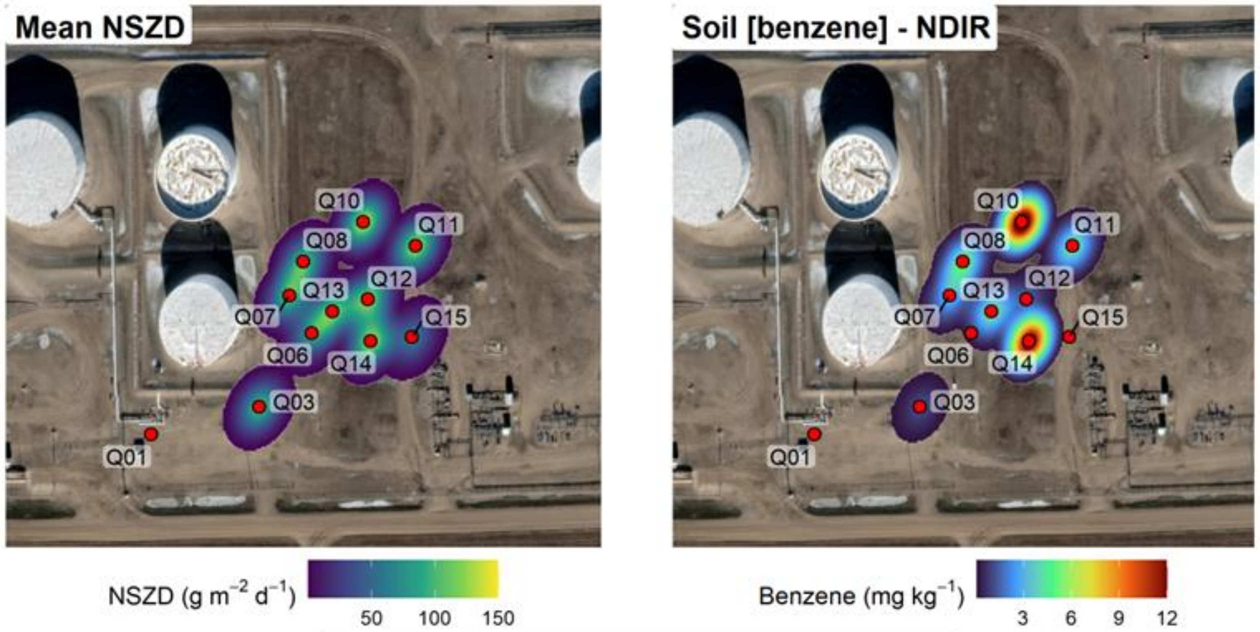


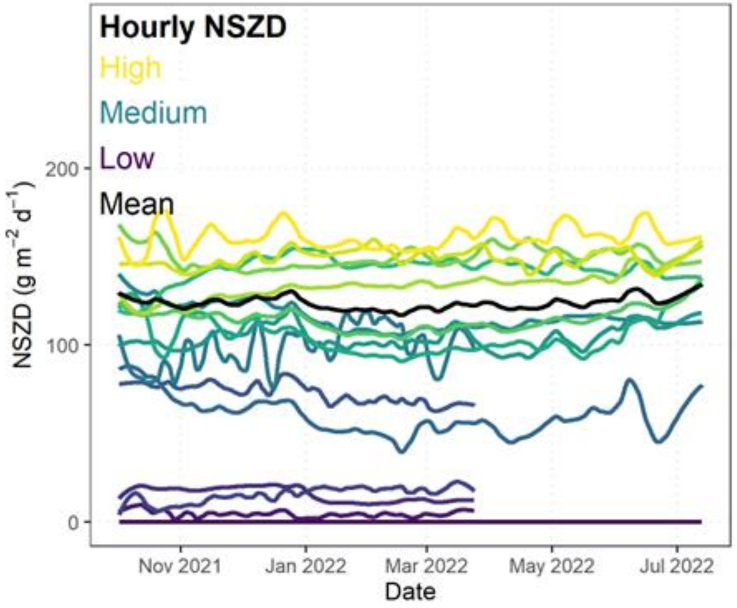




RESULTS: JULY 2022



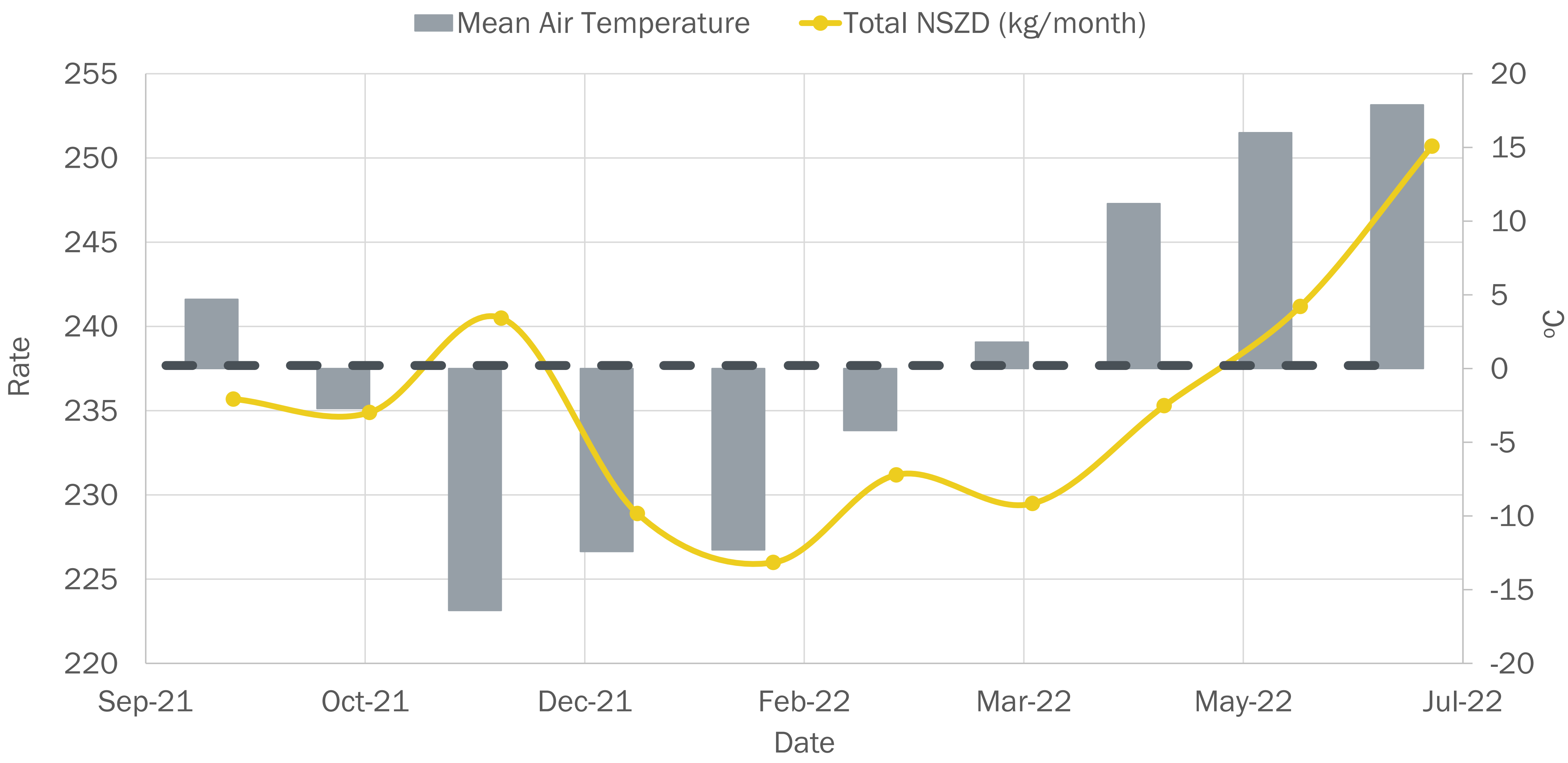




RESULTS: OCTOBER 2021 – JULY 2022

Month	Total NSZD (kg/month)	Benzene equivalent degraded (L/month)	Mean air temperatures (°C)
October 2021	235.7	335.5	4.7
November 2021	234.9	334.3	-2.7
December 2021	240.5	342.4	-16.4
January 2022	228.9	325.9	-12.4
February 2022	226.0	321.7	-12.3
March 2022	231.2	329.1	-4.2
April 2022	229.5	326.7	1.8
May 2022	235.3	335.0	11.2
June 2022	241.2	343.4	16.0
July 2022	250.7	356.9	17.9

RESULTS: OCTOBER 2021 – JULY 2022



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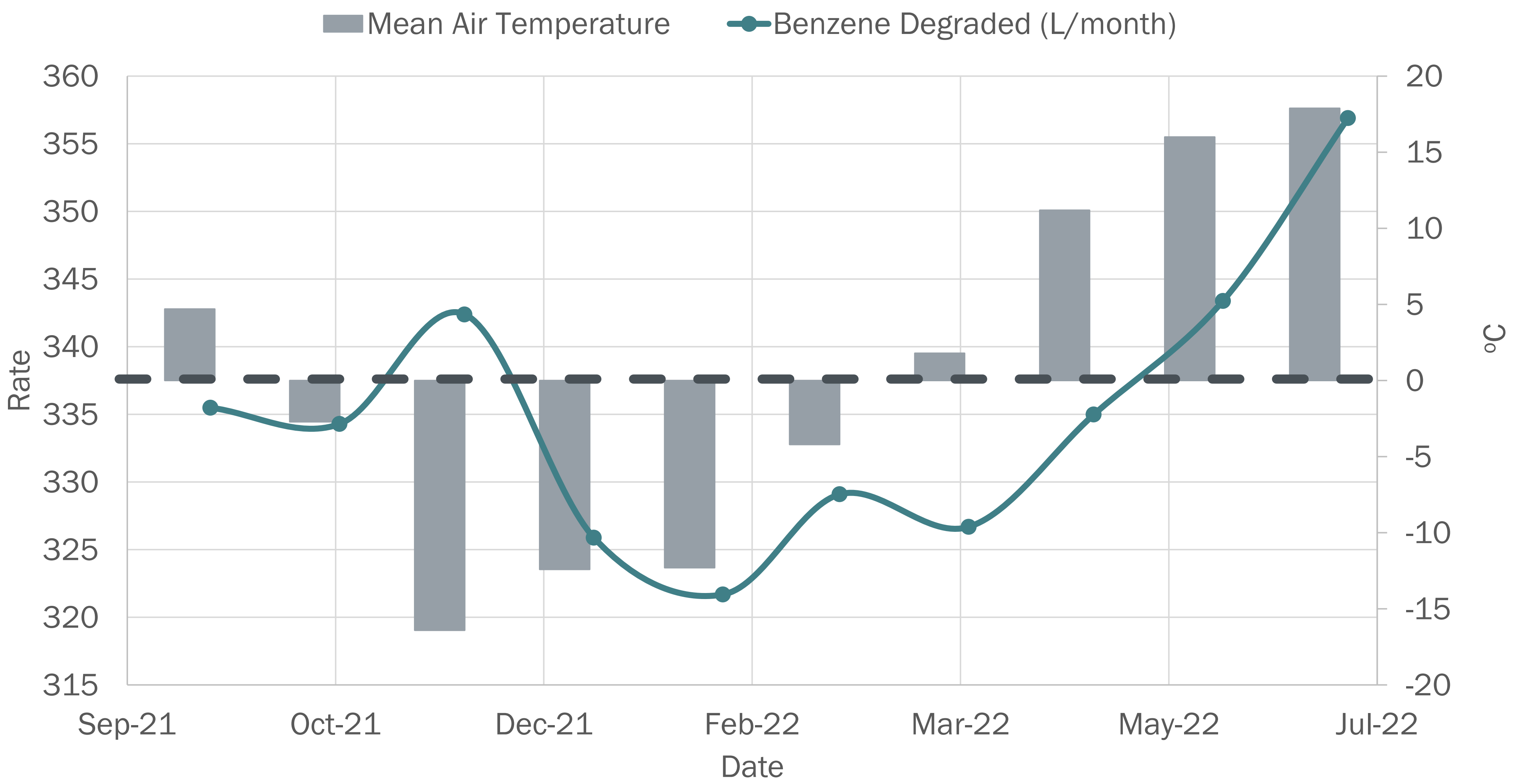

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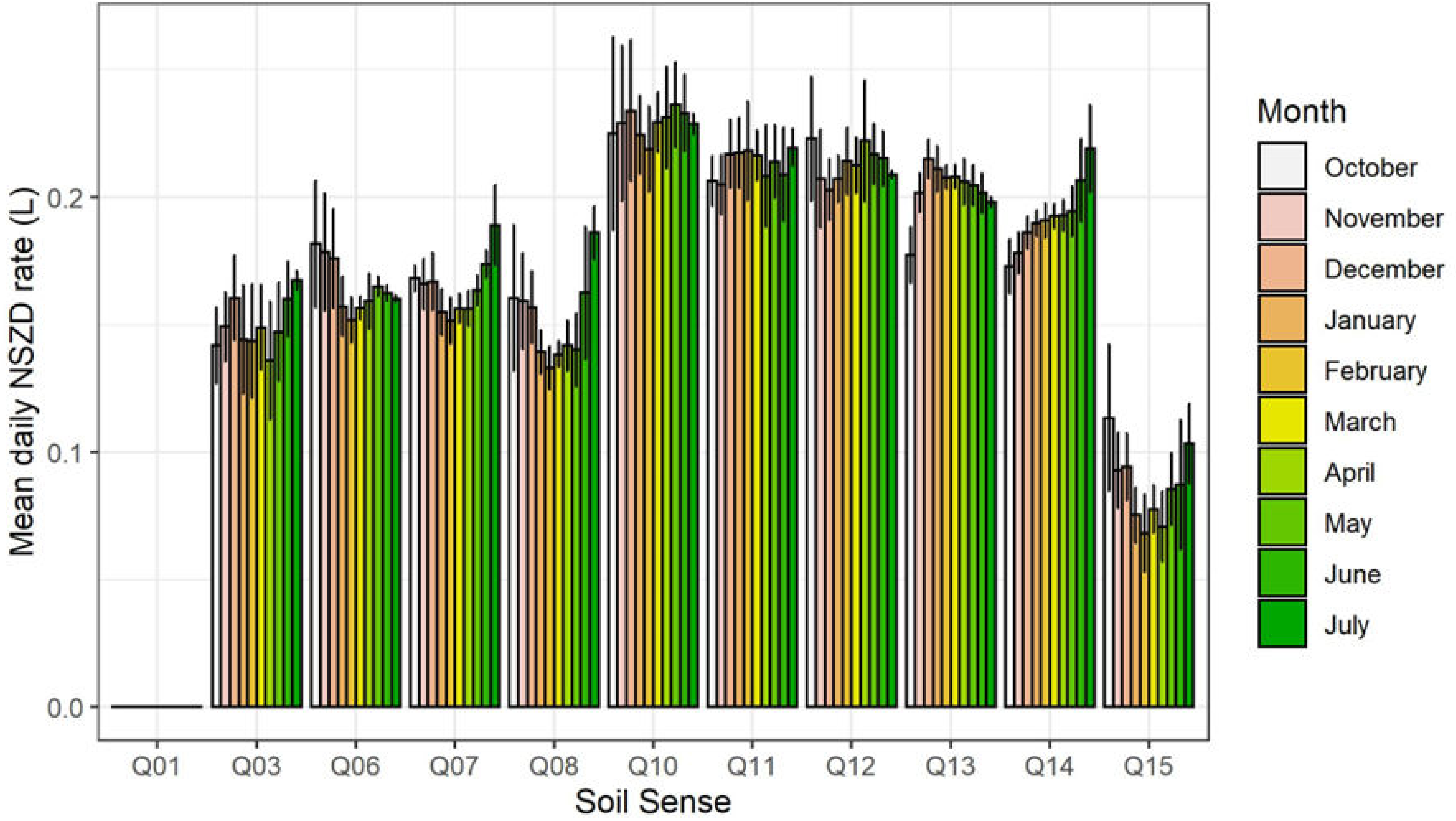
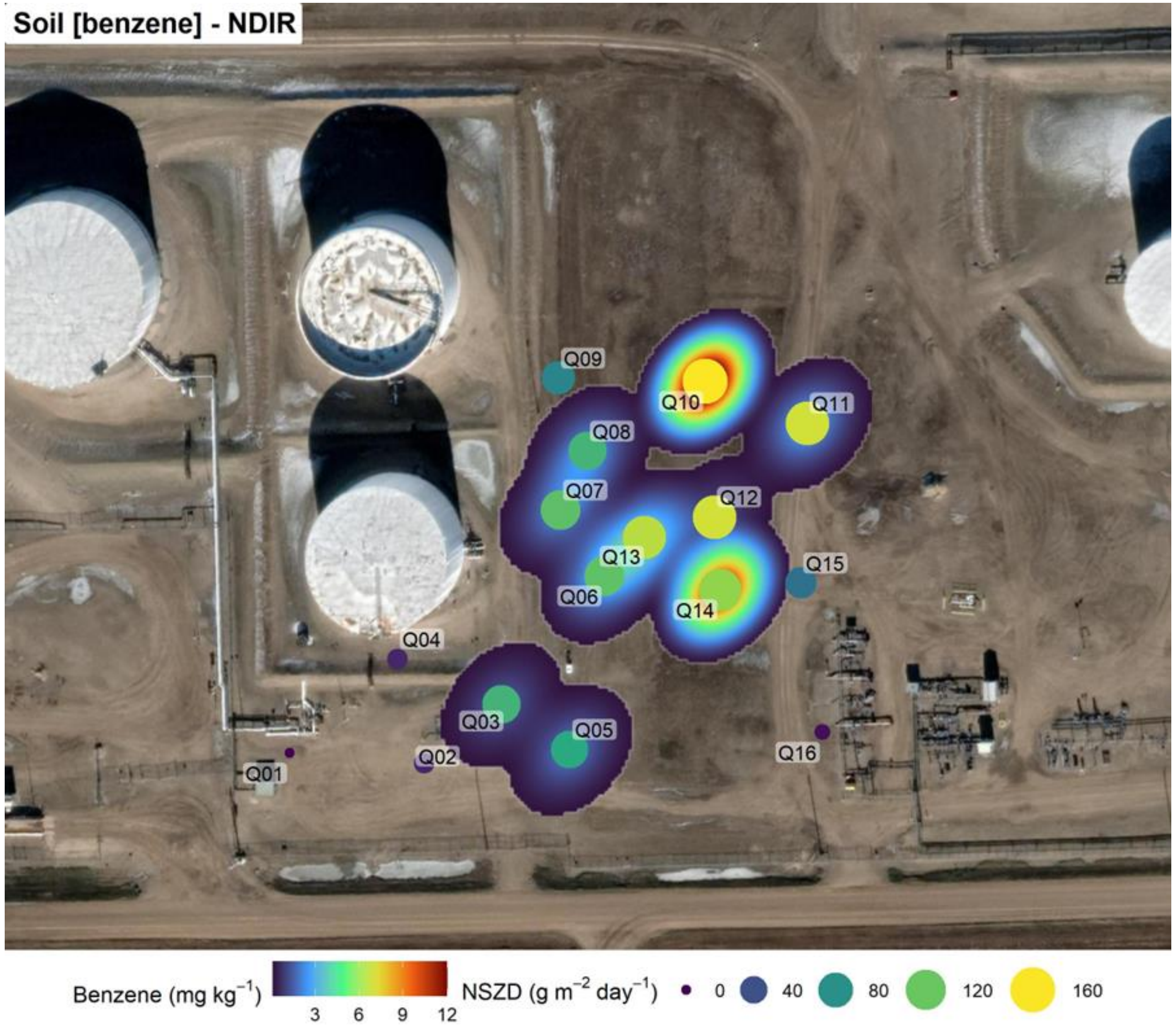
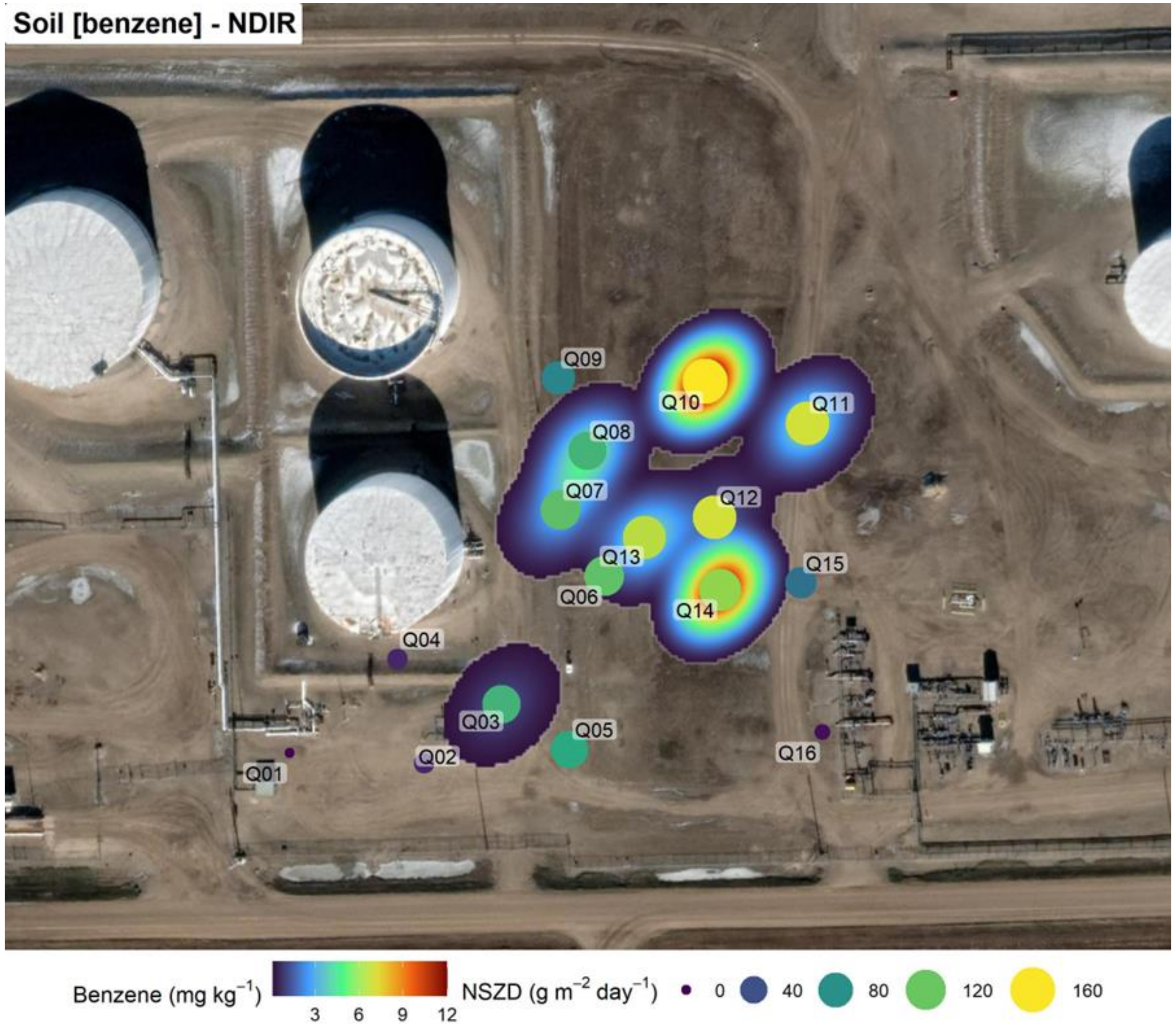


RESULTS

October 2021

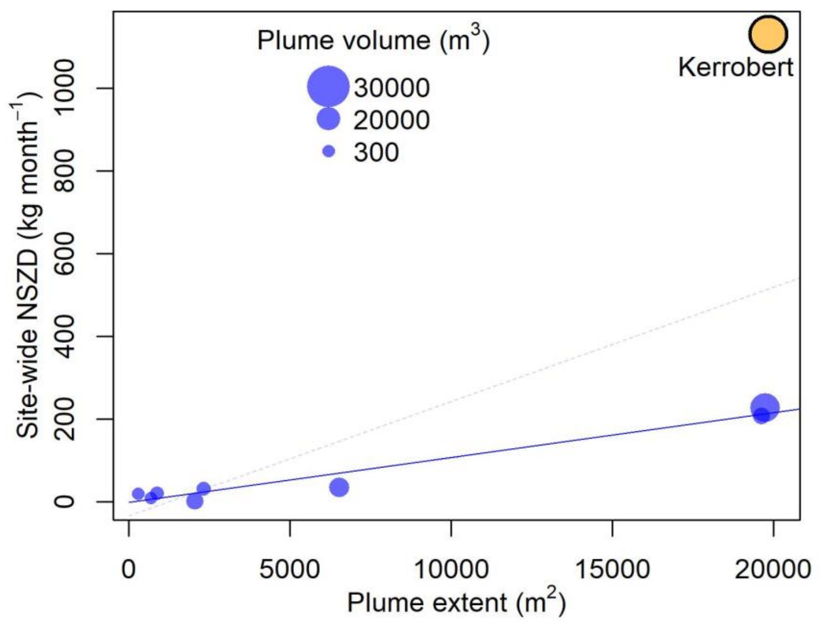


July 2022

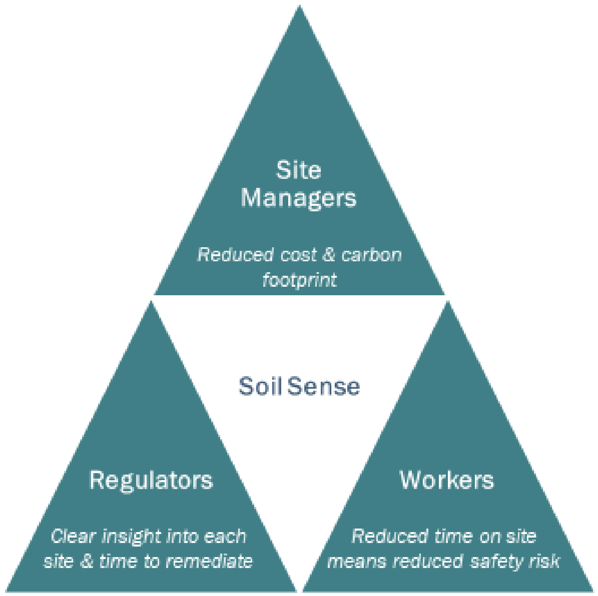


DISCUSSION

- Mean NSZD = 123.7 g/m²/d (October 2021-July 2022)
  - NSZD rates relatively constant ranged from 124.3 – 131.2 g/m²/d
  - Site wide activity = 8.4 kg/d
- Comparable to other similarly sized sites



- Able to:
  - Build comprehensive data set
    - Provide high density data stream
    - Valuable data for decision makers
    - Reduce future environmental monitoring costs



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