



TETRA TECH

High-Resolution Monitoring for Thermal Remediation Optimization



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NASA, Kennedy Space Center: Anne Chrest

complex world | CLEAR SOLUTIONS™

Goals/Overview

- ERH Remedy Overview
- Data Results & Objectives
- Monitoring Toolbox
- Performance Visualization



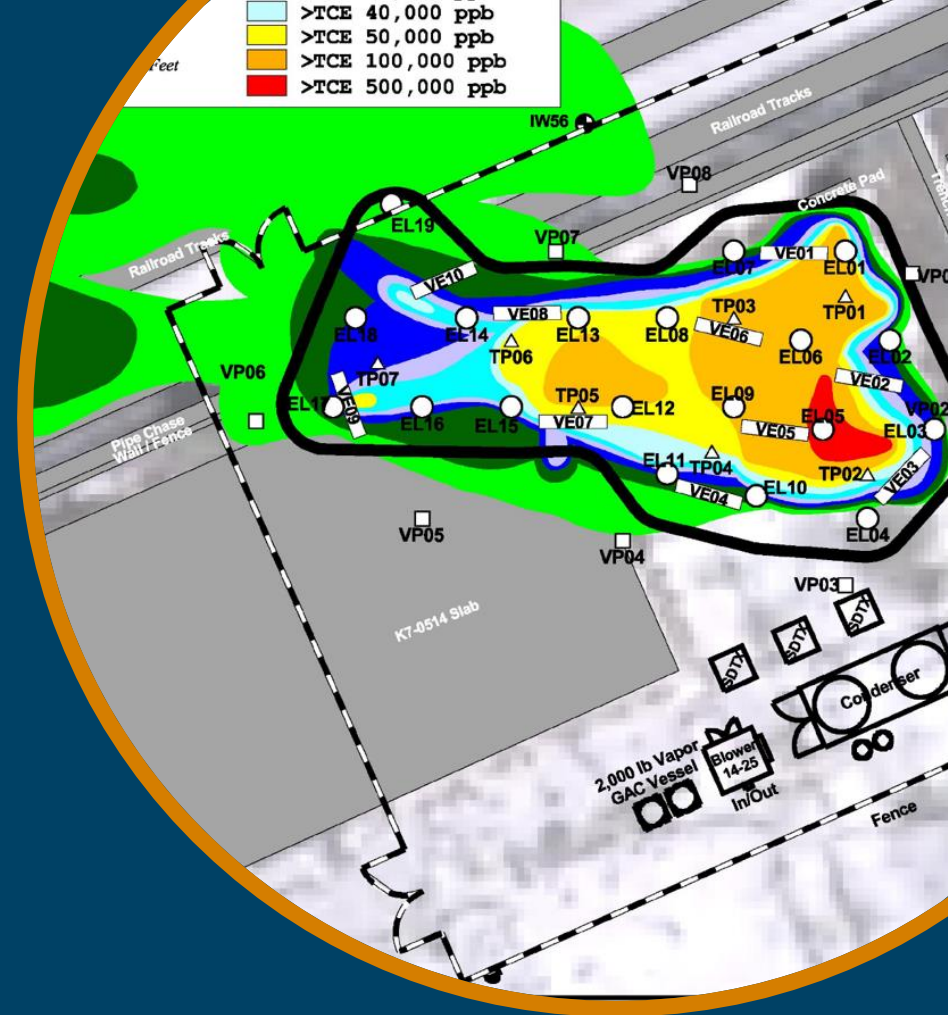


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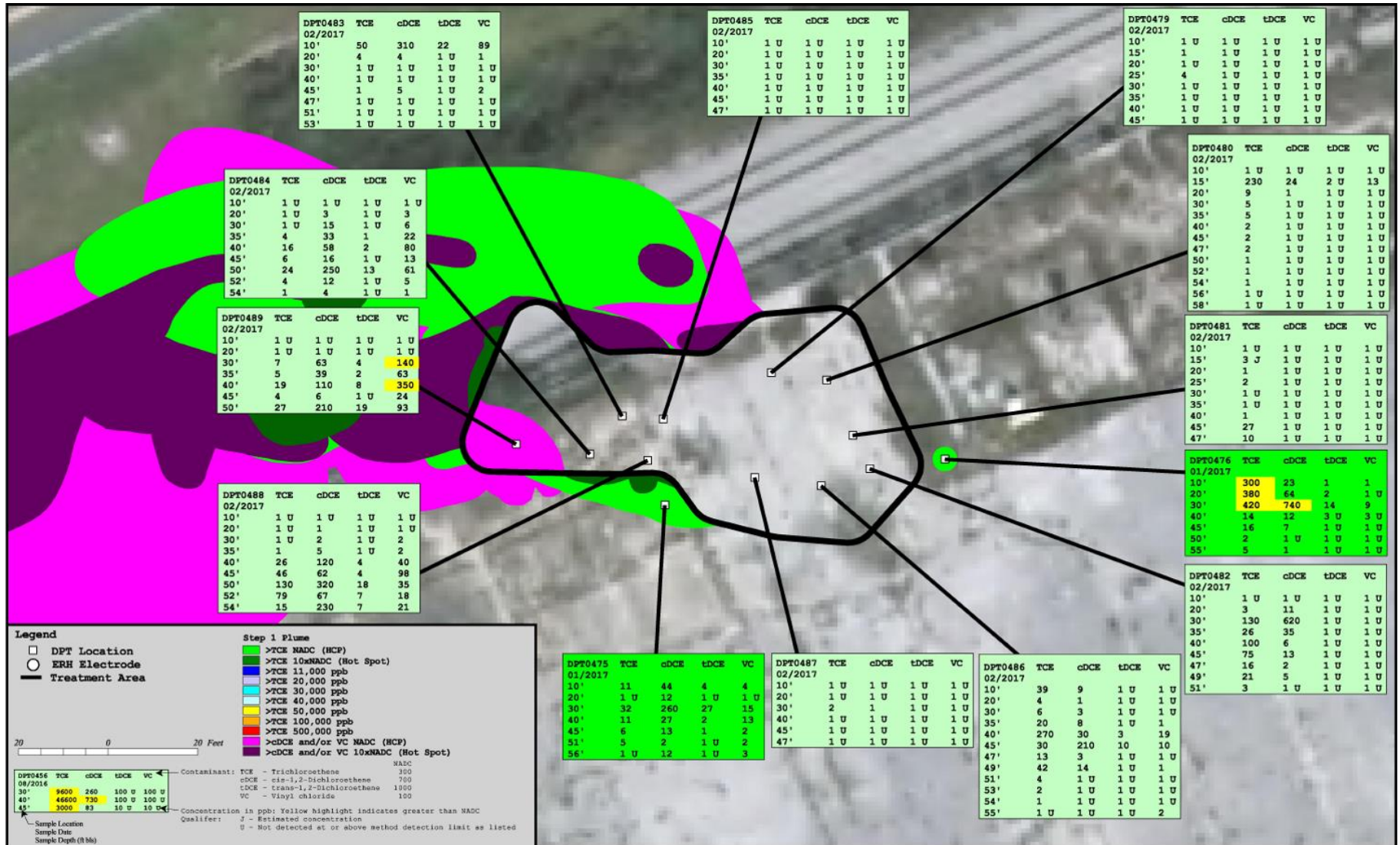


Remedy Overview

- TCE DNAPL source area
- Treatment area: >10,000 ppb TCE
- Treatment objective: <300 ppb TCE (FDEP NADCs, incl. daughters)
- 19 vertically nested electrodes (3 elements/electrode)
- Co-located VE & 10 VE laterals
- 7 temperature monitoring probes (12 sensors/each)
- 8 vacuum monitoring probes

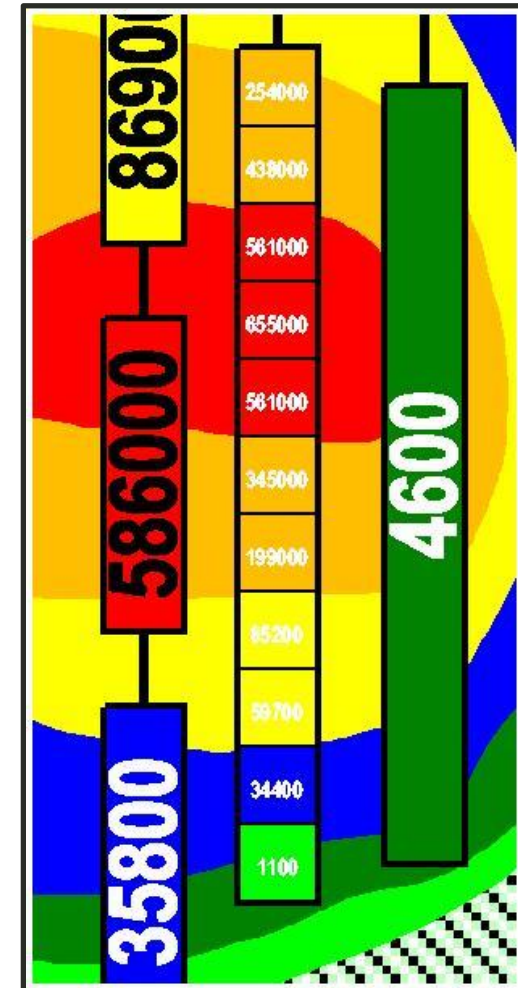


ERH Confirmation Groundwater Results (Spoiler Alert!)

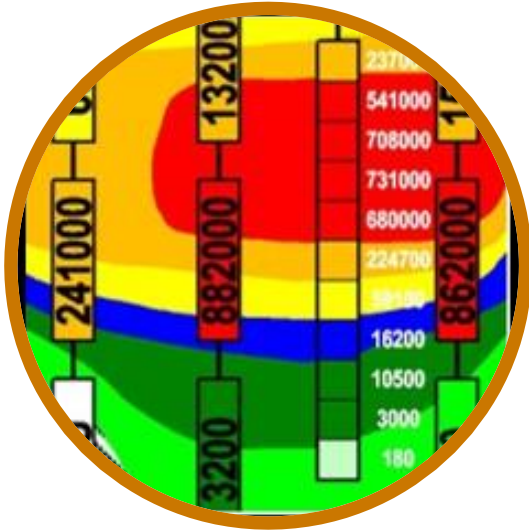


A Performance Monitoring Conundrum

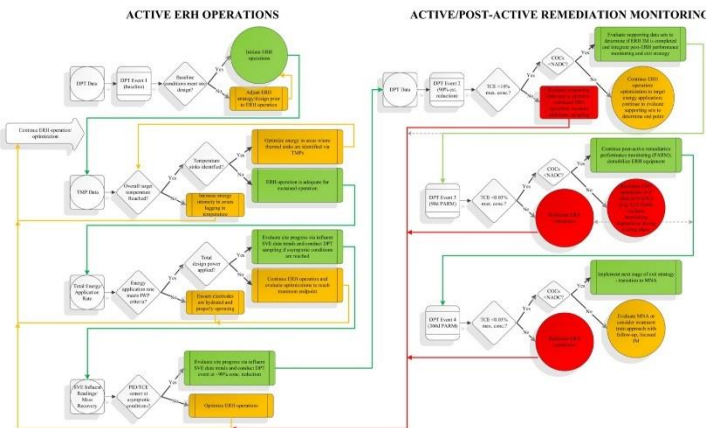
- Complex interbedding in source
- Site characterized at high resolution
 - Up to 1 foot vertical resolution
 - OoM variations in small increments
- Monitoring wells did not to portray source conditions
- Low confidence in use of monitoring wells for ERH performance monitoring
- Need of monitoring approach to assess source removal in discrete intervals



How can we confidently measure performance?



- Multiple lines of evidence strategies, e.g.
 - Chemical data
 - Temperature
 - Vapor extraction influent
 - Energy applied/power density
- High resolution performance monitoring
 - New: DPT hot sampling methods at high resolution (>100 samples per event)
 - Up to 1' vertical resolution (discrete)
 - Adaptive sampling intervals
 - Spatial flexibility
 - Common practice: Temperature
- Iterative optimization



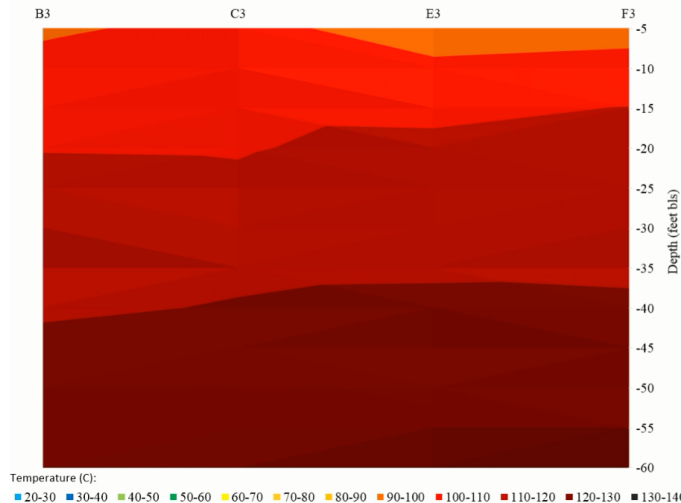
DPT Groundwater Sampling During ERH



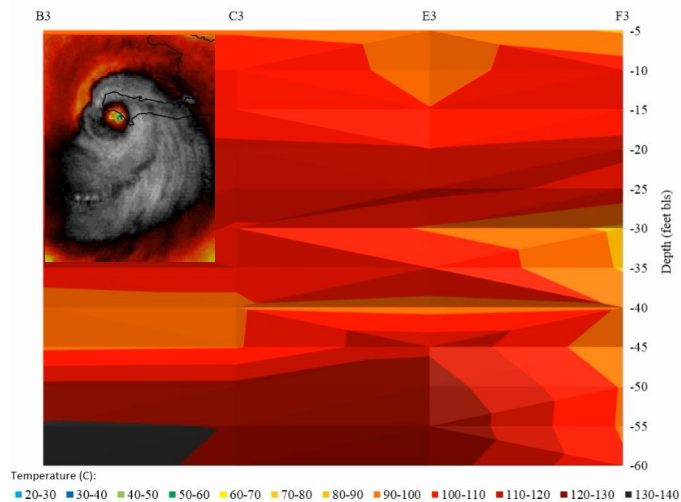
- Challenges:
 - Artesian conditions (ΔP)
 - Steam flash & thermal hazards
 - Sample conditioning
- Approach:
 - Closed boring, waterloo-type discrete sampler approach
 - Bench-proofed sample conditioning approach
 - Adaptive sampling protocols
 - Specialized H&S practices
 - PPE
 - Crew rotation
 - Cooling systems
 - On-site lab analyses

Temperature Visualization

7/16/2016



10/14/2016

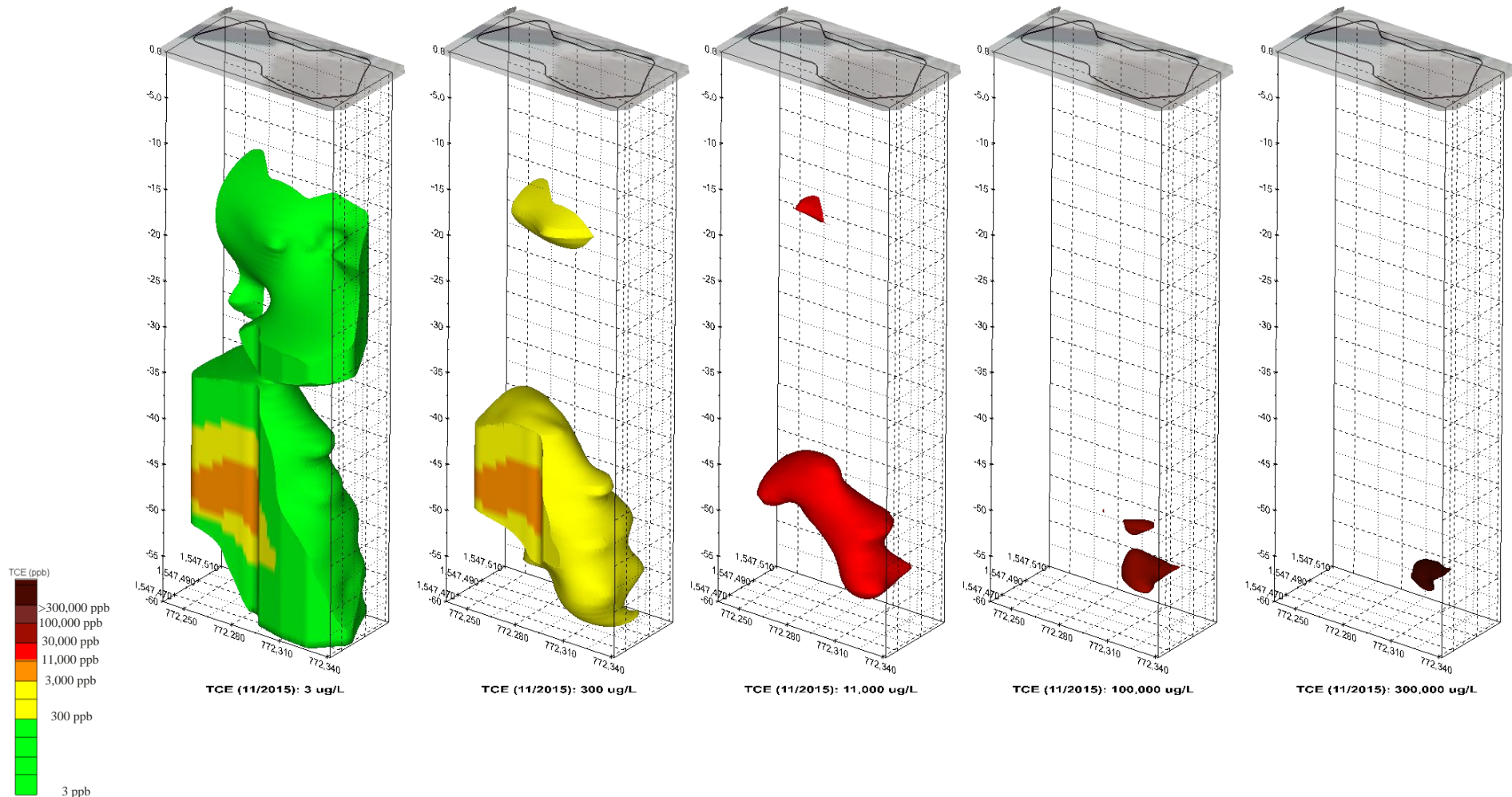


- Excel-based macro temperature visualizations (84 sensors)
 - Minor labor beyond set-up
 - Parallel & orthogonal orientations
- Day-to-day optimization resource
 - Nested electrodes - voltage flexibility
 - Effects of optimization known quickly
- Effective temperature assessments
 - Temperature benchmarks
 - Estimated heteroazeotrope
 - Estimated water boiling point
 - Zones of heat sinks & loss

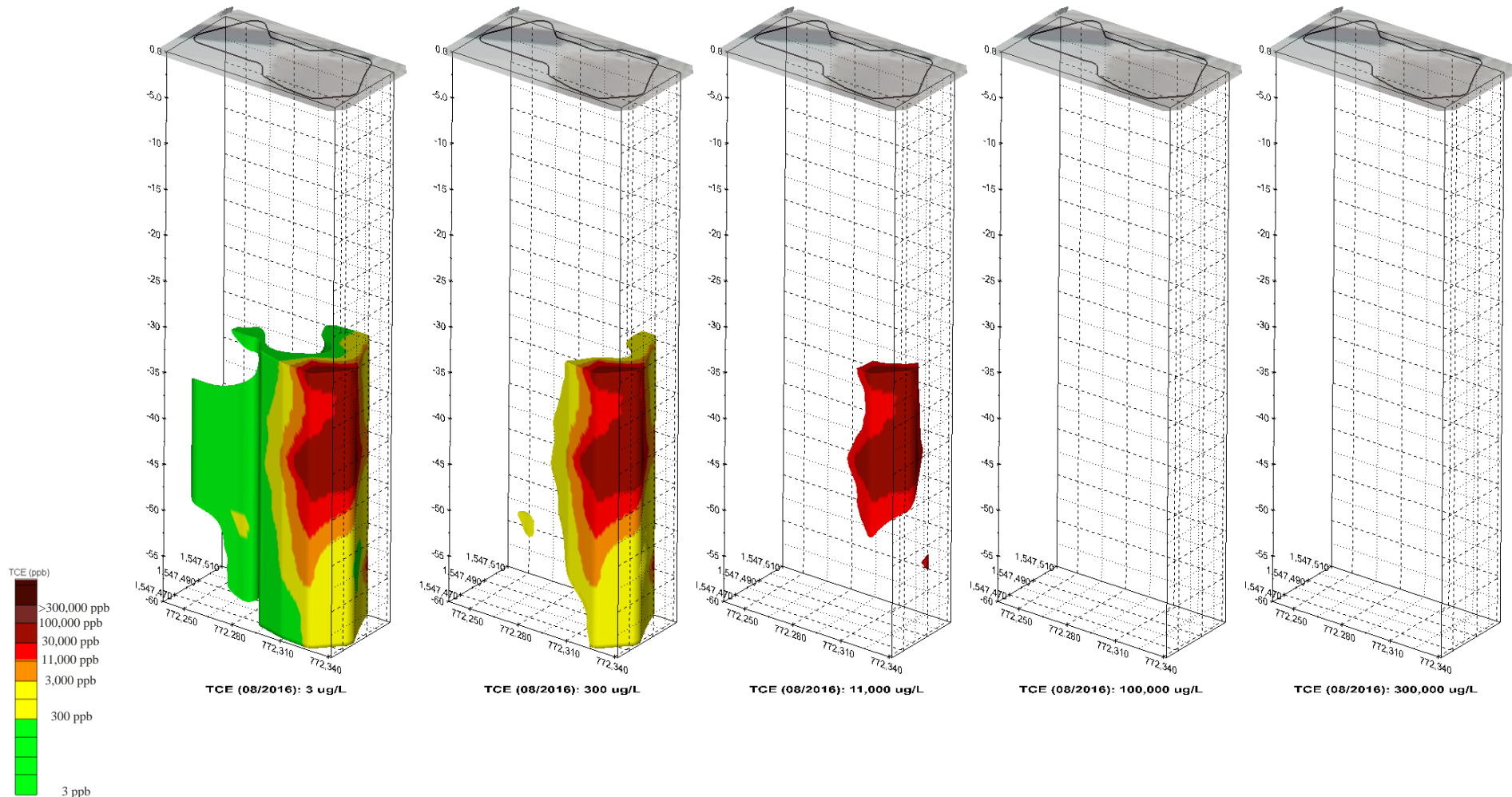
Temperature Visualization (video)



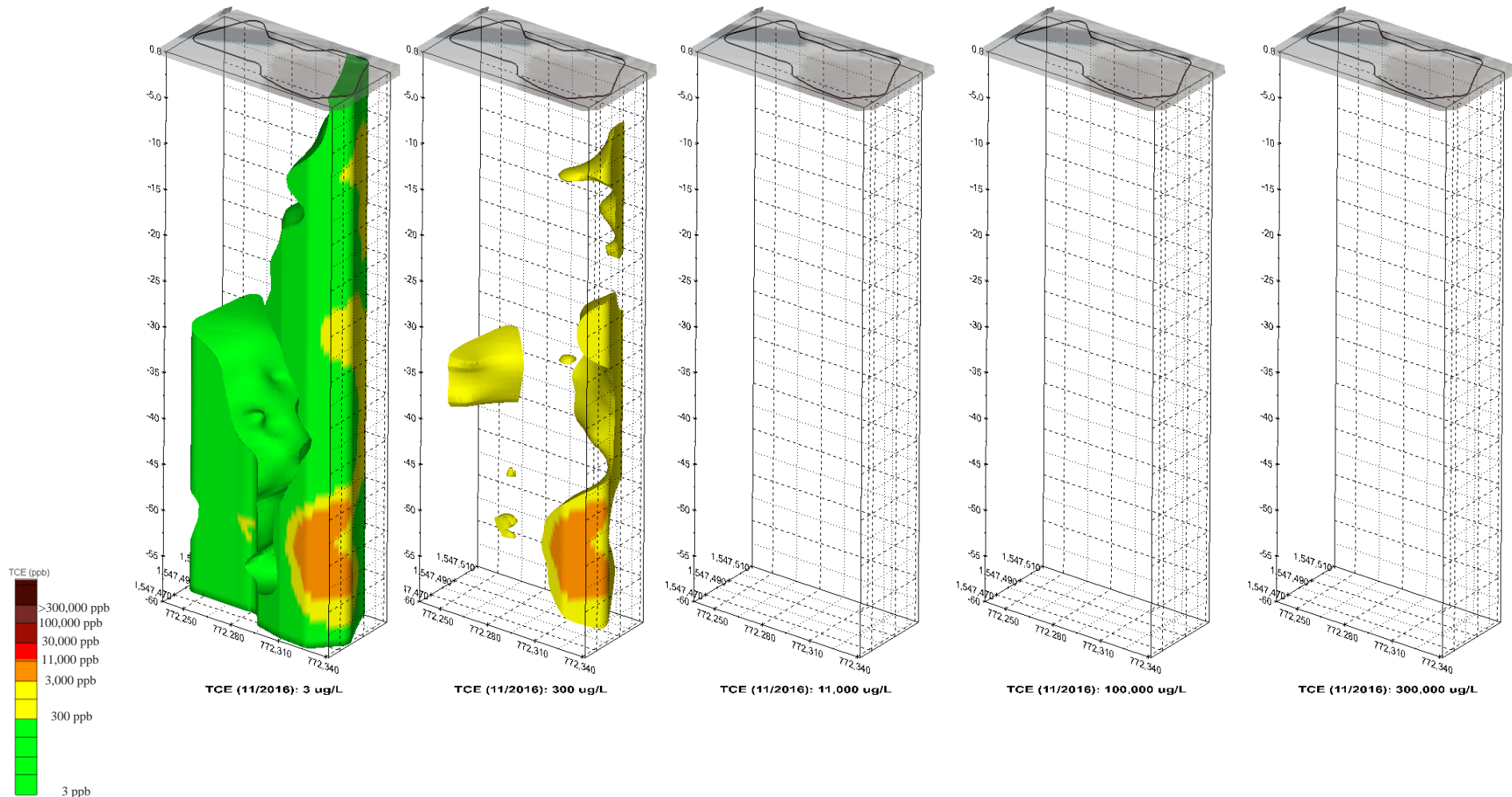
3DVA Chemical Visualization Baseline



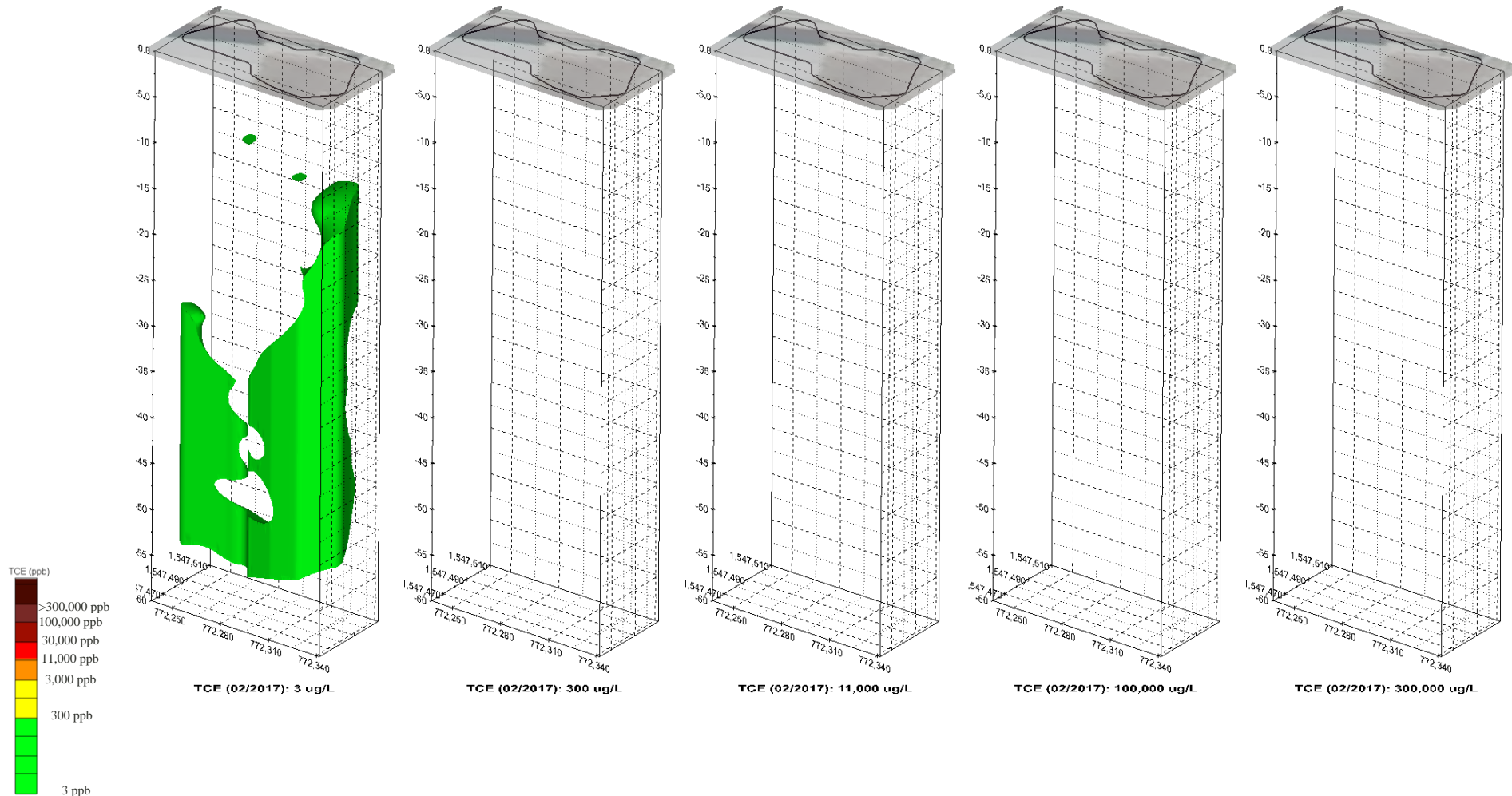
3DVA Chemical Visualization Interim



3DVA Chemical Visualization Interim

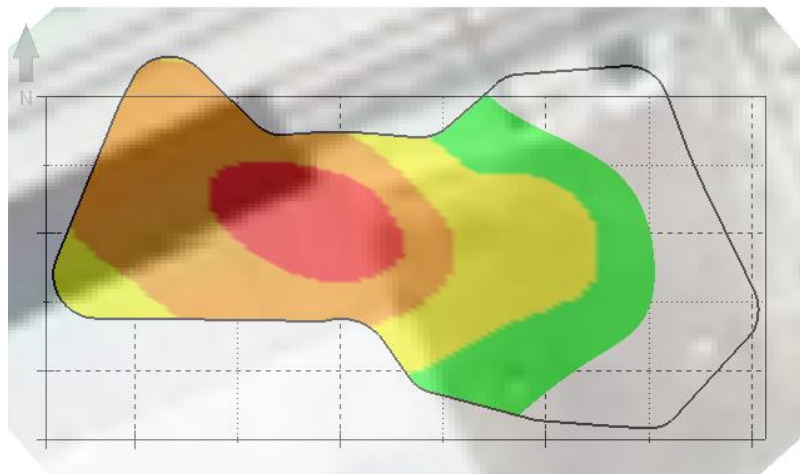


3DVA Chemical Visualization Confirmation

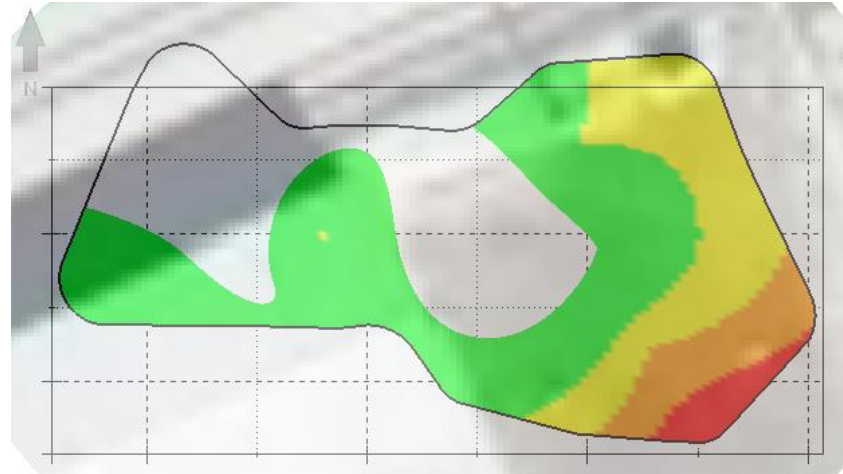


3DVA Chemical Visualization

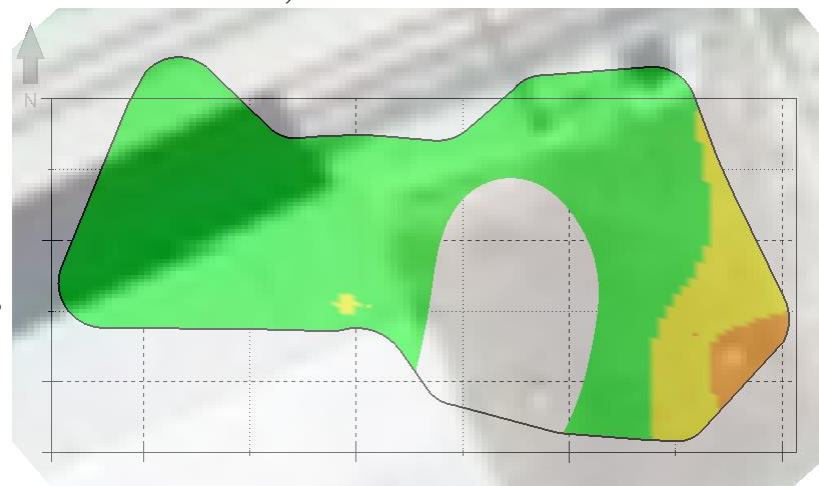
Vertical Slicing - 45 feet bls



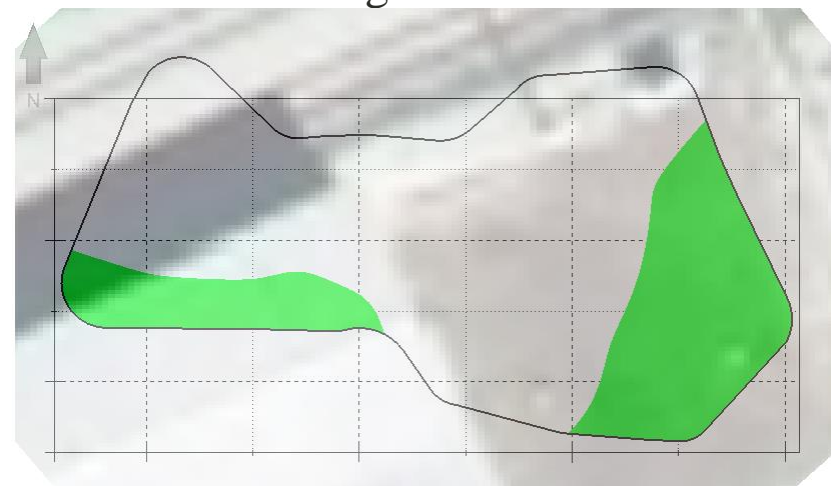
Baseline, November 2015



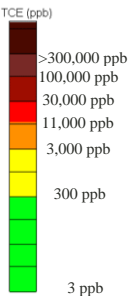
August 2016



November 2016

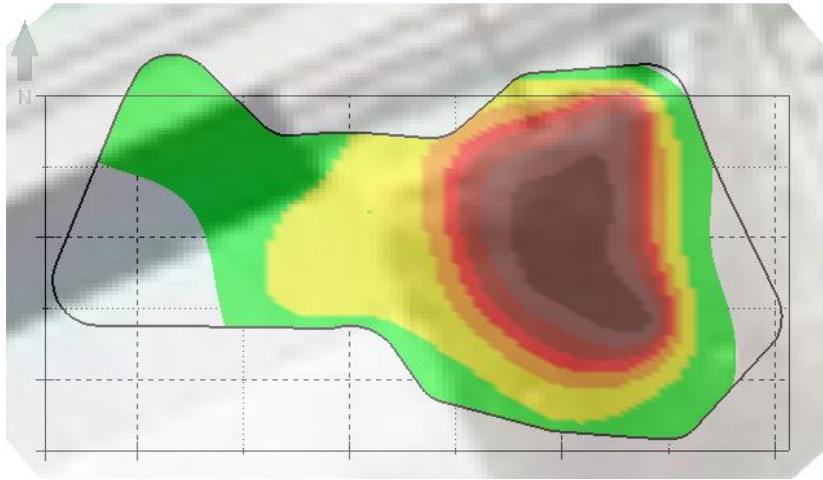


February 2017

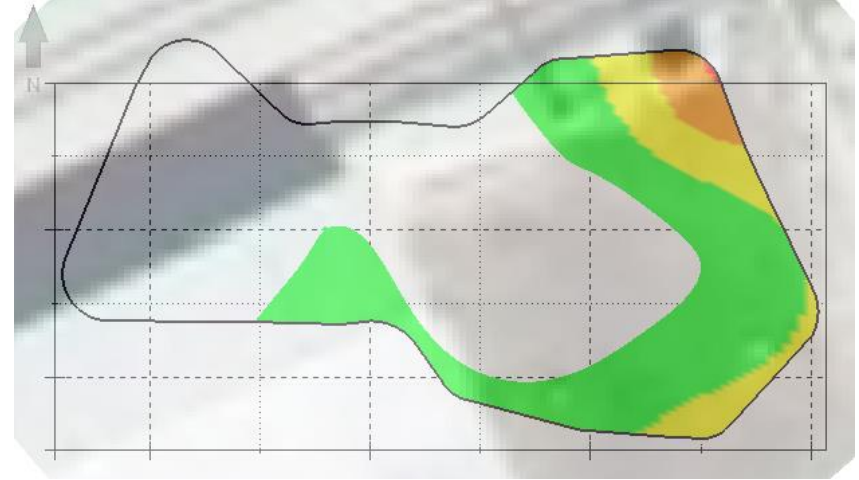


3DVA Chemical Visualization

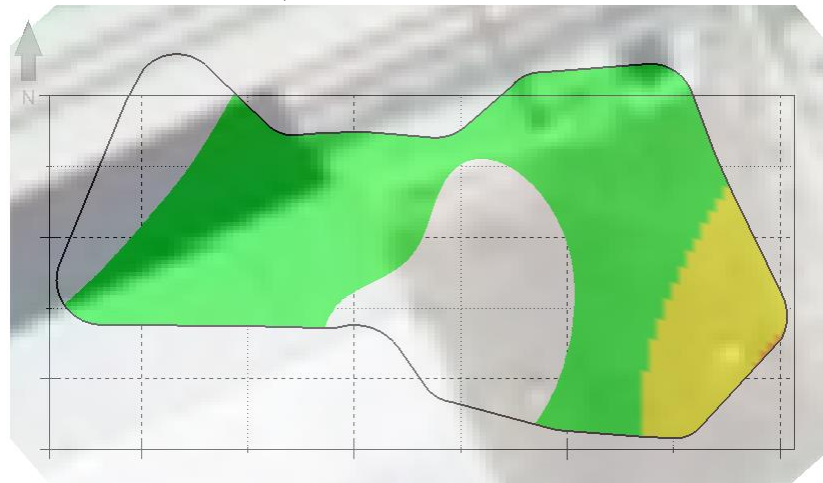
Vertical Slicing - 55 feet bls



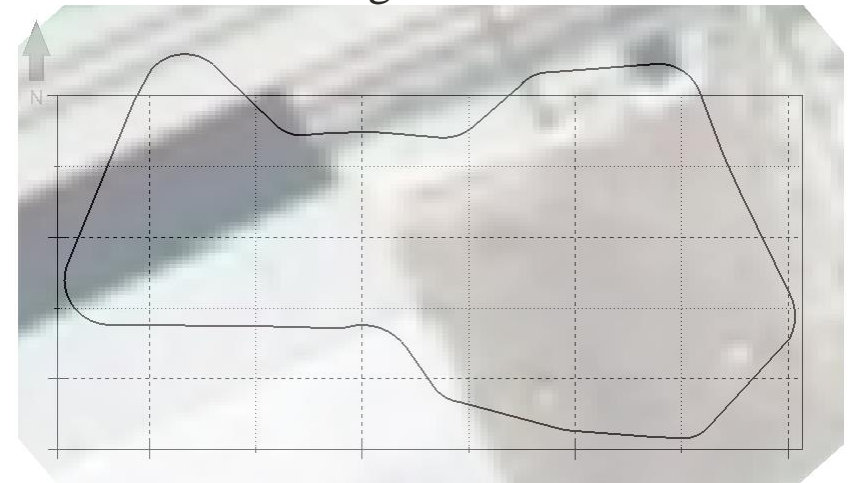
Baseline, November 2015



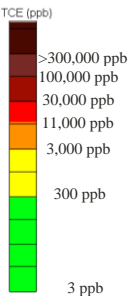
August 2016

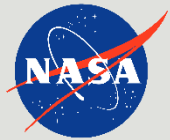


November 2016



February 2017





TCE Magnitude Reduction

Post-ERH TCE Concentration (µg/L)	Baseline TCE Concentration (µg/L)	% TCE Concentration Reduction	Magnitude Reduction $\text{Log}_{10} [C_f] - \text{Log}_{10} [C_i]$
4	203,000	99.998%	4.7
230	459,000	99.950%	3.3
27	383,000	99.993%	4.2
130	1,430,000	99.991%	4.0
270	443,000	99.939%	3.2
2	241,000	99.999%	5.1
1	116,000	99.999%	5.1
50	68,800	99.927%	3.1
130	37,200	99.651%	2.5
24	8,600	99.721%	2.6
27	40,000	99.933%	3.2

Average % Reduction (of >100 ppm baseline locations): 99.981%

Average % Reduction (of <100 ppm baseline locations): 99.808%

Average % Reduction (overall): 99.918%



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Take home messages:

- Discrete sampling proved a valuable tool in heterogenous settings; approaches to reduce downtime recommended (e.g., 2 crews)
- Potential need for compatible multi-port permanent monitoring systems
- Always screen performance monitoring methods; MWs not always a fit in source-zone/thermal remedies
- Repeated data visualization – a compelling optimization tool
- Performance guarantees - a valuable tool in thermal applications





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Thank you and Q&A

Acknowledgements:

NASA, Kennedy Space Center

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TRS Group, Inc.

- C. Thomas, D. Oberle, T. Warner, D. Fleming

D4

5 ft	99.0 °C
10 ft	105.8 °C
15 ft	110.5 °C
20 ft	110.7 °C
25 ft	114.3 °C
30 ft	114.9 °C
35 ft	115.5 °C
40 ft	101.3 °C
45 ft	119.8 °C
50 ft	126.8 °C
55 ft	122.0 °C
60 ft	125.4 °C

E3

5 ft	98.5 °C
10 ft	103.1 °C
15 ft	108.9 °C
20 ft	112.9 °C
25 ft	115.1 °C
30 ft	117.7 °C
35 ft	119.4 °C
40 ft	122.3 °C
45 ft	123.0 °C
50 ft	125.1 °C
55 ft	128.7 °C
60 ft	119.1 °C

F

5 ft	
10 ft	
15 ft	
20 ft	
25 ft	
30 ft	
35 ft	
40 ft	
45 ft	
50 ft	
55 ft	
60 ft	

anta:

vacuum: -2.00 PSia

Temp "Condenser IN": 80.6°C

Temp "Condenser OUT": 36.6°C

Blower OUT Data:

Manifold Temp:

Manifold Pressure: 2

Humidity:

Air Flow: