A photograph of a field site where a worker in a yellow hard hat and orange safety vest is kneeling to review documents. In the background, another worker in a green shirt is operating a red piece of industrial equipment. The scene is outdoors with trees and a concrete structure.

HEATED WATER RECIRCULATION TO ENHANCE IN-SITU ABIOTIC AND BIOTIC DEGRADATION

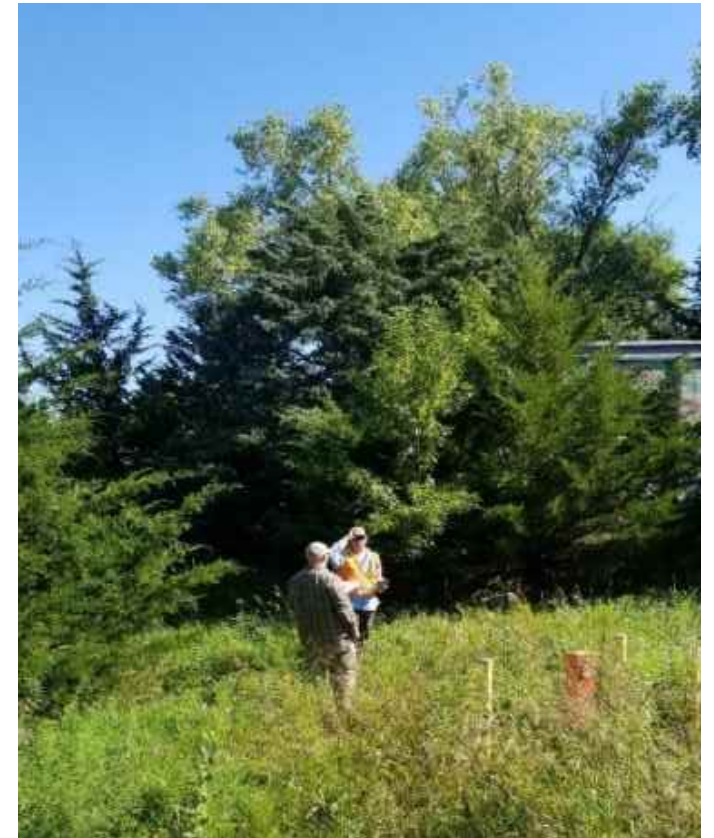
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BATTELLE BIOSYMPIOSIUM 2023



ACKNOWLEDGEMENT OF PROJECT TEAM

- USACE – Mark Mercier (PM), Andrea Sansom (Chemist), Nick Geibel (Geo.), Quang Le (Eng.), Marissa Lucento (Risk), Molly Maxwell (EM CX)
- EGC, Inc. (Prime) – Scott Quint, Rene Hefner
- Trihydro – A. Hoyt, A. Vann, C. Carlson, M. Olson, T. Speckmann, Many Others
- SiREM – P. Dennis, X. Druar, M. Healey
- Buhr Electric, H2K Technologies, Peterson Drilling, Remington Technologies



SITE HISTORY

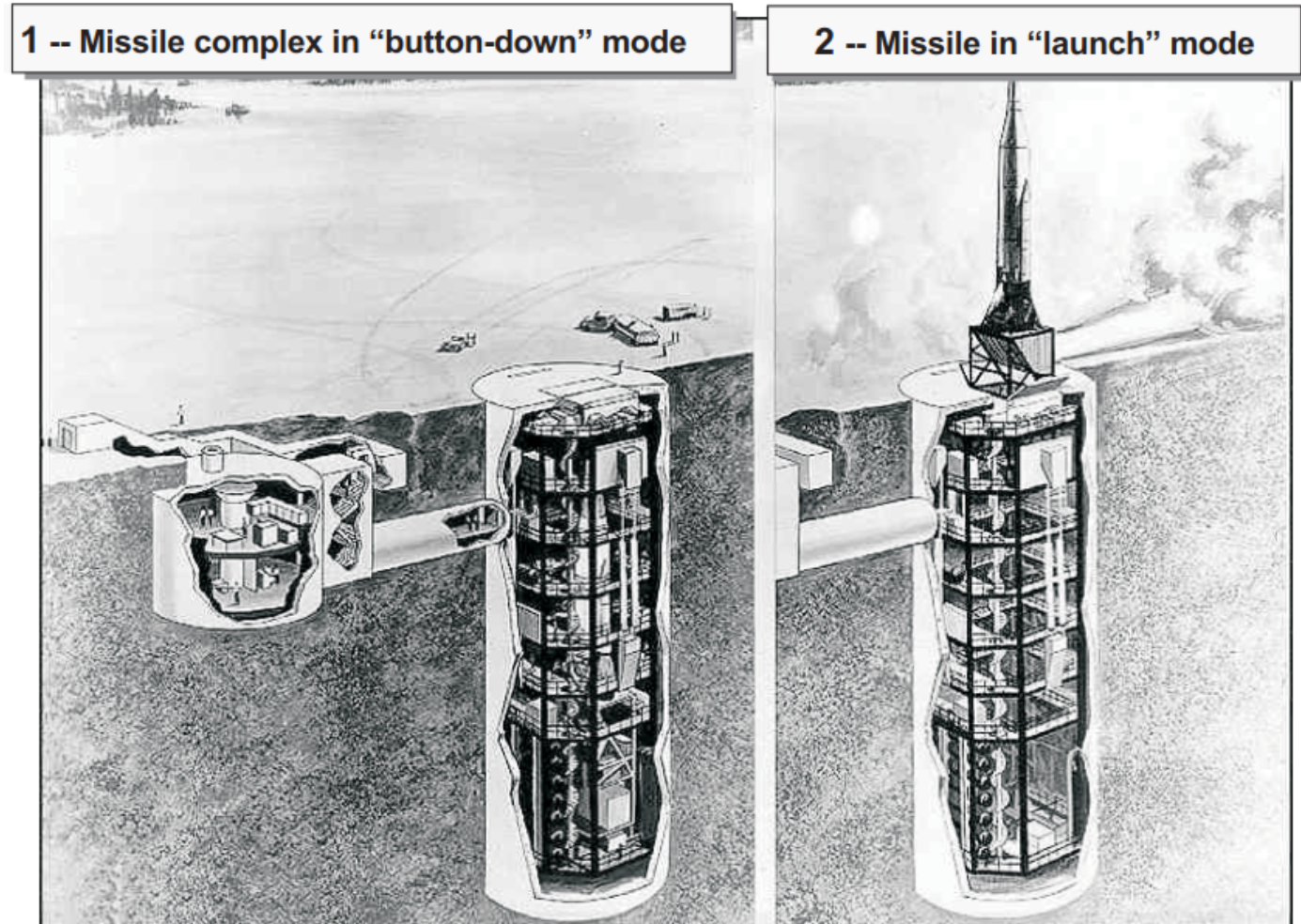
- Atlas type “F”
- Near Lincoln, NE
- 170-ft deep silo for 82-ft tall liquid-fueled rocket
- Subgrade launch control center (LCC)
- Quonset huts for crew
- Leach field



Atlas F site in Willow, OK, photo provided by M. Maxwell

SITE BACKGROUND

- Currently privately-owned
- TCE present in groundwater from commissioning/training/testing
- USACE manages legacy impacts through Formerly Used Defense Sites (FUDS) program



Graphic from USACE 2009 RI

REGULATORY HISTORY

- 2009 RI
- 2010 FS
- 2015 ISB Pilot Test
- 2016 Decision Document
 - Monitored Natural Attenuation (MNA)
 - “Potential addition of amendments and/or microbial consortiums to optimize”
 - Aquifer Use Watch Area



Photo not from Site 7 nor from Nebraska

REMEDIAL ACTIVITIES

- 2008 Begin groundwater monitoring during RI
- 2015 ISEB Pilot Test
 - Injection at 32 injection wells screens, typically nested (pink)
 - 960,000 gallons of 1% emulsified vegetable oil (EVO)
 - Bioaugmentation culture
- 2016 Continued semiannual monitoring to track MNA

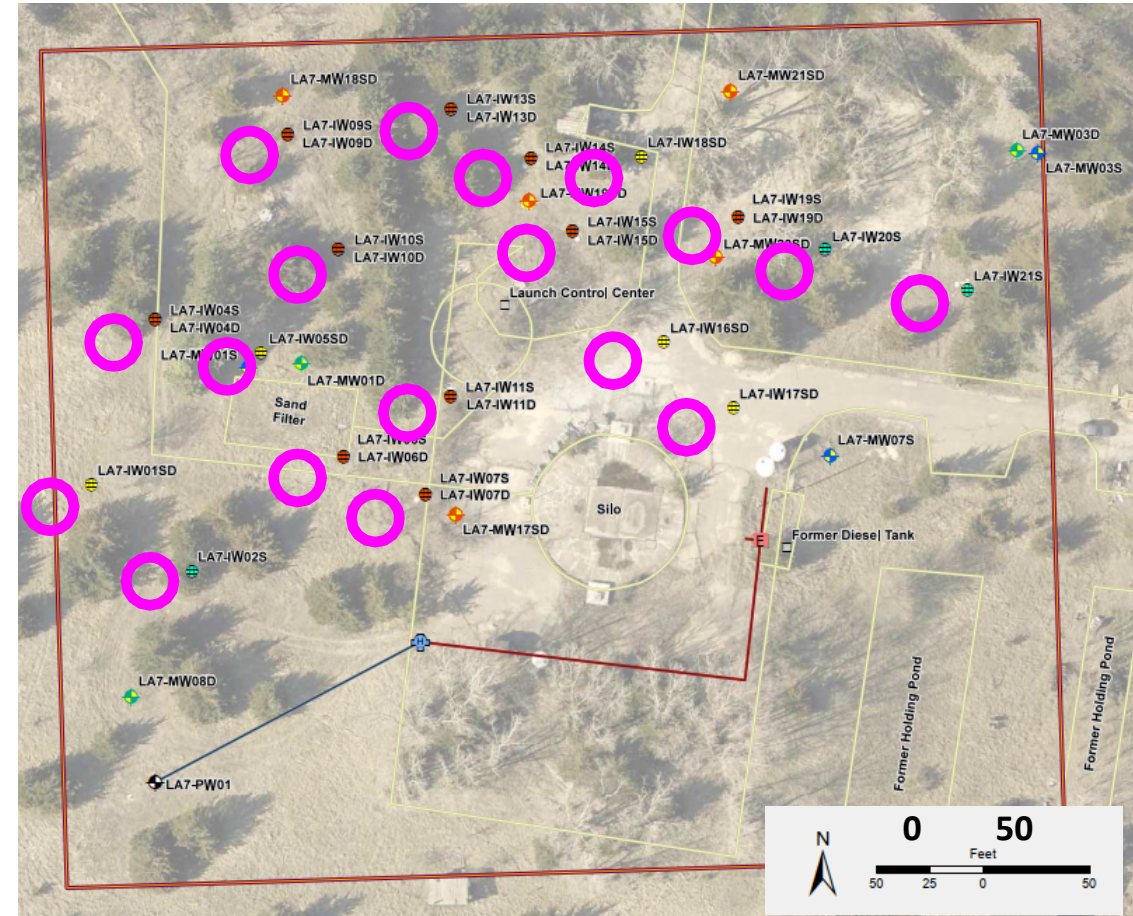


Figure modified from USACE 2018

OPTIMIZATION

- Pivot from passive MNA and injection-based ISEB
- 2019 Performance Work Statement to optimize MNA
 - Heating
 - Recirculation
 - ISEB Amendment
- Response Complete by Oct. 2023
 - 4 quarters of TCE below standard
- Site Closeout by Feb. 2024

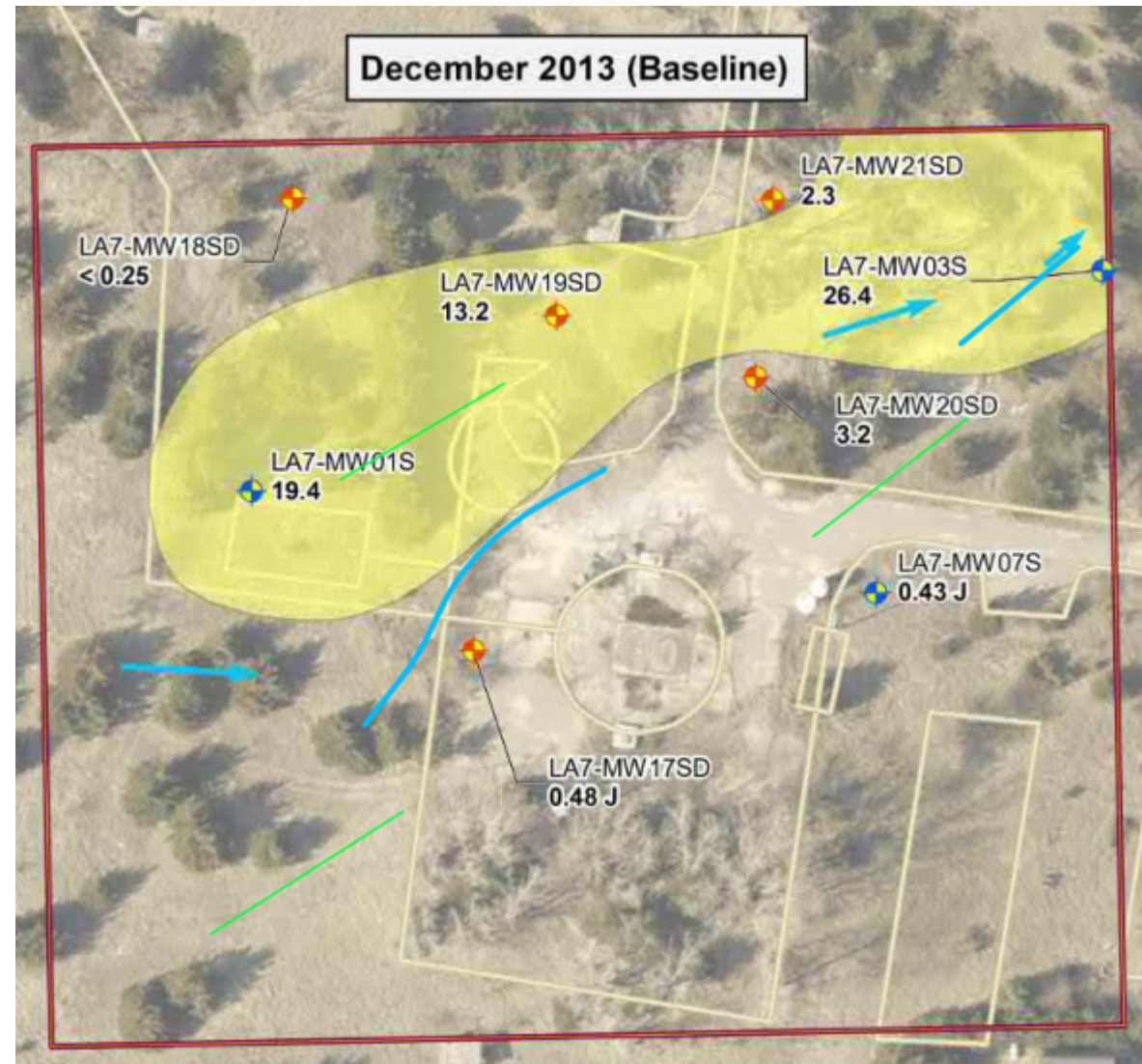


Photo not from Site 7 but from different site in Nebraska

SITE IMPACTS

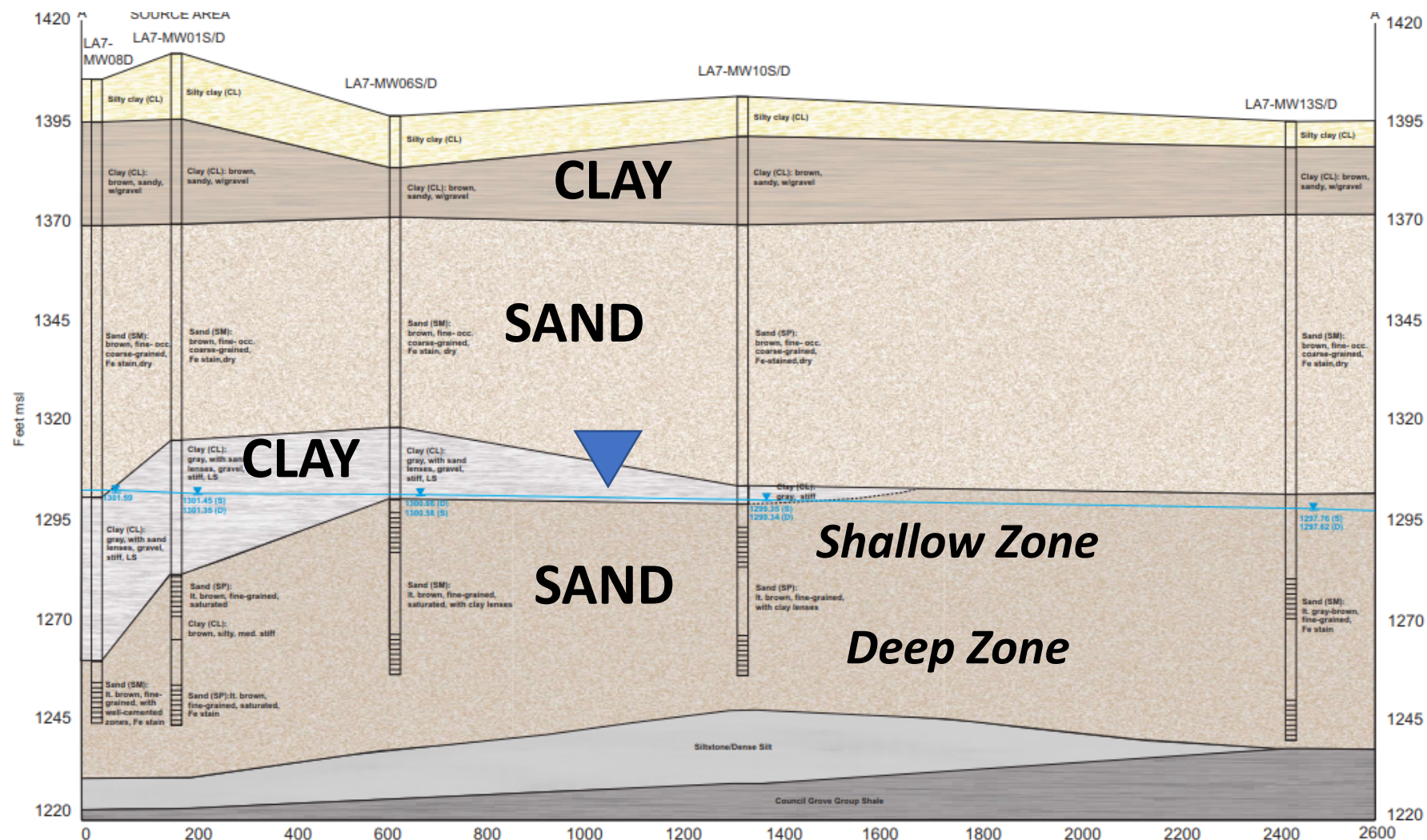
Silo Parcel Groundwater Upper End Concentrations

- TCE = 30 ug/L
- cis-DCE = 10 ug/L
- trans-DCE = 8 ug/L
- VC = non-detect to 0.5 ug/L
- Shallow and deep zones



SITE GEOLOGY / HYDROLOGY

- Sand
- Interbedded clay
- Flow to ENE
- $K = 11 \text{ ft/day}$
- Sat. thick. = 70 ft
- $T = 770 \text{ ft}^2/\text{day}$
- Seepage velocity = 30 to 60 ft/yr
- Pumping rates = 10 to 100 gpm



Cross Section from USACE 2009 RI

OUTLINE



- Introduction / Site Background
- Design
- Results
- Lessons Learned
 - Hot water injection / recirculation
 - Capture zone analysis
 - Heat transport modeling
 - ISEB amendment

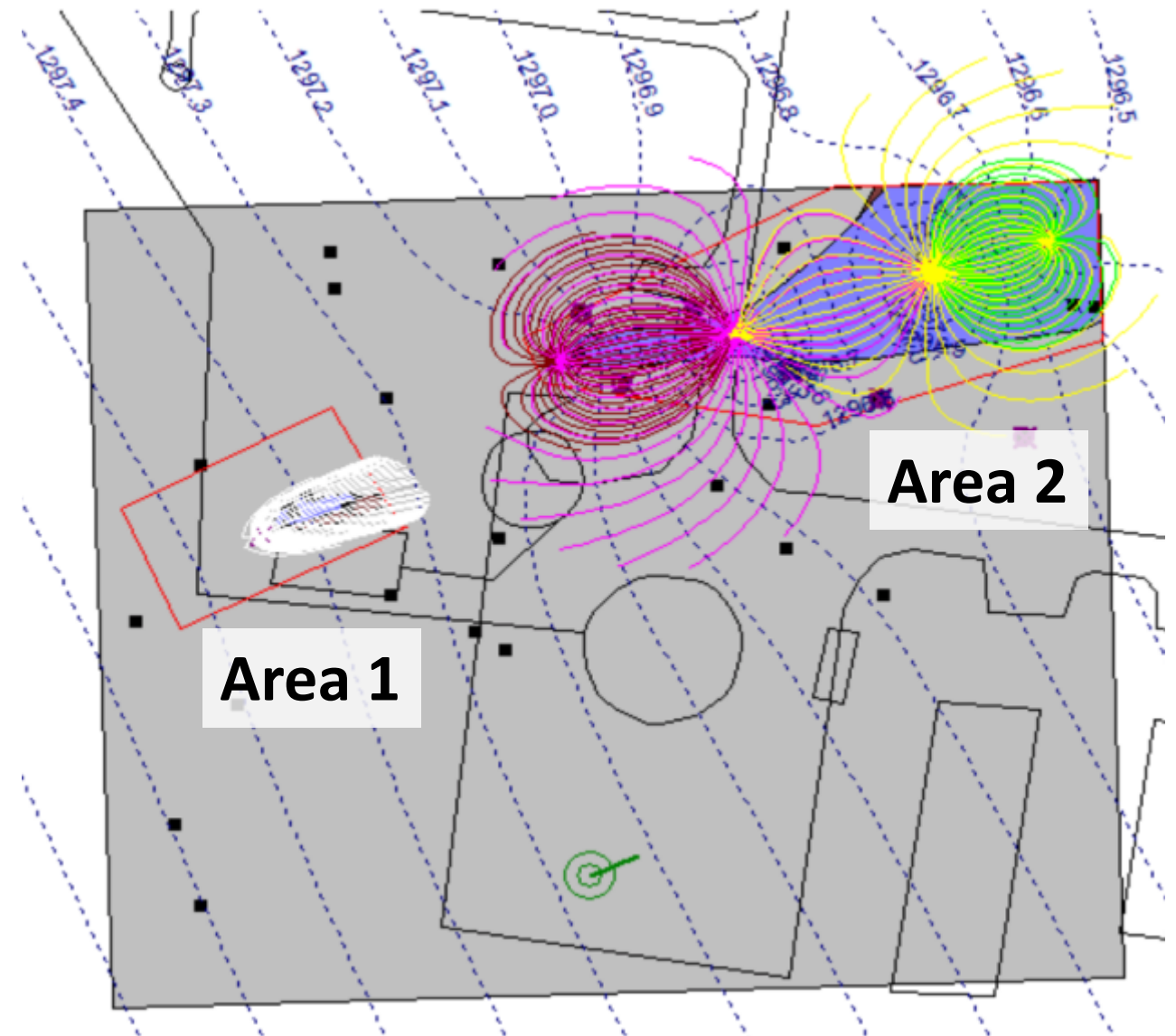
HOT WATER INJECTION / RECIRCULATION

- Physical replacement of TCE-impacted GW
- Hot water as heating medium
- Focus optimization on specific locations
 - TCE impacts
 - Silo Parcel



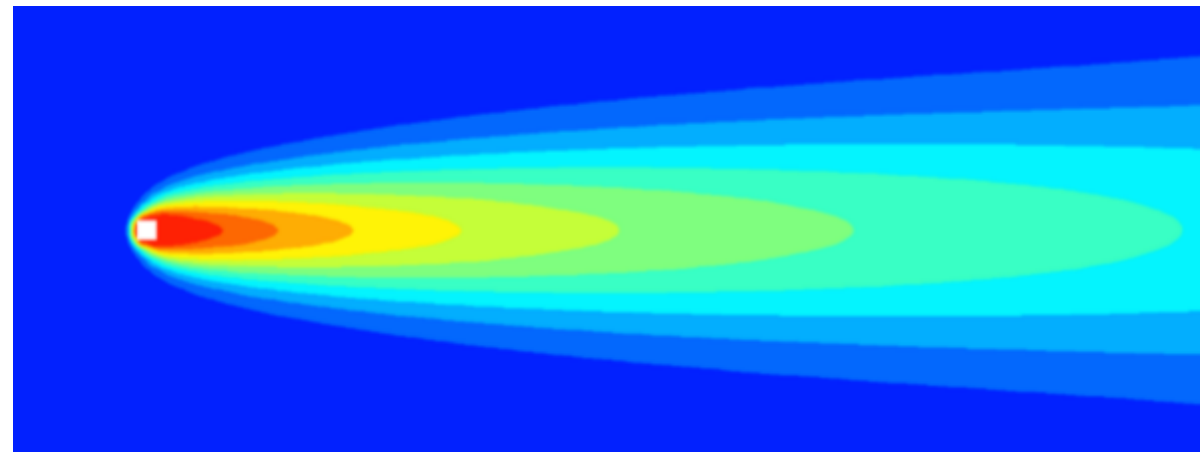
CAPTURE ZONE ANALYSIS

- Optimize well locations and flow rates
- USEPA's WhAEM model
 - Inputs: Hydraulic conductivity, gradient, saturated thickness, pumping rates
- Final Area 2 iteration shown at right



HEAT TRANSPORT MODEL

- Evaluate hot water injection
- USGS VS2DHI code

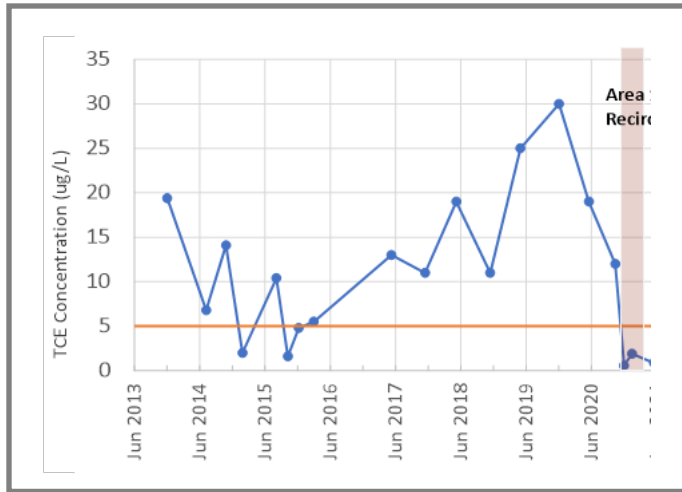


LAB BENCH TESTING

- Microcosms at 12°C and 27°C
- Microbial rates faster at higher temperature
 - 2x faster TCE
 - 4x faster sulfate
 - 4x faster methane
 - >4x faster VFAs*



Photos courtesy of SiREM



OUTLINE

- Introduction / Site Background

- Design

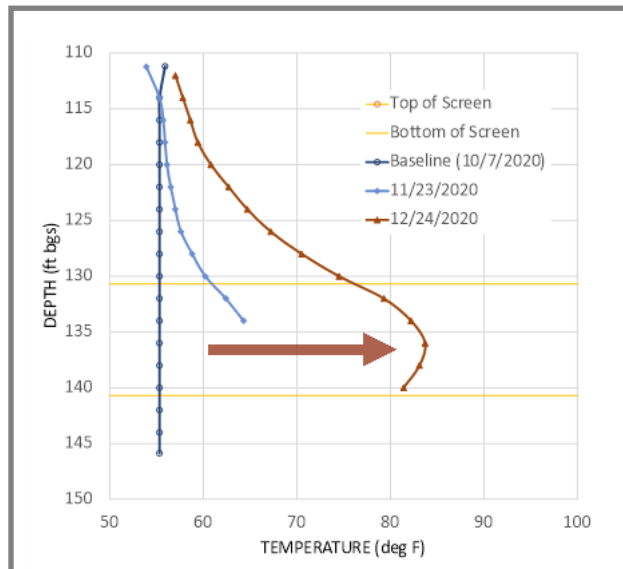
- **Results**

- Lessons Learned

- TCE treatment

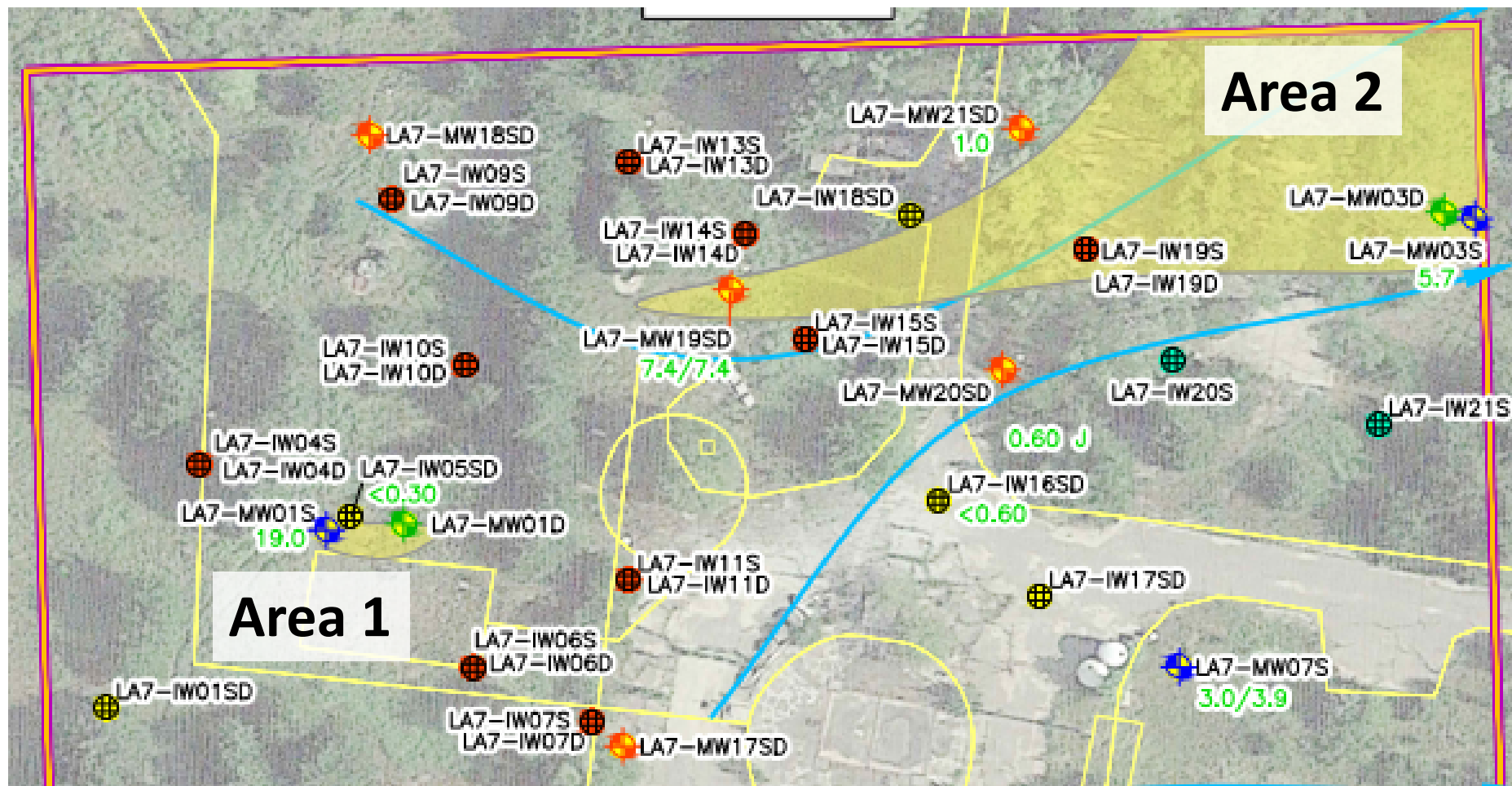
- Heat transport

- Microbial populations



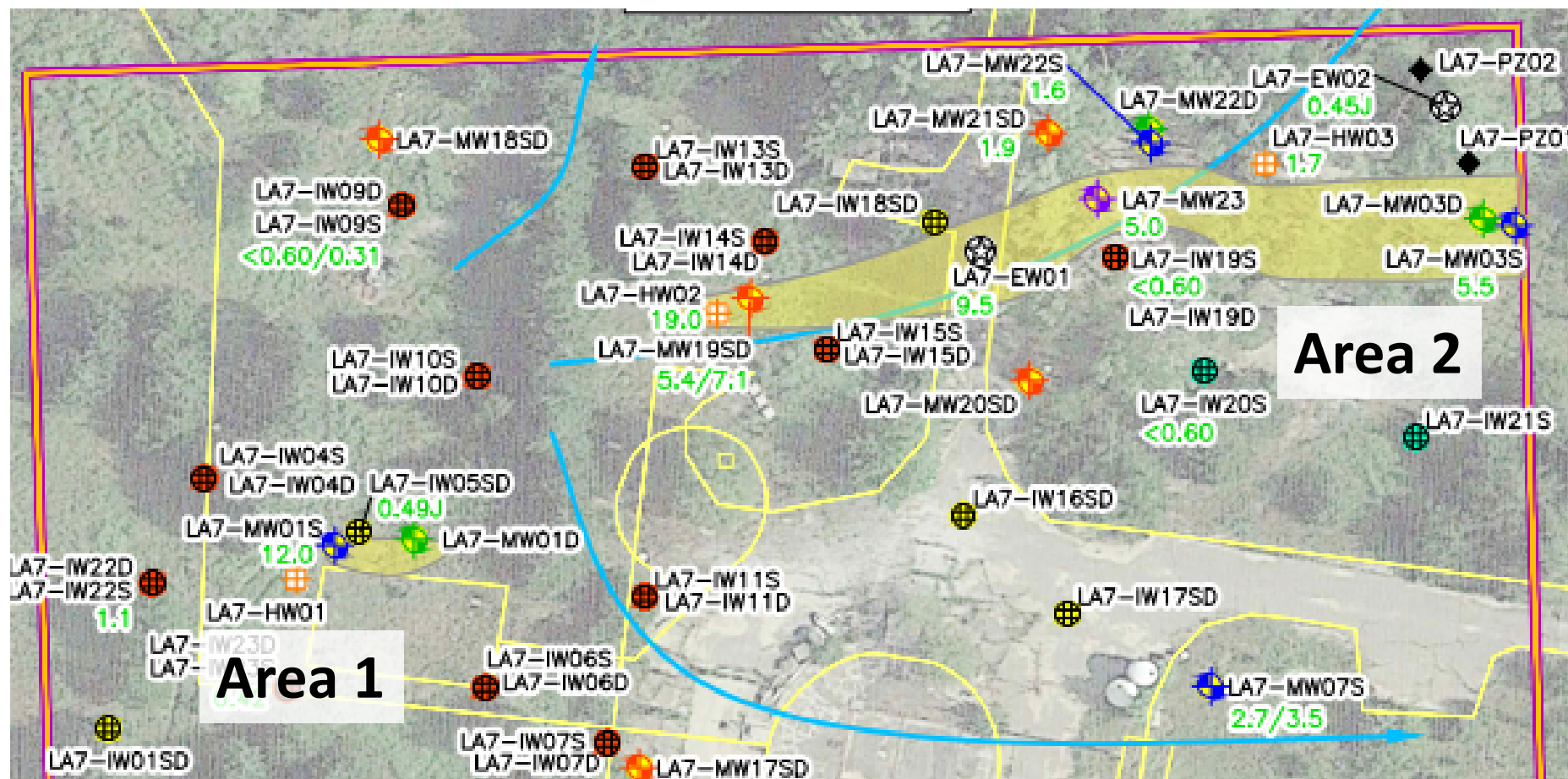
TCE – SITE-WIDE

May 2020
Before
Optimization



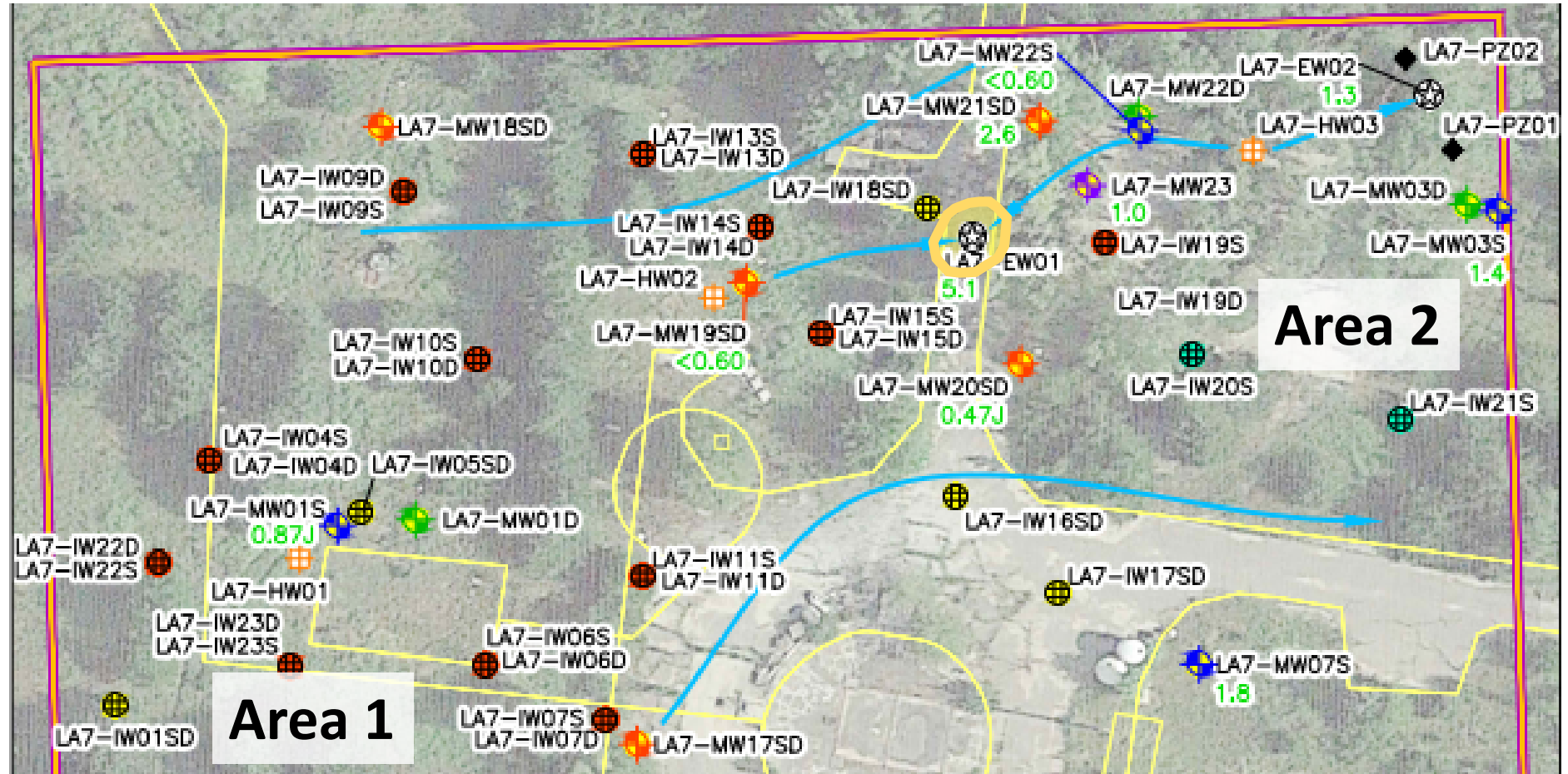
TCE - SITE-WIDE

October 2020
 Before
 Optimization
 More Wells



TCE – SITE-WIDE

May 2021
 After Area 1
 Recirculation
 and ISEB
 and ISEB
 4 Months Into
 Area 2
 Recirculation

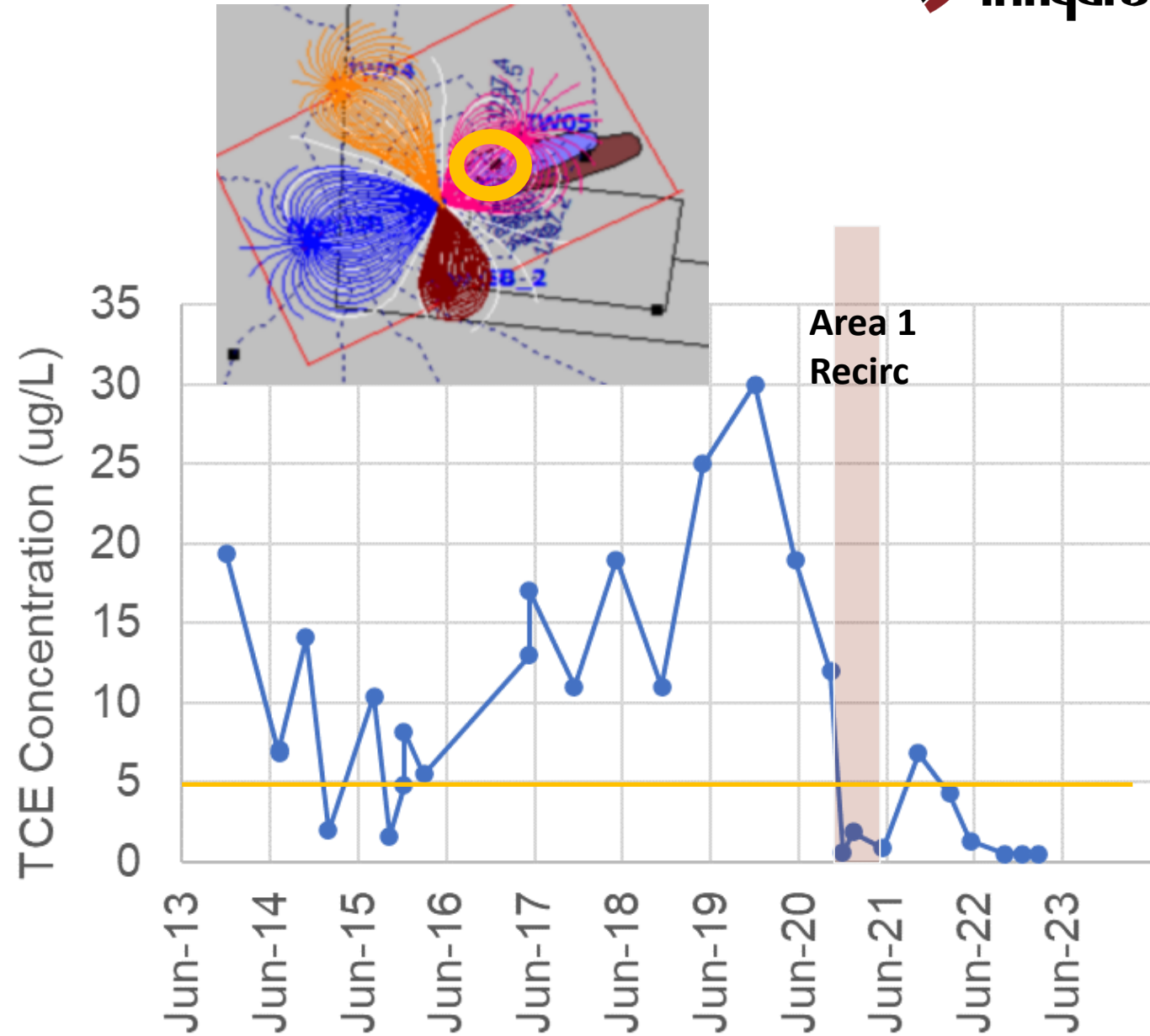
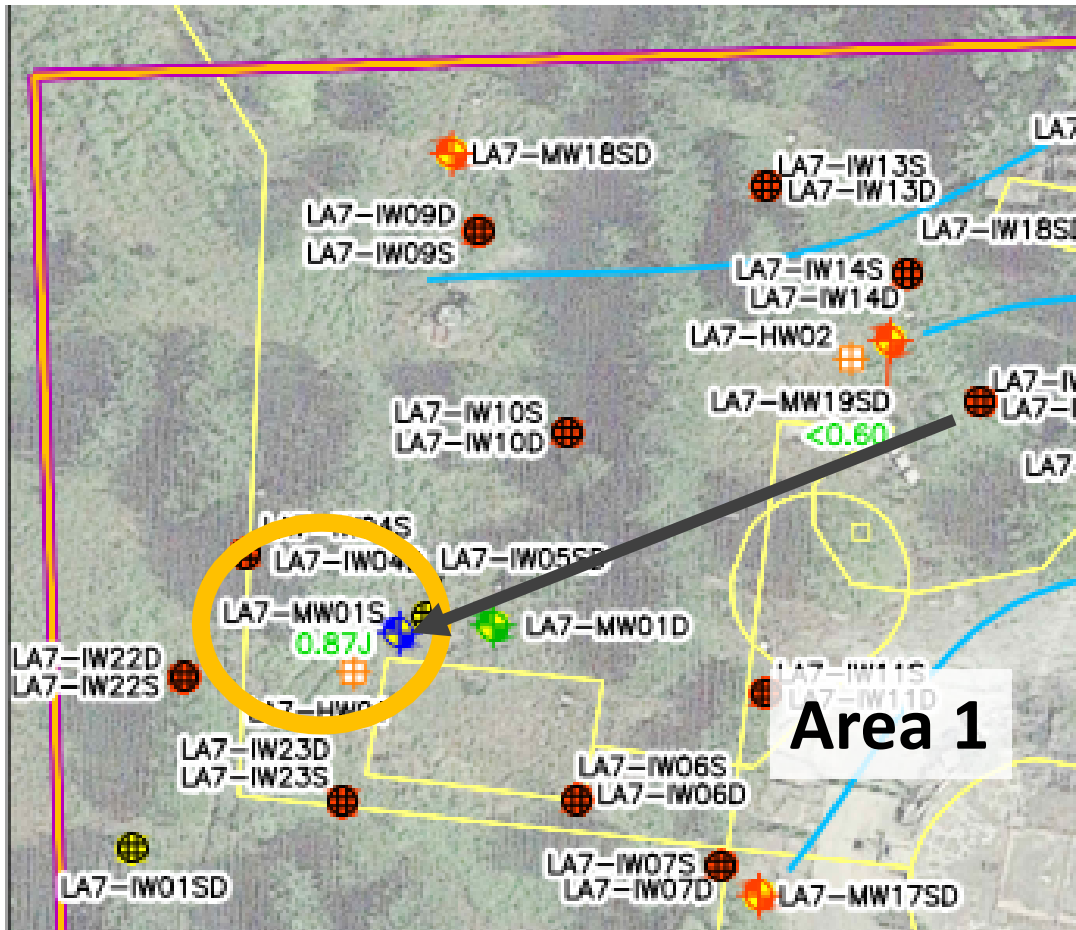


TCE – SITE-WIDE

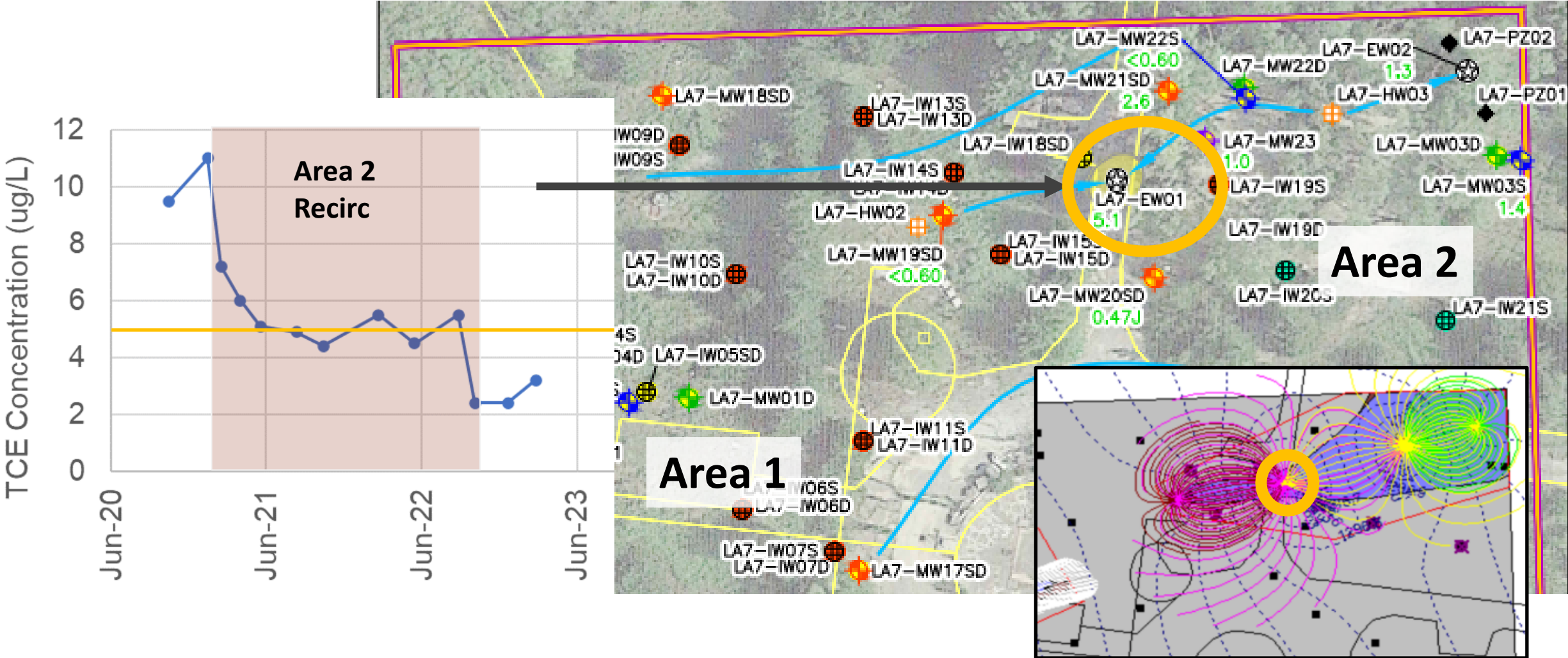
May 2022
 After Area 1
 Recirculation
 and ISEB
 and ISEB
 16 Months
 Into Area 2
 Recirculation



TCE - MW01S

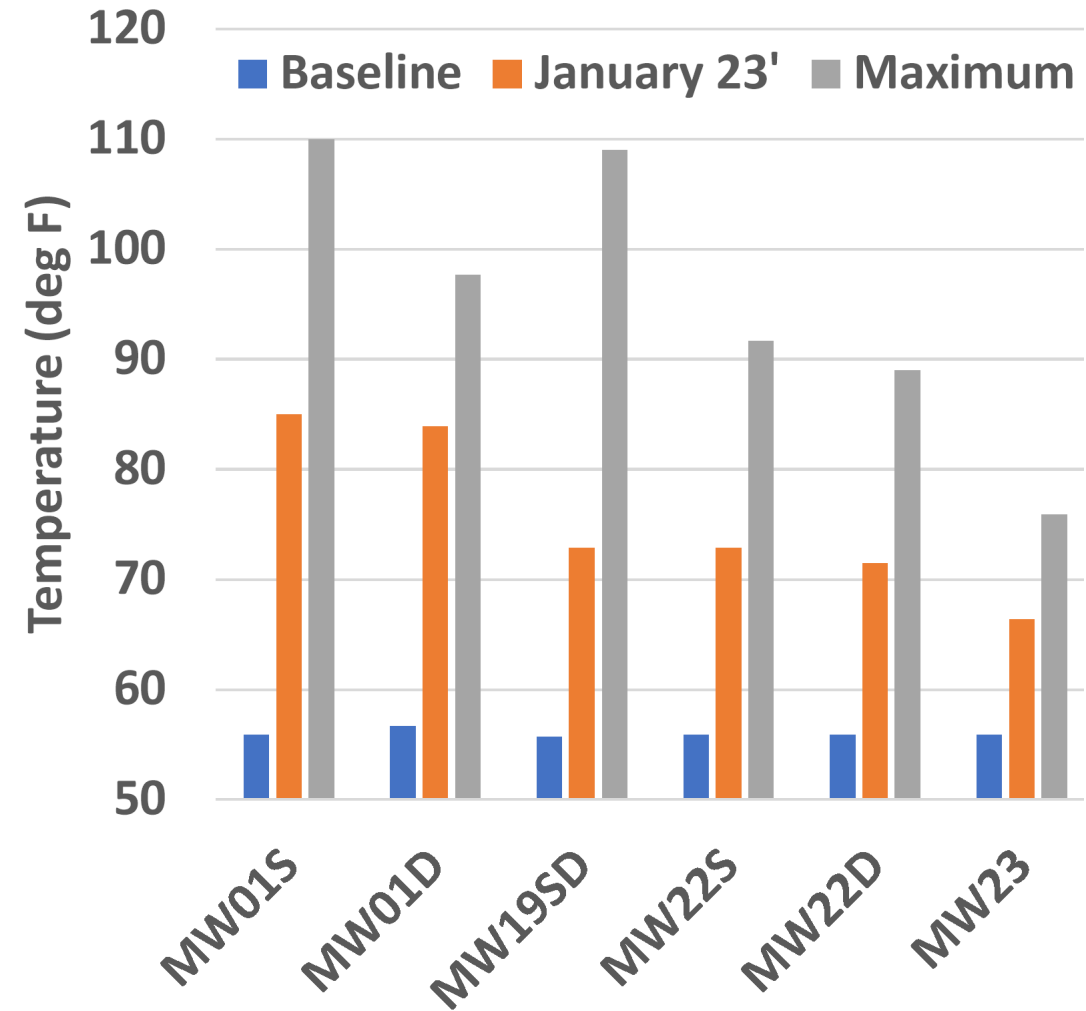


TCE - EW01



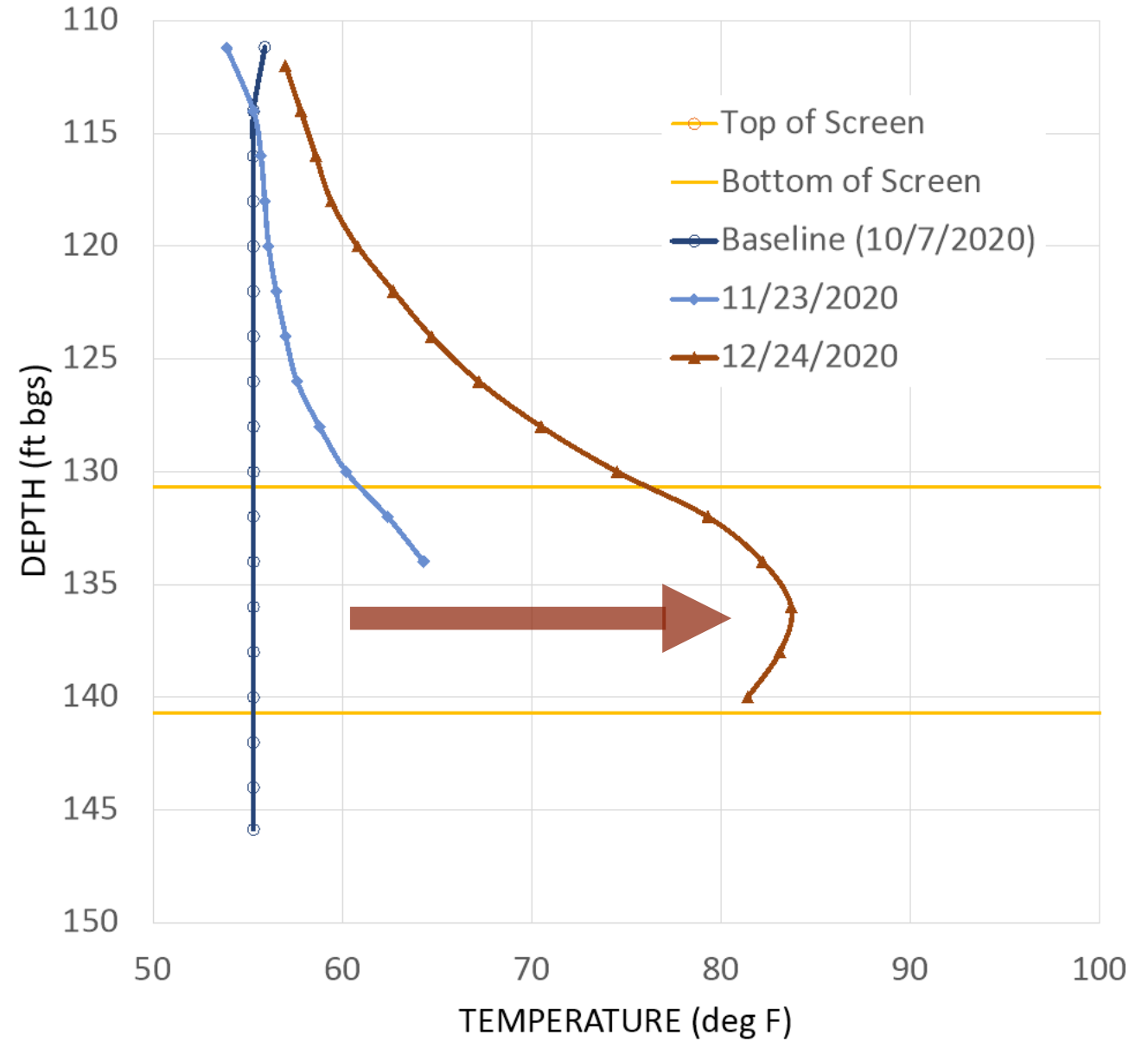
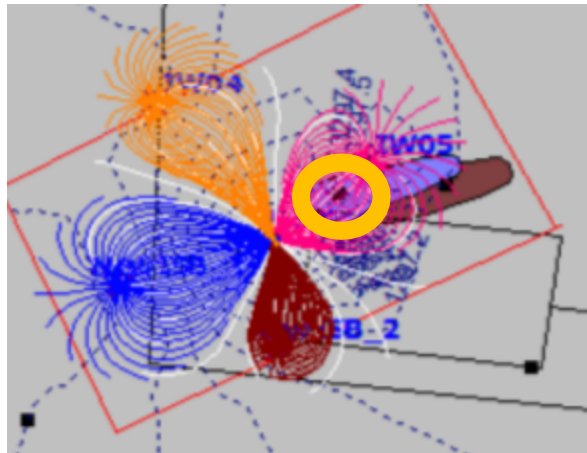
HEATING

- Consistent 56 F at baseline
- Rapid increase Area 1 (MW01S, MW01D)
- Slower, steady increase Area 2 (MW19SD to MW23)



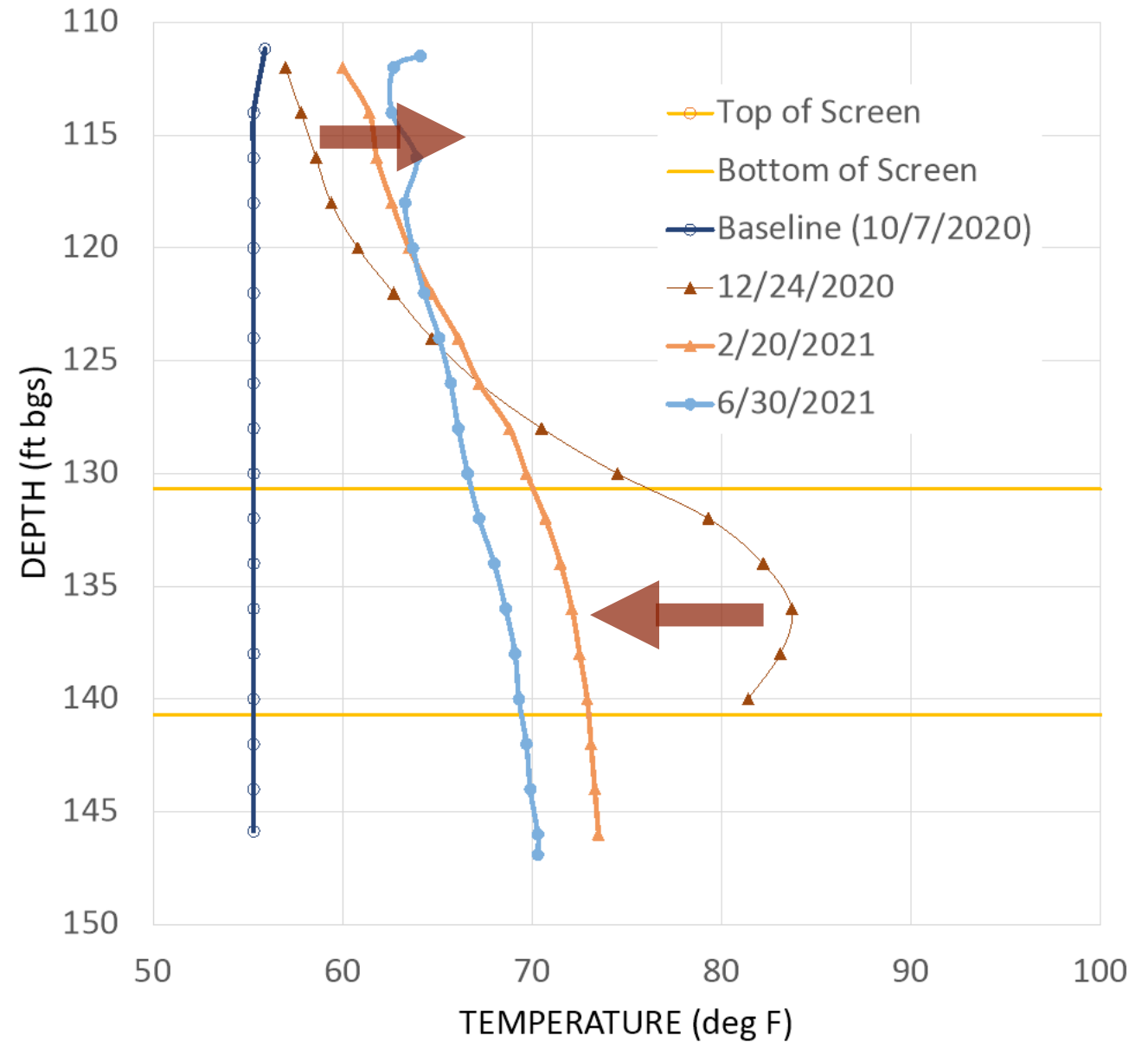
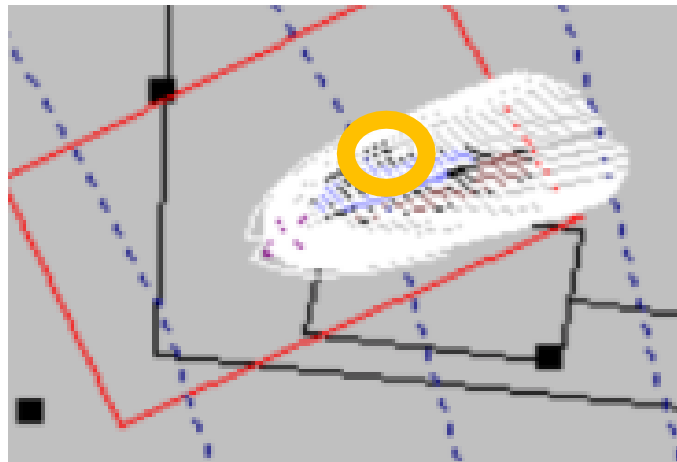
HEATING - MW01S

- Area 1 recirculation temperature increase to 85F



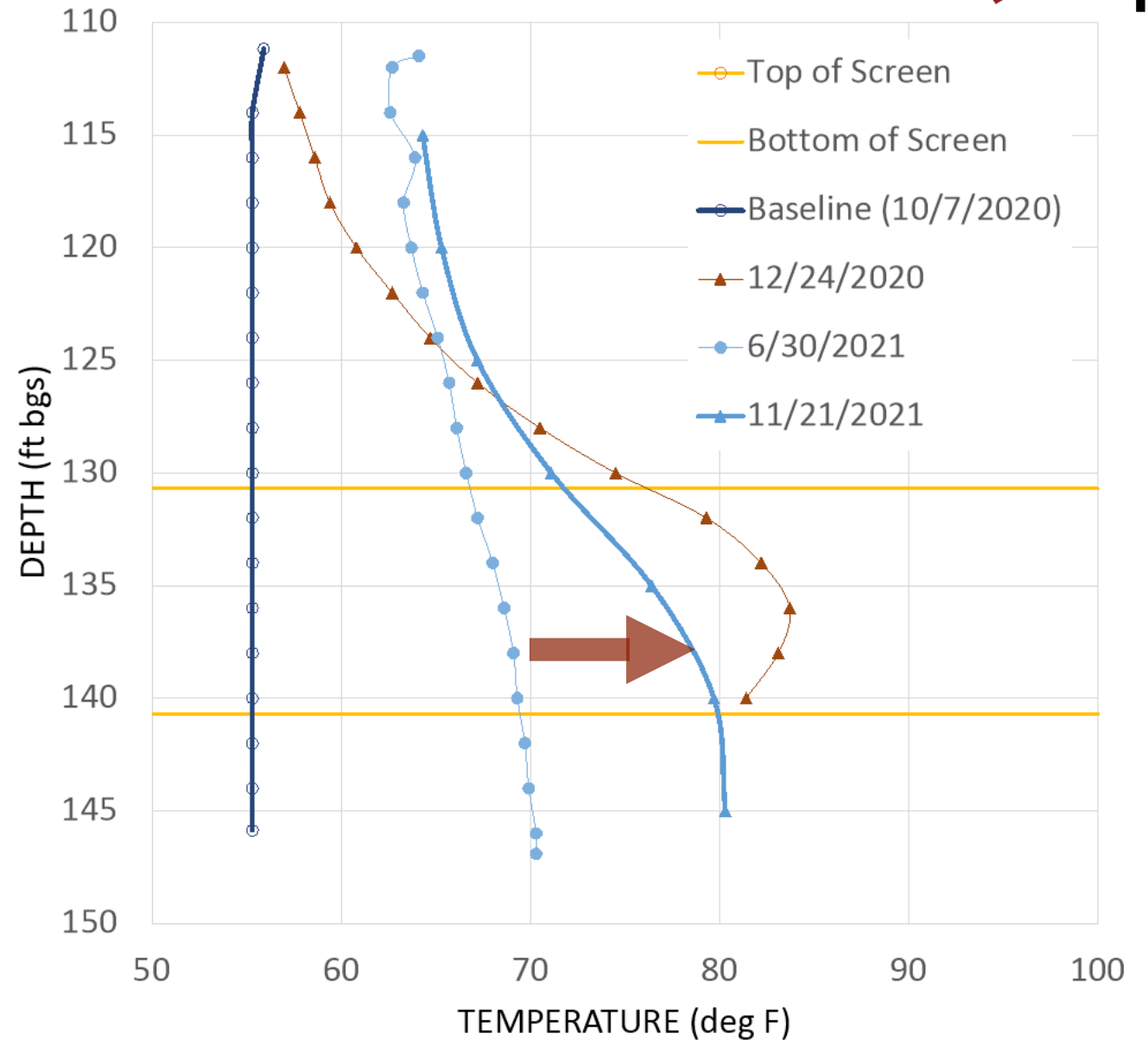
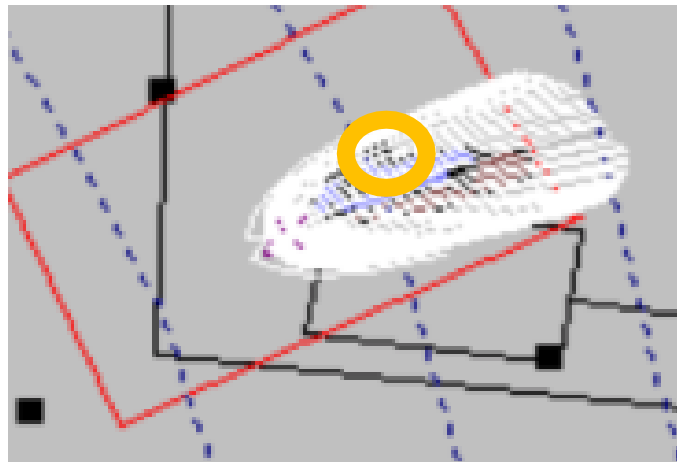
HEATING - MW01S

- Area 1 passive 0.5 gpm hot water injection



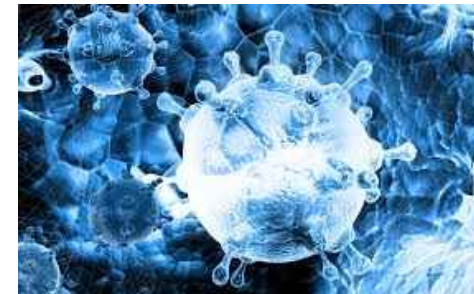
HEATING - MW01S

- Area 1 less passive 2.3 gpm hot water injection



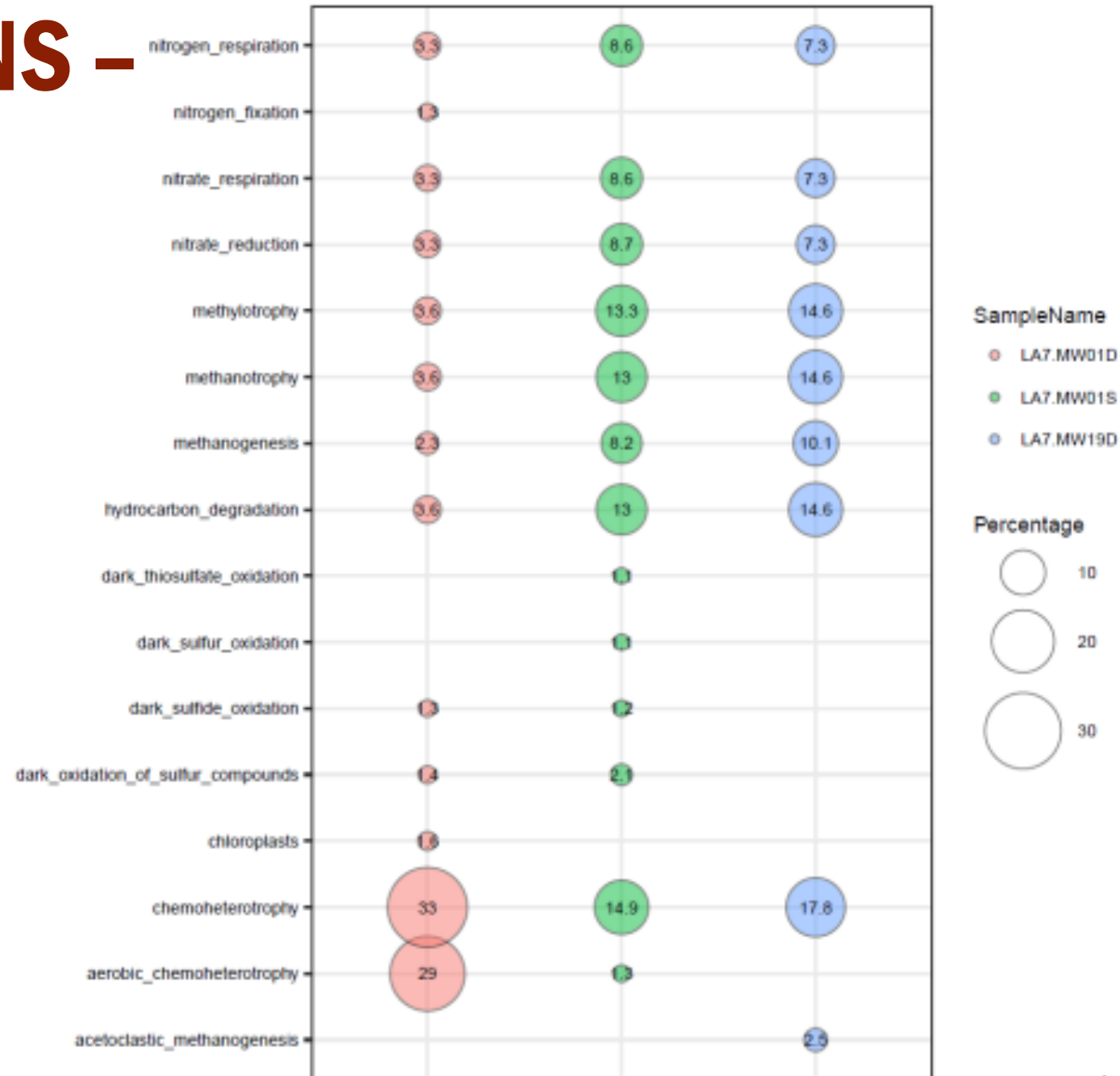
MICROBIAL POPULATIONS - qPCR

- *Dehalococcoides* – typically non-detect
- *Dehalobacter* – non-detect
- *Geobacter* – detected in most locations



MICROBIAL POPULATIONS – NEXT GEN SEQUENCING

- Dechlorinators other than *Dehalococcoides* detected-
Geobacter Dehalogenimonas
- Methanogenesis/
methanotrophy dominant
processes
- Residual effects of 2015
biostimulation?



CONCLUSIONS

- Recirculation of hot water effective for heat delivery and TCE removal
- Higher temperatures stimulate microbial processes
- Optimization of MNA on track for Response Complete in 2023



QUESTIONS / DISCUSSION

WHAT

WHY

WHERE

WHEN

WHO

HOW

CONTACT INFORMATION



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