



Colloidal Zero-Valent Iron Injection and Low-Temperature Thermal for Enhanced Biotic/Abiotic Degradation of TCE DNAPL Source

Erin Waibel and Clint Jacob, June 2024

Outline:

- General Approach
- Project Overview
- Bio with Abiotic Enhancement
- Low-Temperature Thermal
- pH Buffering
- Effectiveness



General Approach

// Biotic + Abiotic

Biodegradation:

- ▲ EVO as electron donor

Chemical Degradation:

- ▲ Reactive iron (ferrous sulfate or zero-valent)

// Low-Temp Thermal and pH Buffering

- ▲ Arrhenius equation

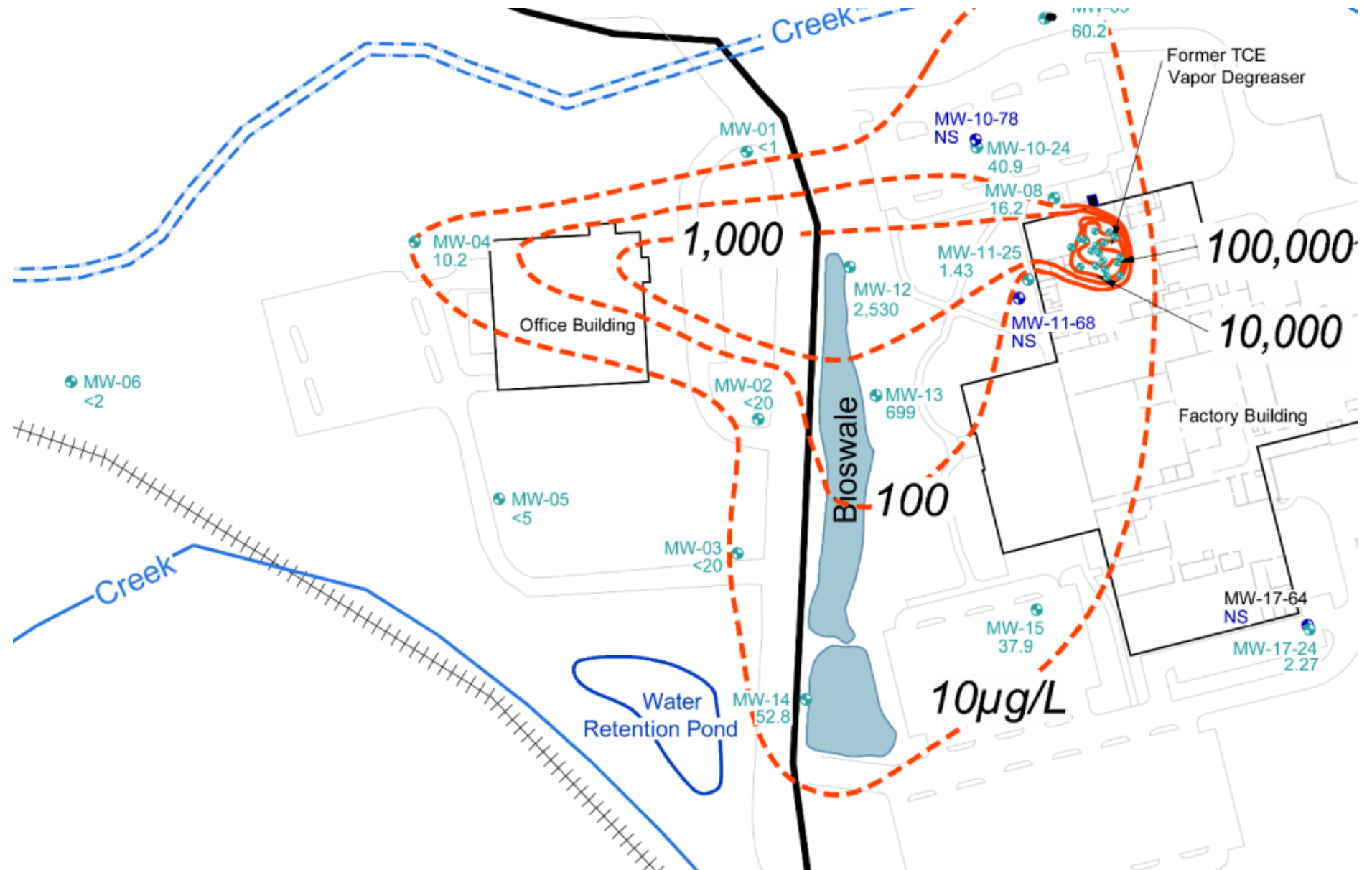
- ▲ *For every 10°C increase in temperature, approx. doubling biological and chemical reaction rates*

- ▲ *Dehalococcoides* sp. (DHC) sensitive to low pH

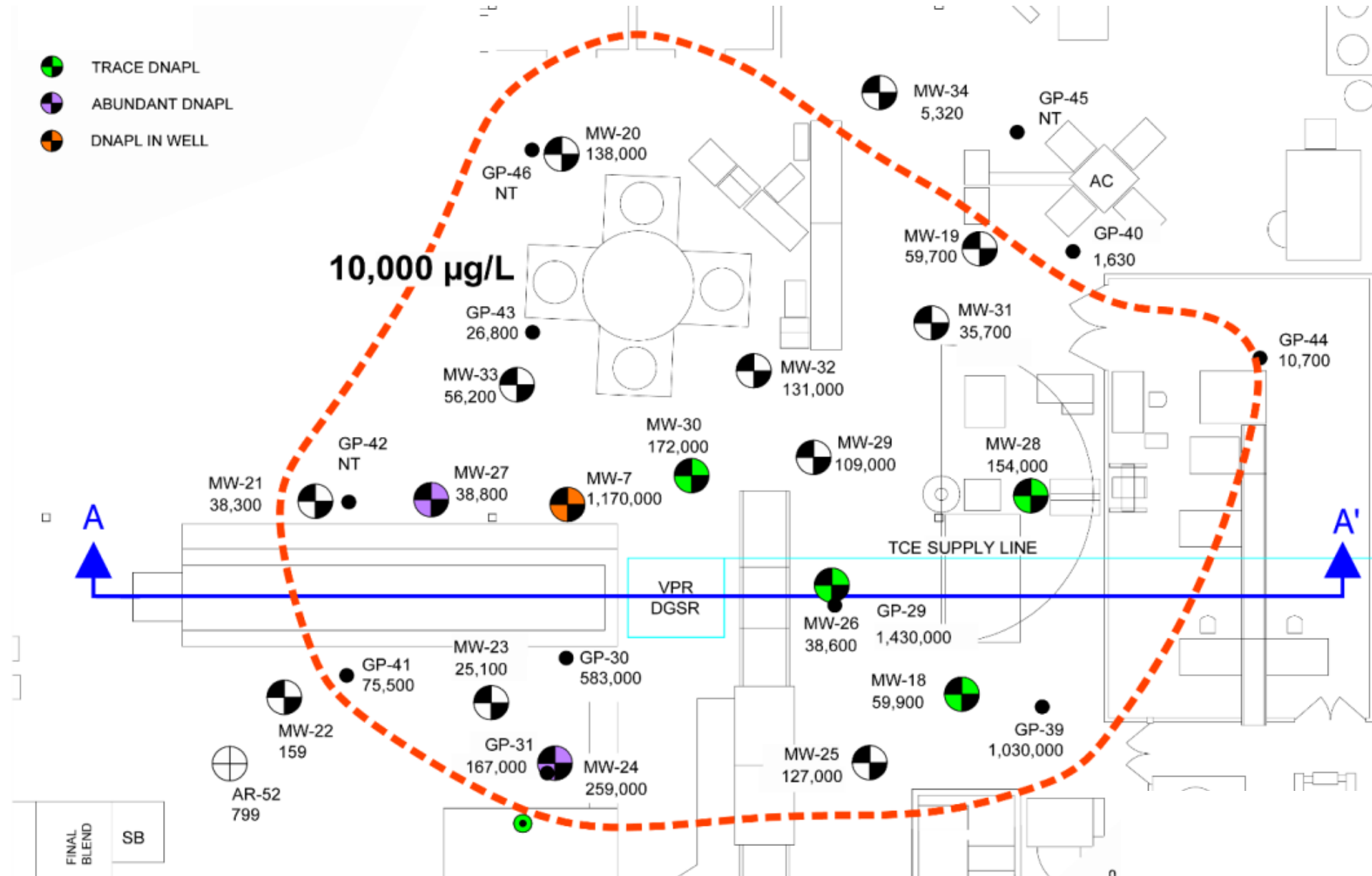
- ▲ *Prefers 6-8, but not less than 5.5*

Project Overview

// The Problem

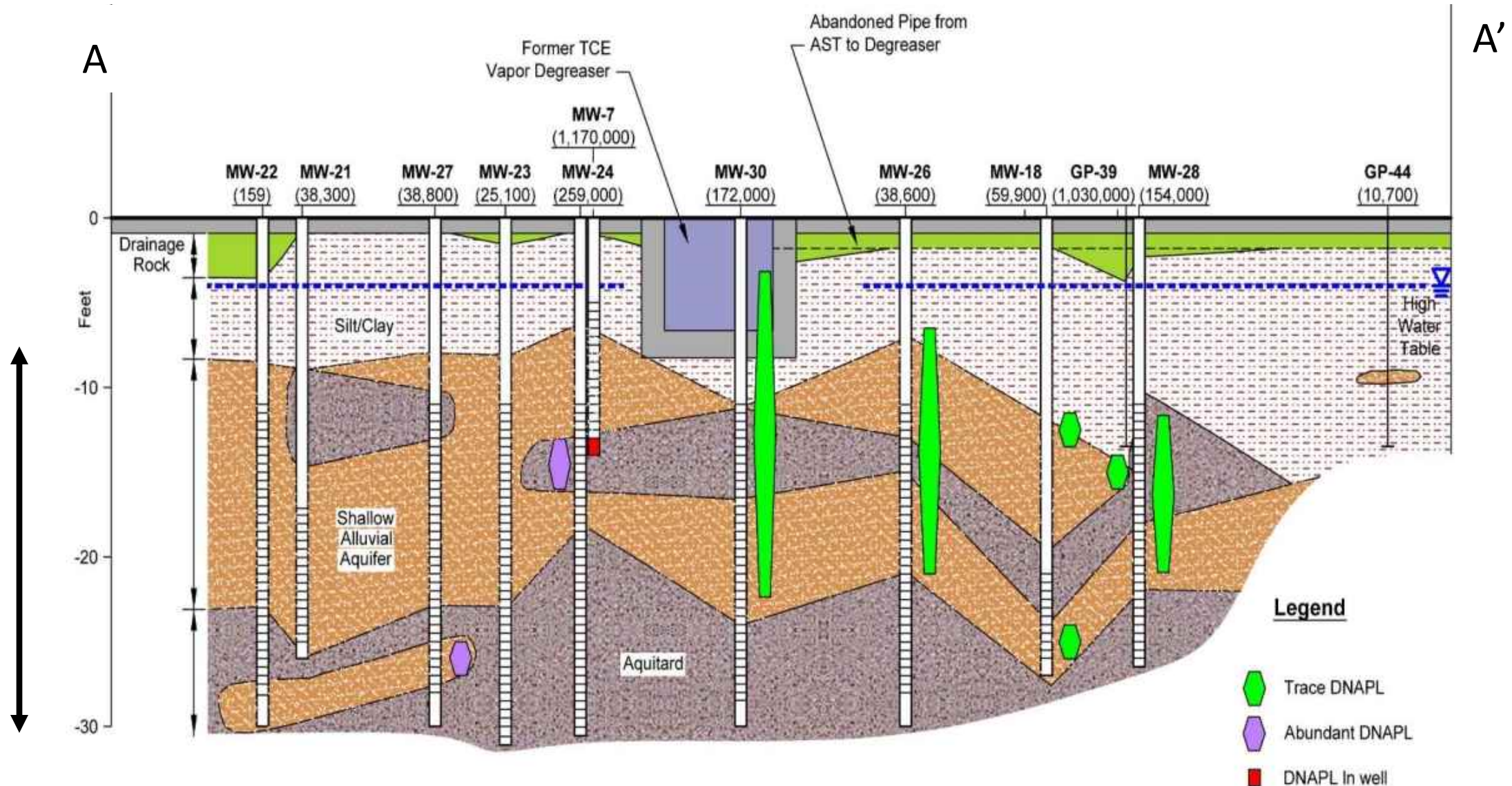


// The Problem



// The Problem

Target:
8-30'

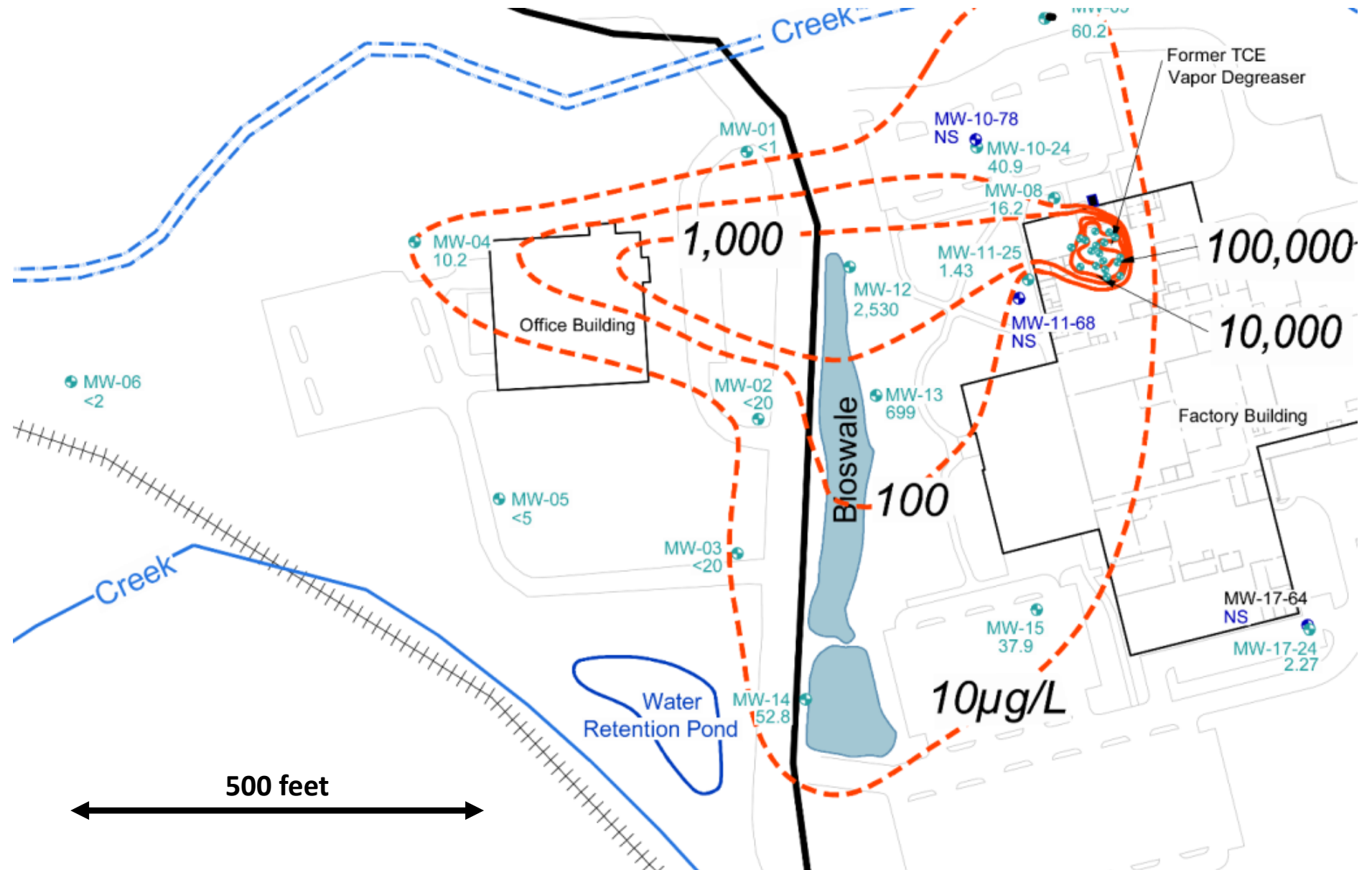


// Bioremediation Approach

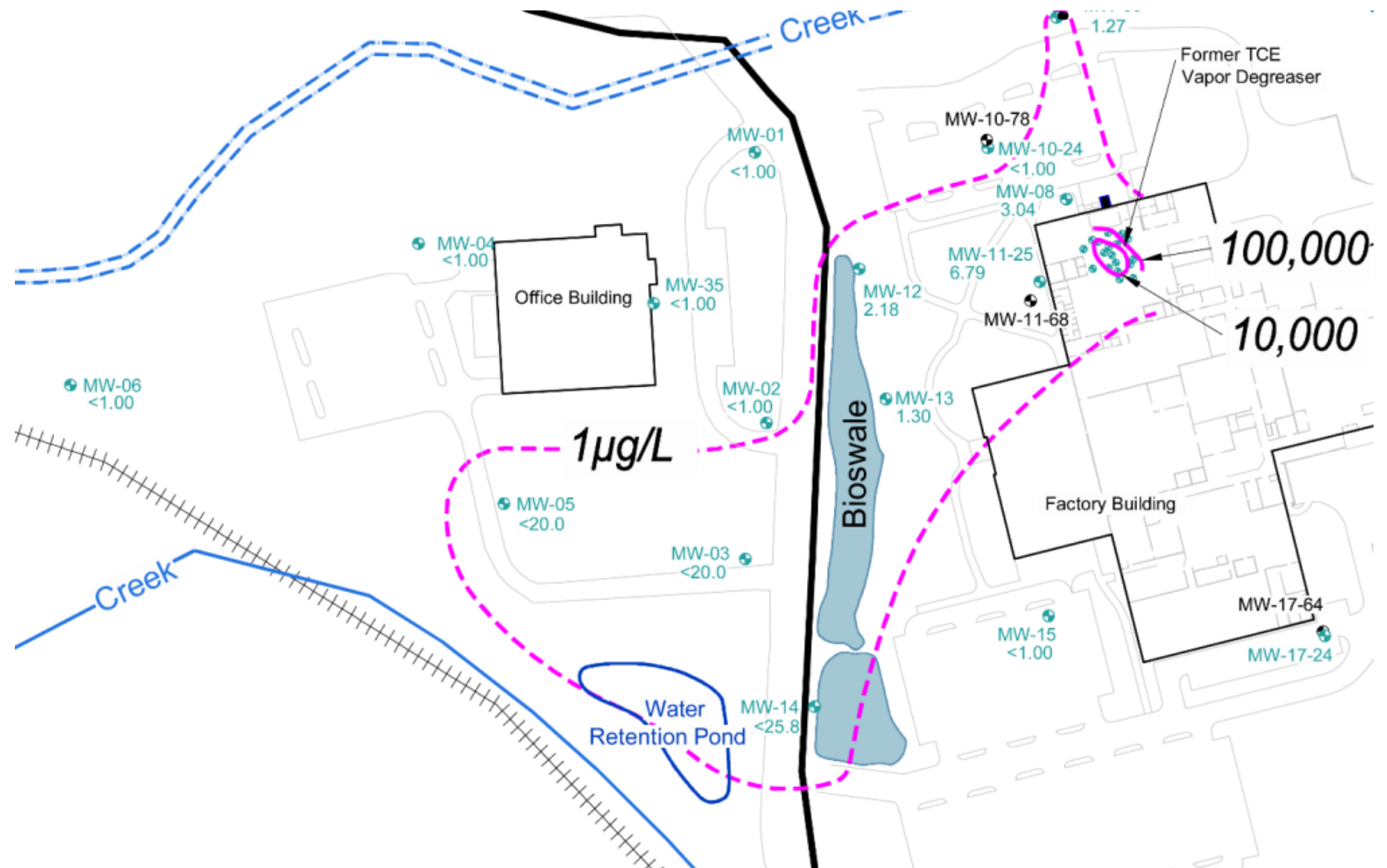
Concentrated EVO (>20%) to sequester and treat mass in Source (Henry et al 2005):

1. Reduced source K and flux to plume
2. Partitioning and dissolution of TCE to EVO
3. Long term electron donor for Enhanced Reductive Dechlorination

// Baseline TCE



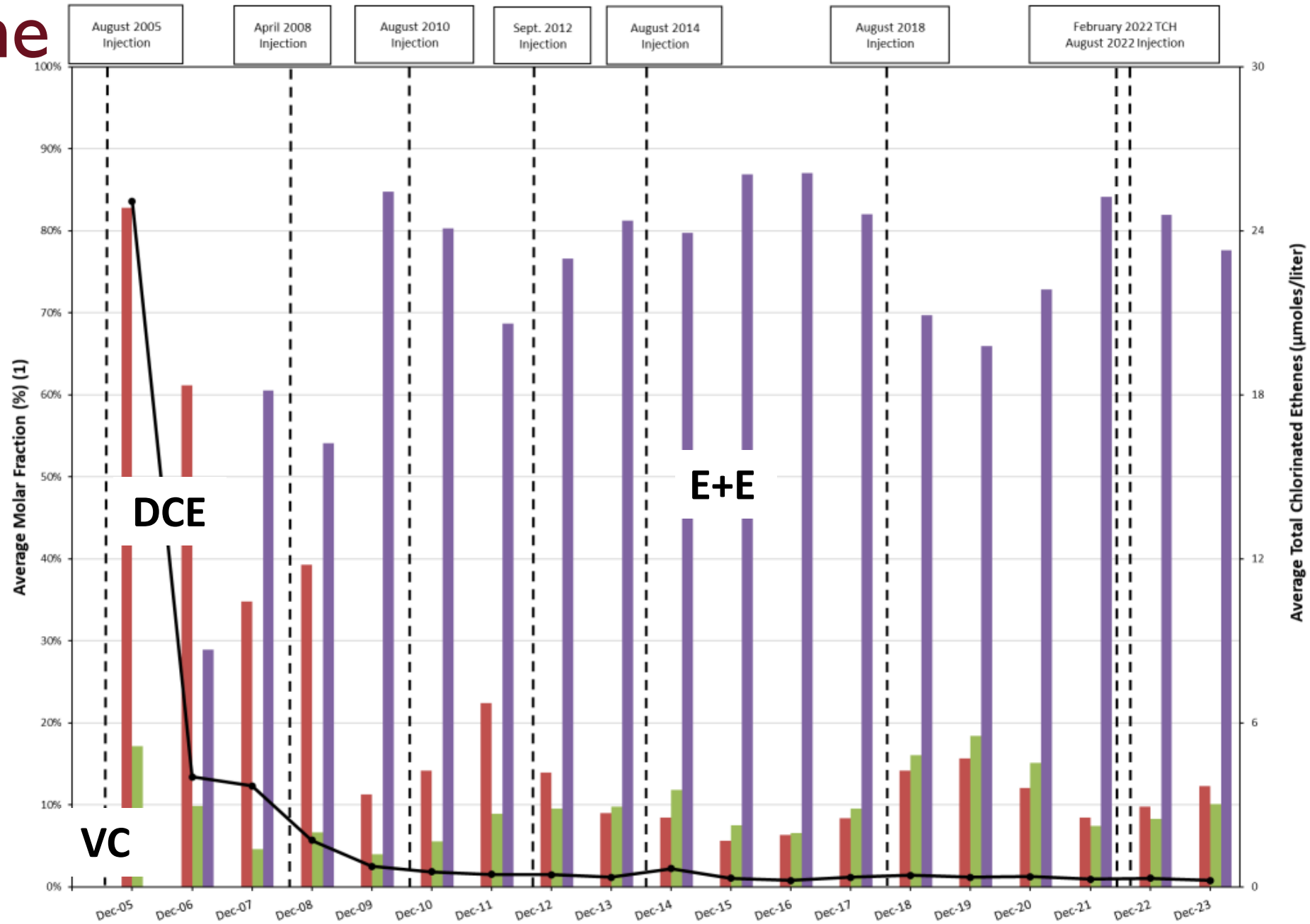
// TCE – 16 Months



// Rapid Plume Treatment

Reduced Flux
and Enhanced
Reductive
Dechlorination

...but
Persistent
DNAPL
Source



Bio with Abiotic Enhancement

// Bio = Sequential Reductive Dechlorination



// Abiotic = Reductive Elimination

PCE → Dichloroacetylene

TCE → Chloroacetylene

DCE → Acetylene

→ Ethene → Ethane → CO₂ and H₂O

Concurrent, complimentary

No VC



// Bio Injections – Ongoing Source Treatment

32,000 to 53,000 gal of 20%+ EVO

15-17 source wells



Solae (2005-2012):

Textrol BR (90% soybean oil and 10% surfactant)

JRW Bioremediation (2014-Present):

LactOil® 80/98 (veg oil, ethyl lactate, and surfactants)

// Source Treatment Enhancements

1. Stimulate Abiotic

- ▲ 2014 Ferrous Sulfate
- ▲ 2018 and 2022 cZVI

2. Low-Temperature Thermal

- ▲ Startup in February 2022
- ▲ 7 Heater Wells

3. pH Buffer Injection

- ▲ August 2022
- ▲ 11 source wells >100 µg/L TCE

REGENESIS:

S-Micro ZVI™ (colloidal zero-valent iron)

RNAS Remediation Products:

Neutral Zone® (colloidal calcium carbonate buffer)

TerraTherm:

Low-temperature thermal conduction heating system installation and operation



// Ferrous Sulfate vs cZVI

2014—Ferrous Sulfate

- ▲ 2,800 gallons (23,350 lbs) of 25%wt ferrous sulfate heptahydrate
- ▲ 1,350 lbs reactive iron emplaced
- ▲ \$ 3.55 /lb iron

2018—cZVI

- ▲ 110 gallons (1,500 lbs) AquaZVI
- ▲ 600 lbs reactive iron
- ▲ \$ 19.38 /lb iron

2022—cZVI

- ▲ 231 gallons (3,500 lbs) S-MicroZVI
- ▲ 1,400 lbs reactive iron
- ▲ \$ 26.28 /lb iron



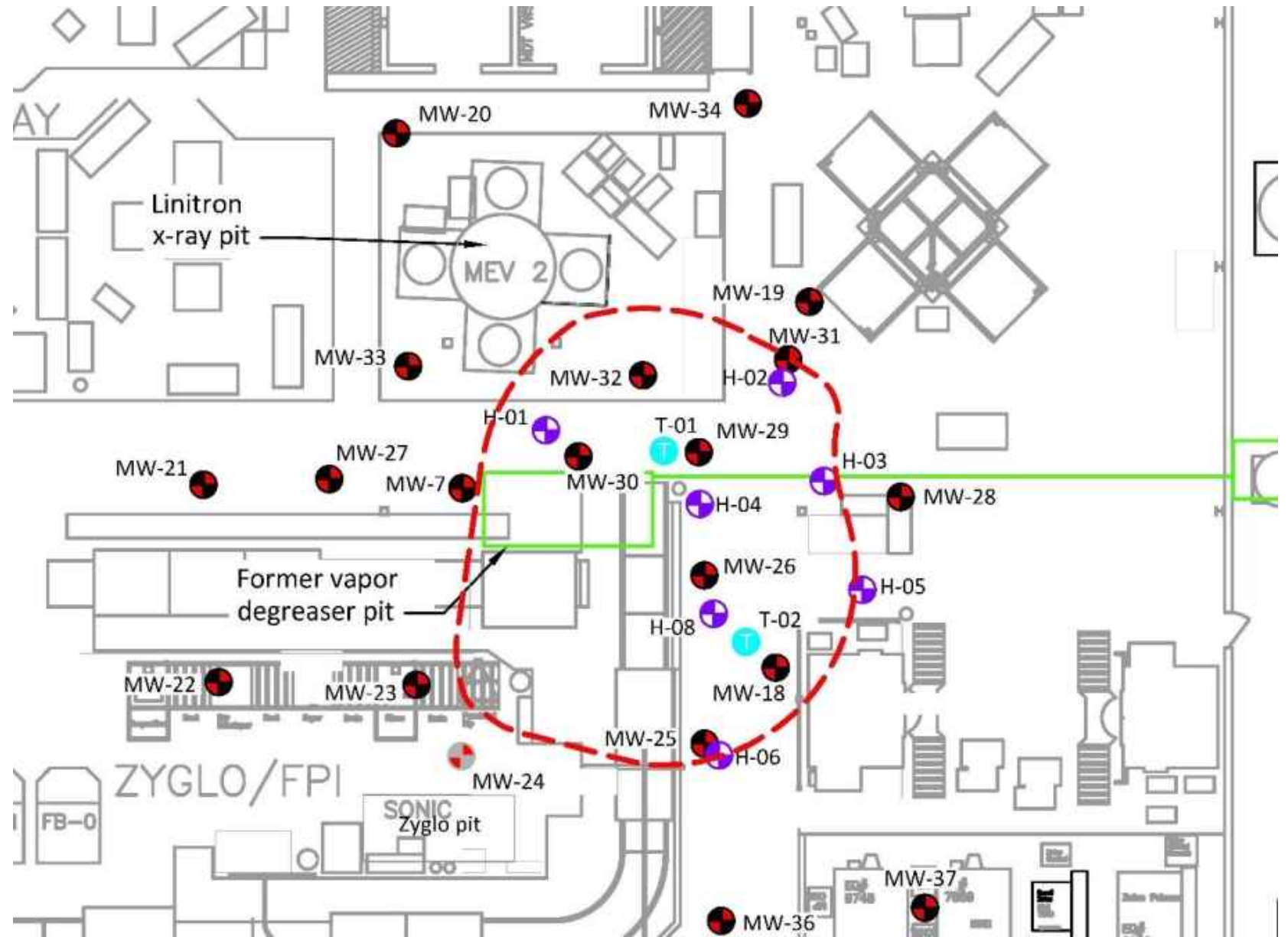
// Ferrous Sulfate vs cZVI



// Low-Temperature Thermal

Thermal Target Treatment Zone:

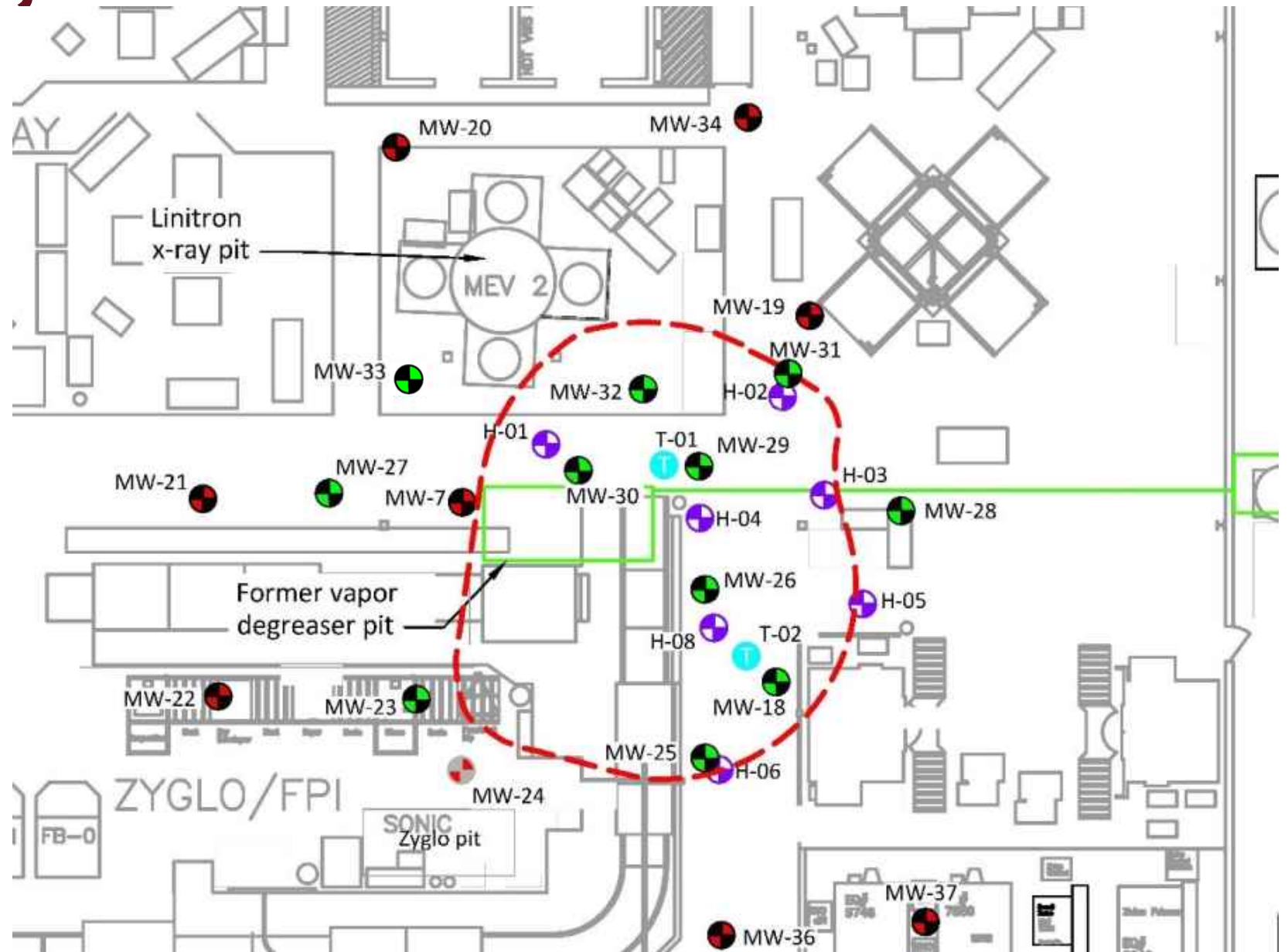
- 1,100 ft²
- 810 yd³
- 10-30 ft bgs
- >10,000 µg/L TCE



// pH Buffer Injection

Buffer Treatment Zone:

- 11 Source Wells
- $>100 \mu\text{g/L}$ TCE

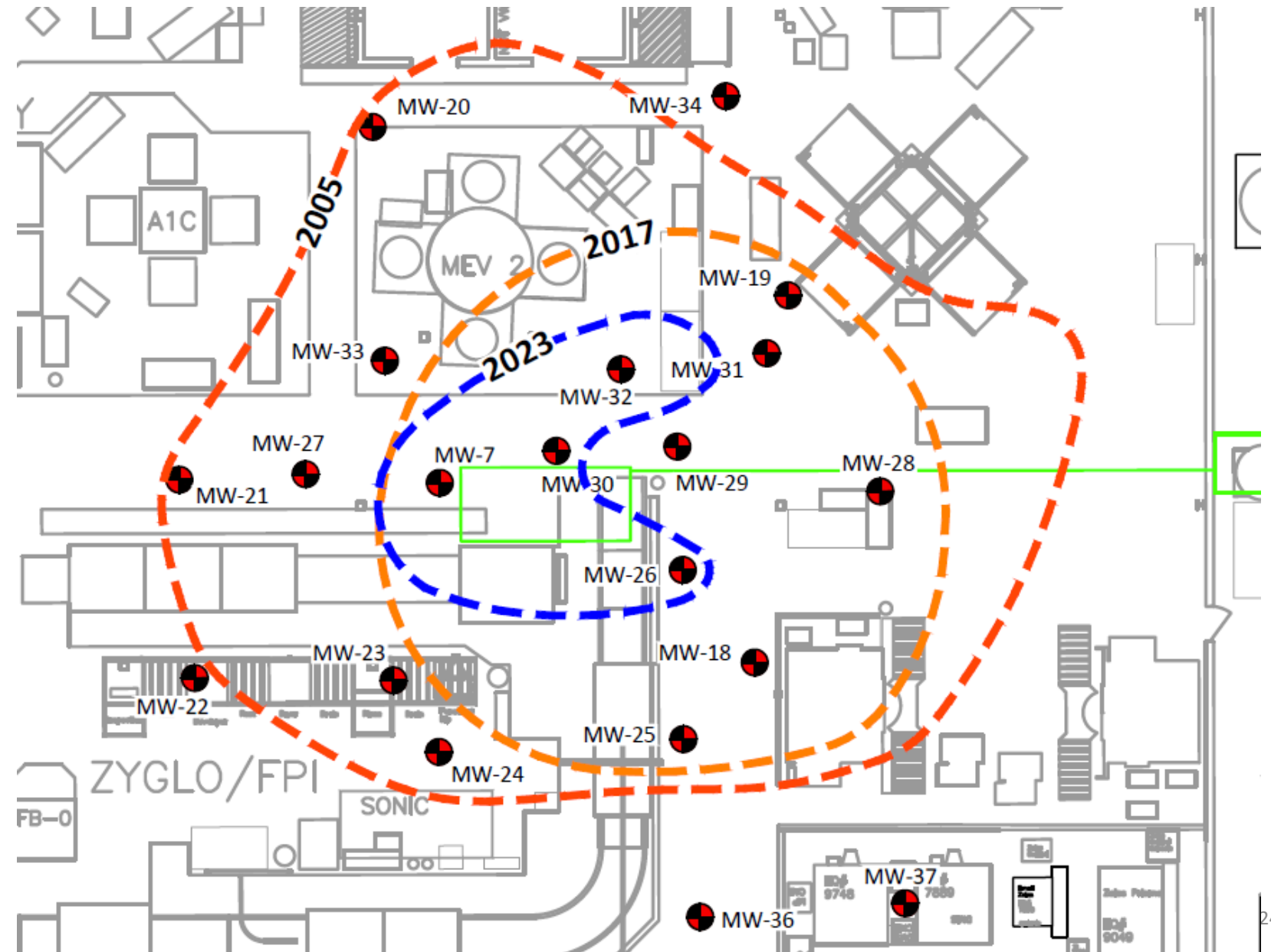


Effectiveness

// Shrinking Source

TCE Source =
10,000 µg/L

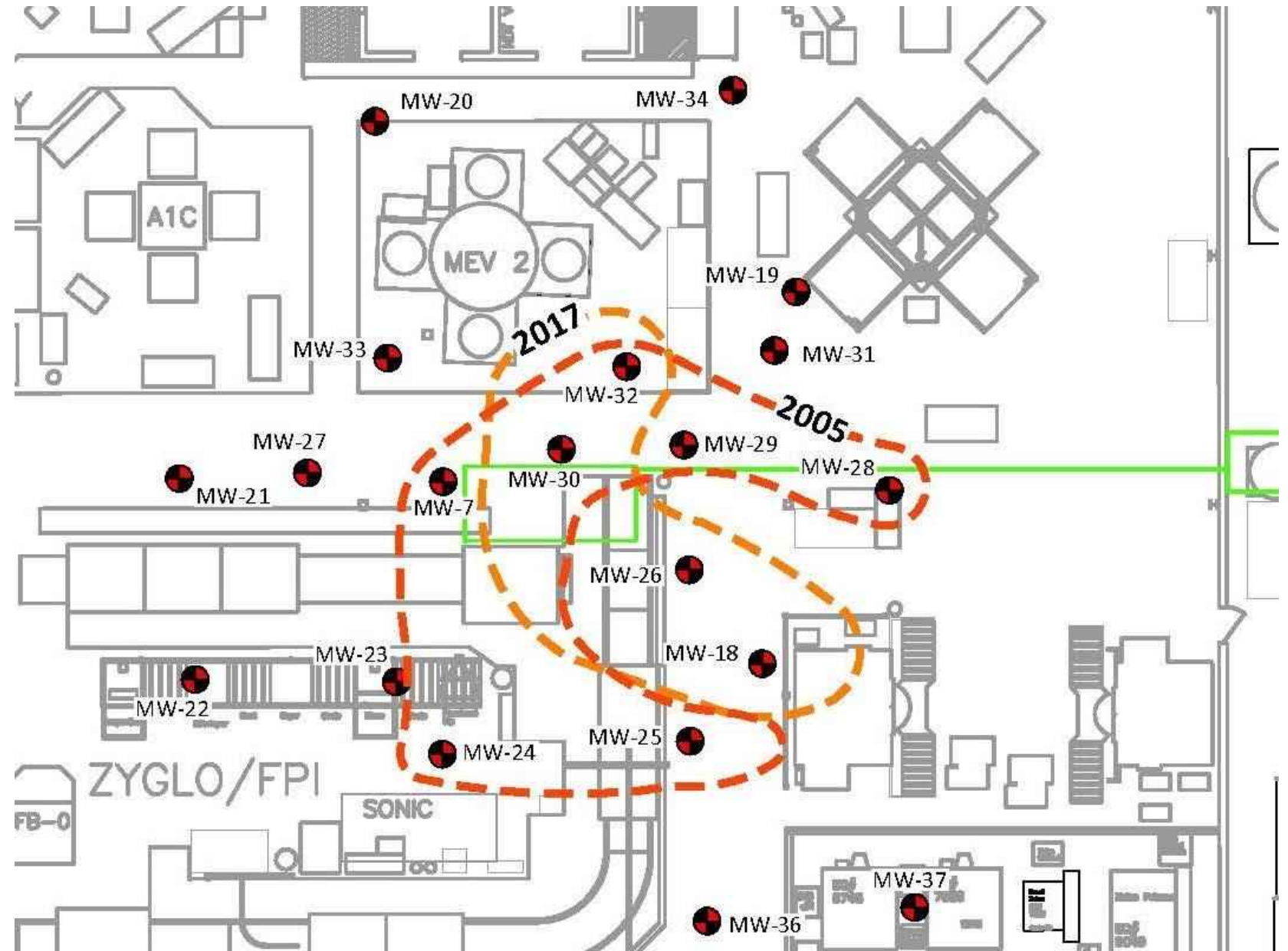
88% reduction in size
from baseline



// Shrinking Source

TCE Source =
100,000 µg/L

2023 all <100,000 µg/L



// Acetylene

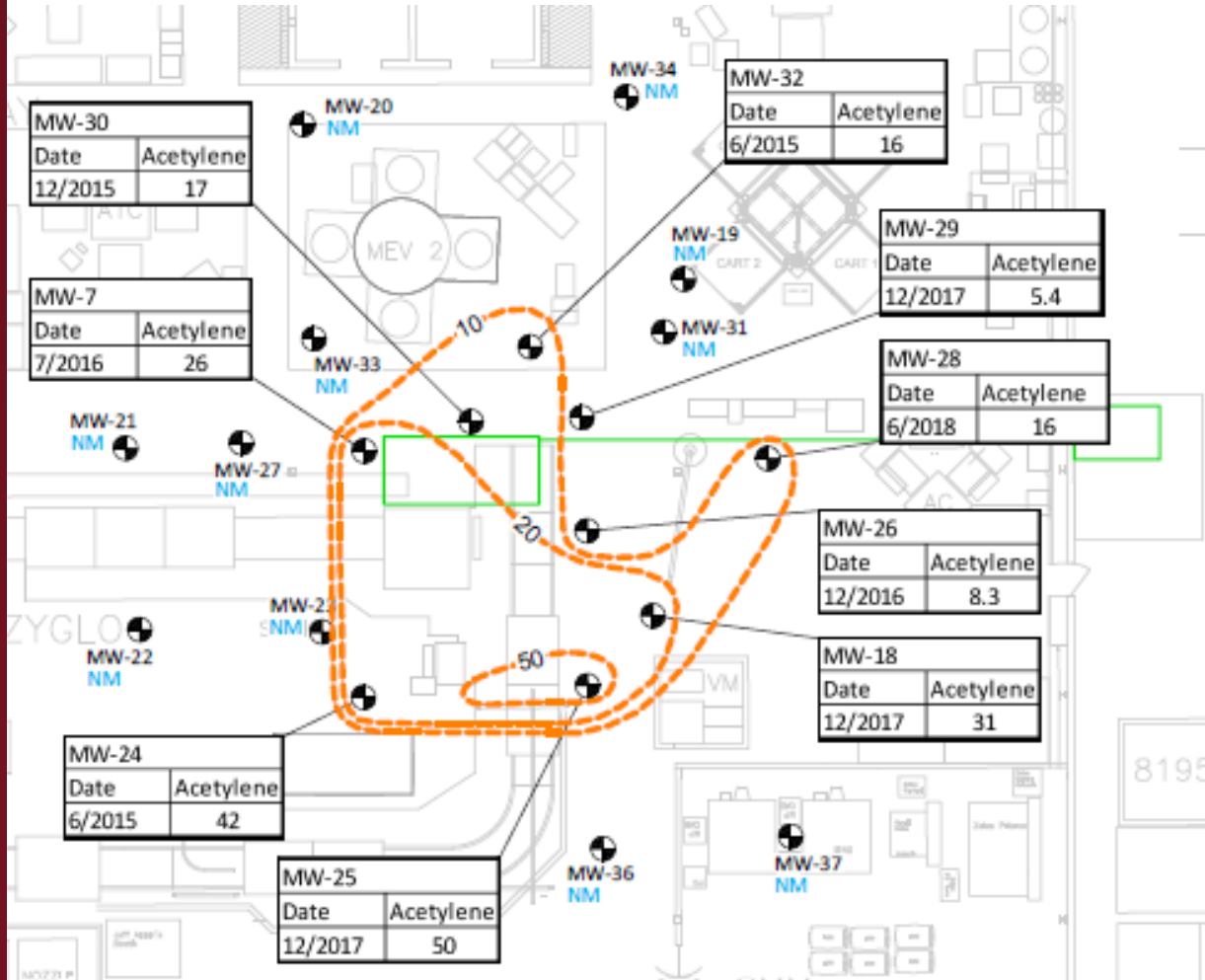
Labile degradation product, commonly not detected

DETECTIONS = FRACTION OF PRODUCTION

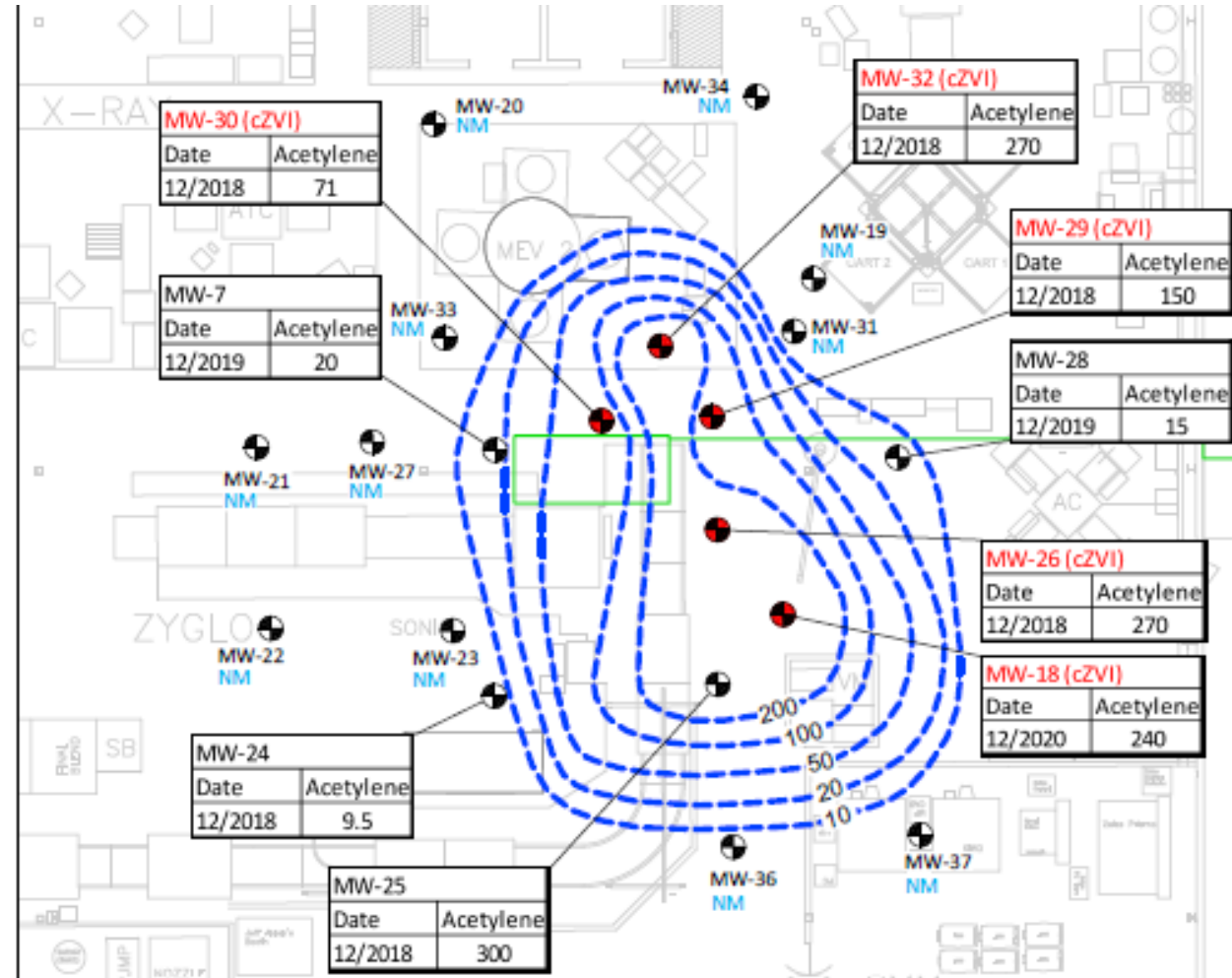
Site Detections:

▲ Bio Only--	6 to 24 µg/L	(baseline)
▲ Ferrous Sulfate--	5 to 50 µg/L	(2x from baseline)
▲ Post- cZVI 2018--	9 to 300 µg/L	(6x from baseline)
▲ Post- cZVI 2022--	4 to 300 µg/L	

// Max Acetylene Pre- and Post- cZVI 2018



5.4 µg/L to 50 µg/L



9.5 µg/L to 300 µg/L

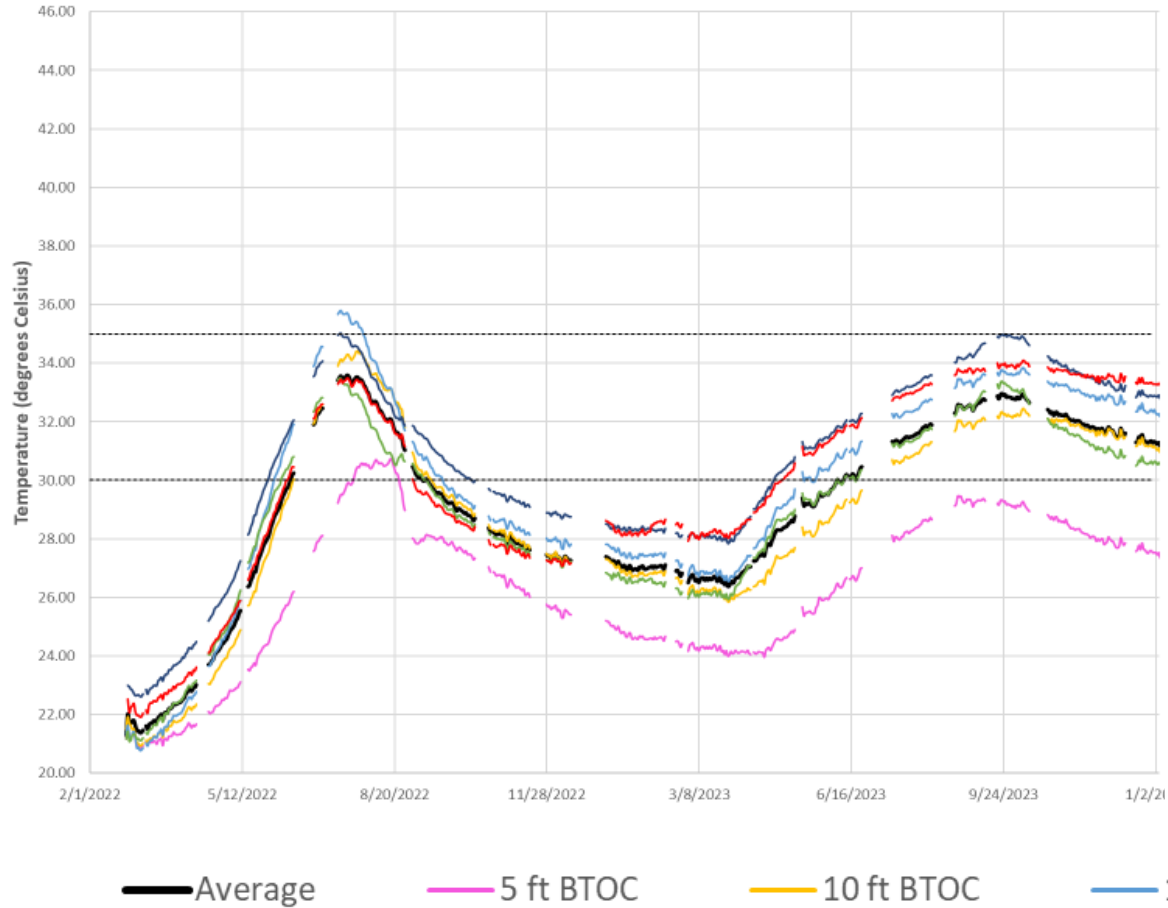
// 2022-Present

- ▲ cZVI
- ▲ Low-Temperature Thermal
- ▲ Buffer

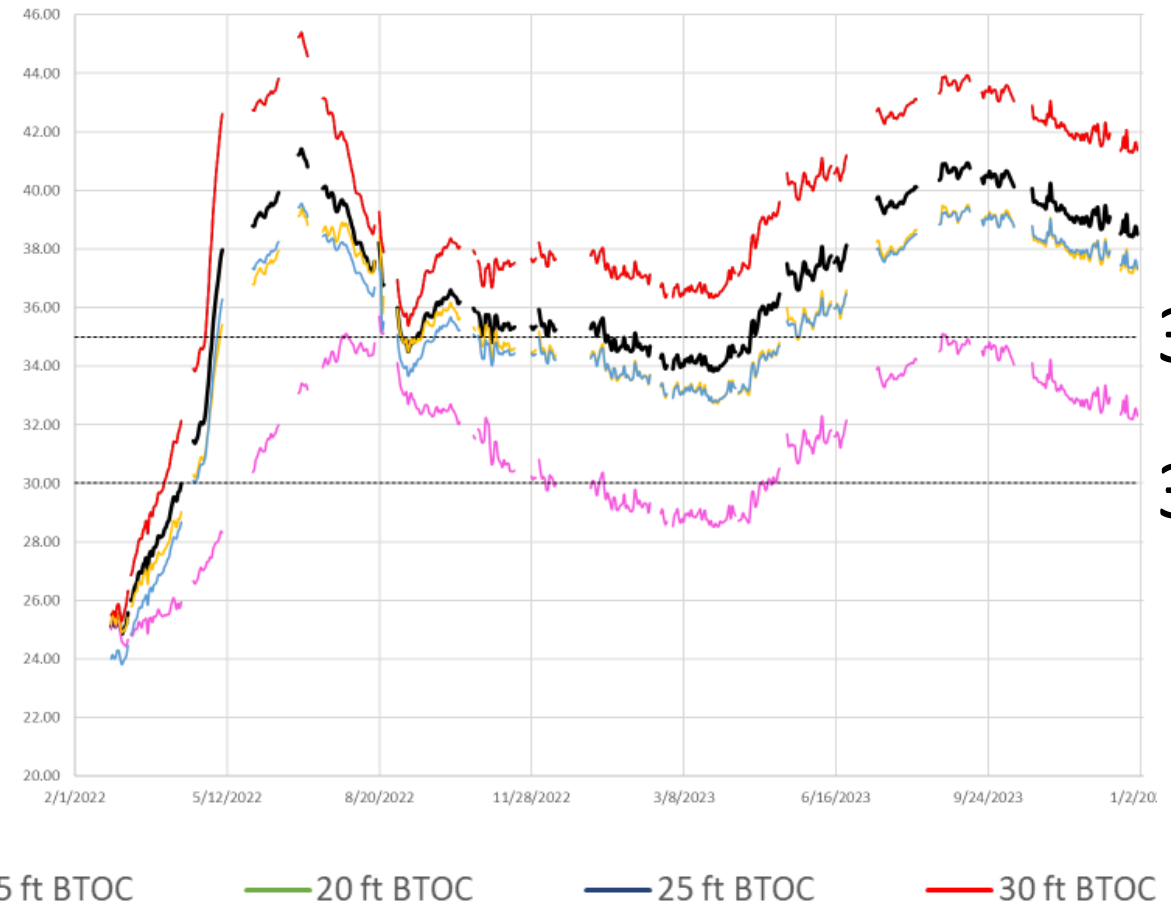


// Low-Temperature Thermal

TMP-1



TMP-2



35°C

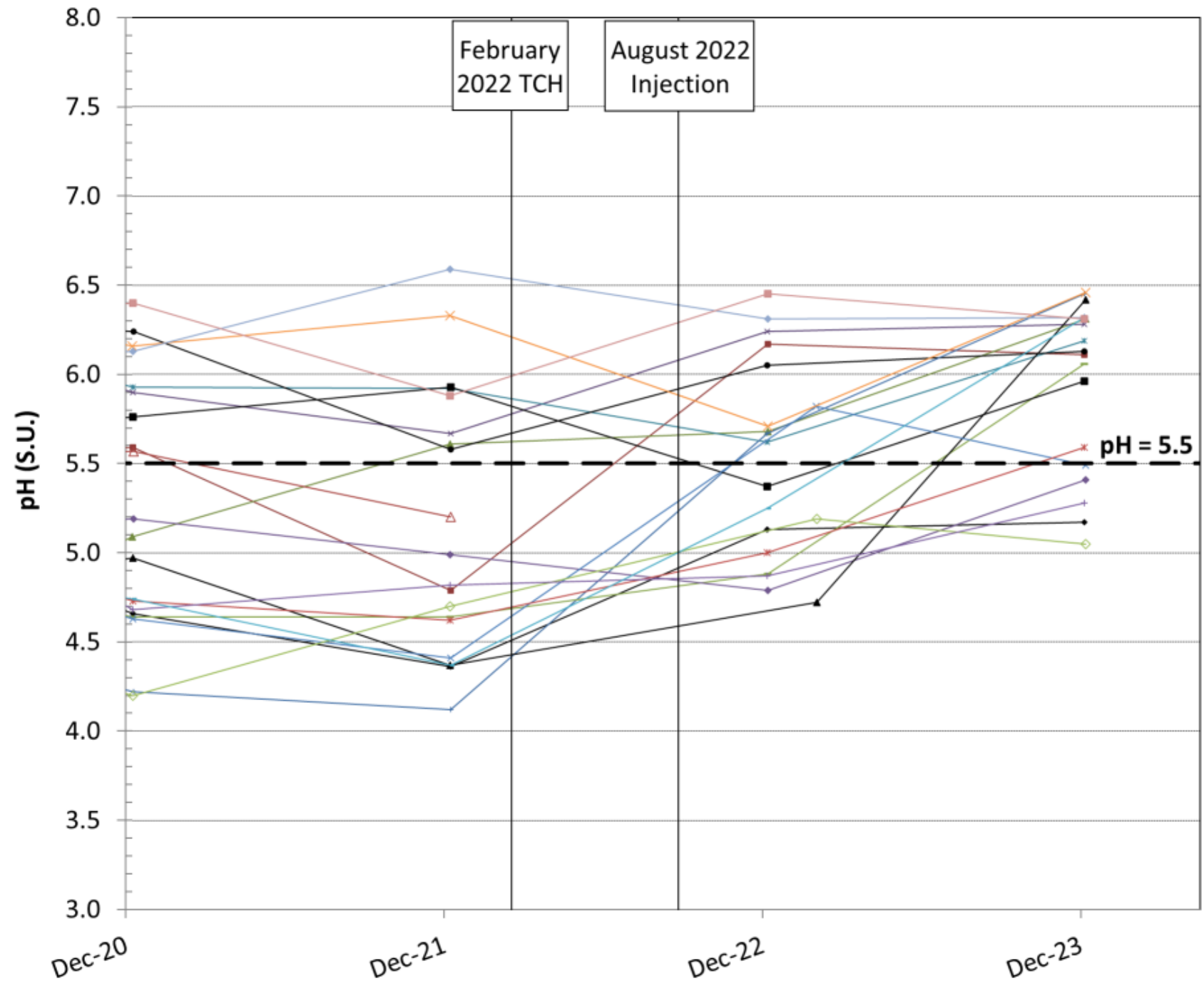
30°C



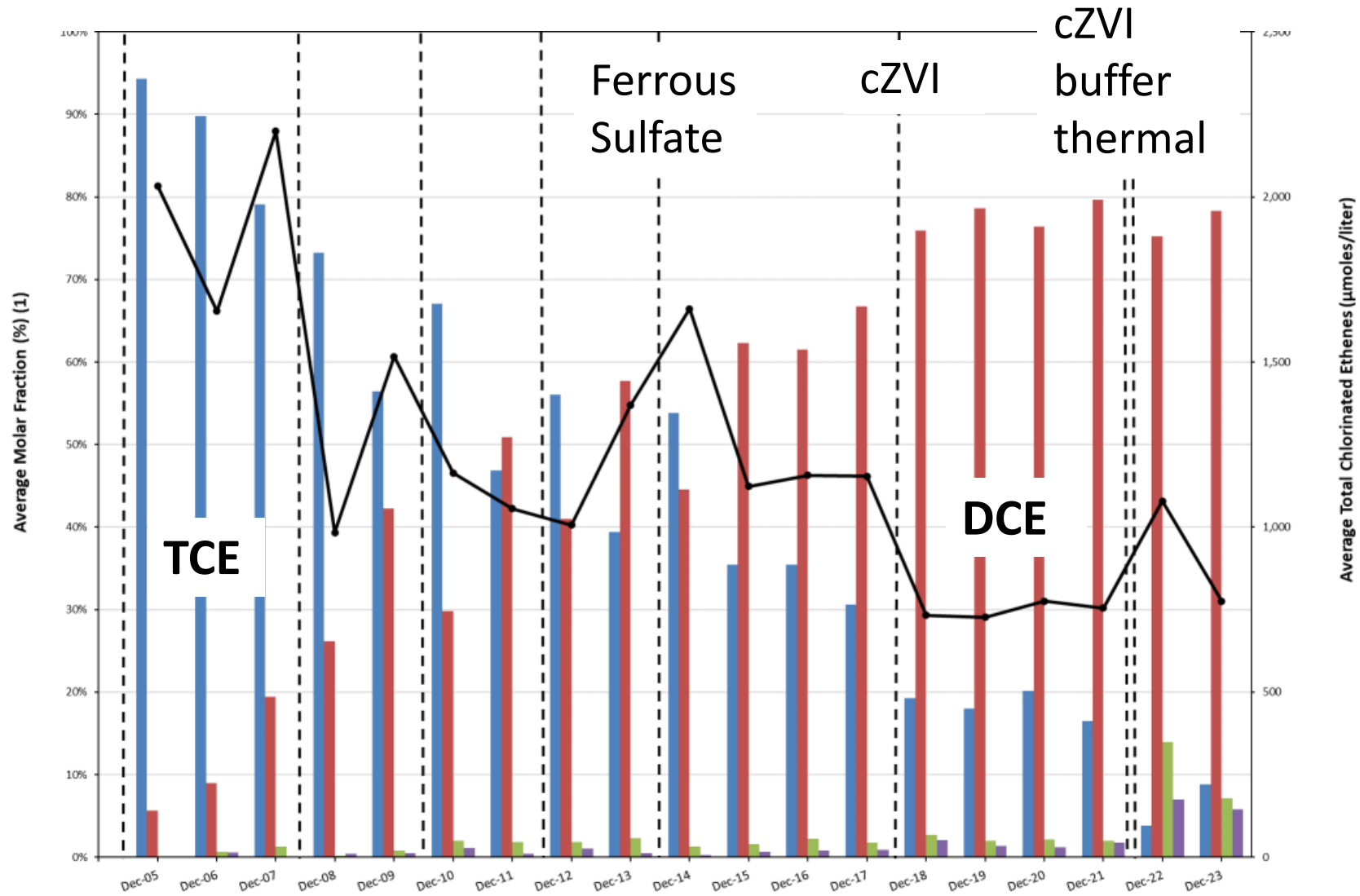
// Buffer/pH

Wells with pH <5.5:

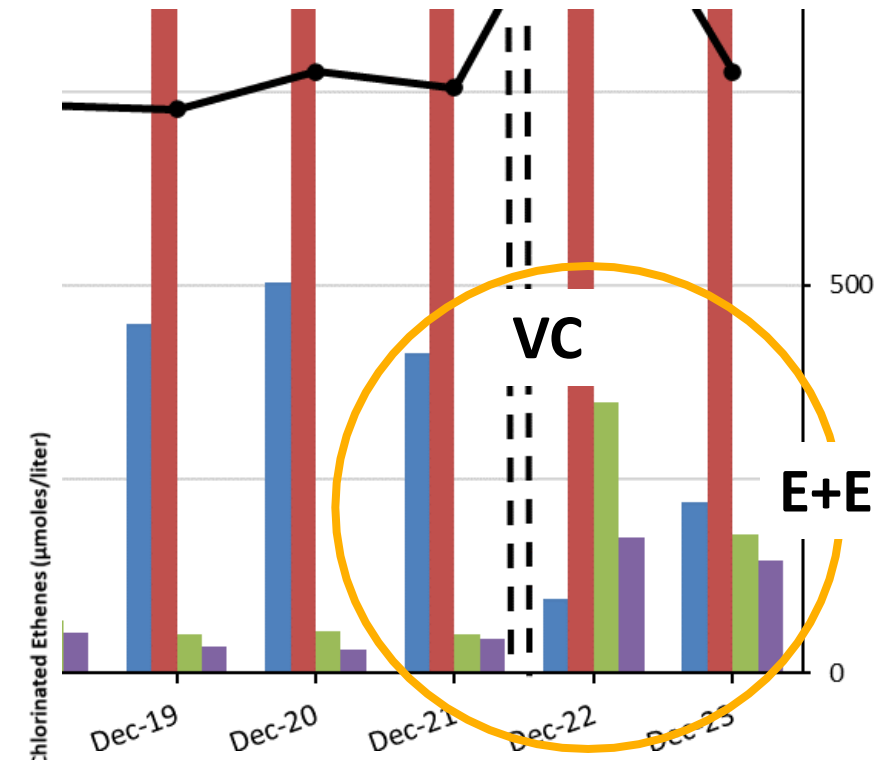
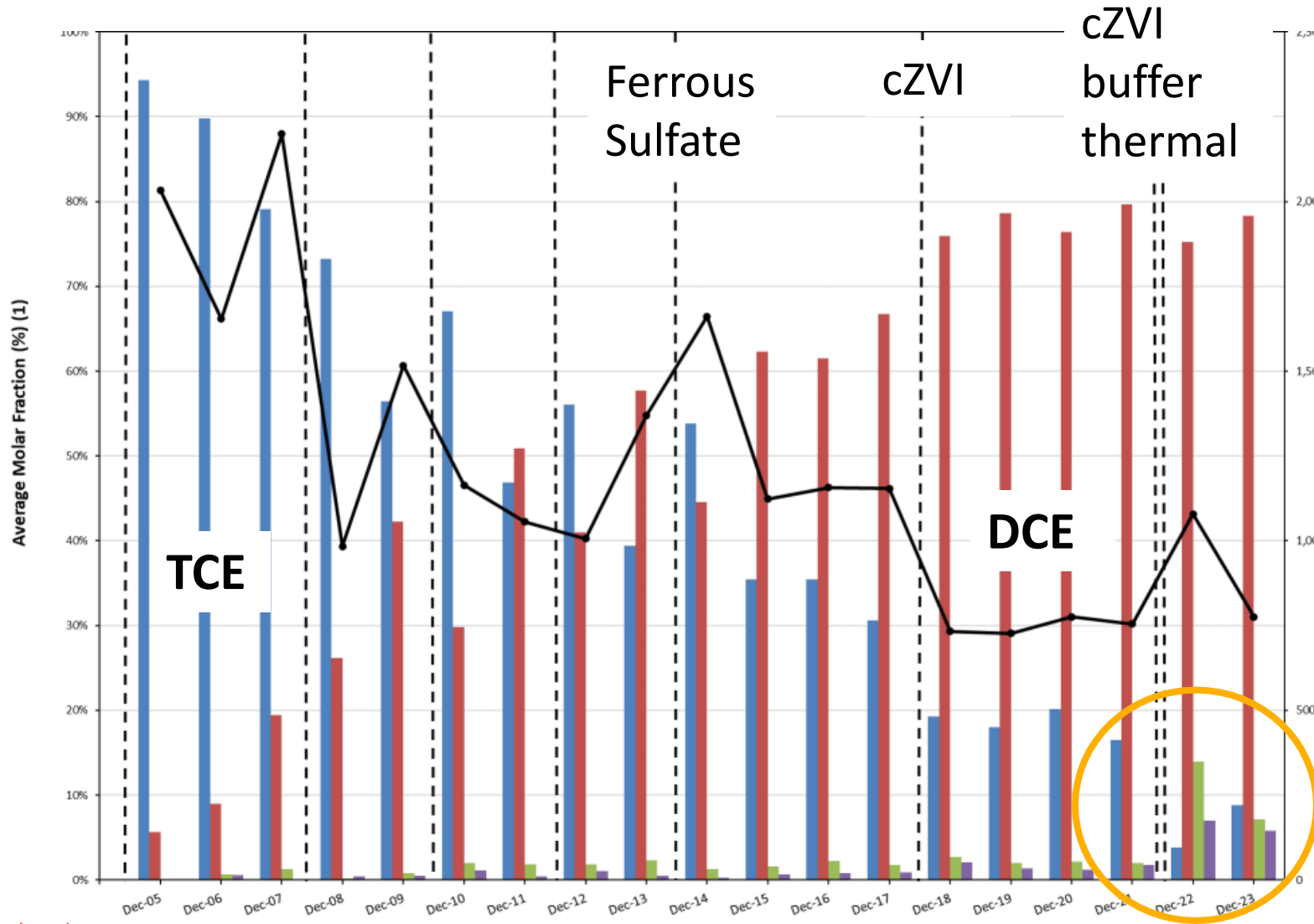
- ▲ Baseline: 0
- ▲ Pre-Buffer: 12
- ▲ Post-Buffer: 9
- ▲ Current: 4



// Source Treatment



// Source Treatment



DCE-stall
Improvement
Increased VC
E+E



// Cost Effective

\$3.2M over 20 yrs

- ▲ RI/FS/RA
- ▲ GW and SV interim actions, monitoring and reporting
- ▲ Plume treated
- ▲ Source shrinking – extent and concentration
- ▲ Thermal Design, Install, O&M 2022-Present: \$425k
Power Consumption ~\$4.5k/year
- ▲ **MINIMIZED DISRUPTION TO PRODUCTION**



Thank You Questions?