



2025 Annual Program Review
June 24-26, 2025



Innovative Bioremediation Approach for Polycyclic Aromatic Hydrogen (PAH) Site Cleanup Using Groundwater Recirculation and Oxygenation

Presenter: Ed Hicks, PE – Versar

Coauthors: Kehinde Ogunsusi – EPA R4, Brett Veselka, PE, Versar, Ernest Mott-Smith, PE, Versar, Kevin Moore – ETEC



Today's Talk Track



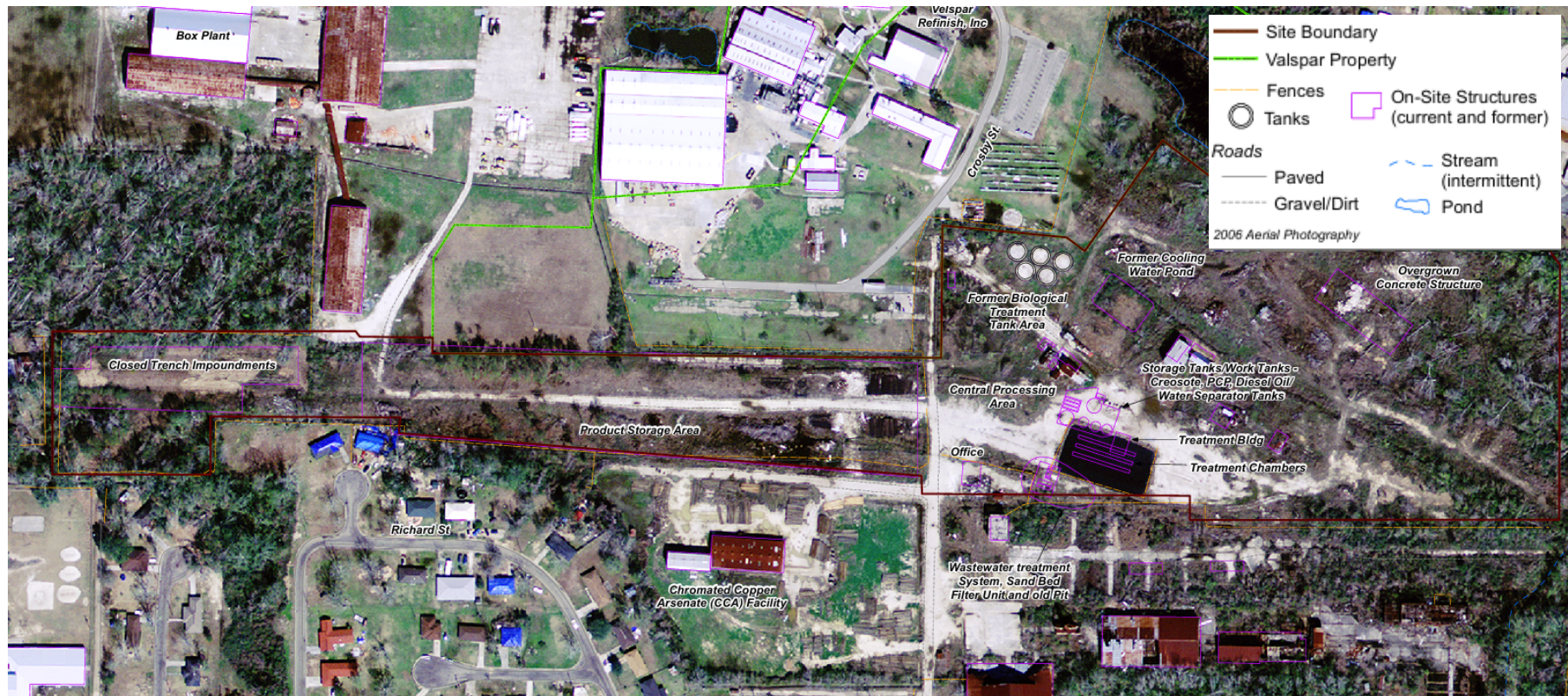
1. Site Information
2. Project Goals
3. Remedy Setup & Operation
4. Results
5. Q&A



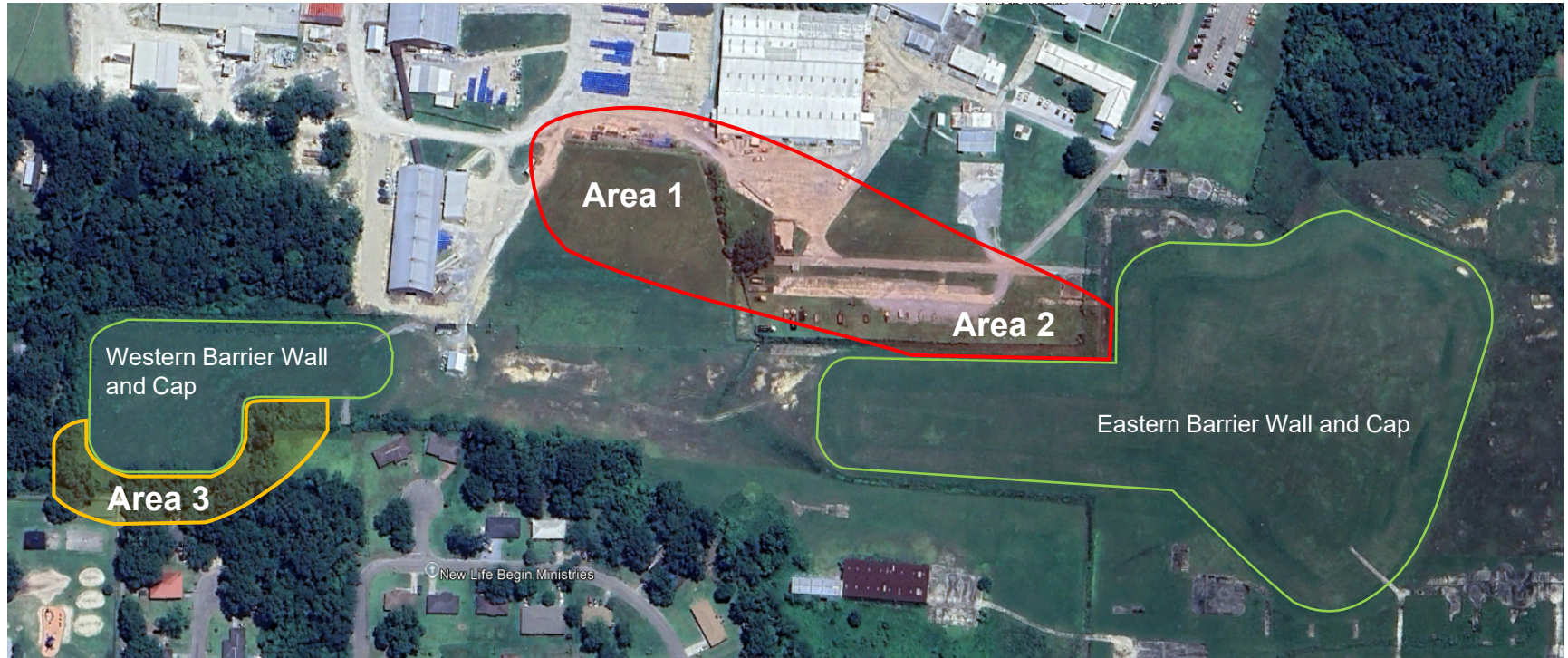
- Picayune, MS, 32 acres
- Wood treating facility from 1946 to 1999; creosote and PCP/petroleum carrier
- Three main source areas/impoundments isolated by barrier walls and caps
- Groundwater - dissolved naphthalene and PAH
- Controlled site surrounded by commercial operations, residences, elementary school
- Three separate dissolved plume Treatment Areas (Area 1, Area 2, Area 3)



Site Historical Layout



Current Site Layout – GW Treatment Areas



Project Goals

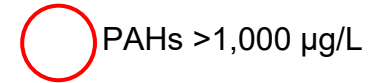
1. GW treatment using Enhanced In Situ Bioremediation (EISB)
2. Prevent plume from migrating to offsite residential area; shrink plume
3. GW Treatment Objective: 1,000 µg/L naphthalene, 100 µg/L naphthalene where practical
4. Evaluate effect of reduced SVOCs in meeting ROD RLs via MNA
5. Ongoing performance monitoring to allow system optimization

Remedy Based Solution

1. Remedial Design Investigation (RDI) to facilitate design basis, Pilot Study in Area 1
2. Injection of infused oxygen, nitrate and bio-amendment nutrients to support enhanced EISB
3. Three designated treatment areas (Areas 1, 2, 3)
4. GW Extraction, Treatment, Oxygenation, Re-injection to sweep oxygenated water across naphthalene plume
5. Performance monitoring well arrays
6. Injection array designed to be scalable with discrete recirculation cells

Treatment approach has versatility for wood treating sites, manufactured gas plant (MGP) sites, and petroleum contamination sites

- Characterize vertical/areal distribution of COCs (soil/GW) in 3 Site Areas Outside Completed BW/Capped Containment Cells (Determine ISCO and/or EISB Needed)
- Investigate for presence of NAPL Stringers (DPT and TarGOST®, SBs, MW's)
- Evaluate Aquifer Hydraulic Conductivity (Slug Tests, Pumping Test)
- Characterize Indigenous Microbial Populations (Naph and PCP Degradars)
- EISB Pilot Study



- Naphthalene a result of source creosote and creosote stringers
- Area 1 - Treatment interval is 50 – 70 ft bgs
- Area 2 - Treatment interval is 60 to 70 ft bgs
- Remedial Treatment Goal = 1,000/100 µg/L
- Naphthalene cleanup standard = 6.2 µg/L (per MDEQ TRG)
- Highest naphthalene concentration = 9,960 µg/L (December 2018)

MW-61D, 50-75 ft bls

- Well graded fine to coarse sand
- Grading to sand w/gravel
- Discrete lenses of silty clay noted in some borings
- Area 1 underlain by blue/green marine clay at ~75 ft bls



- Slightly aerobic aquifer
- Moderate pH and low alkalinity for buffering
- Appreciable levels of Fe, NO₃ and SO₄
- Naphthalene dioxygenase (NAH) enzyme present at levels up to 6,130 cells/mL

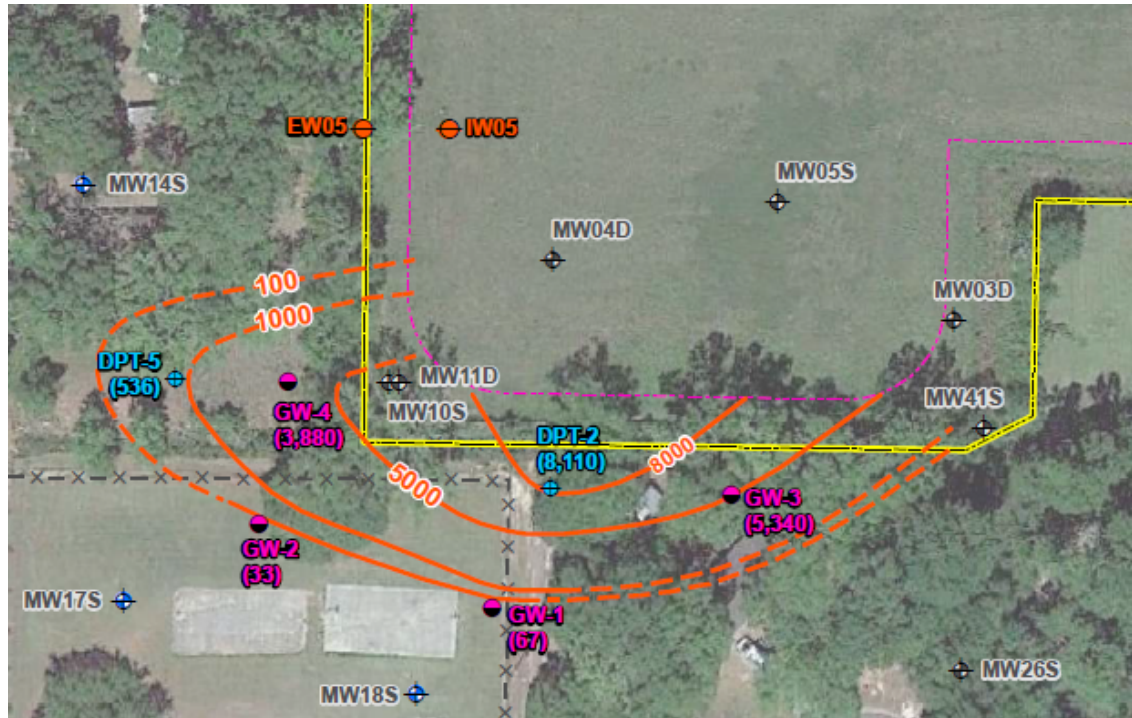
Area 1/2 Geochemistry – Baseline (Dec 2018)					
Parameter	Unit	Low	High	Average	Notes
pH	s.u.	3.4	6.5	5.1	
DO	mg/L	0.09	0.66	0.43	slightly aerobic
ORP	mV	(-)130	170	75	
Total Fe	mg/L	-	9.0	1.8	
Nitrate (NO ₃)	mg/L	-	-	15	
Sulfate (SO ₄)	mg/L	-	-	35	high
Alkalinity	mg/L	-	40	-	low, not well buffered
Hardness	mg/L as CaCO ₃	-	40	-	low
TOC	mg/L	0.73	19.6	4	

Area 3 Naphthalene Plume (March 2018, Baseline)

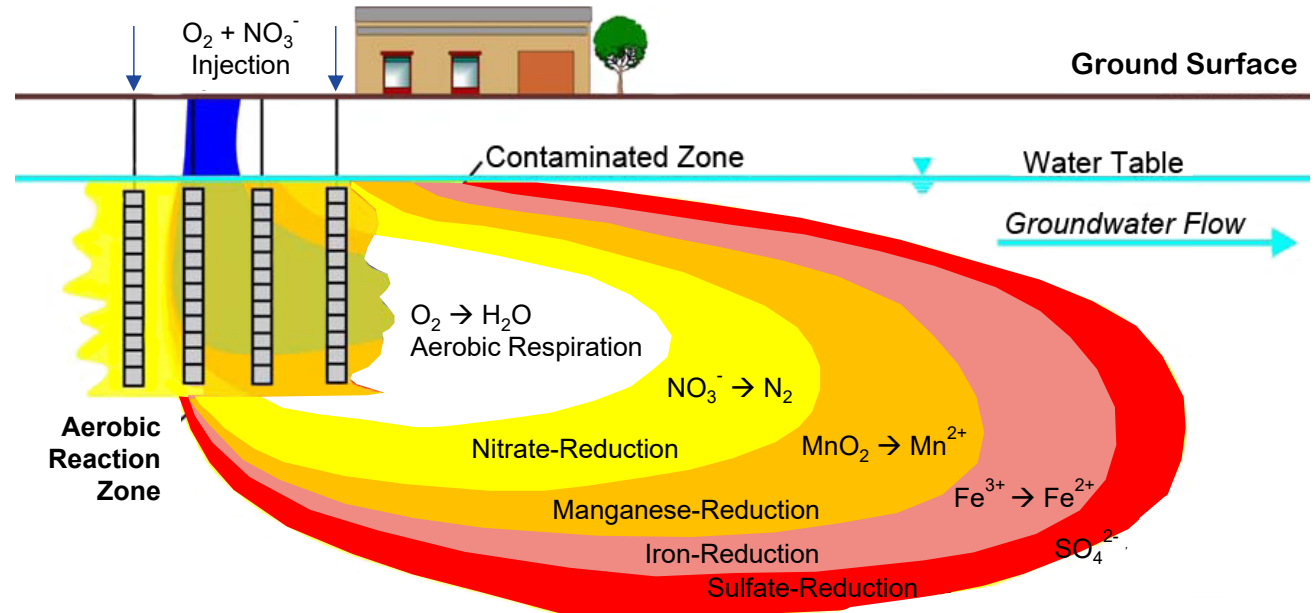
- Area 3 - Treatment interval is 50 – 75 ft bgs
- Highest naphthalene concentration = 8,810 $\mu\text{g/L}$ (December 2018)
- Lithology similar to Area 1/2 (sand, gravely sand underlain by clay)



Typical Area 3 NAPL stringer, SB-100 46-47 ft bgs



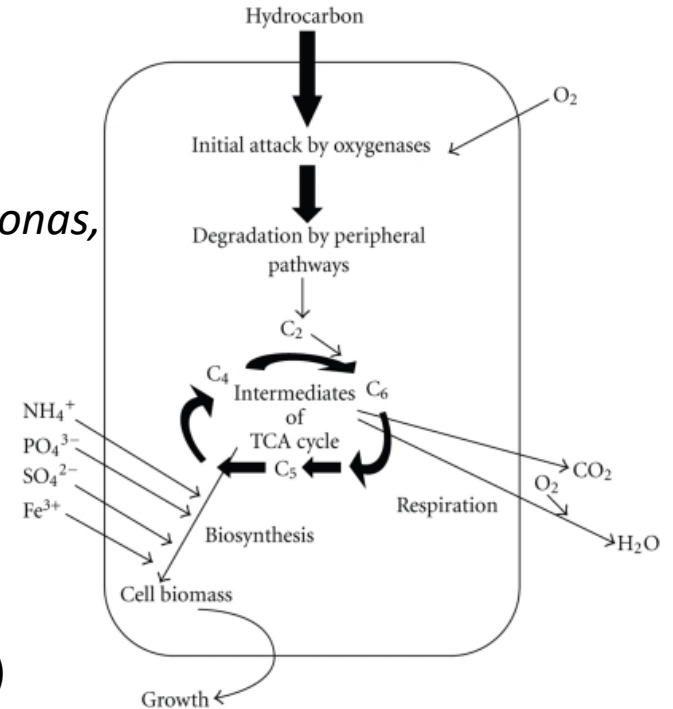
Electron acceptor usage following a bioremediation treatment using oxygen & nitrate



Redox zones of a typical contaminant plume
(Source: Parsons 2004). Modified by ETEC

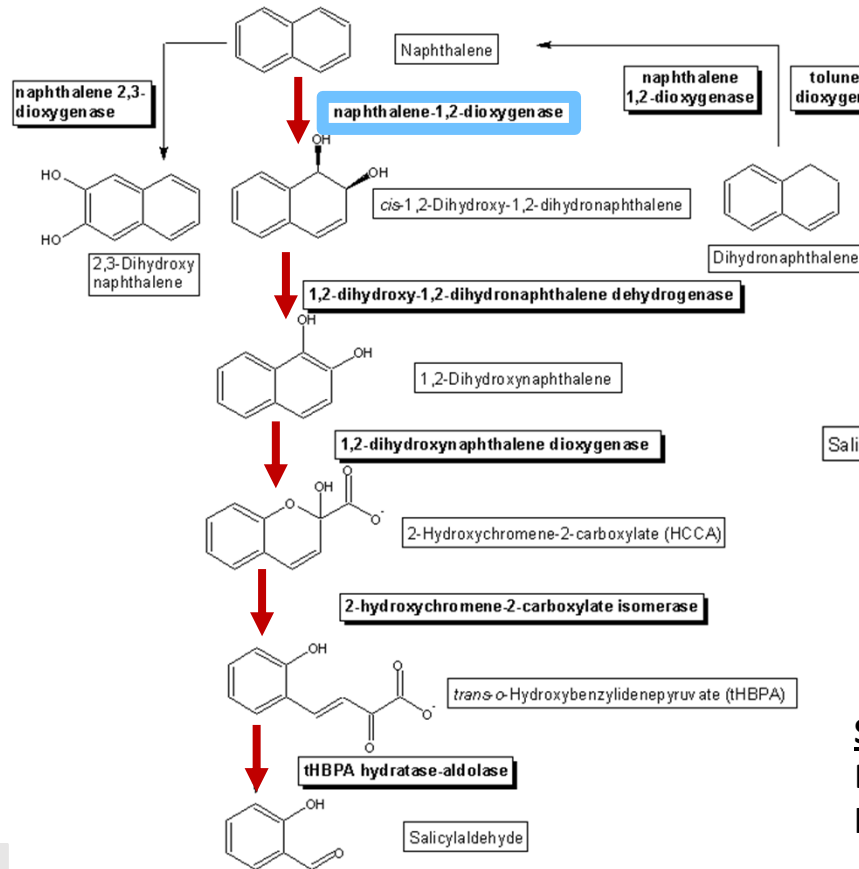
Requirements for Aerobic Biodegradation of SVOCs

- SVOCs (electron donor)
- Oxygen (electron acceptor)
- Specific SVOC degrading bacteria strains (e.g., *Pseudomonas*, *Burkholderia*, *Bacillus*, *Rhodococcus*)
- Supplemental macronutrients
- Nitrogen (e.g., ammonia: NH_3)
- Phosphorus (e.g., phosphate: PO_4^{3-})
- Micronutrients for cell growth and maintenance
- Trace minerals (e.g., K, Ca, Mg, Na, S, Cl, Fe, Mn, others)
- Optimum pH = 6.5 to 8.0 {range 4 to 9}

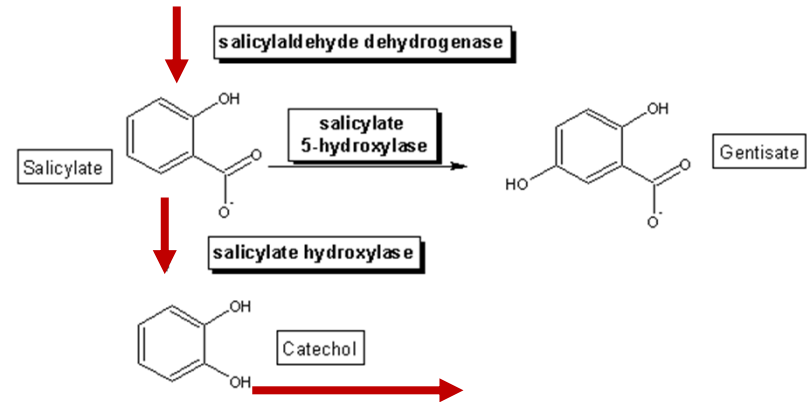


Main principle of aerobic degradation of hydrocarbons (Fritzsche/Hofrichter, 2005)

Naphthalene Aerobic Degradation Pathway



- *Dioxygenase is an enzyme*
- *Several intermediates are acidic*

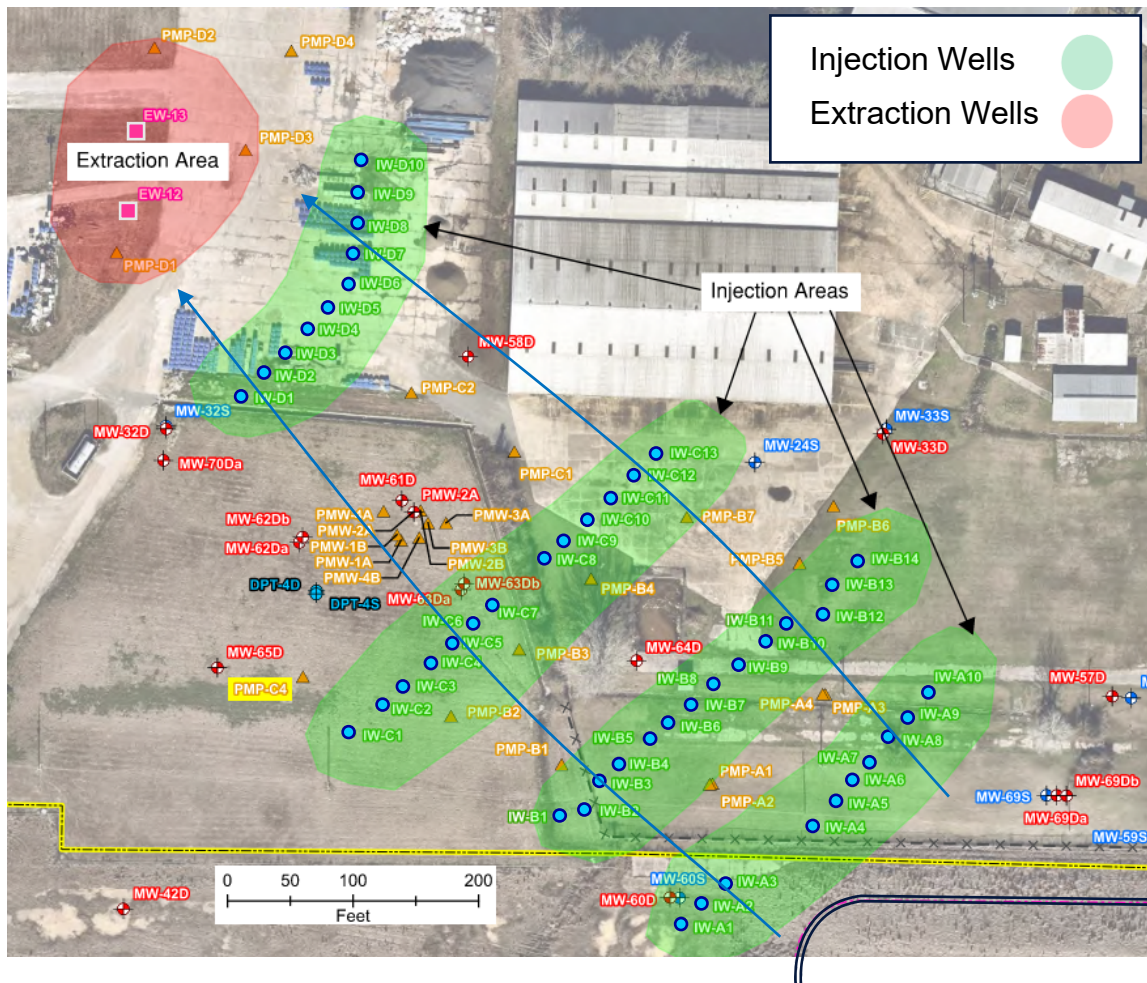


Source:

Dr. Larry Wackett, University of Minnesota, 2009
based upon the work of Eaton et al., 1992

Treatment System Setup – Area 1 & 2

- Groundwater Injection/Recirculation
- Infused Oxygen (~25+ mg/L) into groundwater reinjection to promote aerobic biodegradation



Equipment

- Inlet Manifold
- HDPE Influent Tank
- Bag filter Housings
- GAC vessels to pretreat for naphthalene
- Two 50-gpm DO-ITTM infused O₂ systems
- HDPE Effluent Tank
- Nutrient Tanks
- Dosatron Injectors
- Injection Pumps
- Effluent Manifold

System Features

- Integrated extraction and transfer pump controls
- Programmable controls w/ telemetry
- Low power requirements (200-amp, 240V)



- Injection and Extraction Well Network
- (47) Injection Wells (IWs) – 1.5-inch dia. DPT install, screened 55 to 70 ft bgs
- (10) Extraction wells (EWs) – 4-inch dia. screened 50 to 70 ft bgs
- Grundfos Redi-Flo3 electric submersible pumps
- (18) performance monitoring points (PMPs)



Bioremediation Injection Amendments

- CBN™ Nutrients (100% soluble, 60% nitrate by weight)
 - nitrogen compounds (NH_4 , $\text{NH}_3\text{-N}$, NO_3)
 - ammonium chloride (NH_4Cl) - discontinued
 - phosphorus, phosphate
- FeSolv™ addition to reduce mineral scaling, iron-sequestration product with phosphorus
- Sodium bicarbonate (NaHCO_3) to raise pH and provide buffering



Total Bio Amendments Added

- 28,000 lbs dissolved oxygen
- 11,300 lbs CBN™ nutrients
- 6,780 lbs nitrate
- 5,080 lbs nitrogen

Remedial Expansion/Optimization (2022 - 2024)

- (18) IWs expanded in July 2023 to (47) IWs to address and accelerate bioremediation of the naphthalene plume and to address newly discovered areas of naphthalene
- (2) new downgradient Extraction Wells (EWs) added
- (5) EWs taken offline within recirculation cells
- (1) Added an off-gradient water supply well
- (14) performance monitoring wells (PMPs) added
- System shutdown in May 2024

Treatment System Summary

- 40-gpm average recirculation rate
- 1.4 million gallons/month
- 96 million gallons total

Significant inorganic scaling on pumps and lines

- Ferric oxides (FeOH_x) from indigenous Fe and amended O_2
- Ferrous carbonate (FeCO_3) may have been produced from reaction of amended Cl ion (NH_4Cl) and 2NaHCO_3 with Fe



- Iron carbonate hydroxide (CHFeO_4^{-3}) also possible with low pH



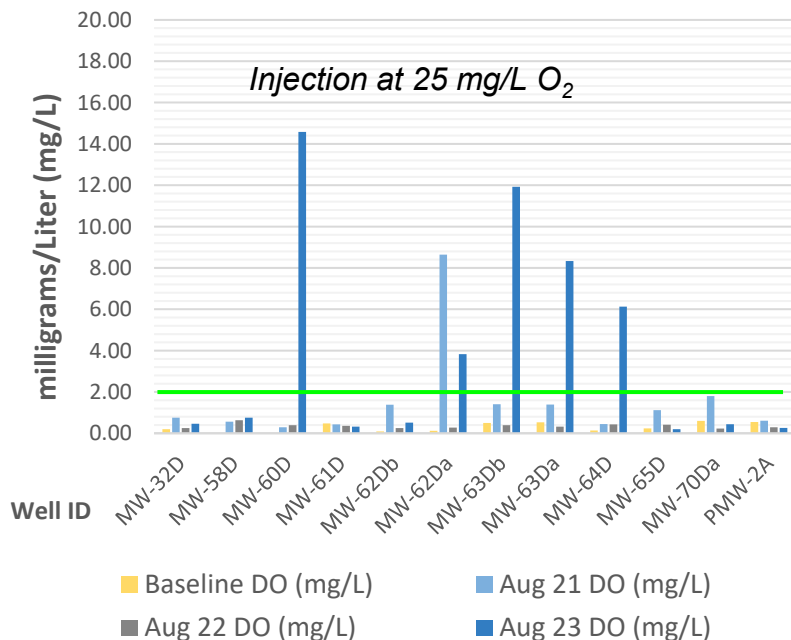
- Low groundwater alkalinity, hardness, and pH (low langelier index) did not indicate potential for calcium carbonate (CaCO_3) scaling
- FeSolv [tetrakis(hydroxymethyl)phosphonium sulfate] (THPS) was used as a sequestrant/biocide to control these precipitates



Results: Dissolved Oxygen – Area 1 & 2

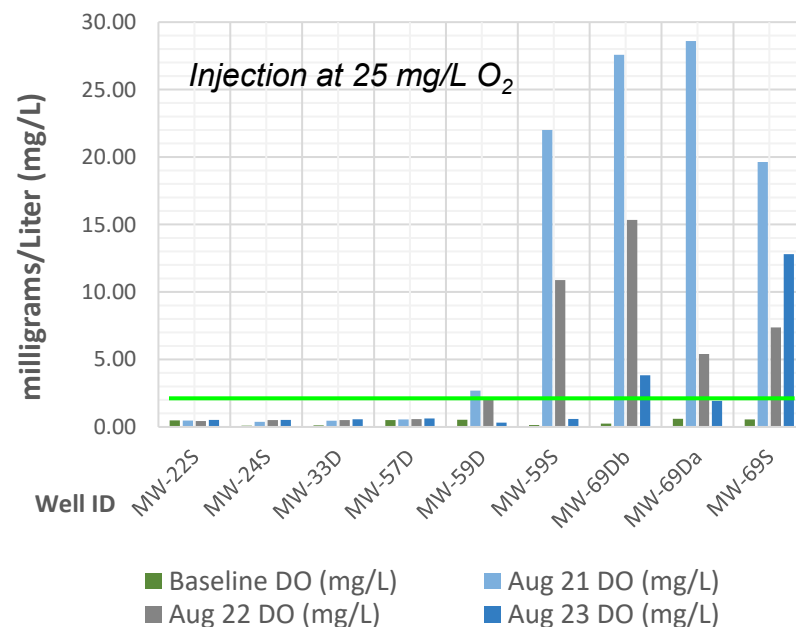
Area 2 DO

Dec 2018- August 2023 Measurements



Area 1 DO

Aug 2020 - May 2023 Measurements

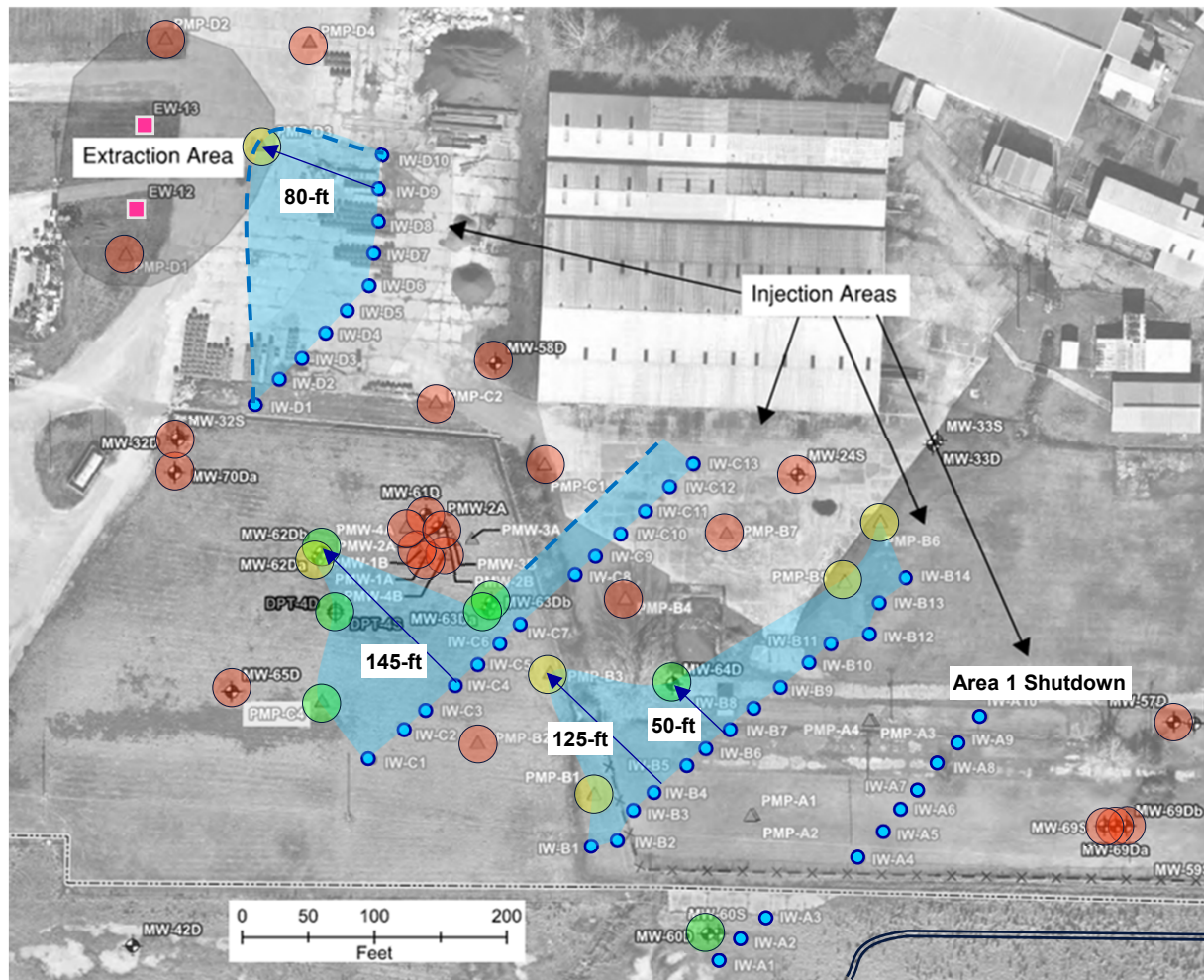


Results: Dissolved Oxygen – Area 2 Drift

August - September 2023

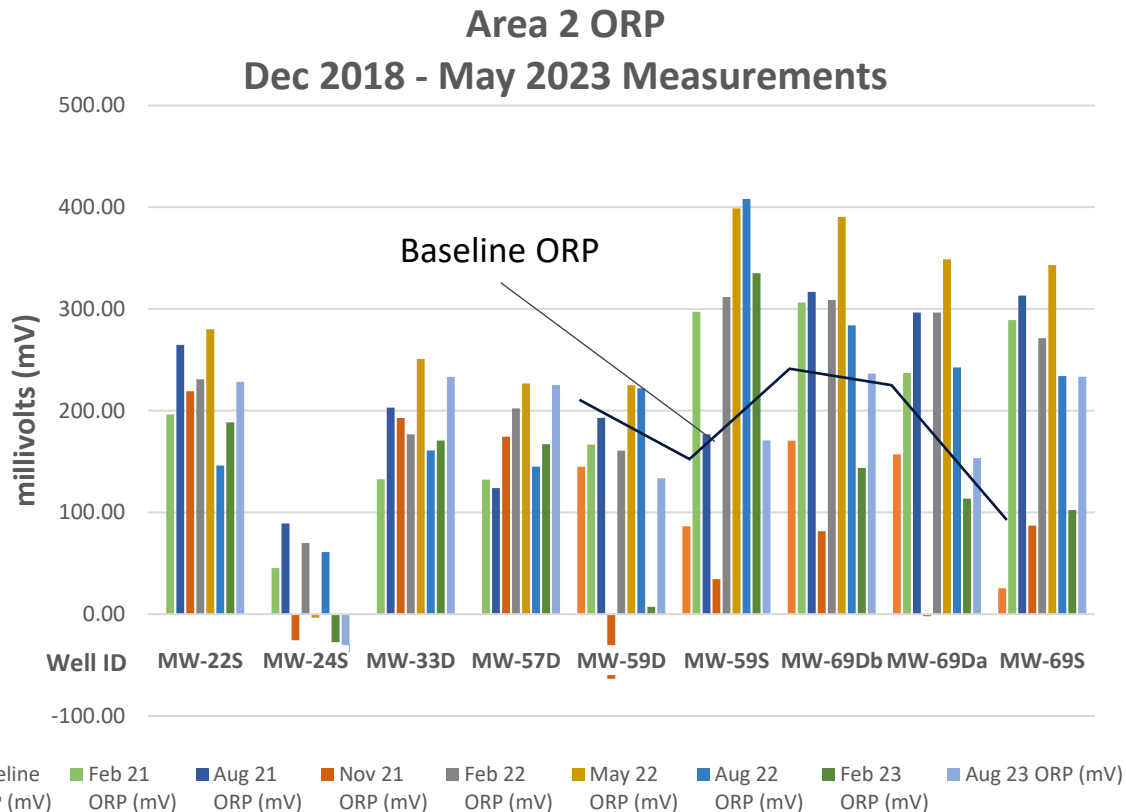
(3 - 4 months post
optimization)

- DO > 10 mg/L
- DO > 2 mg/L
- DO < 1 mg/L



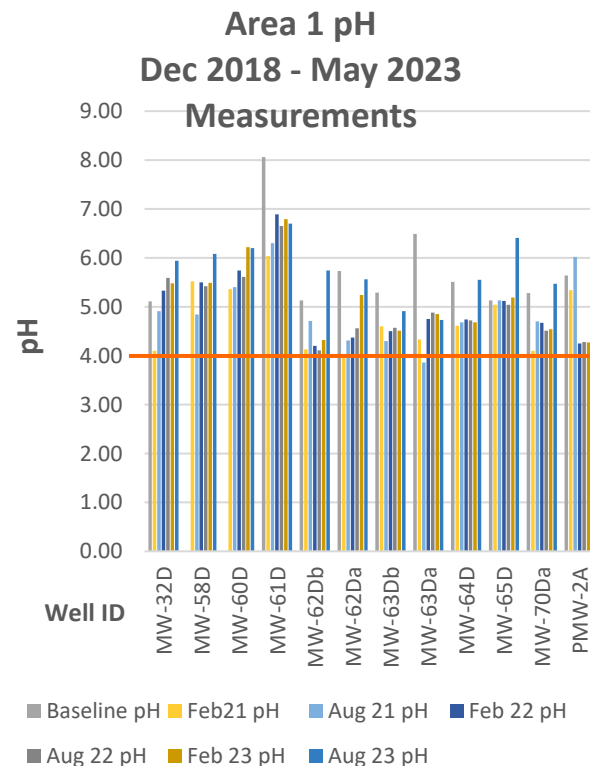
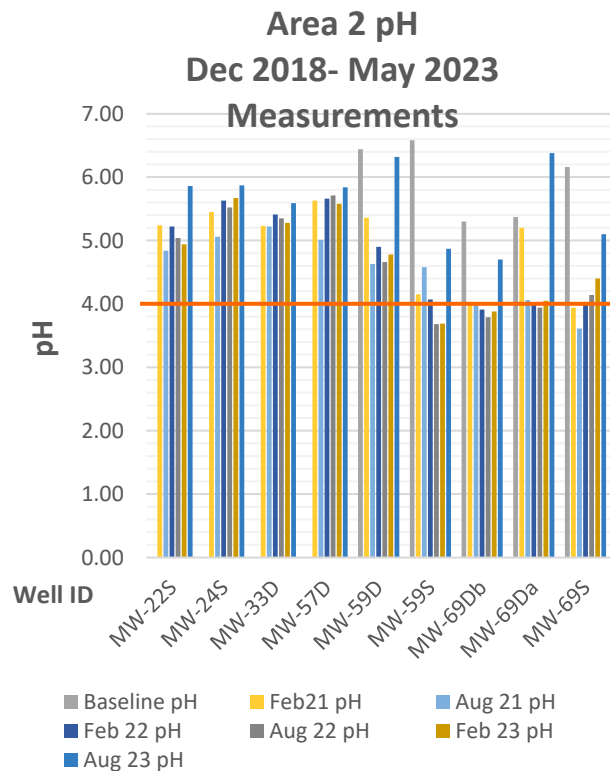
Results: ORP – Areas 1 & 2

- Area 1 - 275% increase in ORP (2019 to 2023)
- Area 2 - 50% increase in ORP (2019 to 2023)
- Variable results infers DO consumption and variable flowpaths
- Good correlation to DO data



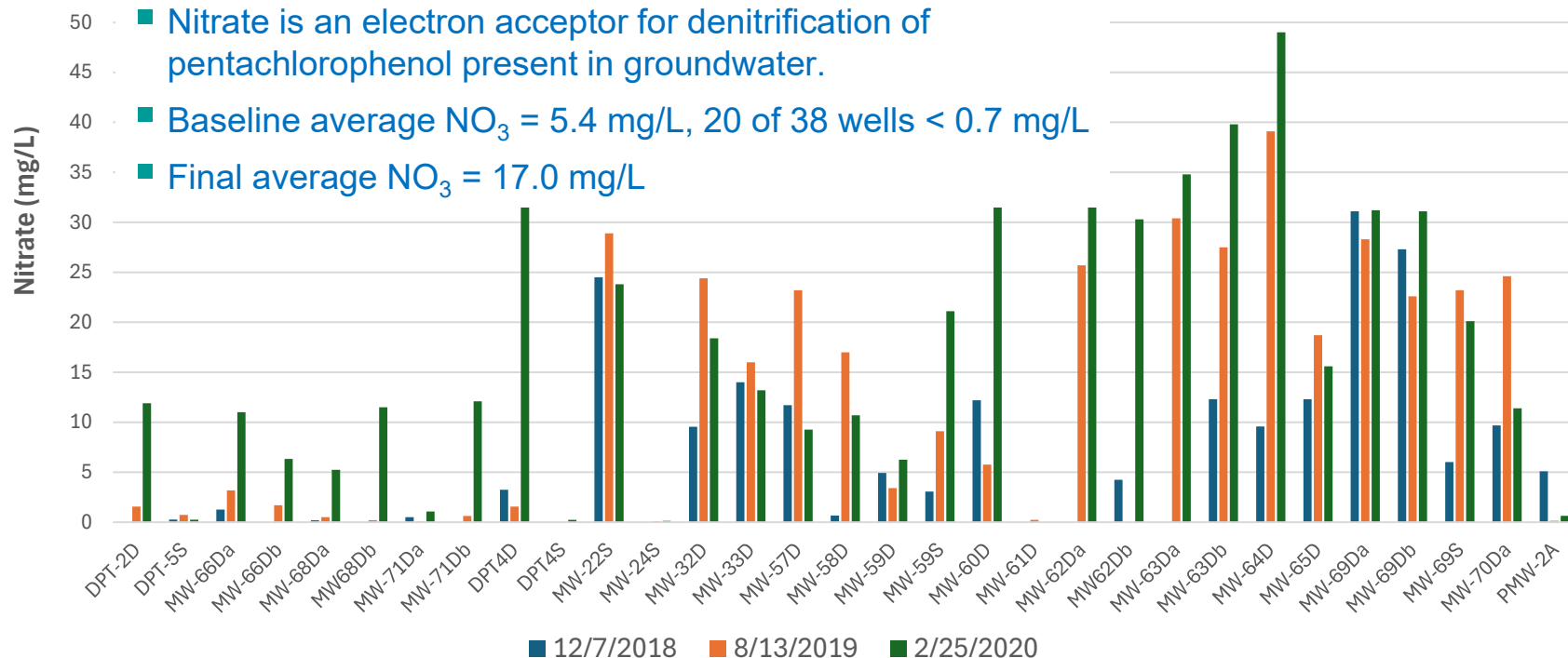
Results: pH – Areas 1 & 2

- Area 1/2 baseline pH ranged from 5.1 to 6.0
- Areas 1 and 2 Aug-23 pH averages 5.6 and 5.7, respectively
- Soil pH is low (~4.6)
- pH > 4 (ideally 5) needed for biodegradation
- => ■ Overall reduction in pH attributed to acidic biodegradation intermediate compounds and low alkalinity

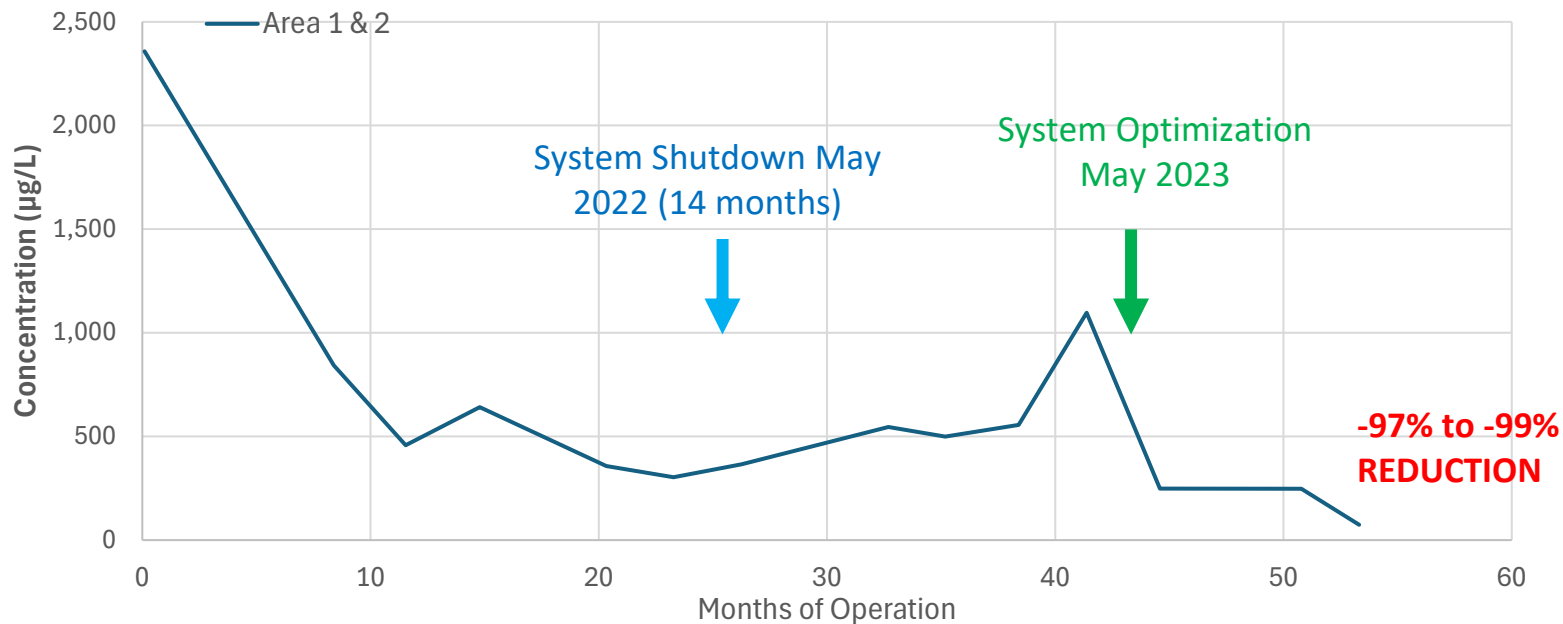


Nitrate Groundwater Concentration, Area 1/2

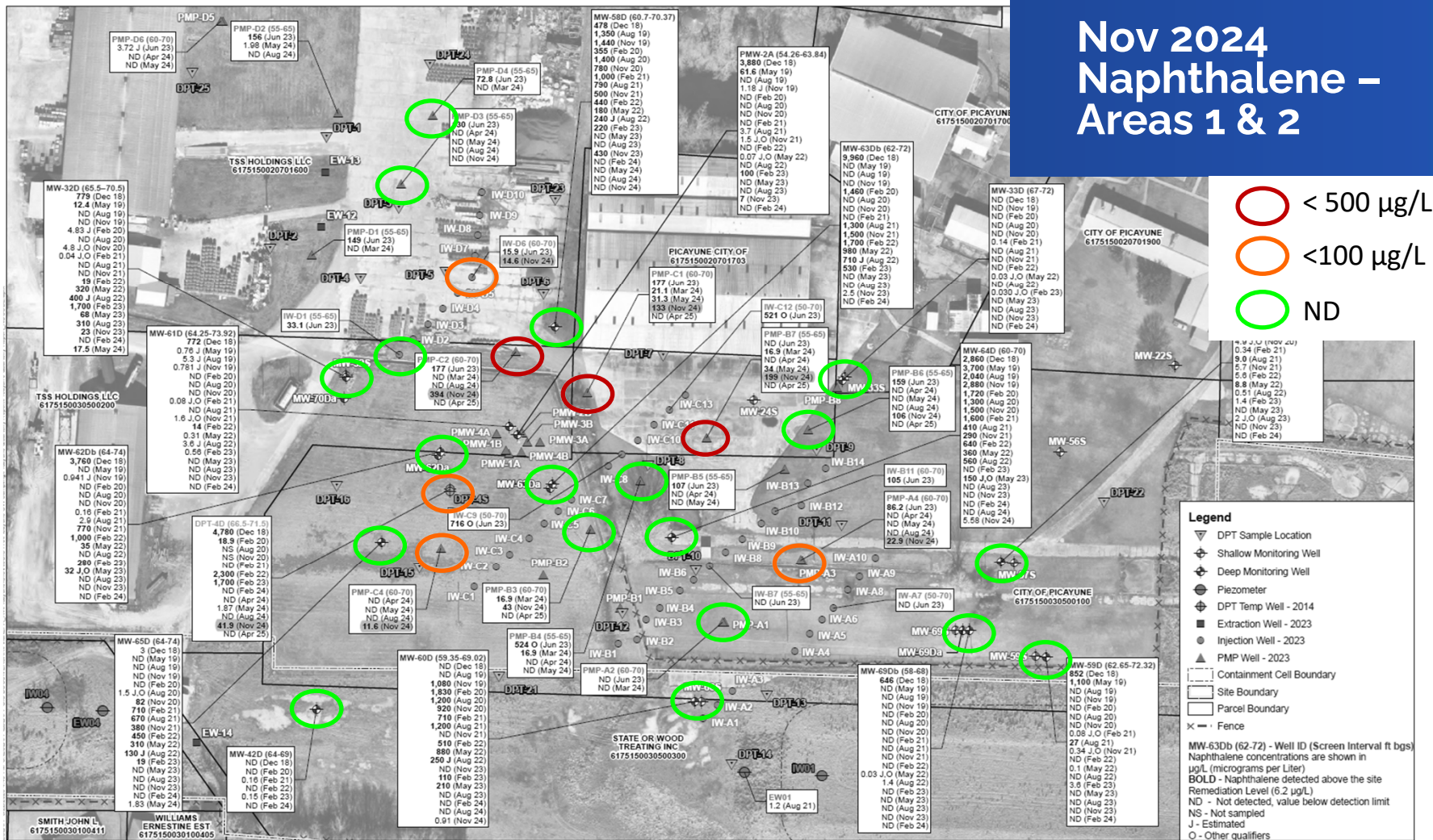
Nitrate (mg/L) 12/2018 to 02/2020



Average Dissolved Naphthalene Concentration

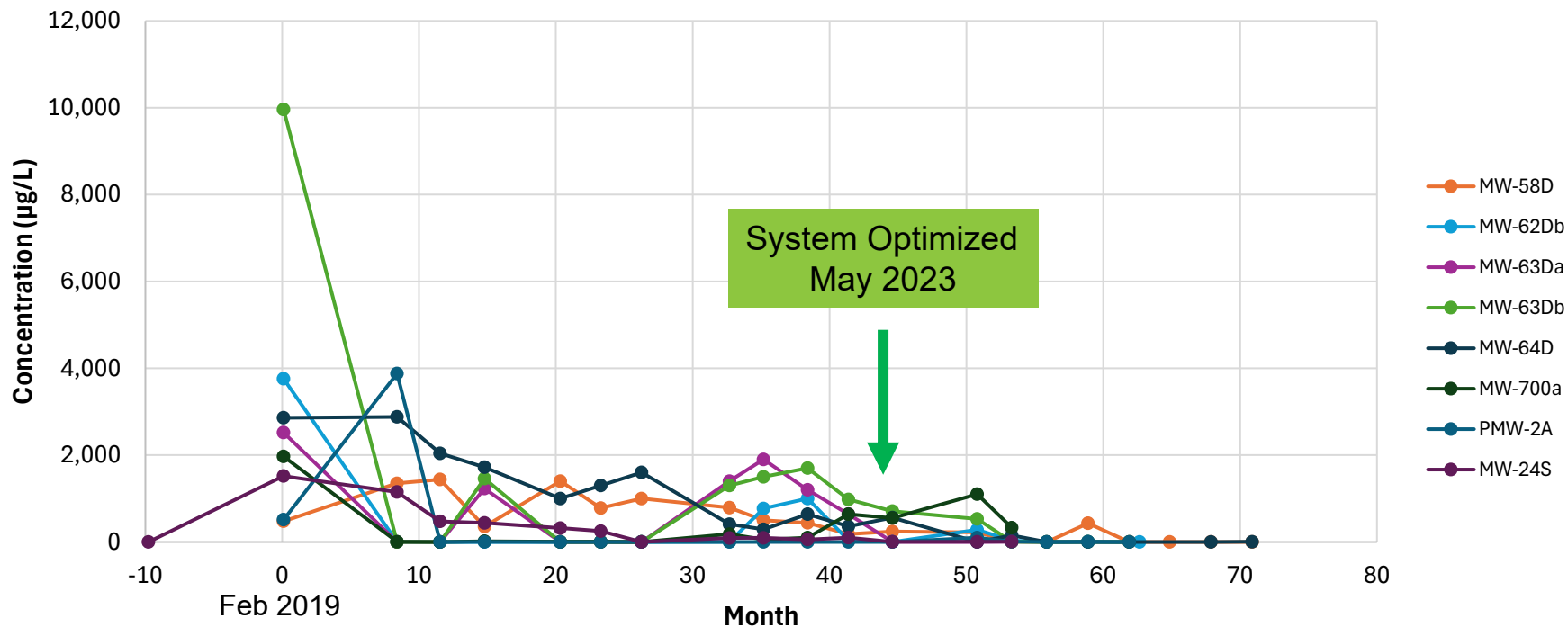


Nov 2024 Naphthalene – Areas 1 & 2



Results: Contaminant – Areas 1 & 2

Area 1 & 2 Naphthalene Concentrations



Successes

- Reduced naphthalene by 97% to 99% in all areas
- Achieved less than 100 µg/L naphthalene goal across the site
- Created oxidative conditions sitewide
- Delivered 28,000 lbs of dissolved oxygen
- Modifications to treatment layout greatly enhanced results
- Two (2) remedial systems provided operational flexibility

Challenges

- Inability to adjust pH to neutral
- Mineral fouling in Area 3 EWs and flow lines
- Large rebound at eastern end of Area 3 - Subsequent Investigation found unknown NAPL source

- Persistent rebound in Area 3 (MW-66A/B) following temporary shutdown confirmed presence of previously unknown source area NAPL stringers
- Use a stronger buffer to raise pH – sodium carbonate
- Long term profiling of PAH biological degrading bacteria and/or NAH analysis
- More detailed analysis of oxygen drift downgradient
- Importance of performance monitoring and system optimization

Questions

Contacts

Edward C. Hicks, PE, PMP

Senior Project Manager

Versar

ehicks@Versar.com

Kevin Moore

National Sales Director

ETEC, Inc.

kevin@etec.bio