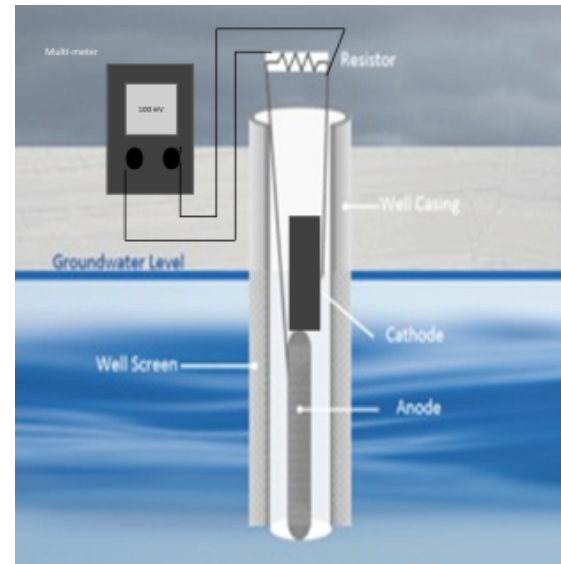


Sustainable Remediation via Bioelectrochemical System for a Petroleum Site

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Co-authors: Song Jin, Paul Fallgren (Advanced Environmental Technologies, LLC)

Aroona Boodram, Steven Sherman, Stewart Abrams (Langan)



CURRENT AND FUTURE SITE USE

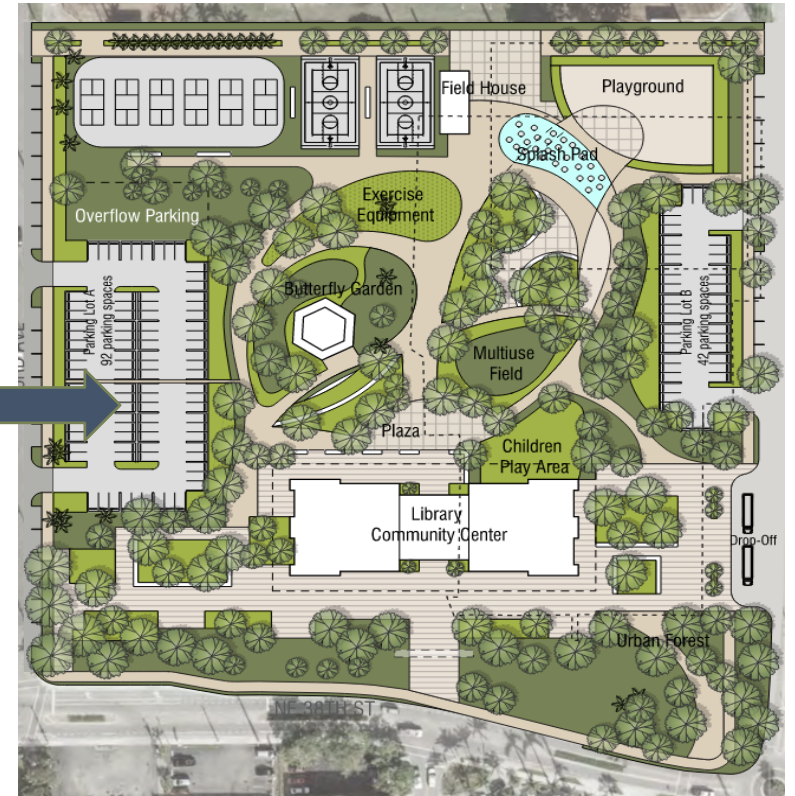
Public
Works



Public
Park

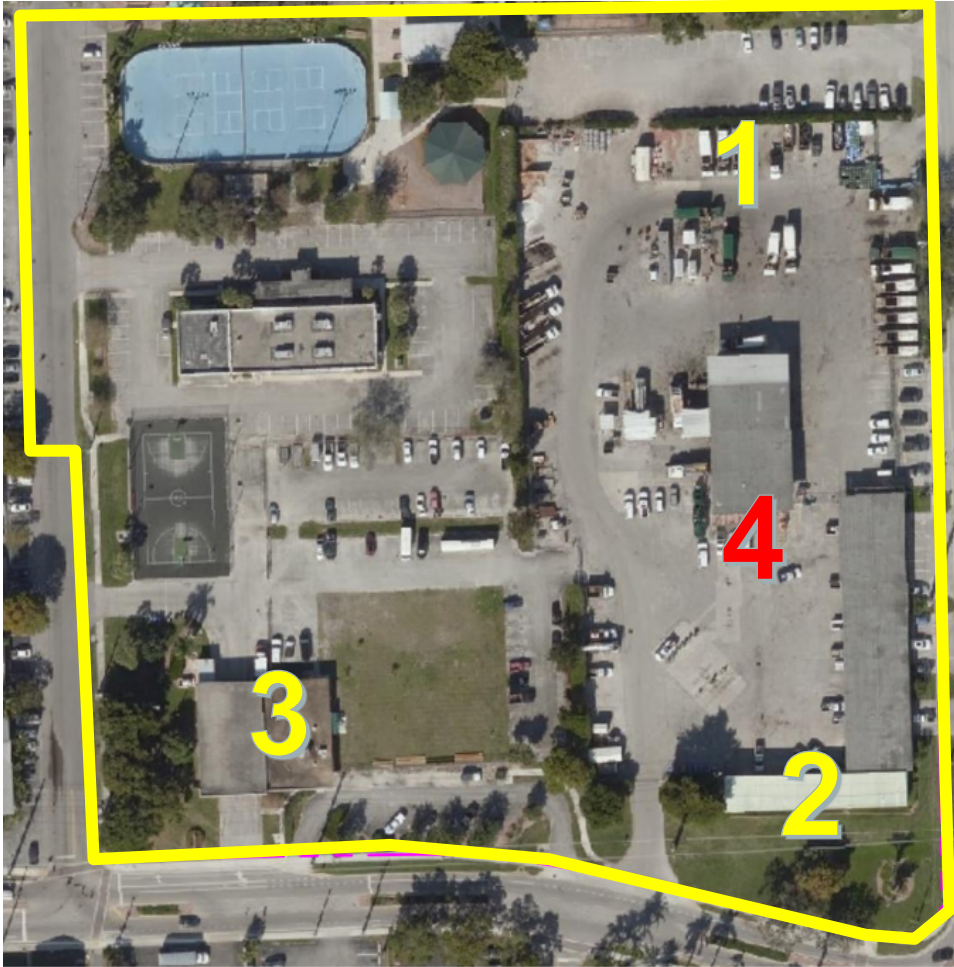


Current Use



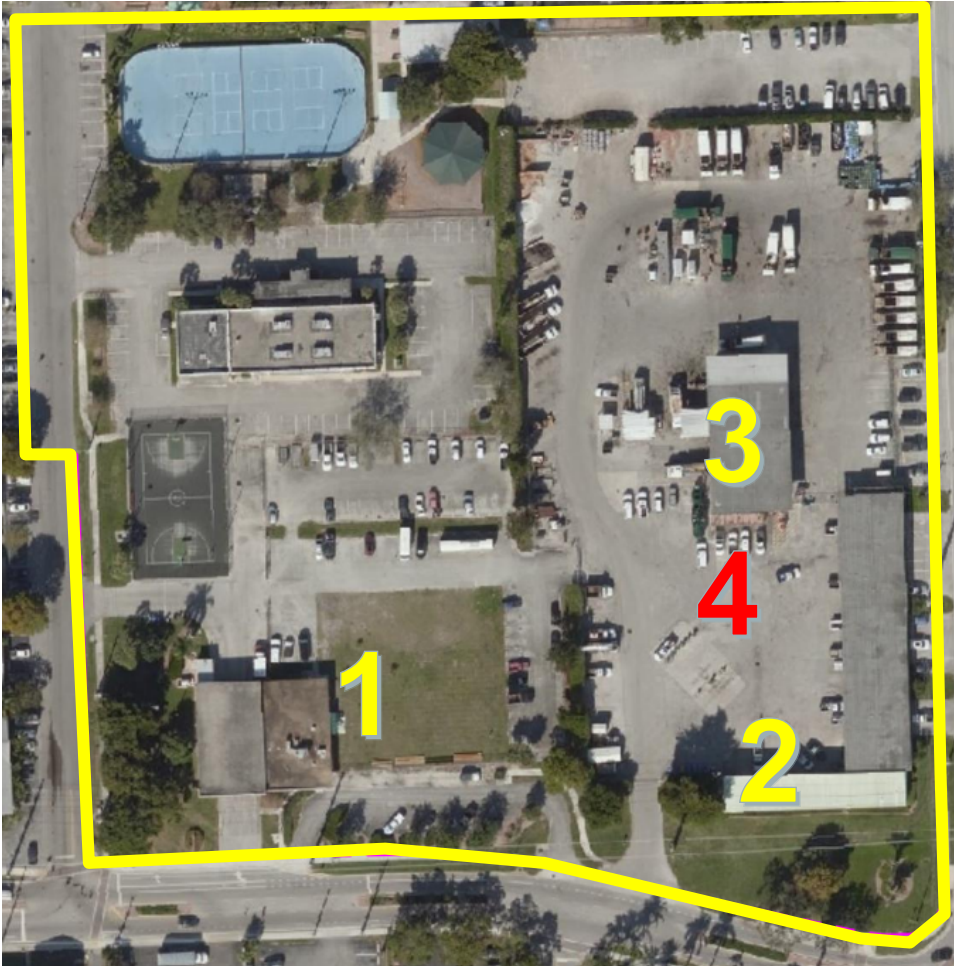
Future Use

SITE HISTORY



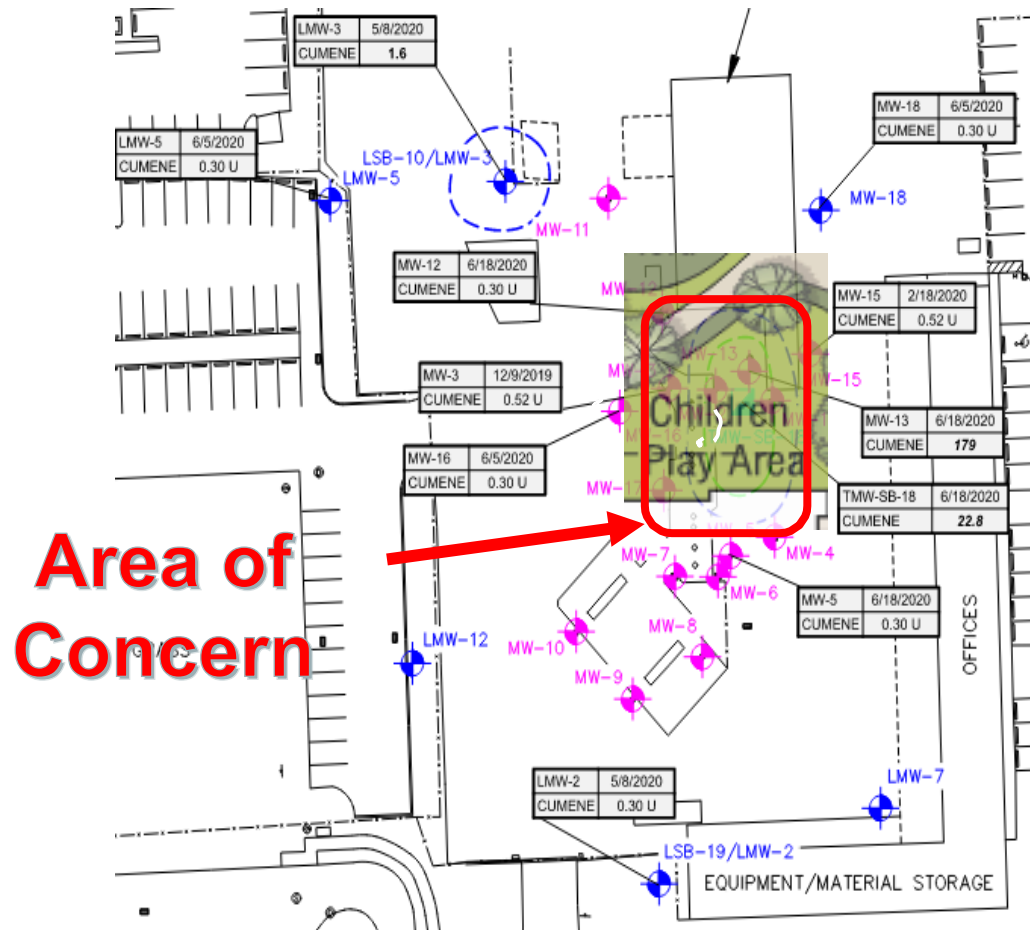
- 1 - Former Agricultural Land
- 2 - Equipment and Chemical Storage
- 3 - Fire Station No. 9
- 4 - Fleet Fueling and Maintenance

ENVIRONMENTAL HISTORY



- 1 - AFFF Discharge from fire fighter training area
- 2 - Arsenic groundwater plume from historic agrochemicals
- 3 - Oil discharge within maintenance bays
- 4 - Petroleum discharge from USTs

SITE ASSESSMENT FINDINGS



Source:

- 1987 Petroleum Discharge from Underground Storage Tanks

Contaminants:

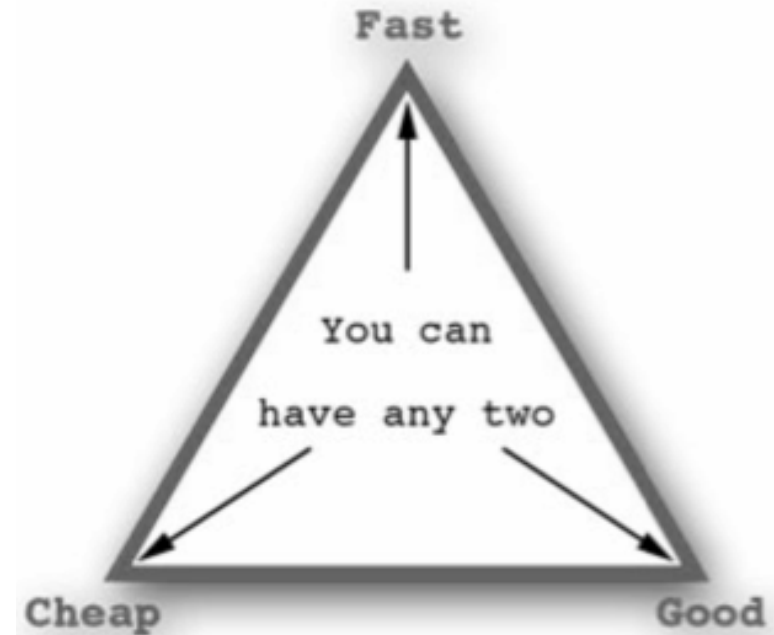
- Benzene, Toluene, Ethylbenzene and Xylenes (BTEX), and cumene
- Polycyclic Aromatic Hydrocarbons (PAH) - Naphthalene and 1- and 2-methylnaphthalenes

Groundwater:

- No discernable groundwater flow
- 2-4 ft below ground surface

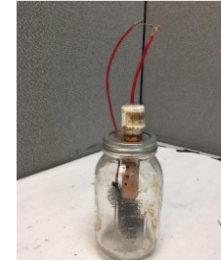
REMEDIATION GOAL

- Remediate BTEX and PAH
- Minimize interference with fleet operations
- Low-cost solution
- Cleanup in 5 years



TREATABILITY STUDIES

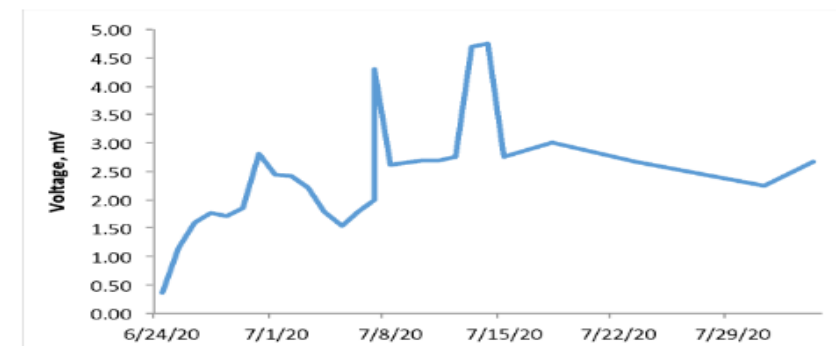
- Chemical Oxidation
 - Alkaline activated persulfate to determine soil oxidant demand (SOD) and oxidation effectiveness test.
- Limited Effectiveness:
 - Naphthalene and methylnaphthalenes were not treated.
 - Mobilized aluminum, arsenic and lead from soil into the groundwater
- E-Redox®
 - Bench-scale testing conducted at Advanced Environmental Technologies, LLC (AET) facility in Fort Collins, Colorado.



Example bench-scale E-Redox® test unit

Date	Days	Naphthalene, ug/L		1-Methylnaphthalene, ug/L		2-Methylnaphthalene, ug/L	
		Control	E-Redox	Control	E-Redox	Control	E-Redox
6/24/2020	0	9.1	9.1	4.8	4.8	4.4	4.4
7/7/2020	13	3.0	<0.1	1.3	<0.1	1.2	<0.1
7/28/2020	34	93	< 5	NA	NA	NA	NA
8/3/2020	40	52	<1.1	34	<1.1	46	<1.1

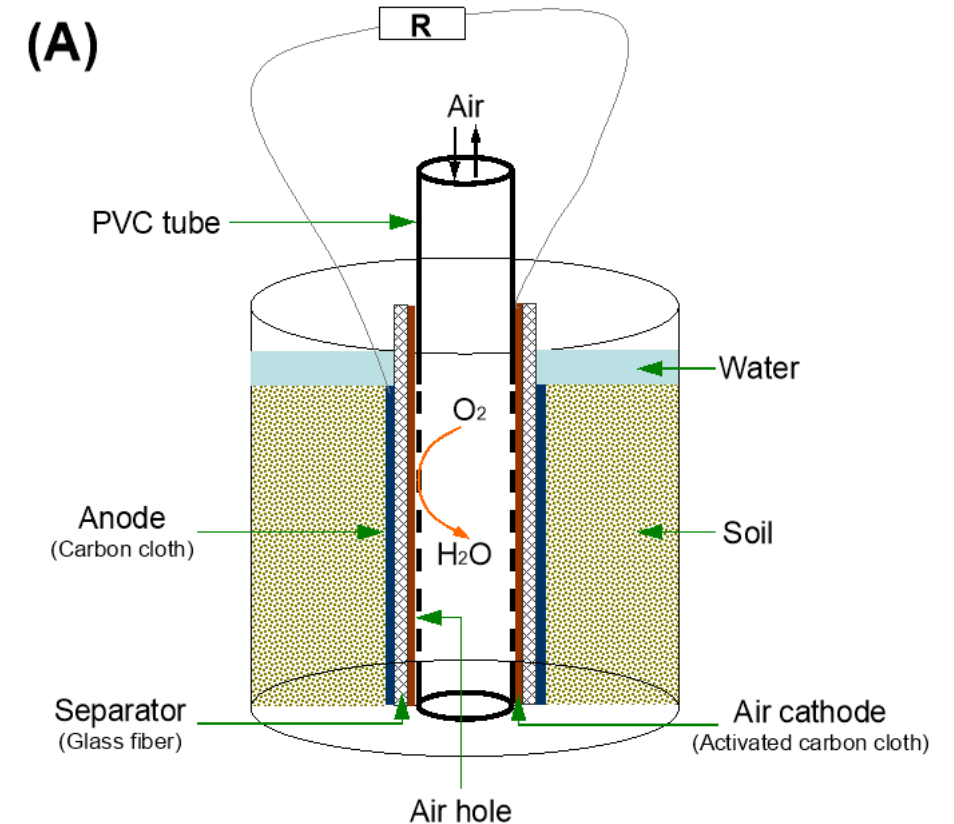
PAH in groundwater from bench-scale Reactor (NA = Not Analyzed)



Voltage product from bench-scale E-Redox® Device

WHAT IS E-REDOX[®]

- E-Redox[®] is an electrochemically induced oxidation-reduction technology patented by Advanced Environmental Technologies (AET).
- E-Redox[®] technology is patented in Australia, China, Canada, and USA

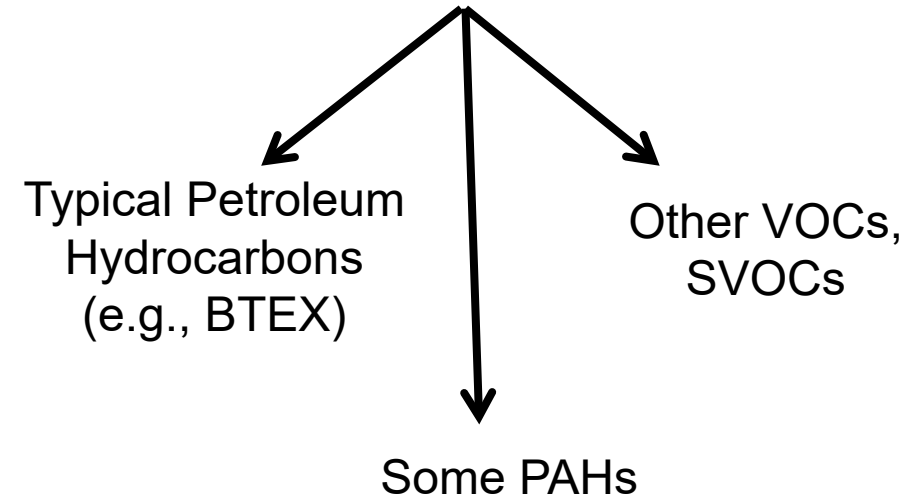


WHAT IS E-REDOX[®]

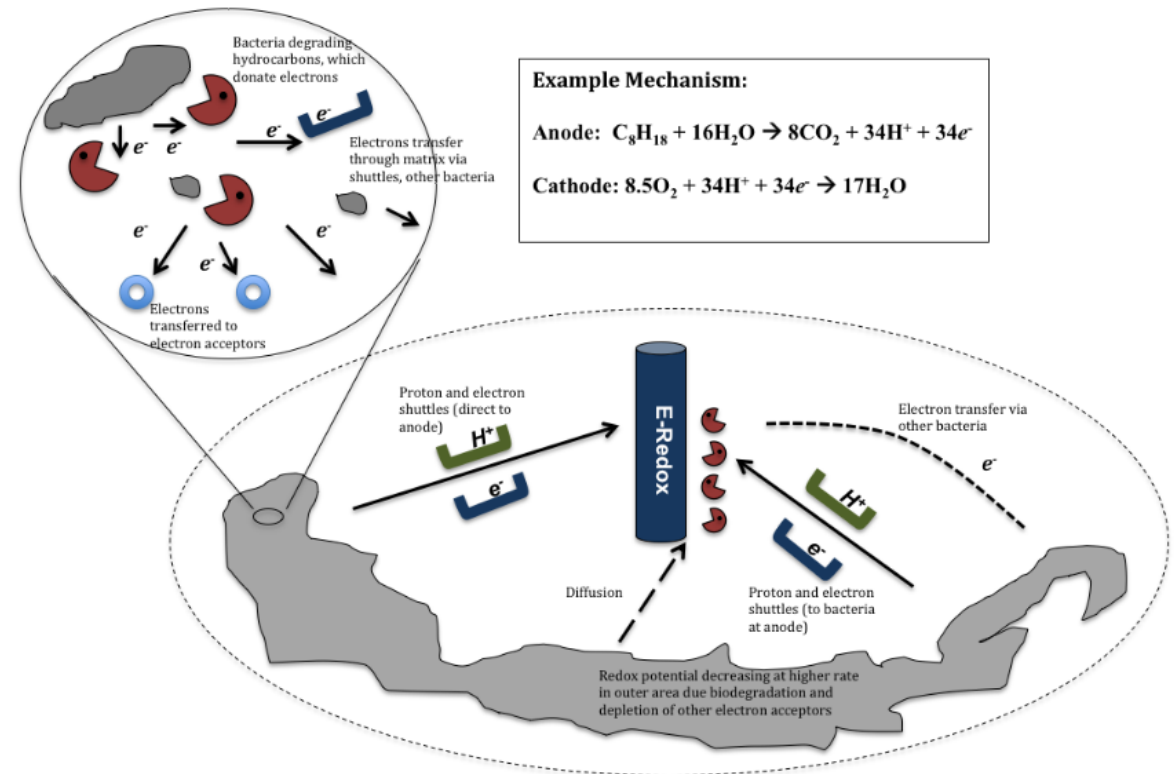
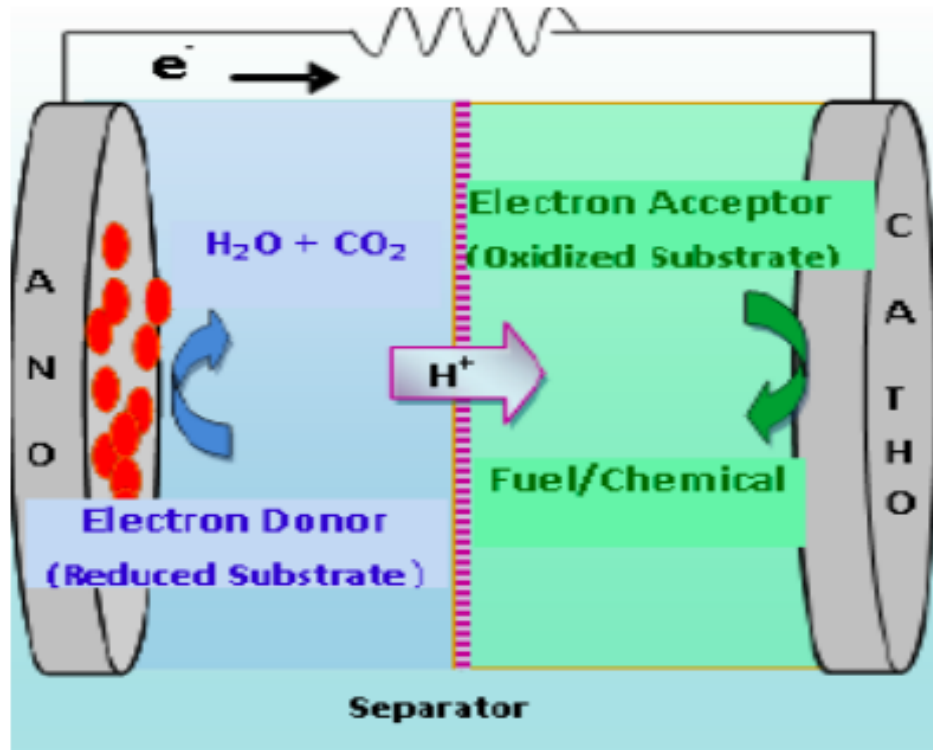
- E-Redox[®] -O is one class of E-Redox[®] based on oxidative reactions.
- E-Redox[®] -O provides an electron receptor, and generates a low voltage electron current by removing electrons regenerated during bioremediation

Boost
bio(oxidative)degradation

E-Redox[®] (Ox)



E-REDOX[®] MECHANISMS



OPERATIONS AND MAINTENANCE

Routine Procedures:

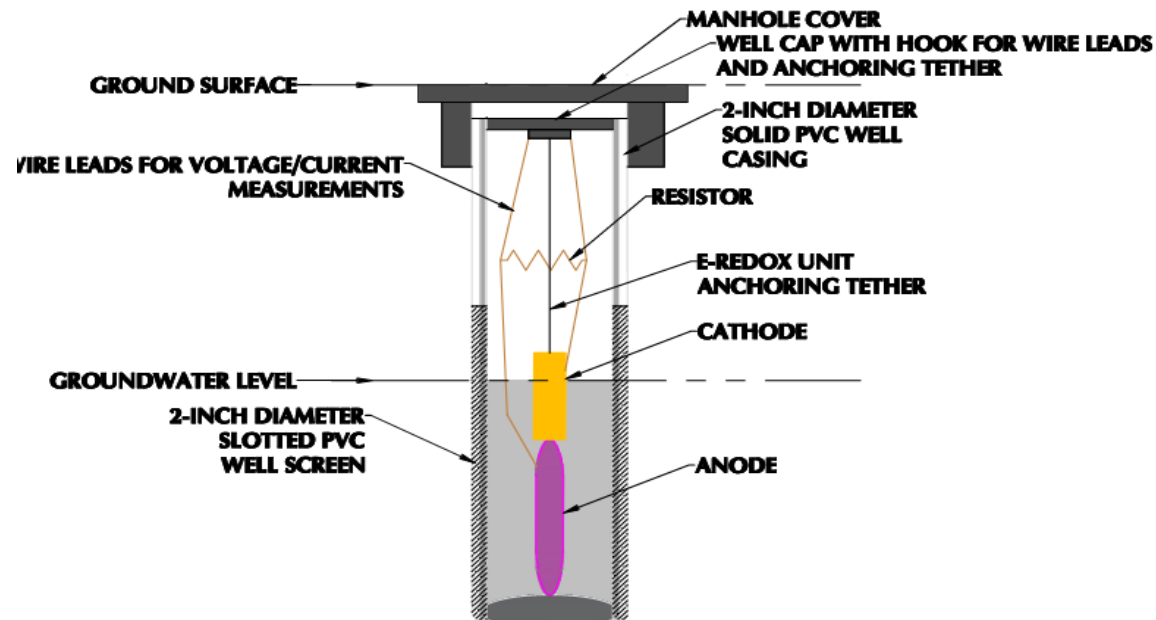
- Voltage profiles in the E-Redox® device are a real-time in situ tool for monitoring of biodegradation and potential deficiencies – **BioRemeter™**
- Monthly O&M includes collecting voltage readings and visually inspecting cathode and anode conditions.
- Quarterly O&M includes collecting groundwater samples.
- Low voltages may be a result of fouling of the cathode from biofilm overgrowth, which blocks the reactive surfaces.
- Cathodes may be replaced quarterly when



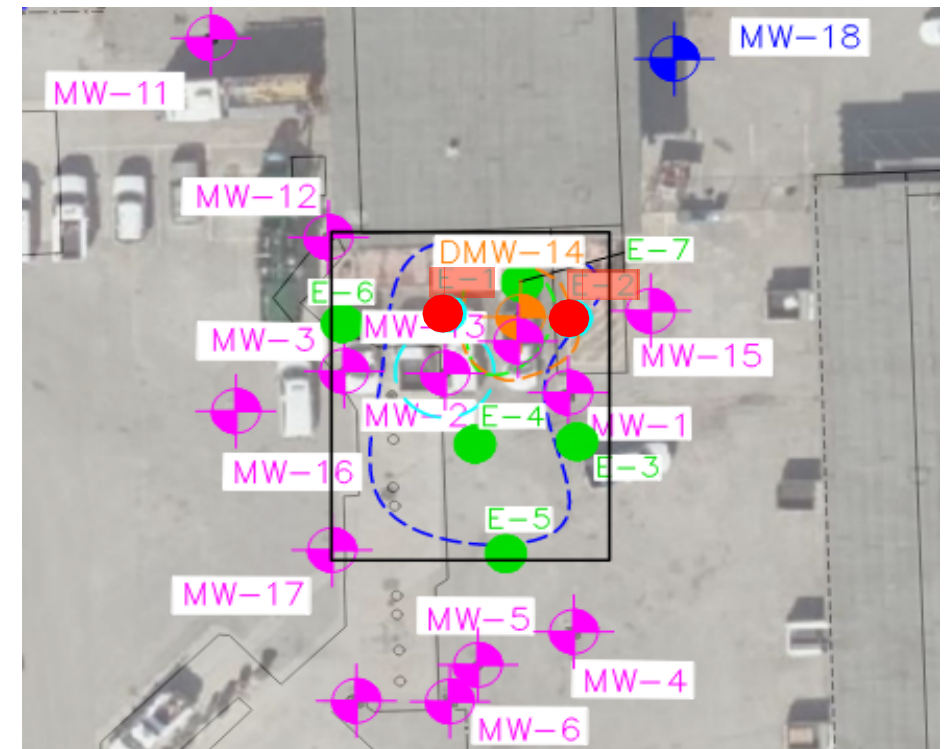
Broken connection between anode and cathode.

E-REDOX[®] PILOT STUDY

- Two E-Redox[®] units (E-1 and E-2) were installed near the well with highest concentrations (MW-13) to demonstrate field effectiveness over one year.



E-Redox[®]
Setup

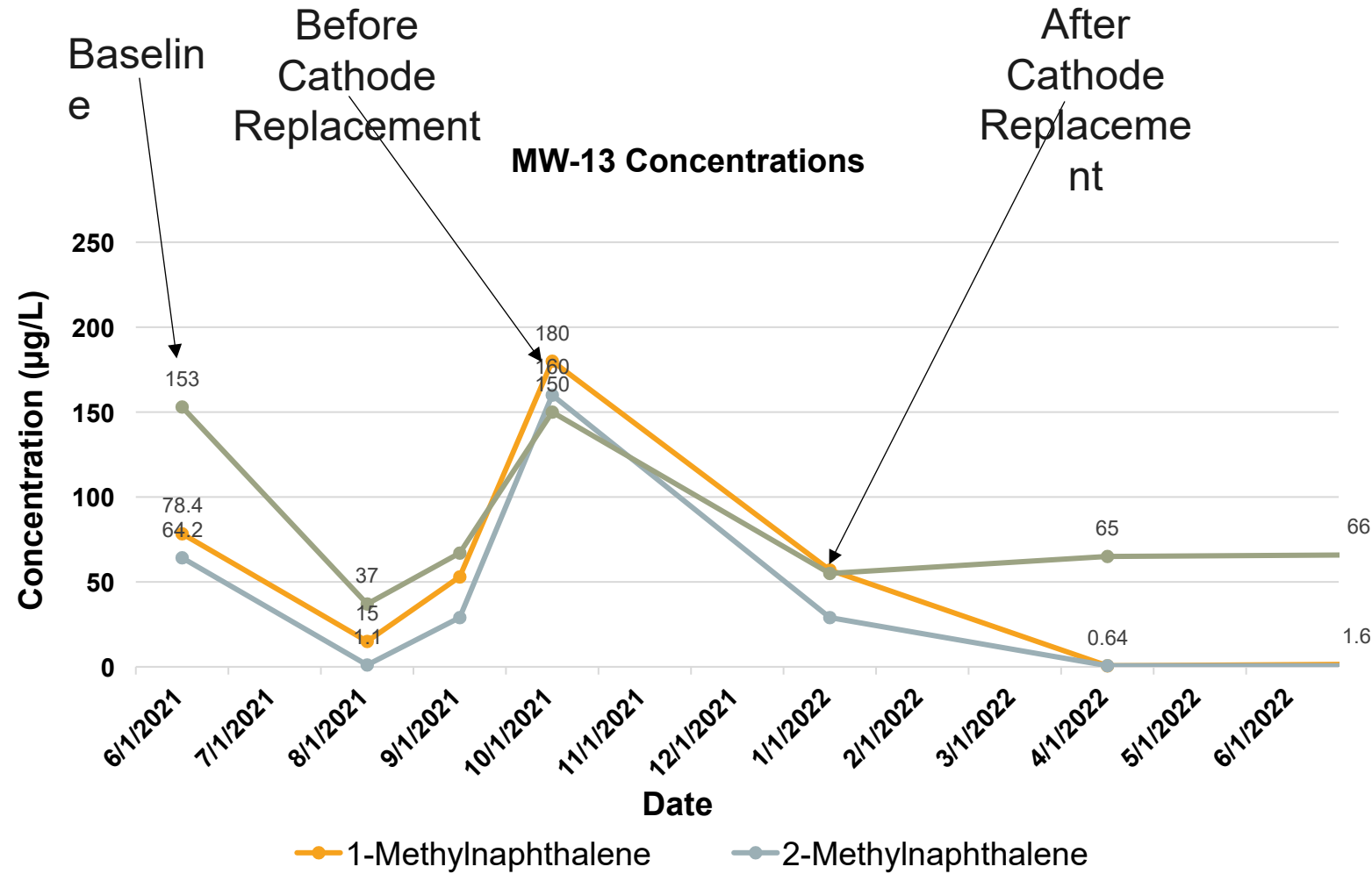


Pilot Test Well
Diagram

E-REDOX® PILOT STUDY

Performance Monitoring:

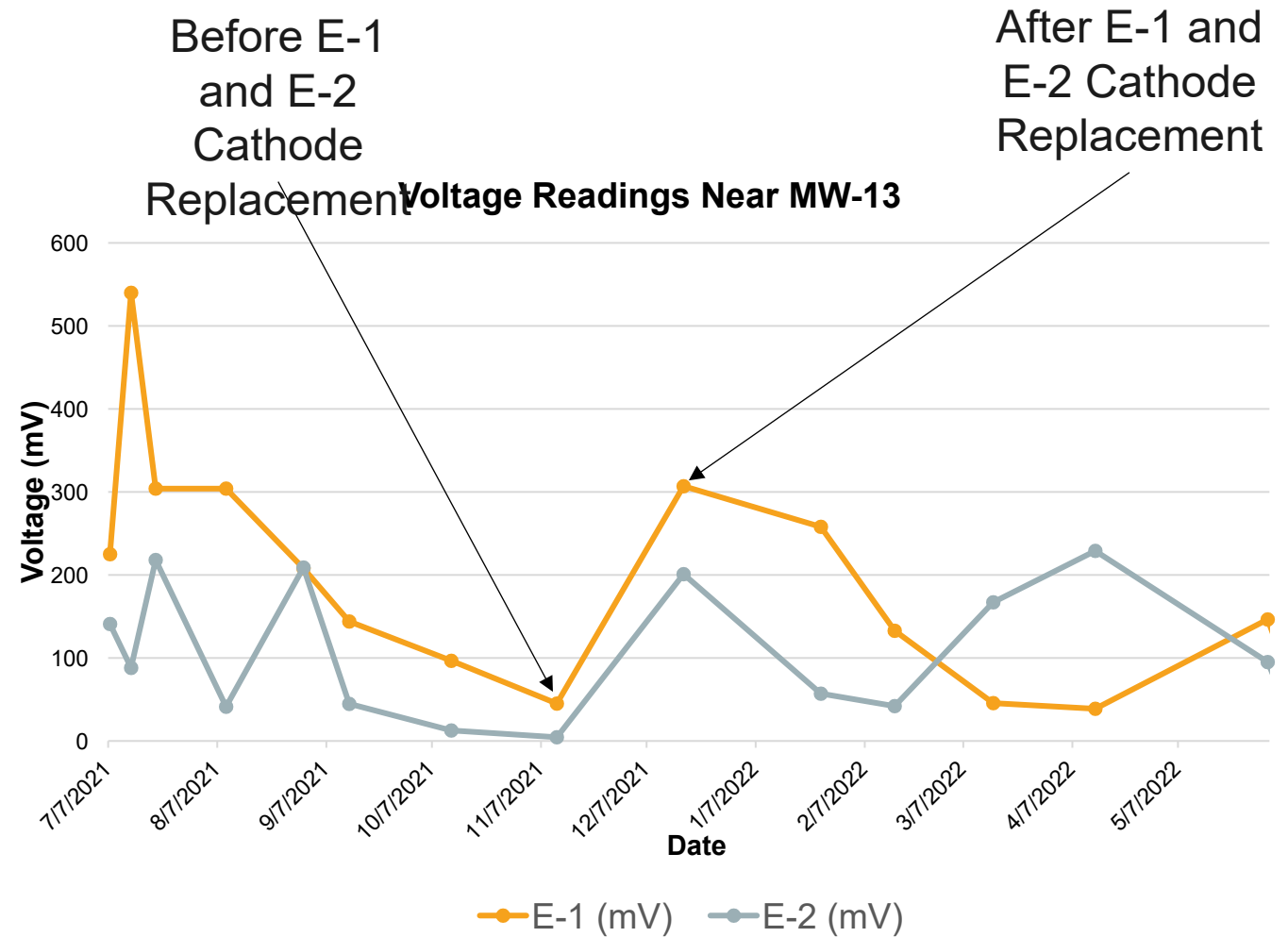
- Baseline and quarterly for one year.
- Petroleum compounds decreased in MW-13 during first sampling event
- Petroleum compounds increased during the second and third monthly sampling events in September and October 2021.
- Improved results and voltage



E-REDOX[®] PILOT STUDY

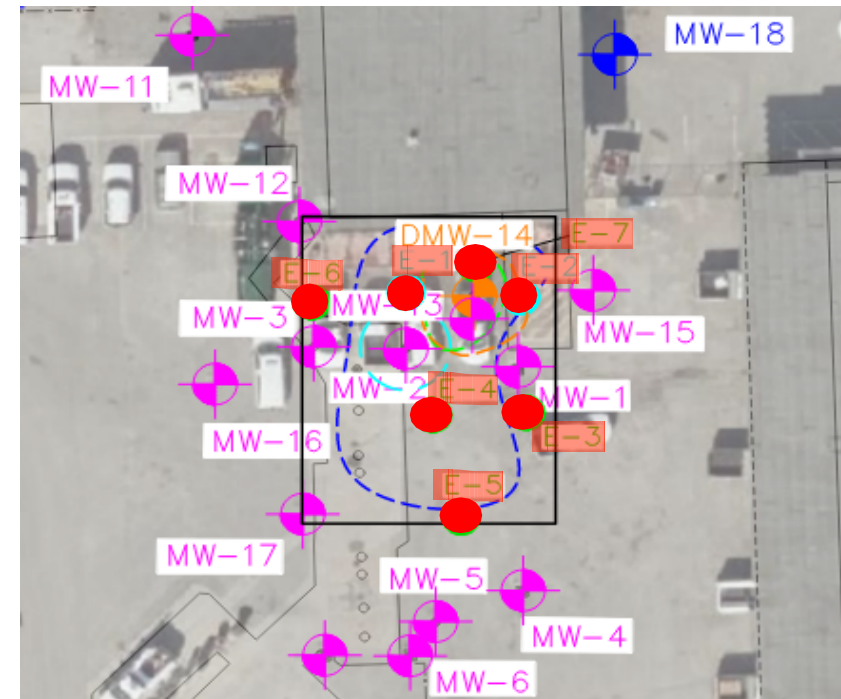
Performance Monitoring:

- Steady voltage decline over time
- Improved results and voltage after cathode replacement.



E-REDOX® FULL SCALE IMPLEMENTATION

Five additional E-Redox® units (7 total) installed with approximate spacing of 20 feet between each unit.



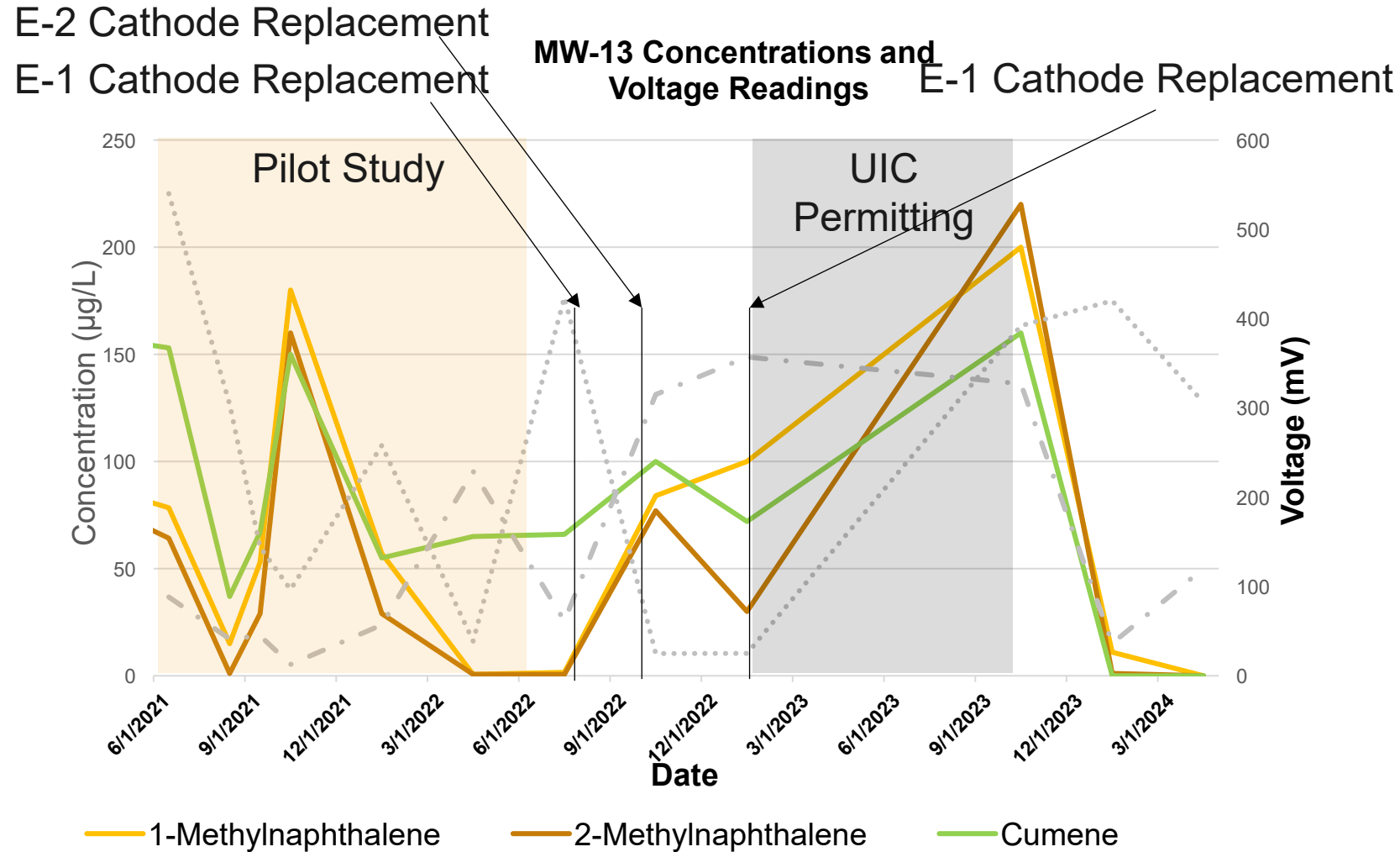
E-REDOX[®] FULL SCALE IMPLEMENTATION

Challenge:

- Decrease in voltage and therefore effectiveness of the E-Redox[®] unit.

Solution:

- Periodic replacement of cathodes



NUTRIENT ADDITION AND UIC PERMITTING

Permitting:

- Underground Injection Control (UIC) Permit from Florida Department of Environmental Protection (FDEP).
- Permit requires leachability testing of raw material for impurities including metals, nitrates, sulfate, bromide, and fluoride and approval by FDEP Innovative Technology Group.
- Quarterly groundwater monitoring of Zone of Discharge around treatment area based on leachability testing results and FDEP Innovative Technology Group requirements.

Approved Nutrient Addition:

- Addition of diammonium phosphate (DAP) and potassium chloride to E-Redox[®] wells.
- Dosage requirements based on 1.4 to 1.8 pounds of DAP per 1,000 cubic feet of water and the volume of water estimated in treatment area.
- Total of 26 pounds of DAP and 3 pounds of potassium chloride is diluted with 100 pounds of water (12 gal



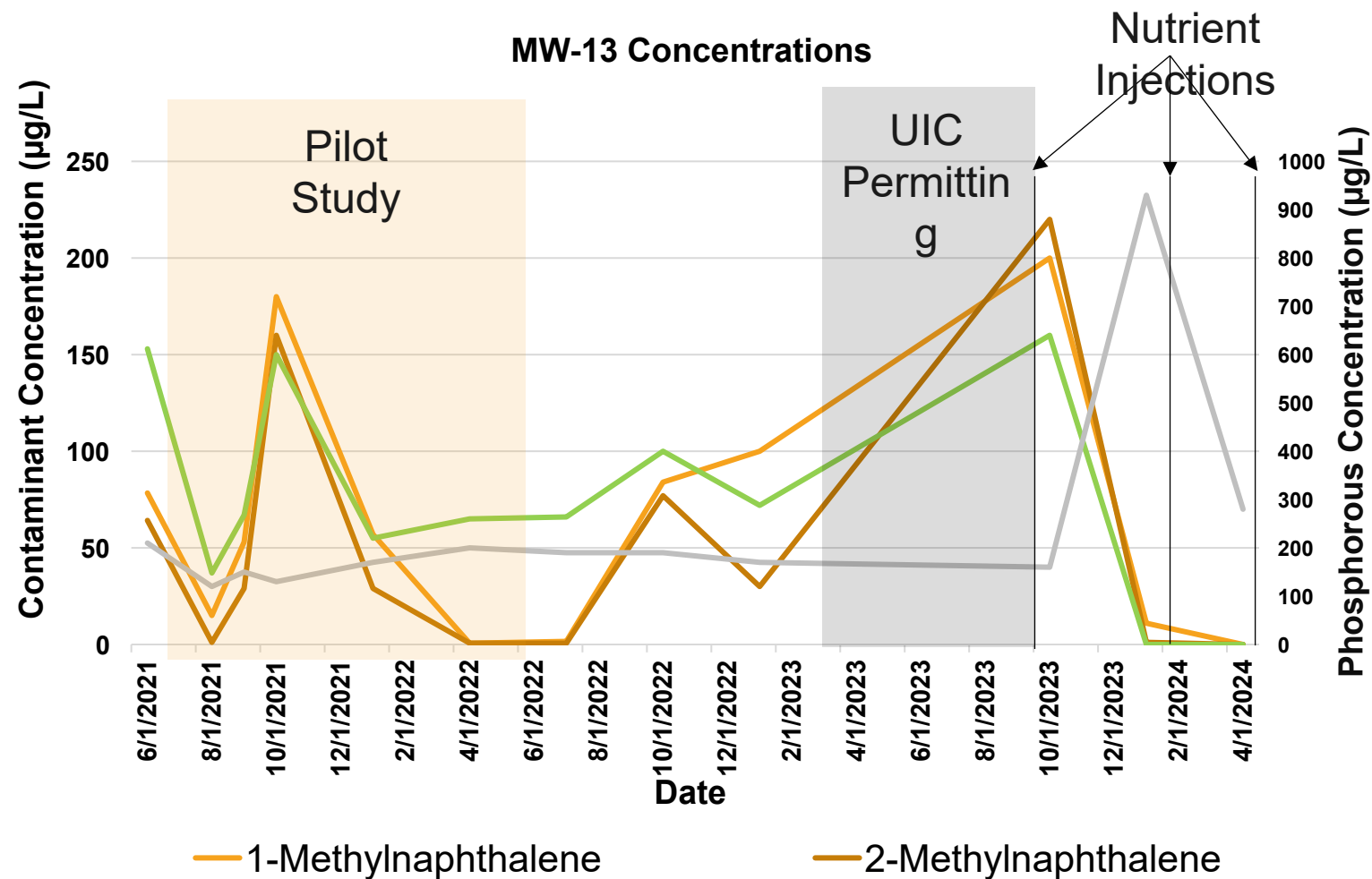
E-REDOX[®] ENHANCED IMPLEMENTATION

Challenge:

- Depletion of nutrients essential for biodegradation.

Solution:

- Addition of diammonium phosphate (DAP) and potassium chloride to replenish nutrient levels in the treatment area



SUSTAINABILITY

TOTAL CO2 EMISSIONS



E-Redox[®]

- 1.07 metric tons, primarily from transportation

Chemical Oxidation

- 23.53 metric tons, primarily from equipment operation

Air Sparge & Soil Vapor Extraction

- 6,117 metric tons, primarily from equipment operation

CONCLUSIONS



A sustained decline in contaminant concentrations can be achieved with E-Redox® (0x).



More robust groundwater monitoring and O&M should be considered for innovative technologies



Understanding the native biochemical system is key to success.



Innovation = New challenges

THANK
YOU!

QUESTION
S?