

Chemical vs. Biological Oxidation

– Key Selection Criteria and Case Studies using a Combined Approach

Josephine Molin & Brant Smith, Nordrocs, September 15, 2026

Josephine Molin

Technology Applications
Manager, ISCO

Evonik Corporation | Soil &
Groundwater

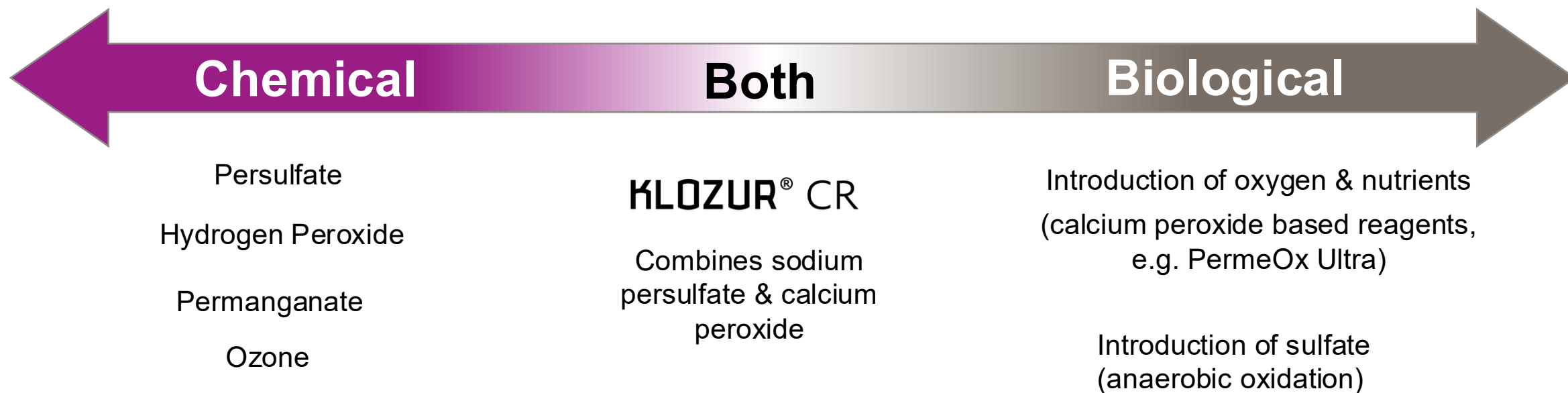


Oxidative Technologies

- In situ chemical oxidation (ISCO) and enhanced aerobic bioremediation (EAB) are two of the most widely used remediation technologies
- Both technologies are based on adding electron acceptors into the subsurface:
 - ISCO → direct oxidation by thermodynamically powerful oxidants, such as for example persulfate
 - EAB → uses microbes to facilitate the reaction typically with oxygen as the electron acceptor
 - Anaerobic Oxidation → biological reaction using sulfate as the electron acceptor
- For the treatment of petroleum hydrocarbons or other contaminants that can be treated directly by ISCO or biologically via an oxidative pathway, either technology could be considered from a chemical efficacy standpoint, and technology selection often comes down to other factors
- In many cases, it can be advantageous to combine ISCO and Biological Approached, either in sequence, together or for targeting different portions of a site.
- This presentation will review key selection criteria, using case studies as examples

Oxidative Technologies

- Basic principle:
 - Oxidants are reagents that accept/take electrons from, or oxidize, contaminants of concern → CO₂
- The reaction can be chemical or biologically mediated:



Contaminants Treated by ISCO vs. Biological Oxidation

	ISCO (Alkaline Activated Persulfate)	Aerobic Bioremediation (Oxygen)	Anaerobic Oxidation (Sulfate)
Petroleum Hydrocarbons	Yes	Yes	Some
BTEX	Yes	Yes	Yes
PAHs	Yes	Yes	Short chain
Oxygenates (MTBE)	Yes	Yes	
Chlorinated Solvents	Yes	DCE, VC	
Chlorobenzenes	Yes	MCB	
Chlorophenols	Yes	Yes	
PCB	Yes		
Pesticides	Yes		
Energetics	Yes		

Chemical vs. Biological Oxidation Attributes

Chemical

- Thermodynamically more powerful
- Faster reactions / reaction kinetics
- More oxidative mass per application
- More cost effective for treating higher concentrations
- Ideal for fast mass removal / source zones

Biological

- Treatment typically over extended time frame
- Ideal for plume polishing / achieving low remedial goals
- Less reactive with soil organics → increasingly cost effective for lower concentrations

Combined Remedy: How can ISCO and Bioremediation be Combined?

- Bioremediation occurring naturally following ISCO
 - *E.g.* anaerobic oxidation following persulfate
- ISCO and Bioremediation reagents mixed together and applied in a single application
- ISCO and Bioremediation reagents applied separately either Sequentially or Spatially
 - Sequentially: Typically, start with ISCO for mass removal and follow with bio for polishing
 - Spatially: Typically, ISCO at the source and bio for the plume

Importance of Monitoring Program

Many ISCO Monitoring Programs are not designed to account for likely biotic component. Need to Monitor for:

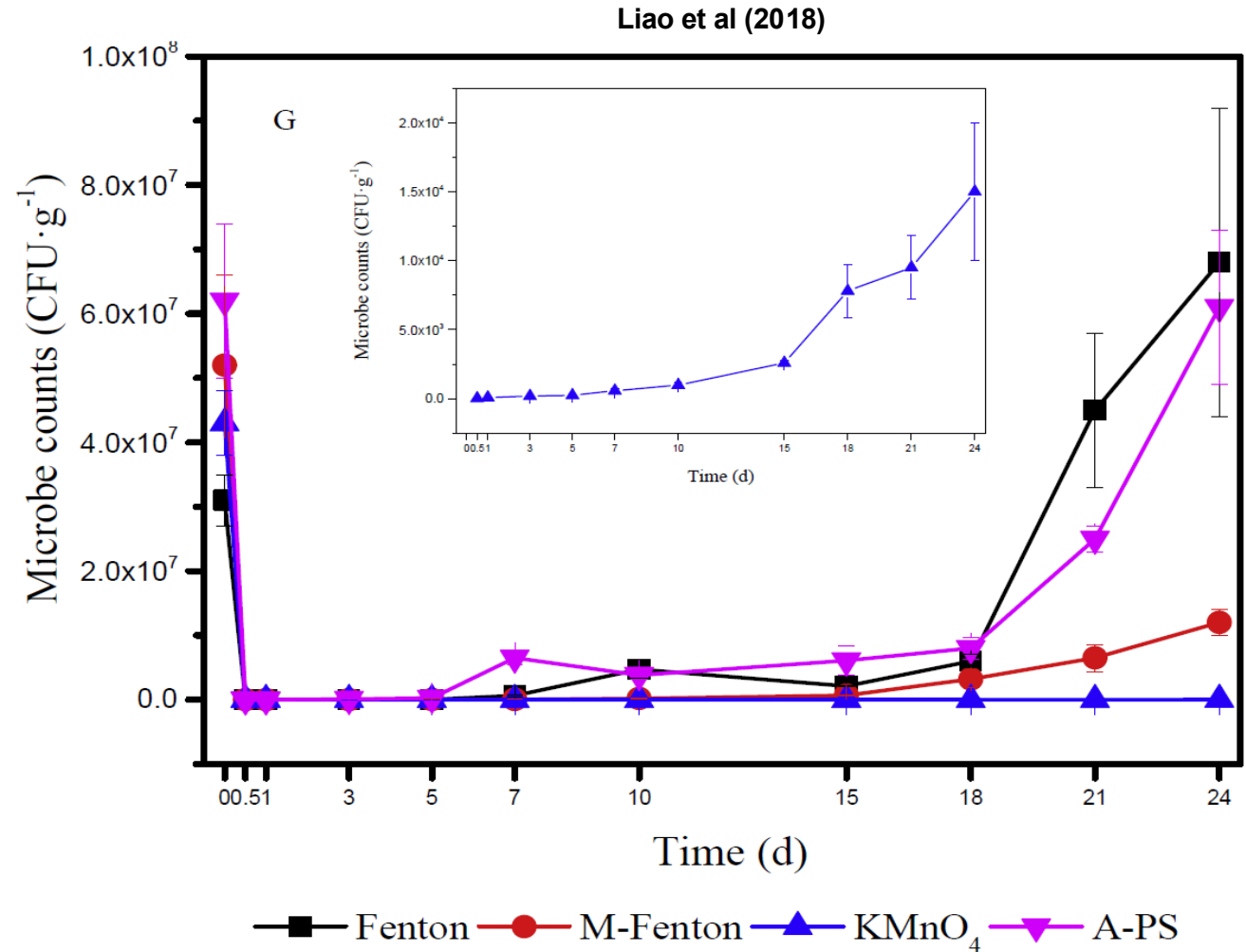
- **Biotic Activity**
- **Appropriate Time Period**
- **Key Parameters**

ISCO's Effect on Microbial Populations

- ISCO does not sterilize soils
- Common to see:
 - Dip followed by recovery
 - Decrease in diversity

Sahl & Munakata-Marr (2006) found:

- 13 different studies where microbial population or biotic treatment was enhanced following ISCO
- Effects observed ranged from immediate to 1 year



Natural Bioremediation Following Persulfate Application

Anaerobic Oxidation

- TPH site in New York City

- Contaminated with GRO (C6-C12), DRO (C10-C26), Benzene and Naphthalene
- Alkaline activated sodium persulfate
- 33,000 Kgs of Klozur® SP

- Post ISCO:

- Site became reductive
- Sulfides detected
- Contaminant treatment continued

Sampling Event (Months)	BTEX (ug/L)	Nap (ug/L)	SP (g/L)	ORP (mV)	Sulfide (mg/L)	Sulfate (mg/L)
Baseline	3,000	170	0	-100	0	0
Application			Up to 140	Up to 350		
6	500	30		-120	1.2	8,500
9	300	20		-140	2.8	5,000
12	180	15		-110	0	4,000

Anaerobic Oxidation

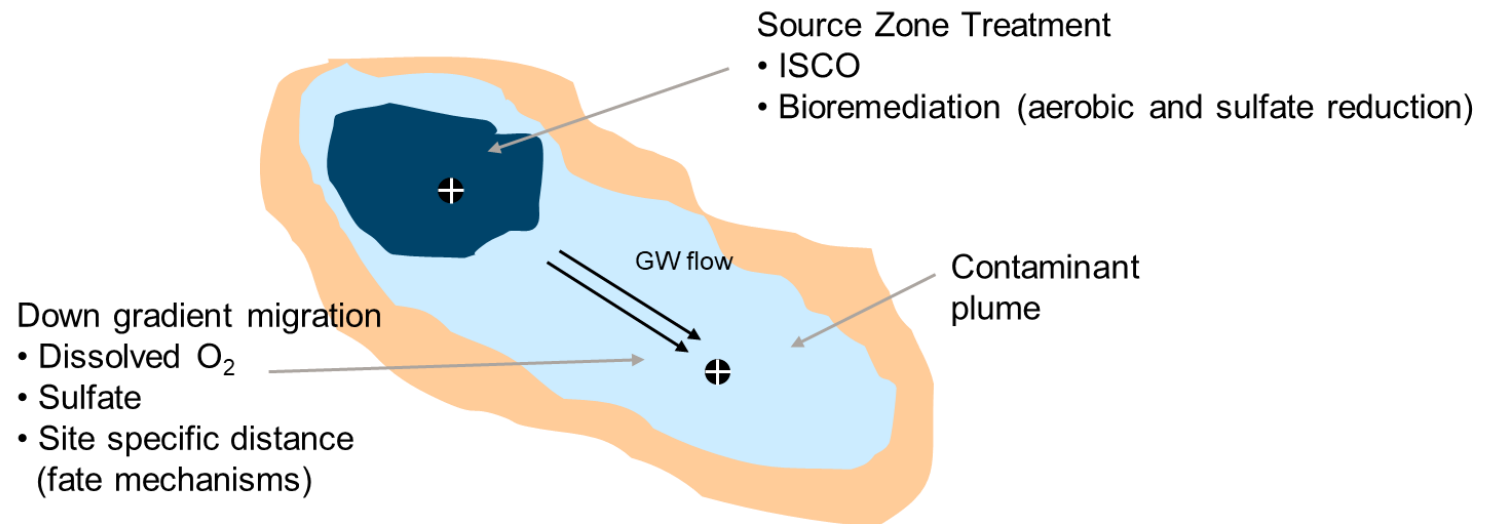
- Sulfate used as electron acceptor
- Contaminant is electron donor

ISCO and Bioremediation In a Single Product: Klozur® CR

- Klozur® CR is a 50/50 blend of Klozur® SP (sodium persulfate) and PermeOx® Ultra (calcium peroxide)
- “CR” = Combined Remedy
- PermeOx® Ultra activates the sodium persulfate (high pH & H_2O_2 activation)
- Initial fast mass reduction via ISCO followed by extended polishing via bioremediation
- Ideal for moderate concentrations and for meeting low remedial goals

Three remedial pathways in single application:

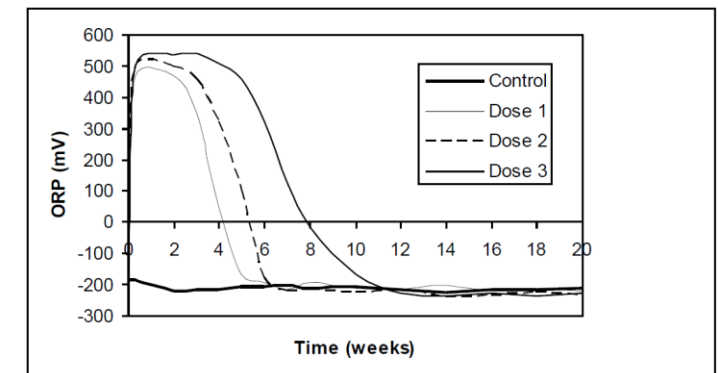
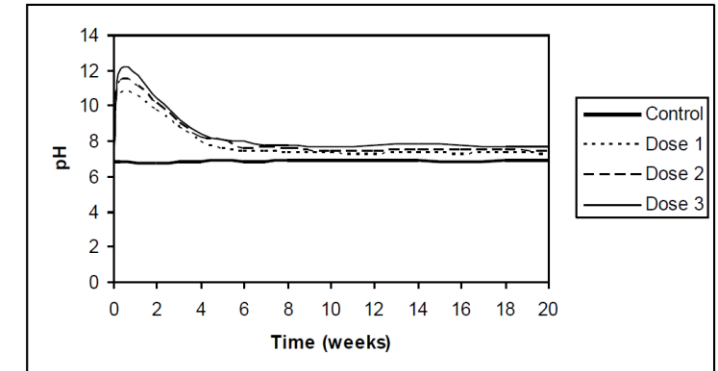
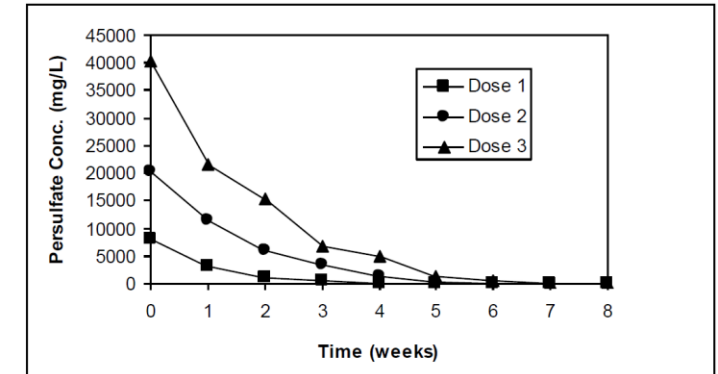
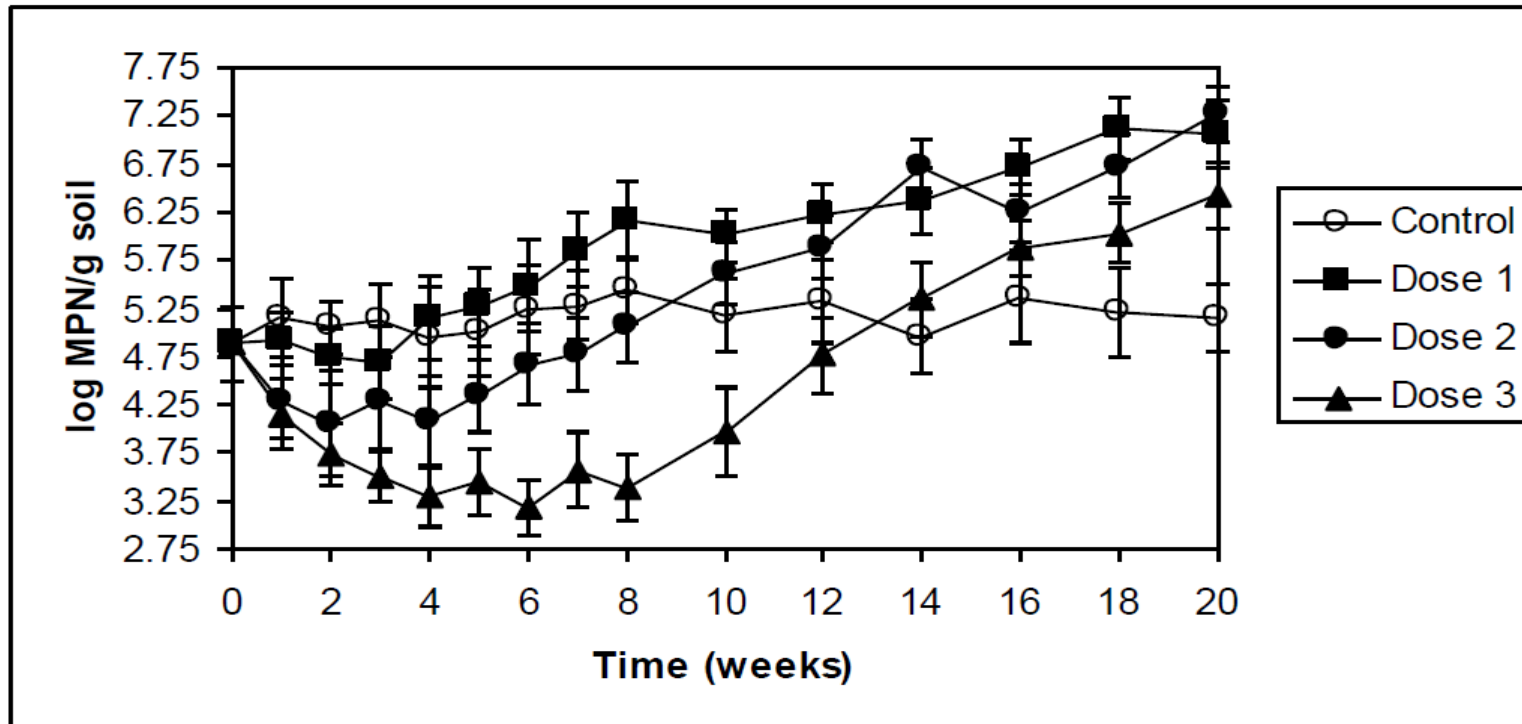
1. ISCO
2. Aerobic bioremediation
3. Anaerobic oxidation



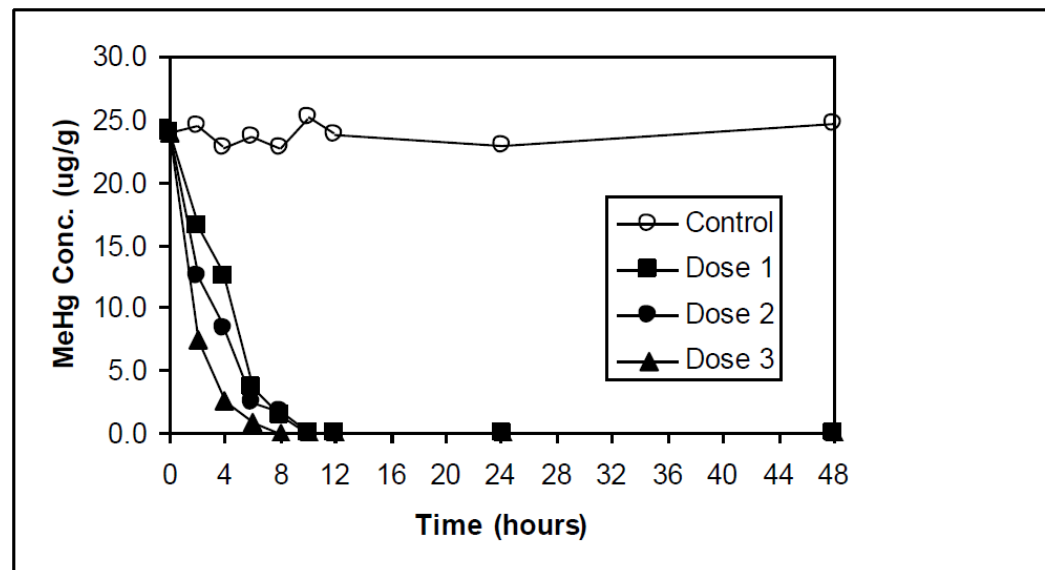
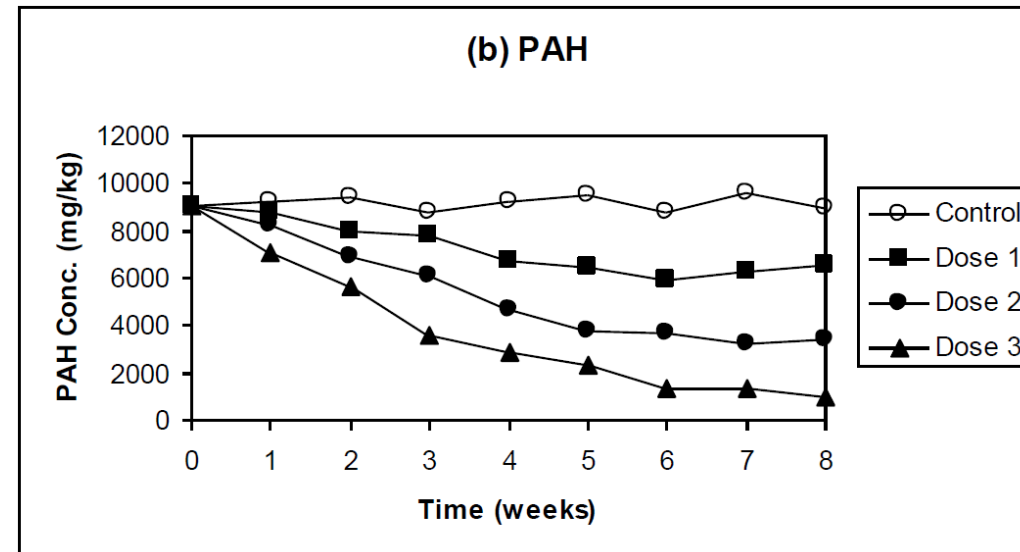
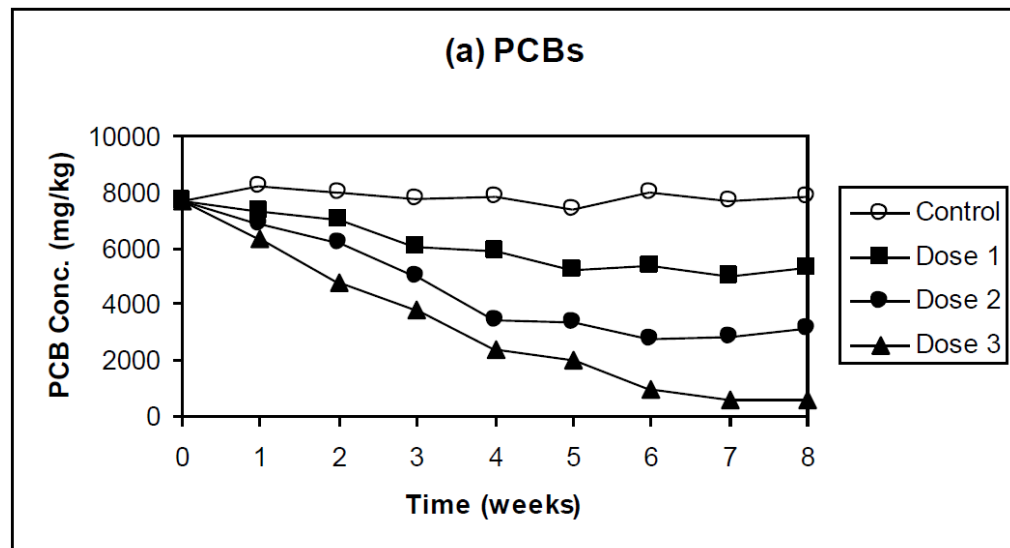
Example Klozur CR Effect on Microbial Populations

- Increase in Sulfate Reducing Bacteria once persulfate consumed
- Potential for biological treatment via 'anaerobic oxidation' (contingent on reducing conditions)

Sulfate Reducing Bacteria Over Time after Treatment with Klozur® CR [Cassidy (2010)]



Klozur® CR Treatment Performance: PCBs, PAHs & Methylmercury



Klozur[®] CR Case Study

Remediation of Former Gas Station in Northern Sweden

Remediation Contractor: Geoserve

Consultant: WSP

Remedial Activities:

- 2019: Source area soil removed (depth limitation—up to 2.5 m bgs)
 - BTEX up to 3,200 mg/kg remaining below excavation
 - GW exceeding guideline values
- 2024: Injection of Klozur[®] CR to address residual soil and GW impacts
- 2026: Supplemental injection of Klozur[®] CR to address remaining contamination closer to building



Remedial Approach

Remediation of Former Gas Station

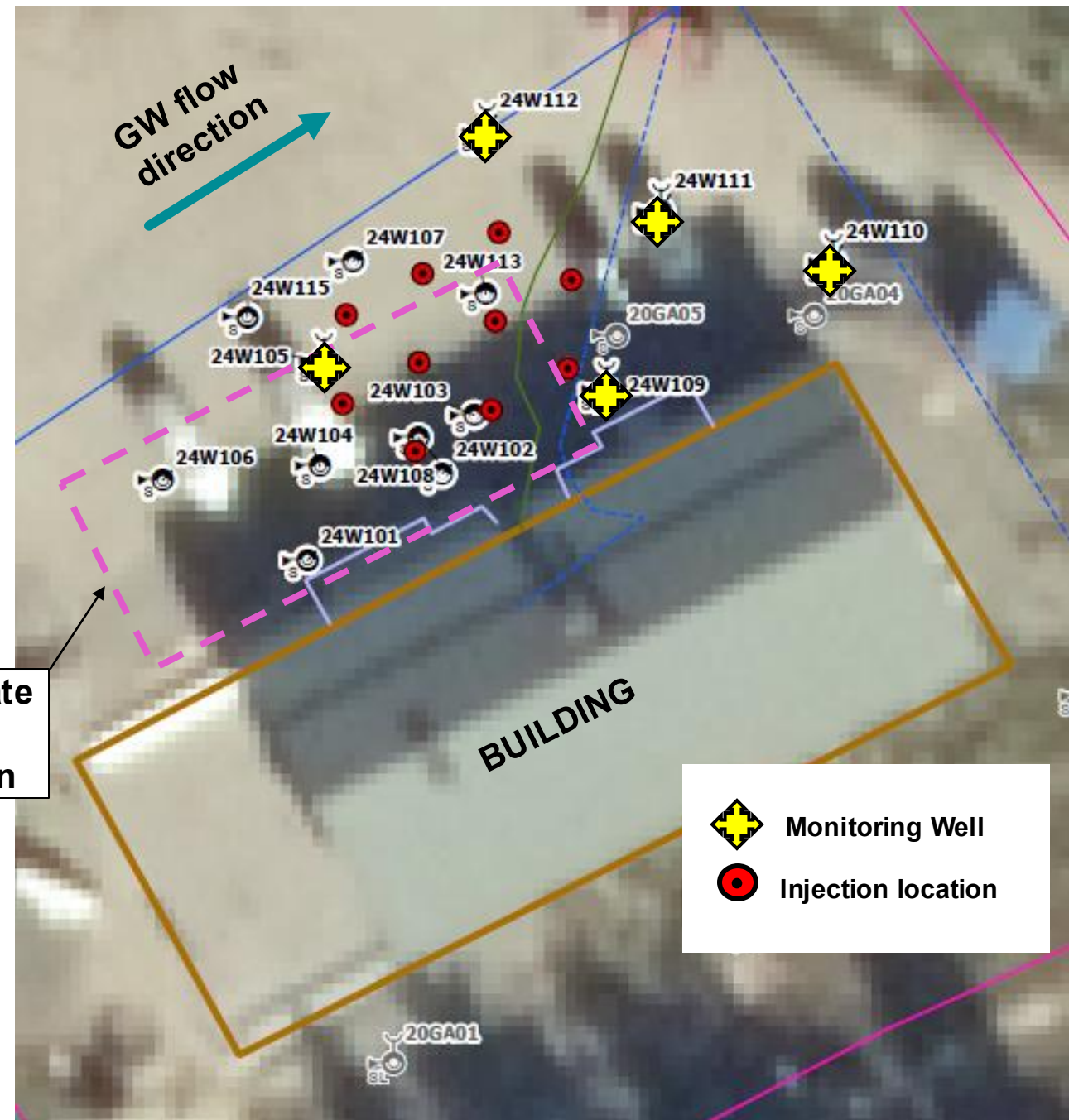
▪ Klozur CR injection (November 2024):

- Total of 2000 kg Klozur® CR injected into 10 TAM-tubes spaced ~3 m apart
- ~100 m² treatment area based on the highest soil concentrations
- Injections from 2 to 4 m bgs
 - GW at ~2 m bgs
- Two monitoring wells with GW exceedances used for performance monitoring (24W105 & 24W109)

▪ Supplemental injection (June 2026):

- 1500 kg Klozur® CR injected into 5 TAM-tubes

Approximate
extent of
excavation



Injection of Klozur® CR via TAM-tubes

Klozur® CR Case Study, Former Gas Station, Northern Sweden

Photos courtesy of Geoserve

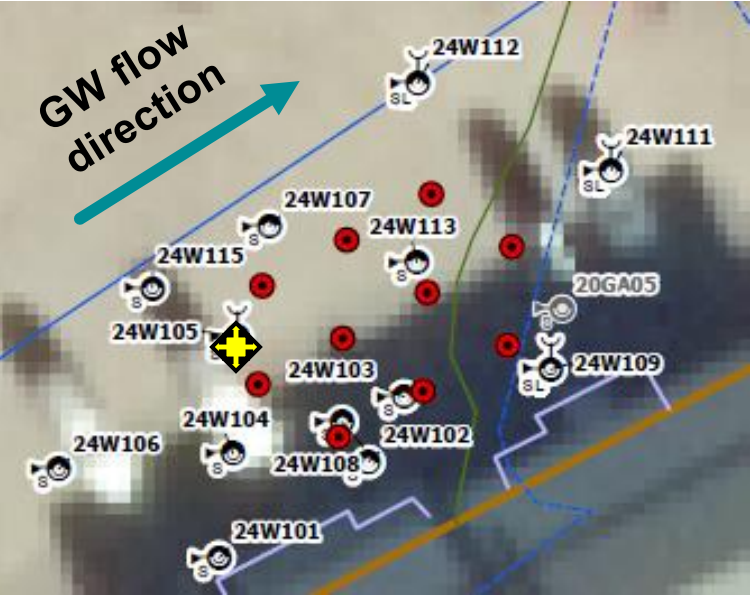
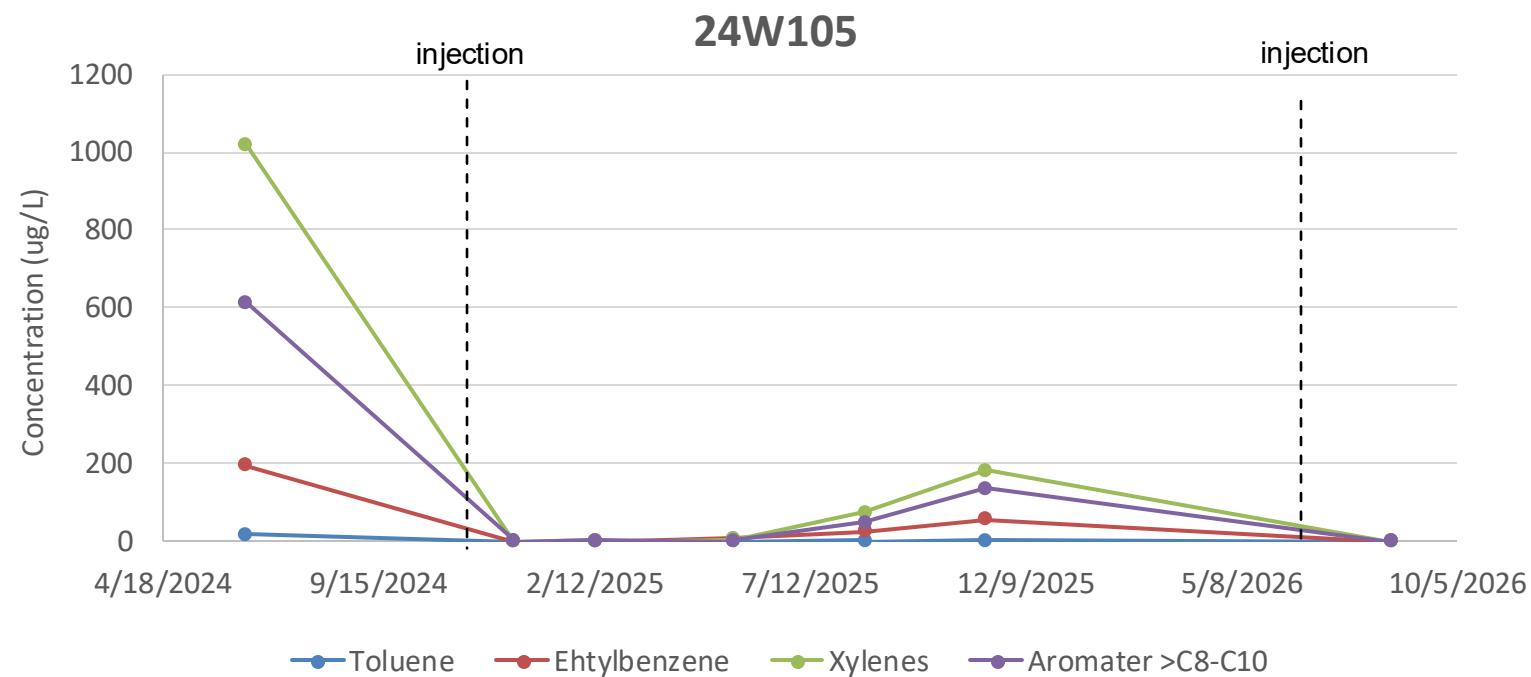


Supplemental
injection closer to
building



Results

Klozur® CR Case Study, Former Gas Station, Northern Sweden



**>99.9% reduction in BTEX,
followed by partial rebound after
10 months.**

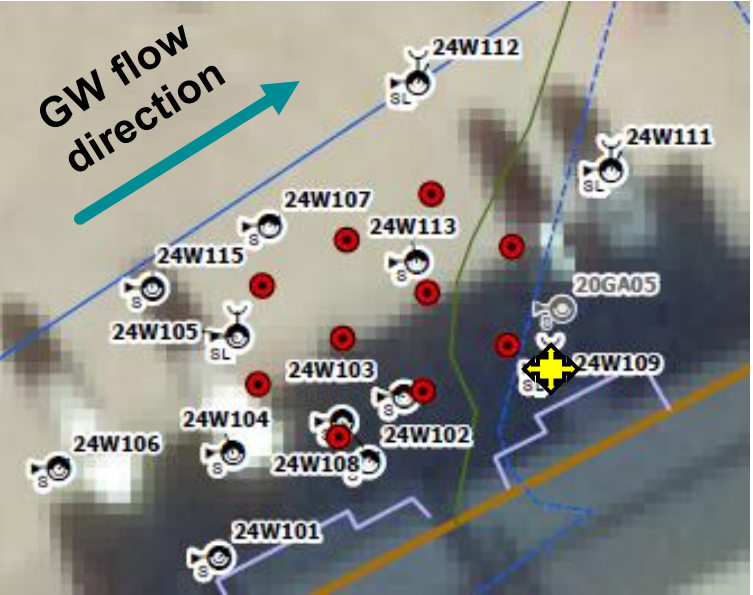
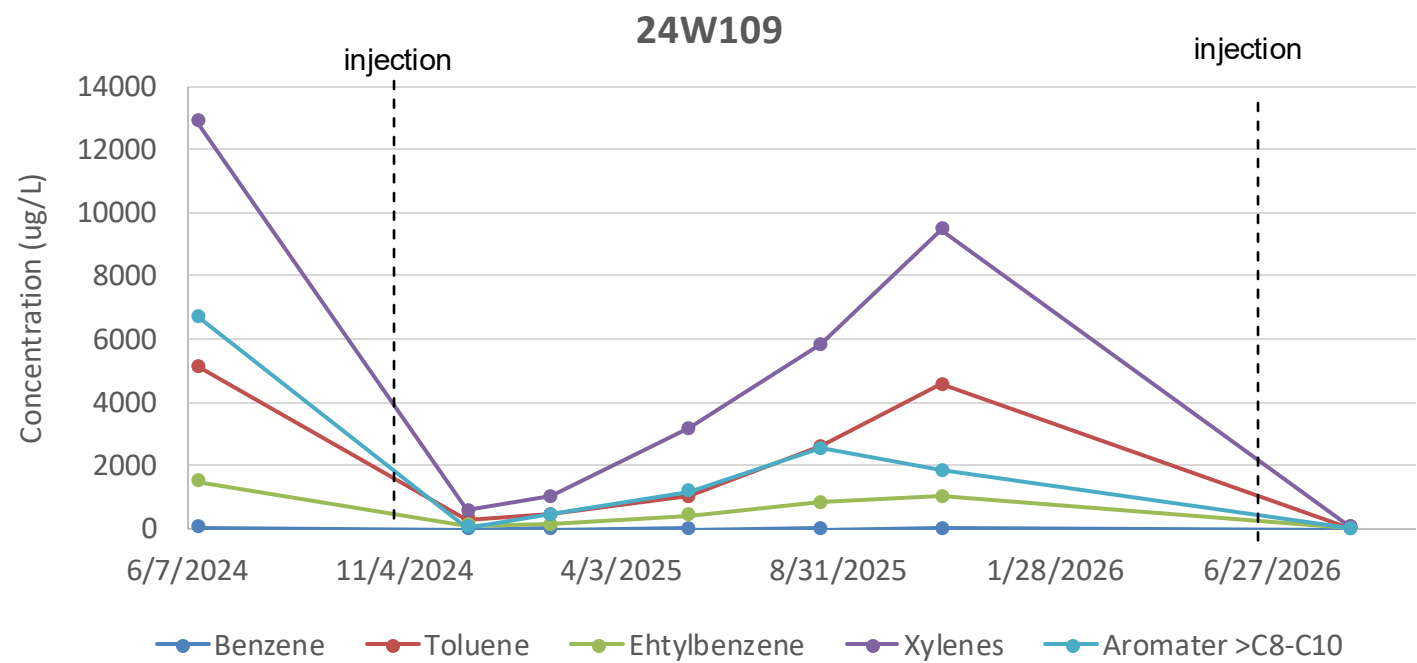
**Concentrations still below goals /
drinking water guidelines &
declined again after second
injection**

	Baseline	1 month	4 months	7 months	10 months	13 months	2 months
ORP (mV)	384	502	441	398	228	124	202
SPC (us/cm)	591	19097	14868	8768	3897	3565	127
Sodium (mg/L)		4130	3210	1920	725	562	12
Oxygen (mg/L)	1.6	23.9	23.5	28.1	26	21.7	12.4
Calcium (mg/L)		294	237	192	106	141	20

* After second application

Results

Klozur® CR Case Study, Former Gas Station, Northern Sweden



95% reduction in BTEX followed by rebound– smaller complimentary Klozur® CR injection performed in June 2026 to address area closer to building

	Baseline	1 month	4 months	7 months	10 months	13 months	2 Months*
ORP (mV)	205	514	247	182	57	-71	505
SPC (us/cm)	450	2814	716	1405	1209	500	3113
Sodium (mg/L)		451	36	220	218	51	743
Oxygen (mg/L)	2.4	8.3	10.7	13.4	3.9	1	15.9
Calcium (mg/L)		65	16	47	52	23	111

* After second application

Case Study on Technology Screening: Former MGP, Stockholm Royal Seaport, Sweden



This project is a collaboration between multiple parties, incl City of Stockholm, PEAB, Golder/WSP, Elander Miljöteknik, RGS, Sheeba, Arkil, Evonik, Geomind

City of Stockholm Technical Project Contacts:
Sofia Billersjö: sofia.billersjo@stockholm.se
Helen Österberg helen.osterberg@extern.stockholm.se

- The old MGP area is being redeveloped into a residential area
- Soil and groundwater impacted by coal tar residue
- Overarching remedial goal is to limit vapor intrusion to new residential buildings
 - Key COCs: Naphthalene, Fluoranthene, Benzene
- Multiple technologies successfully evaluated at the pilot-scale – a flexible strategy is being implemented where the approach is varied based on variations in contaminant profile and concentrations across the site



SHEEBA



Pilot-Scale Technology Evaluation for Saturated Zone

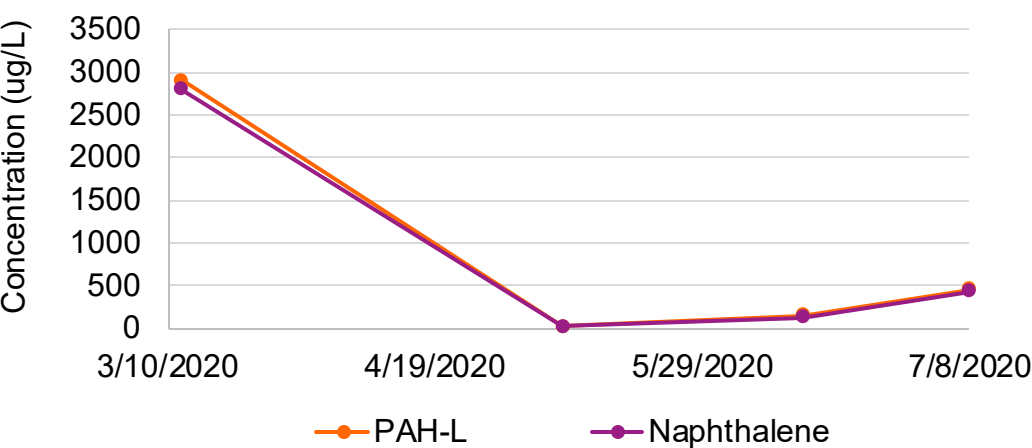
Pilot testing 2017-2020:

- **Chemical oxidation:**
 - Activated persulfate:
 - Sodium and Potassium Persulfate (fast vs. extended release)
 - Activators: alkaline, chelated iron, silica (PersulfOx)
 - Hydrogen peroxide 10 %
 - RegenOx
- **Enhanced biological degradation:**
 - PermeOx Ultra
 - ORC Advanced
- **Enhanced desorption:**
 - PetroCleanze

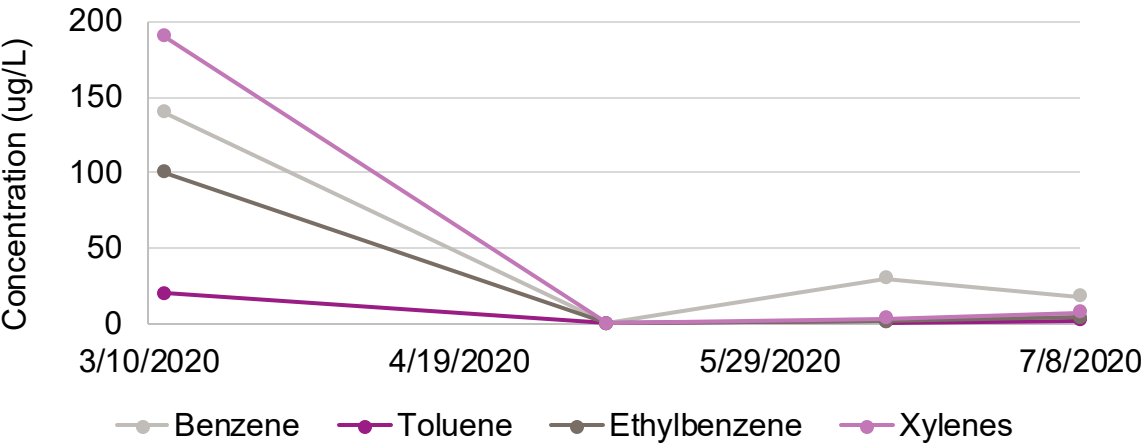


Example Results – Alkaline Activated Persulfate

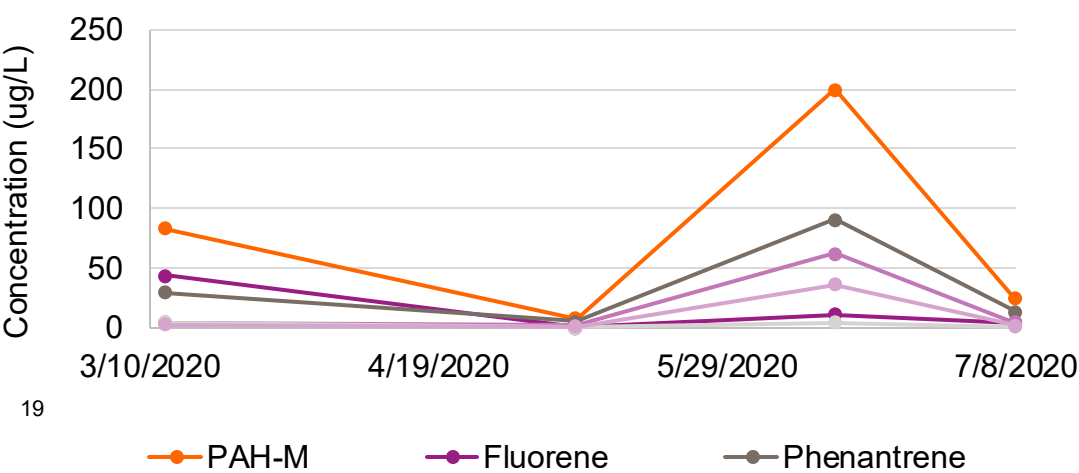
PAH-L



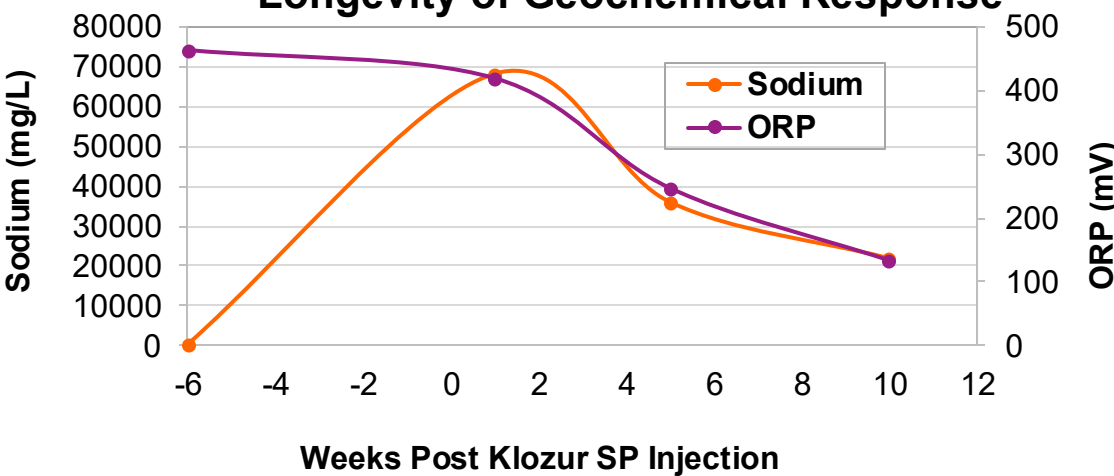
BTEX



PAH-M

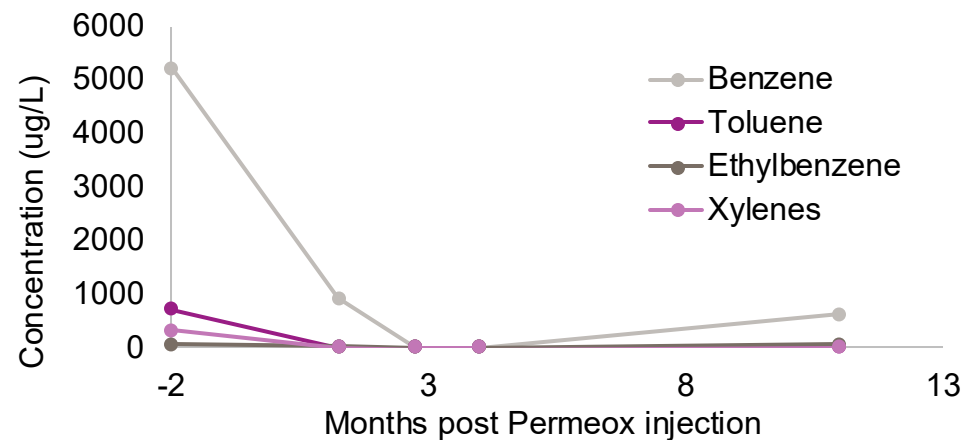


Longevity of Geochemical Response

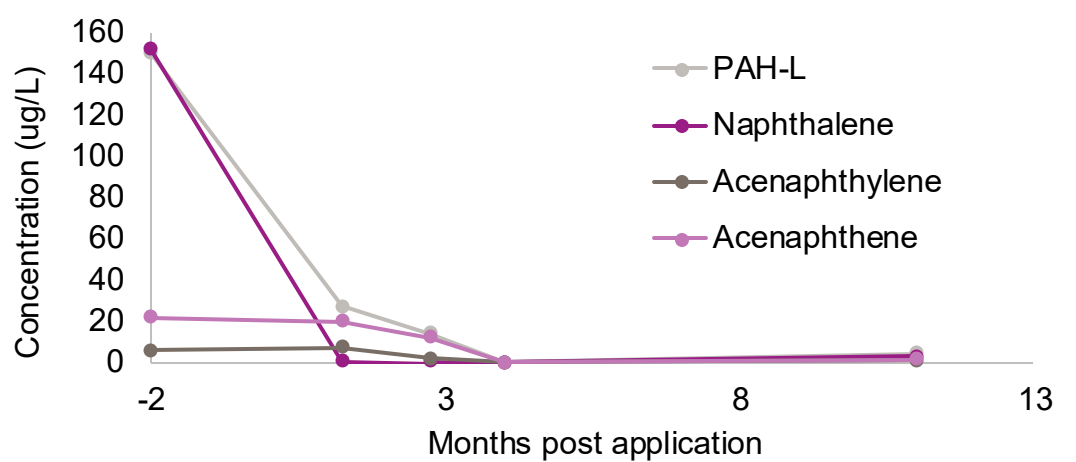


Example Results – Enhanced Aerobic Bioremediation (PermeOx® Ultra)

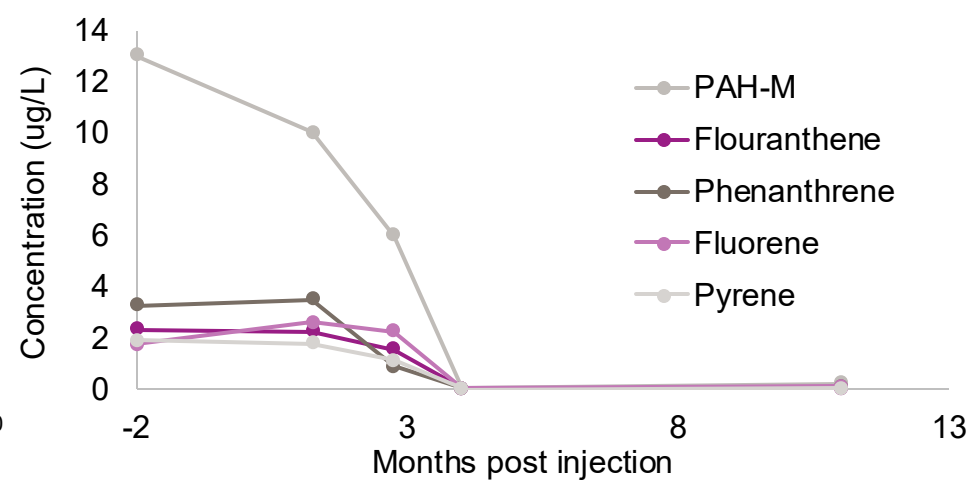
BTEX



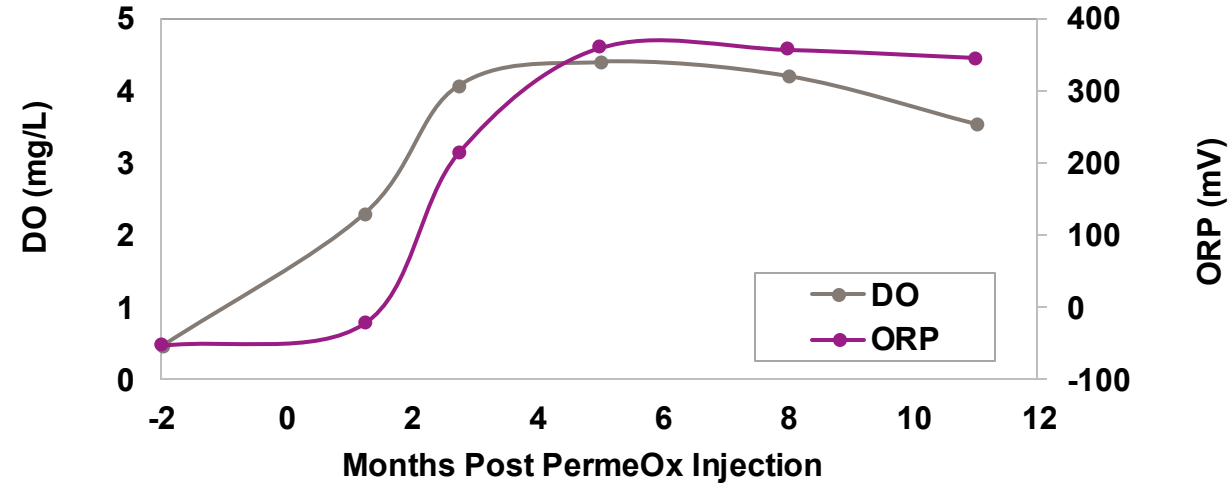
PAH-L



PAH-M

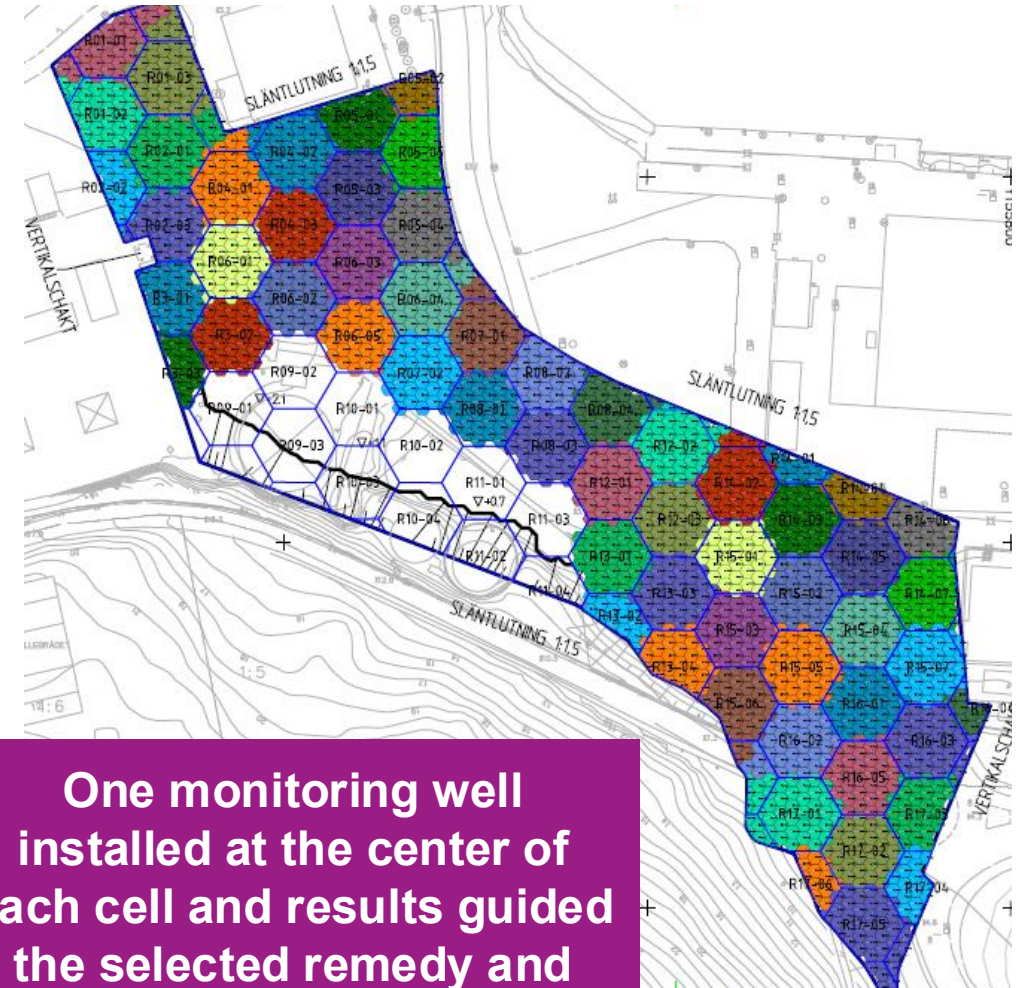


Longevity of Geochemical response



Conclusions & Selected Remedial Approach with Flexible Injection Area Strategy

- Overburden clay layer treated with ISCO-ISS implemented via soil mixing (sodium persulfate activated with high pH from cement)
- Alkaline Activated Sodium Persulfate also selected as primary remedial approach for the underlying saturated moraine zone, with some exceptions
 - Extended-release potassium persulfate / Enhanced Aerobic Bioremediation used in areas where fluoranthene was the primary exceedance
- Areas where BTEX is the primary exceedance / lower expected overall COC mass:
 - Enhanced Aerobic Bioremediation more cost effective



Summary

- Many common contaminants can be treated by either ISCO or EAB
- ISCO is faster acting
- EAB reagents are often longer lasting – helps meeting lower remedial goals / strongly sorbed contaminants
- Typically, ISCO is more cost effective for treating more highly contaminated sites and source areas, and EAB is more advantageous for lower concentrations
- In many cases it is advantageous to combine technologies, either together, sequentially or for targeting different portions of a site

Three Ways ISCO and ISB are Combined

1. Naturally from ISCO residuals or increased DOC
2. Combine reagent application: Persulfate and Calcium peroxide
3. Sequential or Spatial Applications

Thank you!
Questions?



Josephine Molin

Technology Applications Manager, ISCO
Soil & Groundwater
Evonik Corporation
E. Josephine.molin@evonik.com



Brant Smith, PhD, PE

Director of Technology
Evonik Active Oxygens, LLC
brant.smith@evonik.com

Evonik Corporation
Soil & Groundwater Remediation
remediation@evonik.com
www.evonik.com/remediation