Enhanced In Situ Solidification and Stabilization (ISS) Blends: Impacts of Adding Sodium Persulfate and Water Content

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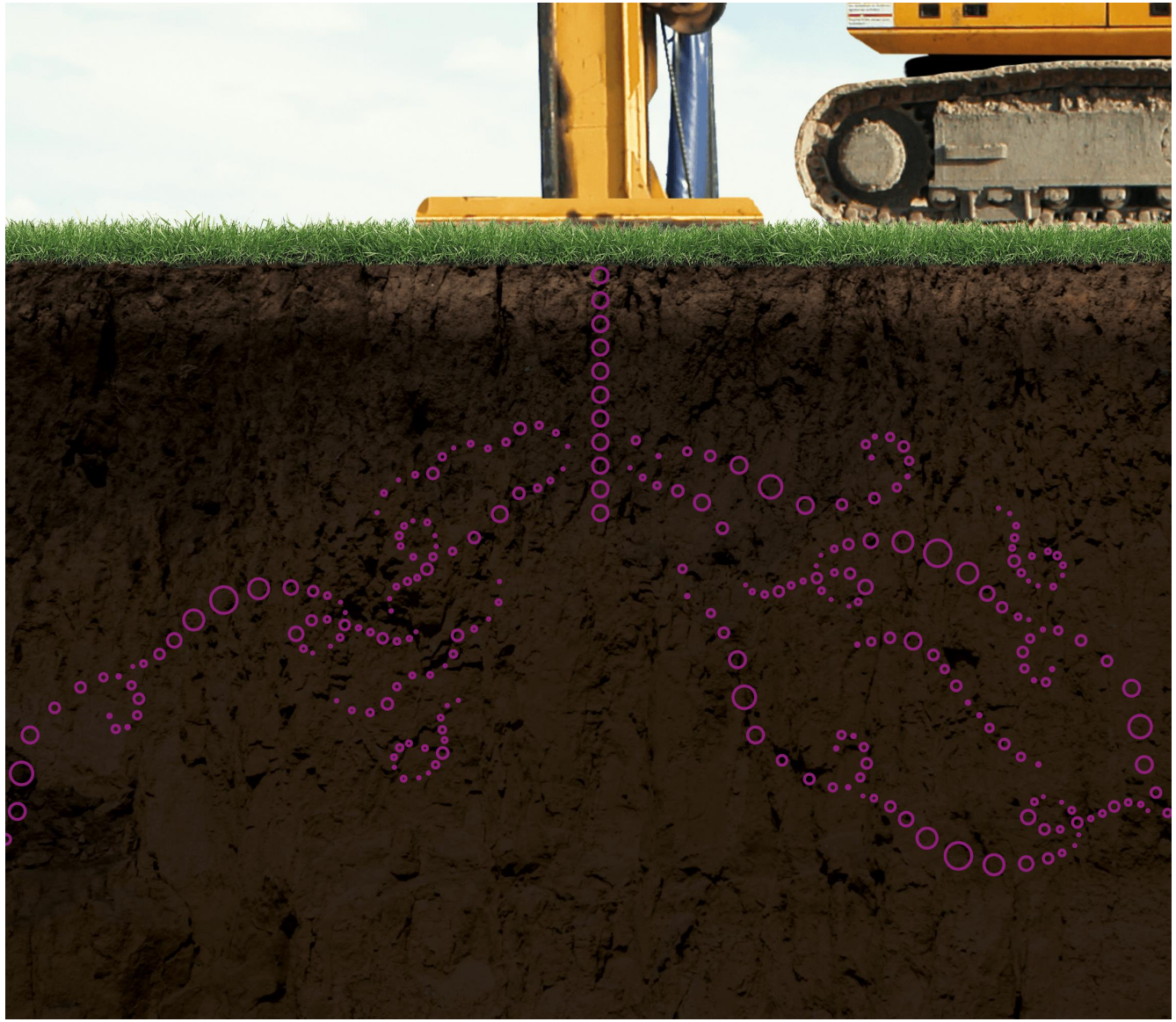
It’s Official!

PeroxyChem, LLC is now Evonik Active Oxygens, LLC



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Overview

- Technology Overview
  - ISS
  - ISCO
- Why Combine?
  - Results
- Effects of Water
- Summary

Courtesy of Lang Tool

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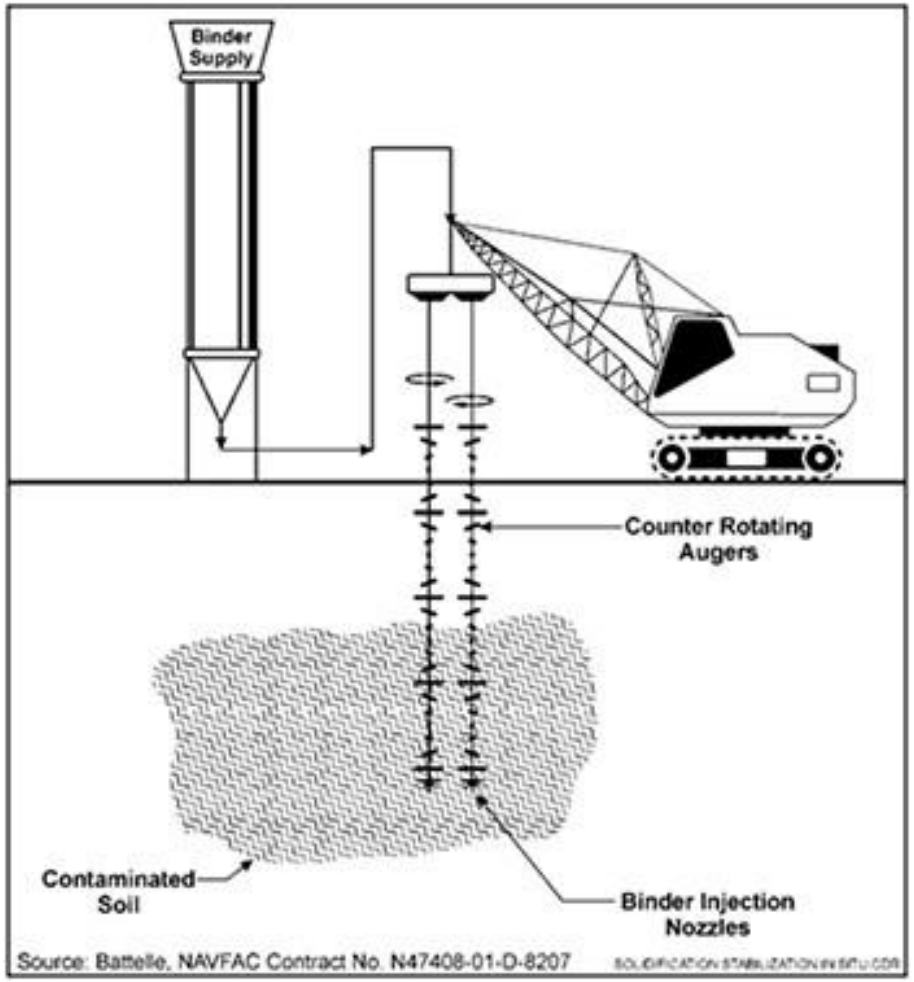
In Situ Solidification and Stabilization

- What it is:
  - Use of soil mixing to blend binding agent(s) with contaminated soils

- Methods:
  - Stabilization:
    - Chemical processes that reduce leachability
  - Solidification:
    - Decreasing of surface area, hydraulic conductivity, effective porosity
    - Increasing compressive strength



Common Objectives of ISS

1. Reduced hydraulic conductivity
   - 2-3 orders of magnitude below native soils
   - 1 x 10^{-6} cm/sec
2. Unconfined Compressive Strength (UCS)
   - "Workable" ~20-60 psi
   - Hardened
     - ISS often targets 50 psi
3. Lower contaminant flux and leachate concentrations

General Relationship between Soil Consistency and Unconfined Compressive Strength

Consistency	Unconfined Compressive Strength (UCS) Ranges			
	psi		kPa (KN/m^2)	
	Low	High	Low	High
Very soft	0	3	0	24
Soft	3	7	24	48
Medium	7	14	48	96
Stiff	14	28	96	192
Very Stiff	28	56	192	383
Hard	>56		>383	

Typical target range for "workable" soils ~20-60 psi

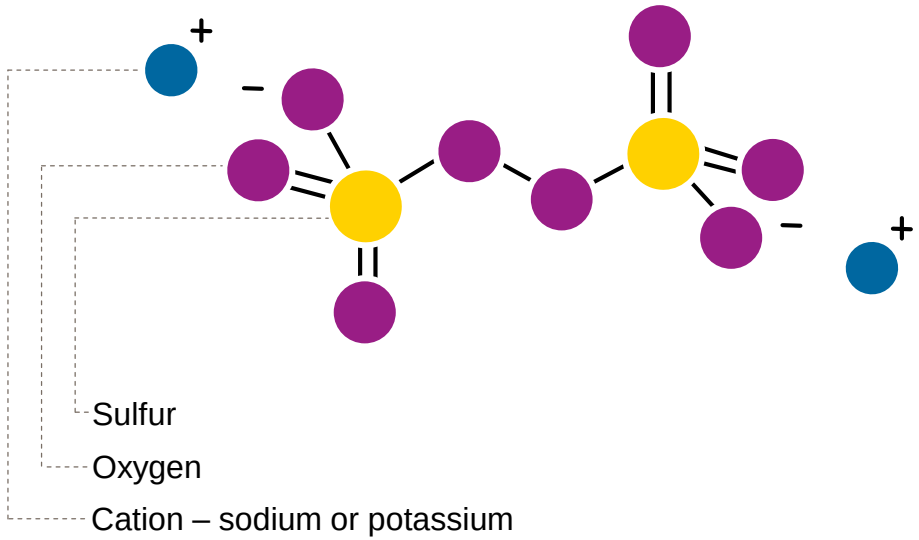
In Situ Chemical Oxidation

- What it is:
  - Adding thermodynamically powerful electron accepters to transform organic contaminants of concern via an oxidation pathway
  - Applied via injection, backfill emplacement or **soil mixing**

- Objectives:
  - Contaminant destruction
    - Reduced risk from less contaminant mass and lower concentrations

All Klozur® persulfates release the persulfate anion

- Sodium and potassium persulfate are used in environmental remediation applications
- A strong oxidant
- Activation results in the formation of oxidative and reductive radicals
- Applicable across a broad range of contaminants
- Extended subsurface lifetime (weeks to months)
- Little to no gas evolution



Free Radical Chemistry:
Persulfates produce free radicals in many diverse reaction situations

$S_2O_8^{-2}$ + activator ⟶ $SO_4^{\bullet -}$ + ($SO_4^{\bullet -}$ or SO_4^{-2})

Activation produces a radical which is more powerful and kinetically fast

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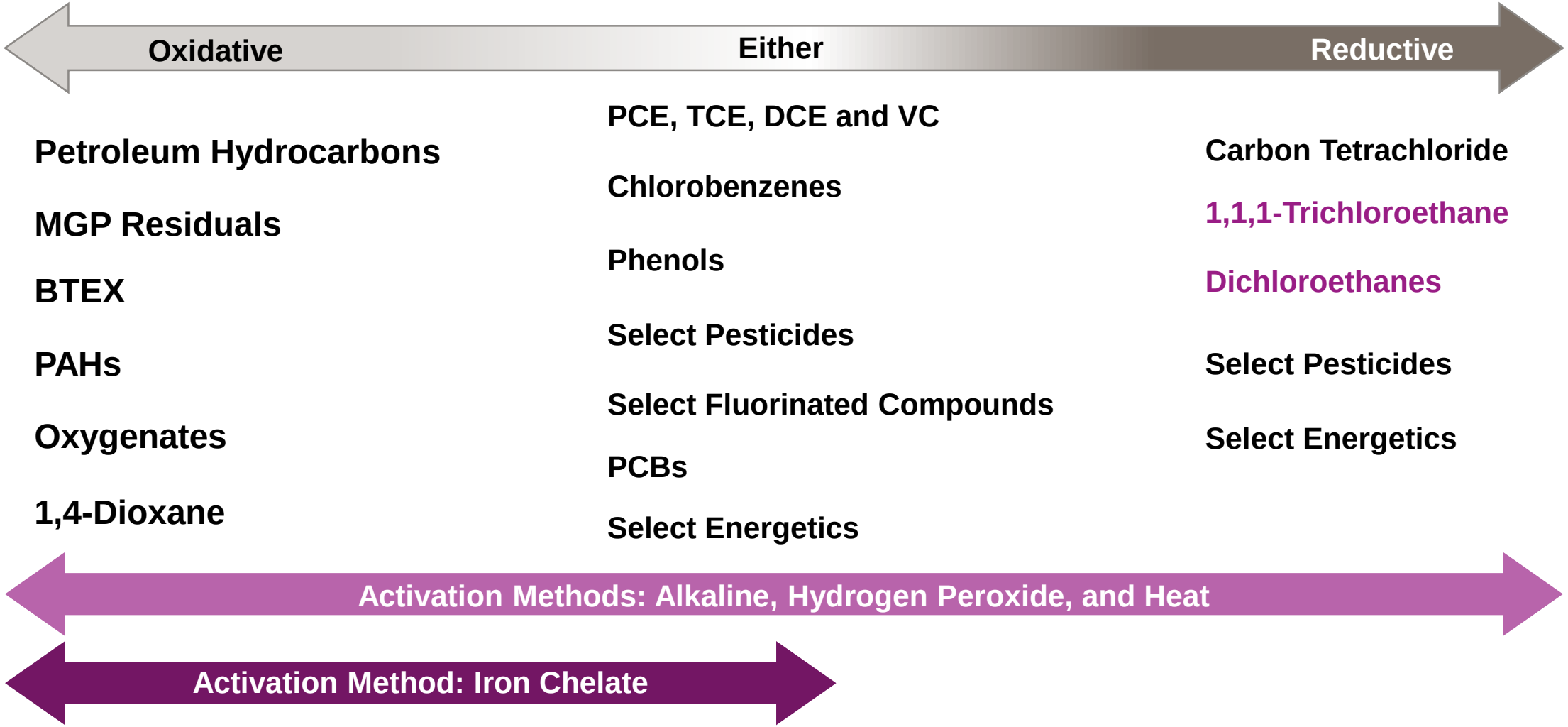
Klozur® Persulfate Degradation Pathways



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Combining the Reagents

- Common ISS reagents create alkaline activated persulfate
  - Portland cement (significant alkali)
  - Blast furnace slag (alkali)
  - Cement kiln dust (significant alkali)

- Adding sodium persulfate to ISS has shown to be beneficial

Courtesy of Ladaurner

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“ISCO-ISS”: Benefits of Adding ISS reagents to ISCO

- Control over post-soil mixing geotechnical characteristics during a soil mixing application
  - Redevelopment
  - Post application monitoring
- Second treatment (combined remedy)
  - Solidification and stabilization from ISS after destruction of ISCO

Former Dry Cleaner:

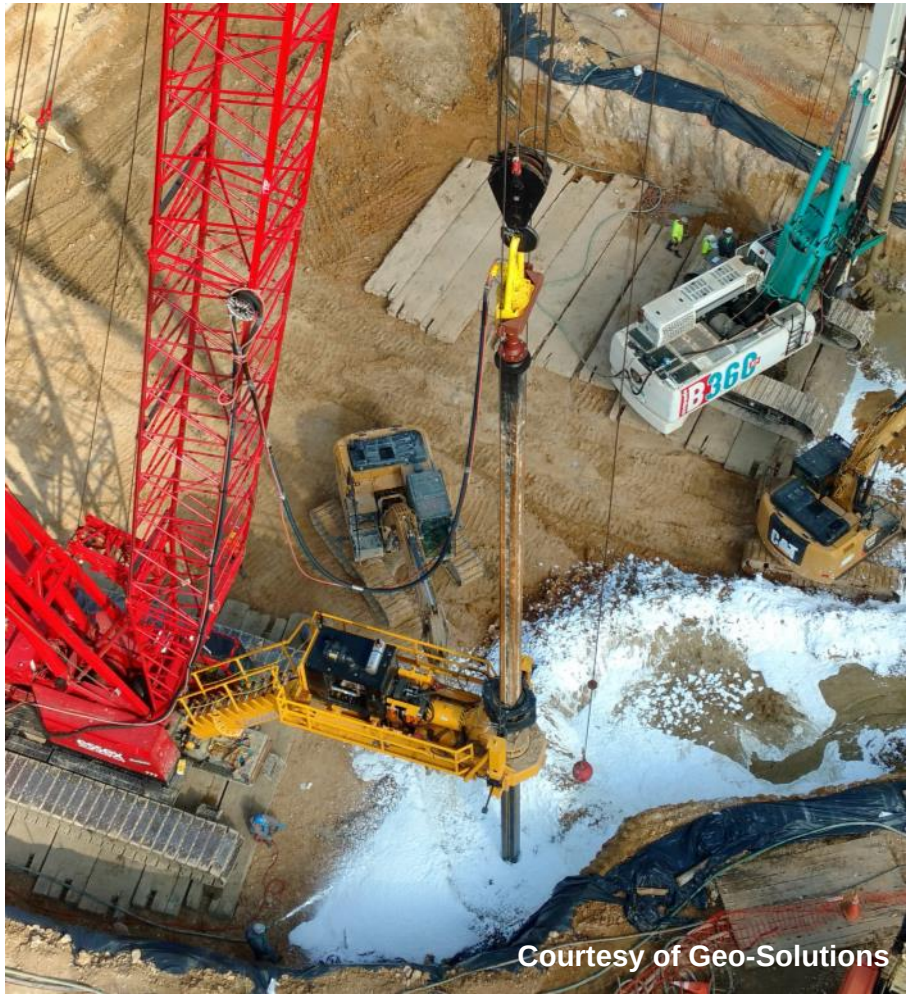
- Klozur SP: 1% or 2% w/w with Soil
- Portland cement: 4% w/w with Soil
- PCE: 94% Destruction
- Soil solidified and site ready for redevelopment

Courtesy of Hamp Mathews

“ISS w/ ISCO”: Benefits of adding Sodium Persulfate during ISS

1. Contaminant destruction reduces long term risk
2. Lower leachate concentrations
3. Higher compressive soil strengths
4. Lower hydraulic conductivities
5. Less soil bulking

Unless otherwise noted the following are results from in-house Evonik testing on contaminated soils



Courtesy of Geo-Solutions

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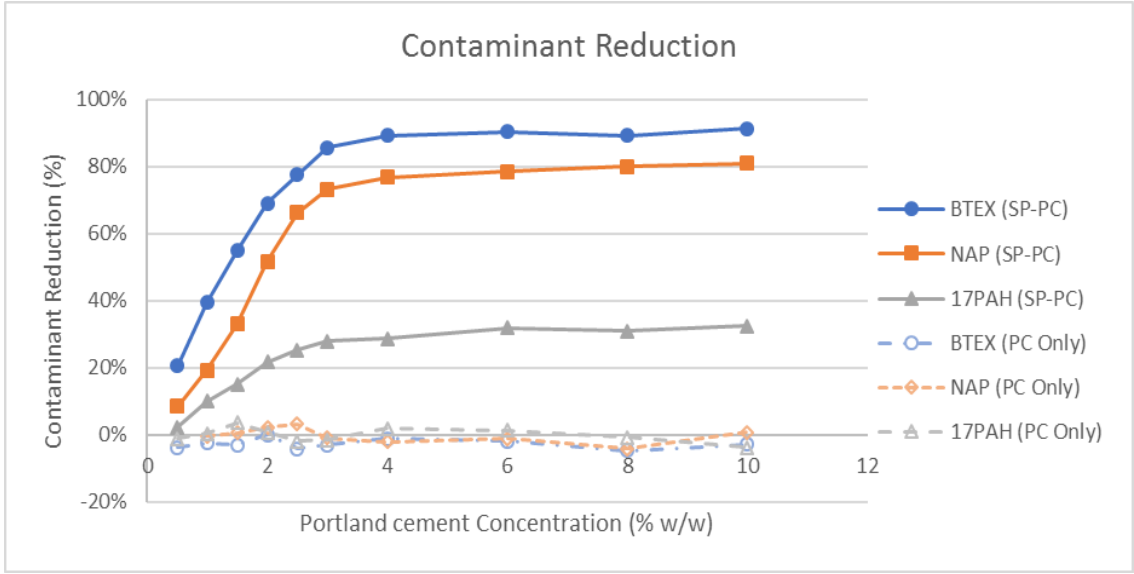
Contaminant Destruction

Srivastava et al (2016), J. Environ Chem. Engineering, 4, 2857-2864

1. MGP impacted soils
   - >36,900 mg/Kg TPH
   - ~6,800 mg/Kg BTEX
   - ~13,400 mg/Kg Naphthalene (Nap)
   - ~16,900 mg/Kg 17 PAHs (not including Nap)

2. Klozur® SP: Portland Cement (PC) ratio (1:2 w/w)
   - **PC facilitates alkaline persulfate activation**

3. ISCO:
   - Persulfate underdosed => targeting partial TPH treatment
   - Preferential treatment of soluble contaminants



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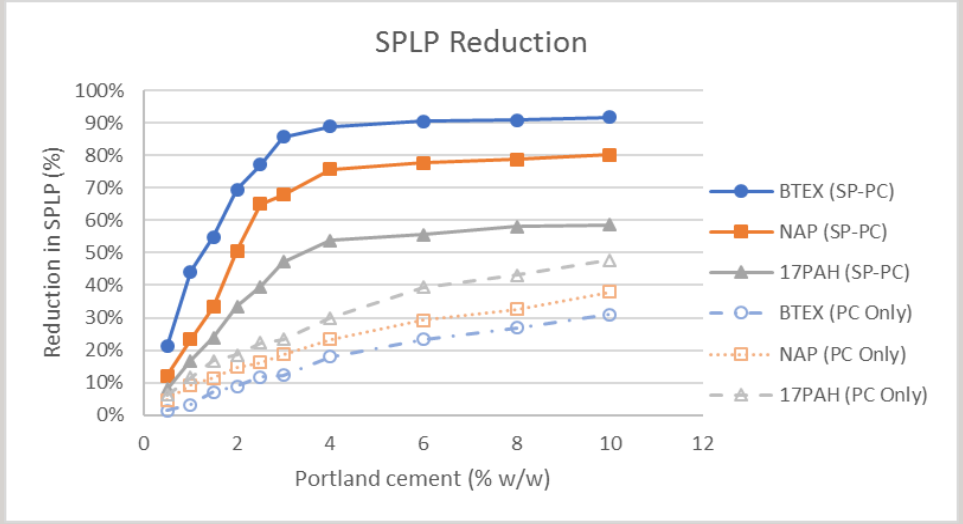
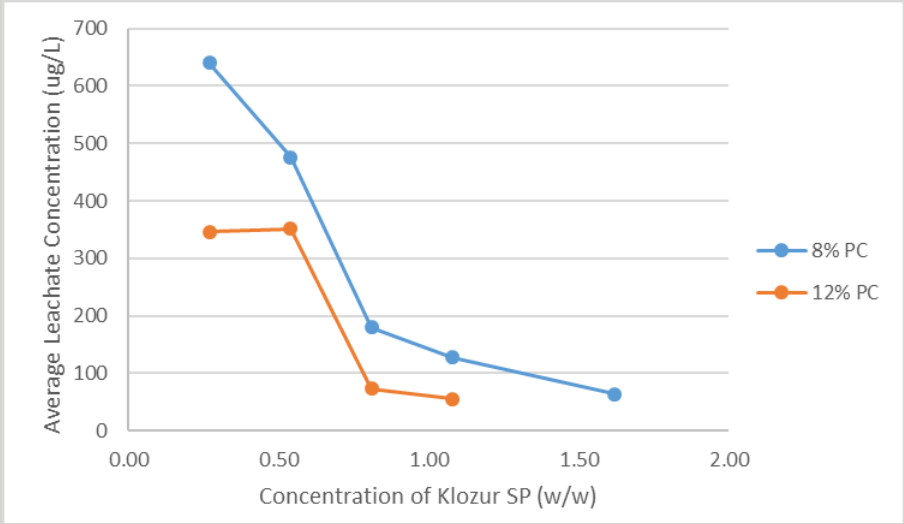
Lower Leachate Concentrations

- Decreasing leachate concentrations observed with increasing sodium persulfate addition
- ISS w/ sodium persulfate had significantly lower leachate concentrations compared to ISS only

Srivastava et al (2016)



Field Pilot Test Results



Courtesy of Brasfond

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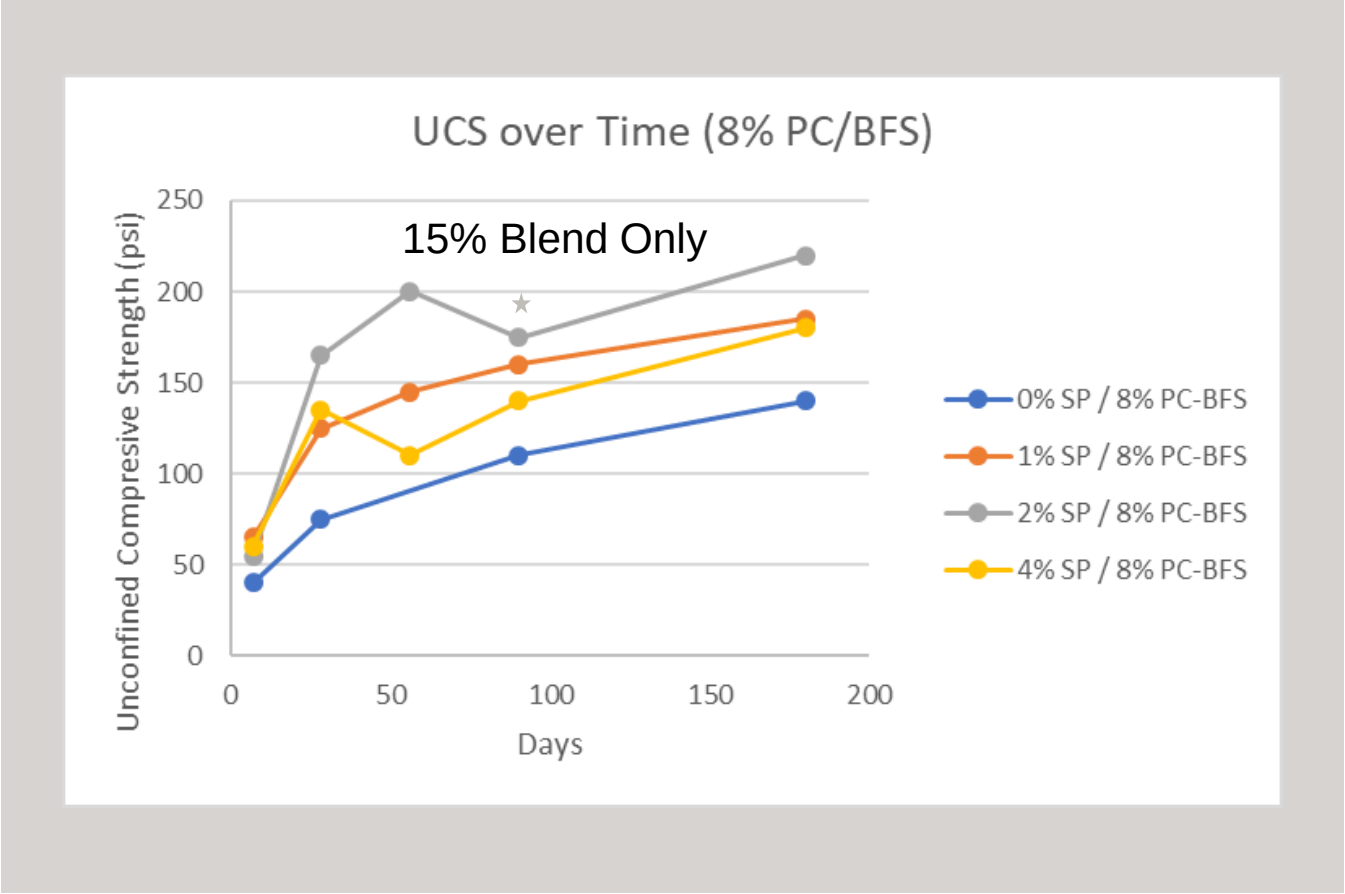
Compressive Strength Over 180 Days

1. Adding ISCO with ISS can result in greater UCS than ISS reagents only

2. 8% BFS blend with Klozur® SP was approximately the same strength as 15% BFS blend only



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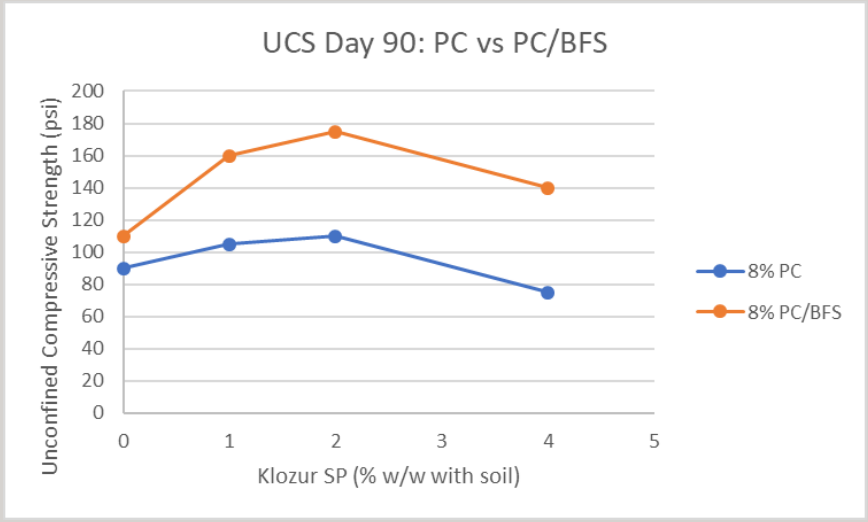
Higher Compressive Strength

- Typically observe adding up to 2% sodium persulfate gives higher compressive soil strength
- Above 2%: results can vary



Klozur® SP (% w/w soil)	8% PC		8% PC/BFS	
	Day 90 UCS (psi)	% of ISS only	Day 90 UCS (psi)	% of ISS only
0	90	100%	110	100%
1	105	117%	160	145%
2	110	122%	175	159%
4	75	83%	140	127%

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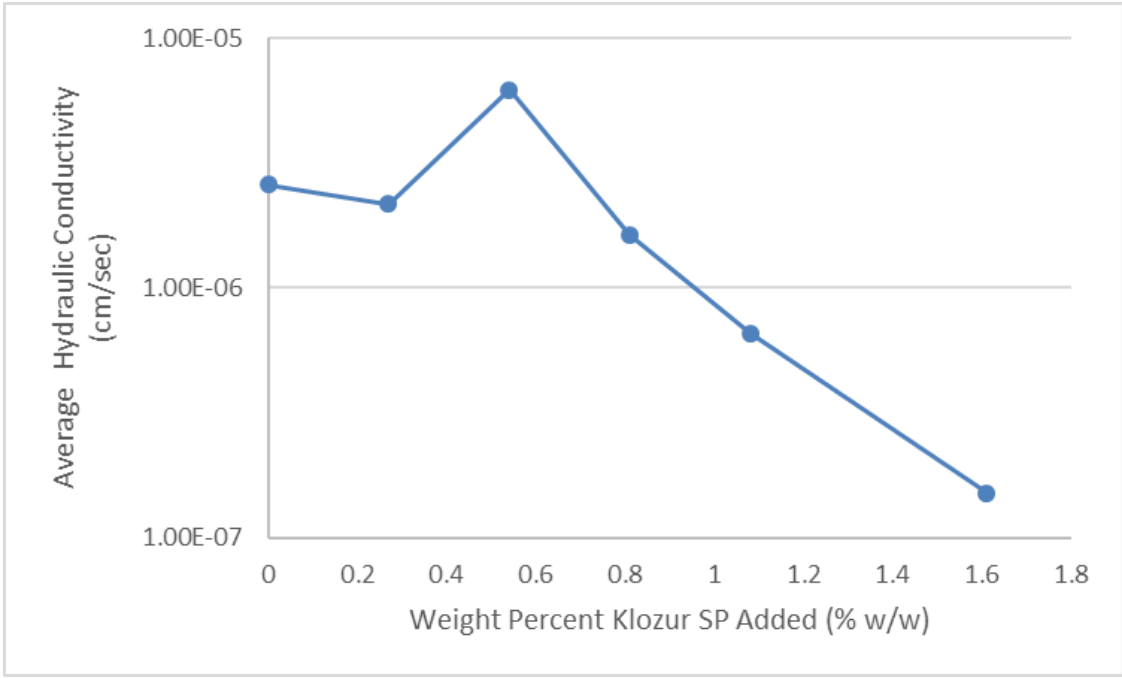
Lower Hydraulic Conductivities with Increasing Sodium Persulfate

Field Pilot Test Results



Courtesy of Brasfond

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Less Soil Bulking

- Adding reagents and soil mixing results in bulking of soil
- Effects of lower HC and higher UCS can be used to decrease total quantity of reagents needed to achieve remedial goals
- ISS w/ sodium persulfate typically results in less bulking of soil
  - Potentially significant cost savings

Effects of Water Content

Even vadose zones can have significant water content

Material	Avg Specific Yield	Avg Specific Retention
Clay	2%	98%
Sandy Clay	7%	93%
Sand	21% to 27%	73% to 79%

Source: Fetter 3rd Ed 1994

Specific Yield (%) + Specific Retention (%) = 100 % of a Pore Volume

Specific Yield: % of Pore Volume that will drain by gravity
Specific Retention: % of Pore Volume that is retained by soils after gravity drainage

Talking about Water

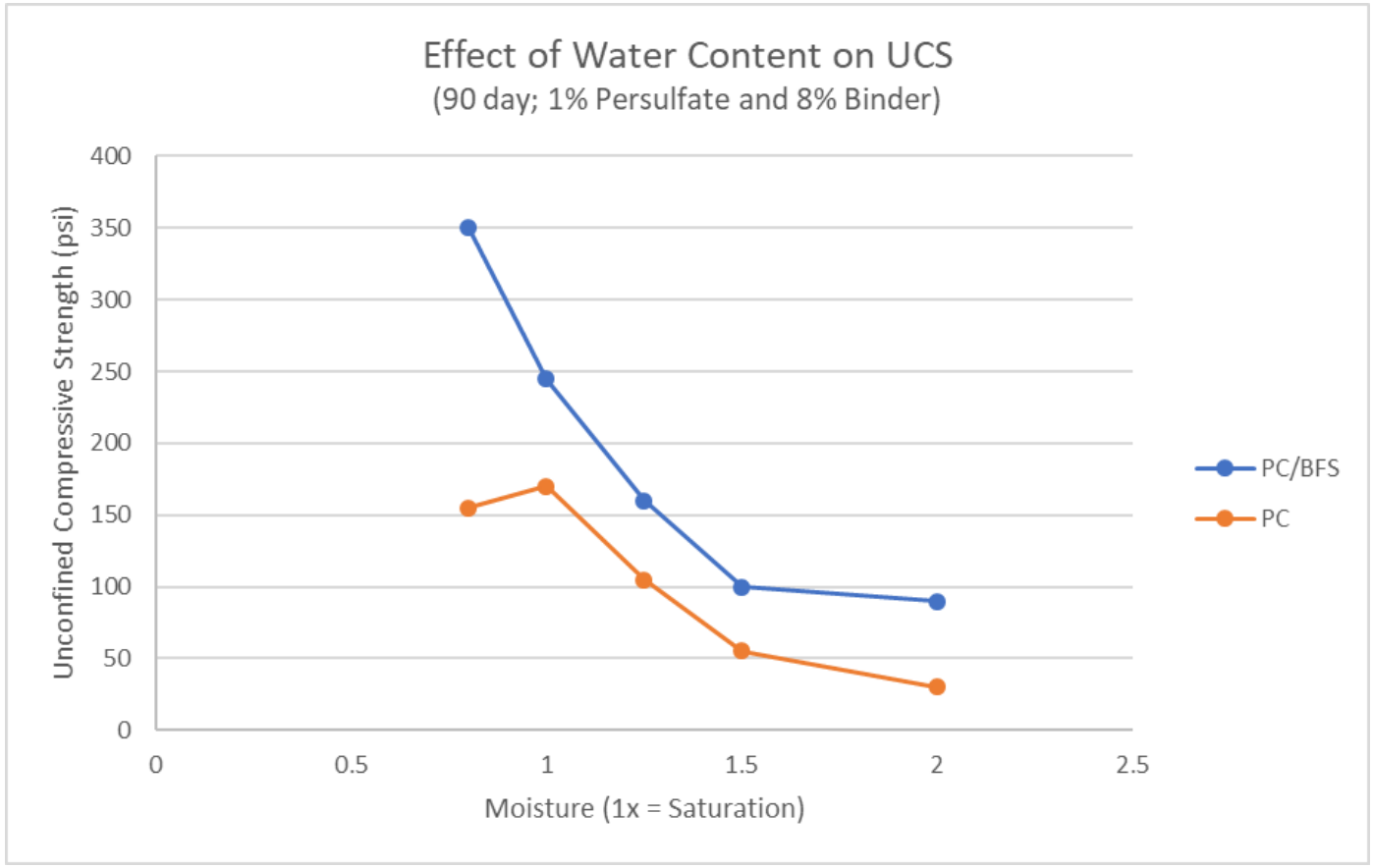
- Pore volumes
- Moisture Content
  - Dry soil (% w/w)
  - Wet soil (% w/w)
- Ratio to binder
  - Concrete ~0.5

Pore Volume	Water Weight (lbs)	Moisture Content (% w/w)		Binder[1] Ratio	% of Total[1]
		Dry	Wet		
0.5	10.9	10%	9%	1.65	8%
0.75	16.3	15%	13%	2.48	12%
1	21.8	20%	17%	3.31	16%
1.25	27.3	25%	20%	4.14	19%
2	43.7	40%	28%	6.62	31%
Notes:	Assume 110 lb/ft3 soil dry bulk density, 35% porosity, 6% Binder, 2% SP				
	1. Dry soil weight				

Works out to 80-85 g SP/L of excess water

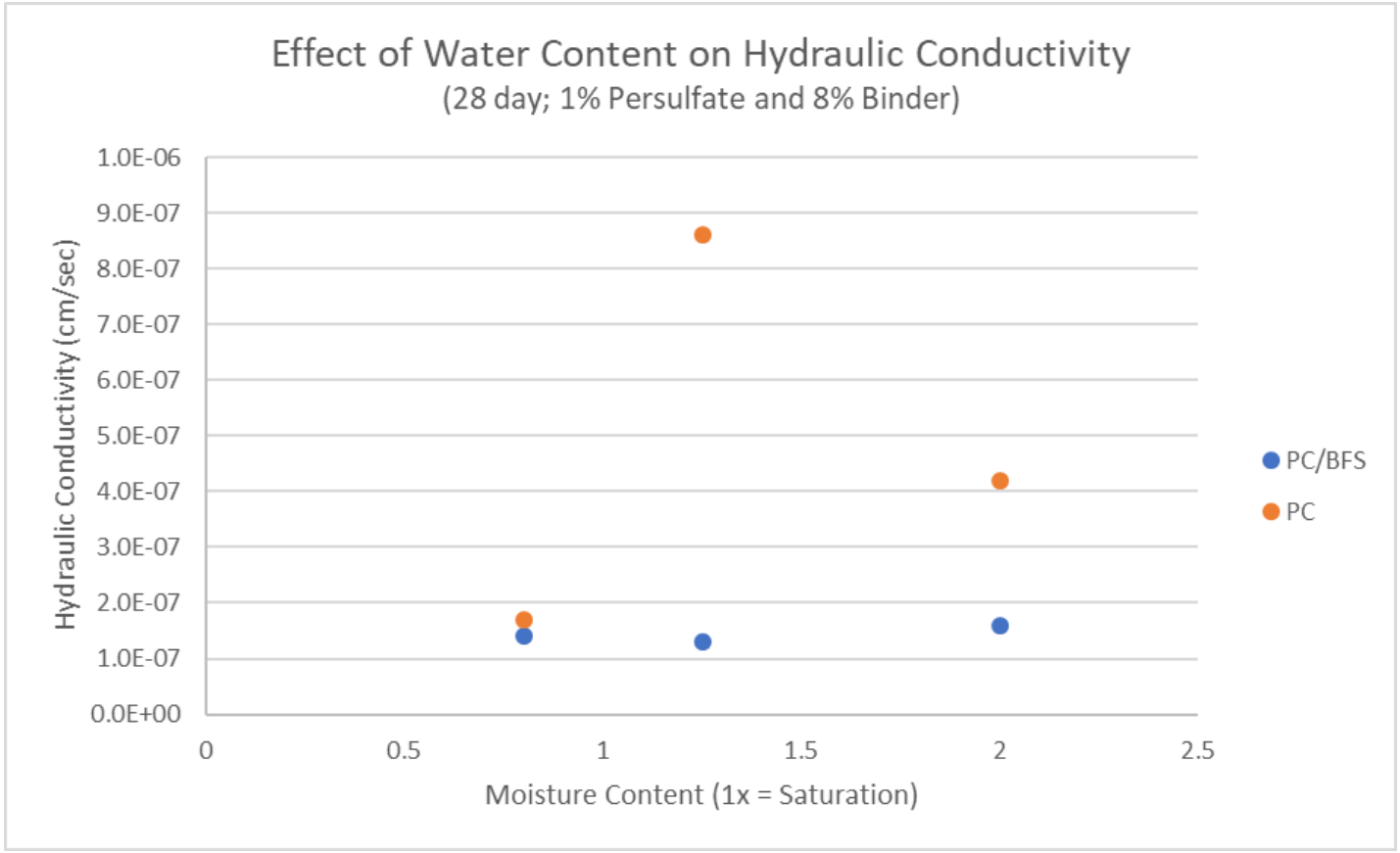
Water Content

1. Increasing water content resulted in decreased UCS
2. BFS blend stronger than PC only
3. PC only 0.8x and 1x very similar
4. Most points above 50 psi
   - Had this been an actual site, <8% binder would have been used



Moisture on Hydraulic Conductivity

- Moisture had marginal to no impact on 28 Day hydraulic conductivity
  - Slight impact to Portland cement
  - PC/BFS very consistent
- Results may be soil specific



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Former Dry Cleaner Site: Kent Cleaners in Michigan

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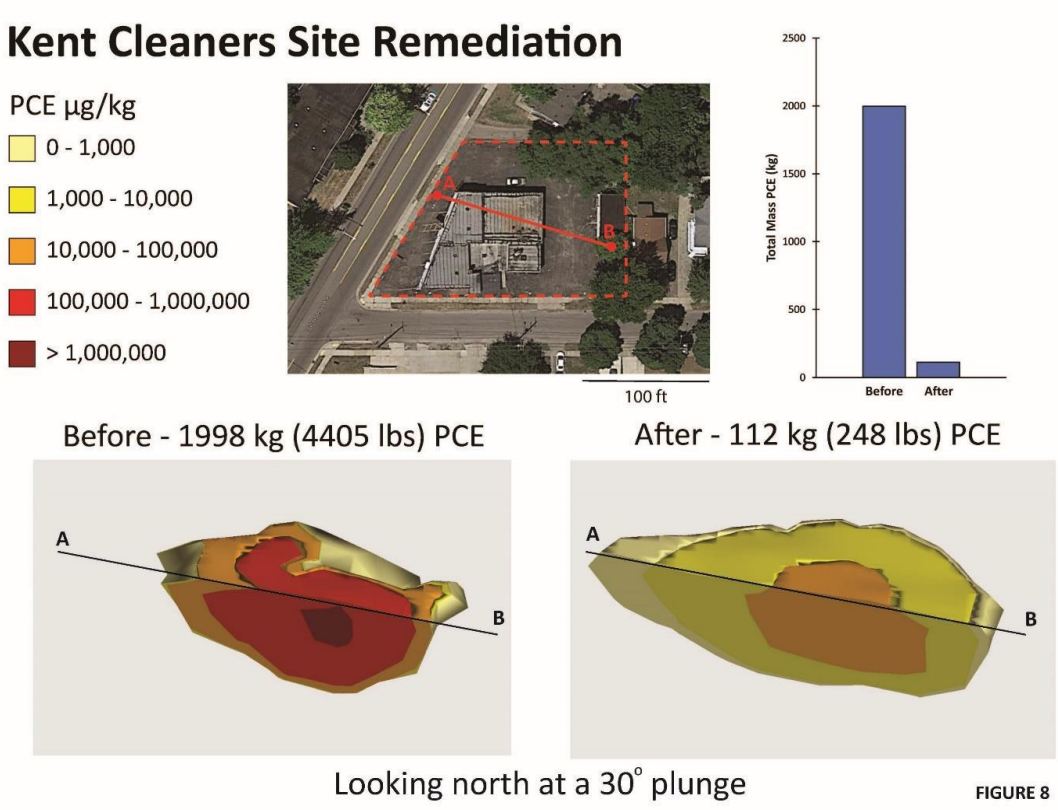
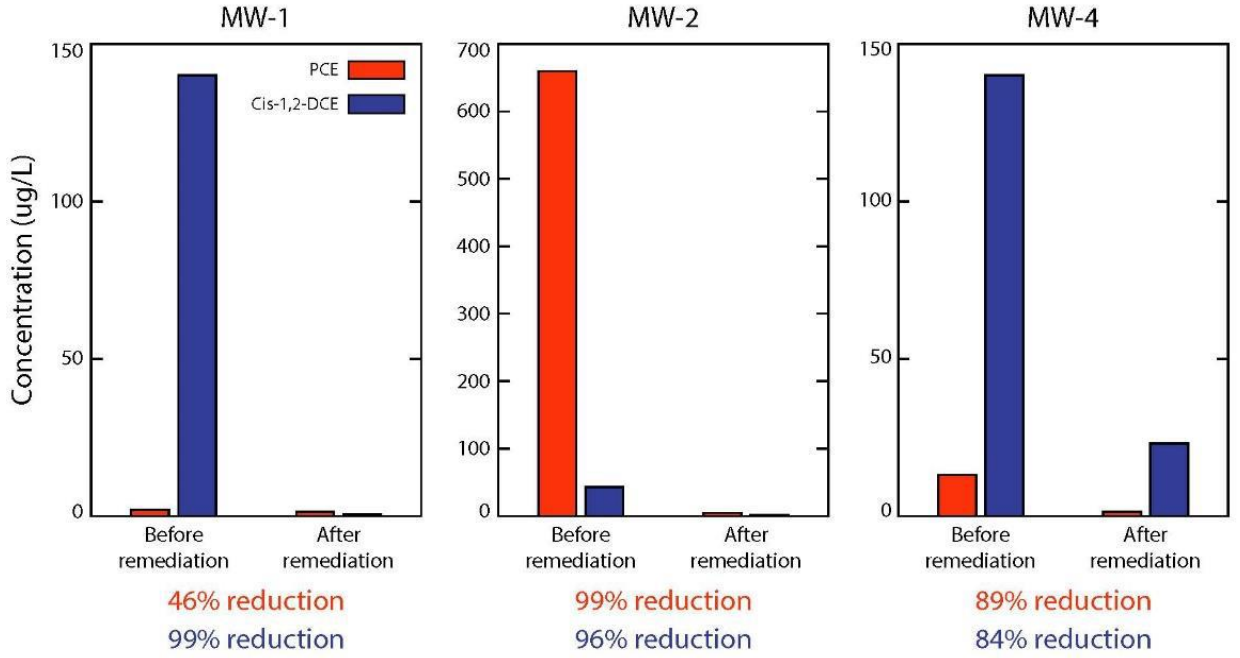
- Portland cement: 4% w/w with Soil





Courtesy of Hamp Mathews

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Summary

- ISS and ISCO are to mature remediation technologies with each having been used for decades
  - ISCO: Contaminant destruction
  - ISS: Reduction in contaminant flux (solidification/stabilization)
- Technologies can be combined
  - ISCO: Adding ISS gives geotechnical strength to site after soil mixing
  - ISS: Adding ISCO:
    - Reduces long term risk due to contaminant destruction
    - Lowers leachate concentration
    - Lower leachate concentrations
    - Higher compressive soil strengths
    - Lower hydraulic conductivities
    - Less soil bulking
- Water content is an important parameter and water existing in soil needs to be considered

Questions?

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