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WEBINAR

Design Strategies and Applications Combining ISCO and ISS

May 26th, 2021
10:30AM (EDT) / 7:30AM (PDT) / 4:30PM (CET)

Our presenters:

Vipul Srivastava
Senior Remediation Specialist
Burns & McDonnell

Joel Parker
Principal Engineer
Hamp Mathews & Associates

Brant Smith
Technology Director
PeroxyChem

Today's Presenters

Vipul Srivastava

Senior Remediation Specialist

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Joel Parker

Principal Engineer

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Brant Smith, PhD, PE

Technology Director

PeroxyChem

PeroxyChem

PeroxyChem
An Evonik Company.

Field-Proven Portfolio of Remediation Technologies Based on Sound Science

Chemical Oxidation
- Klozur® Persulfate Portfolio
  - Klozur ® SP
  - Klozur ® KP
  - Klozur ® One
  - Klozur ® CR
- Hydrogen Peroxide

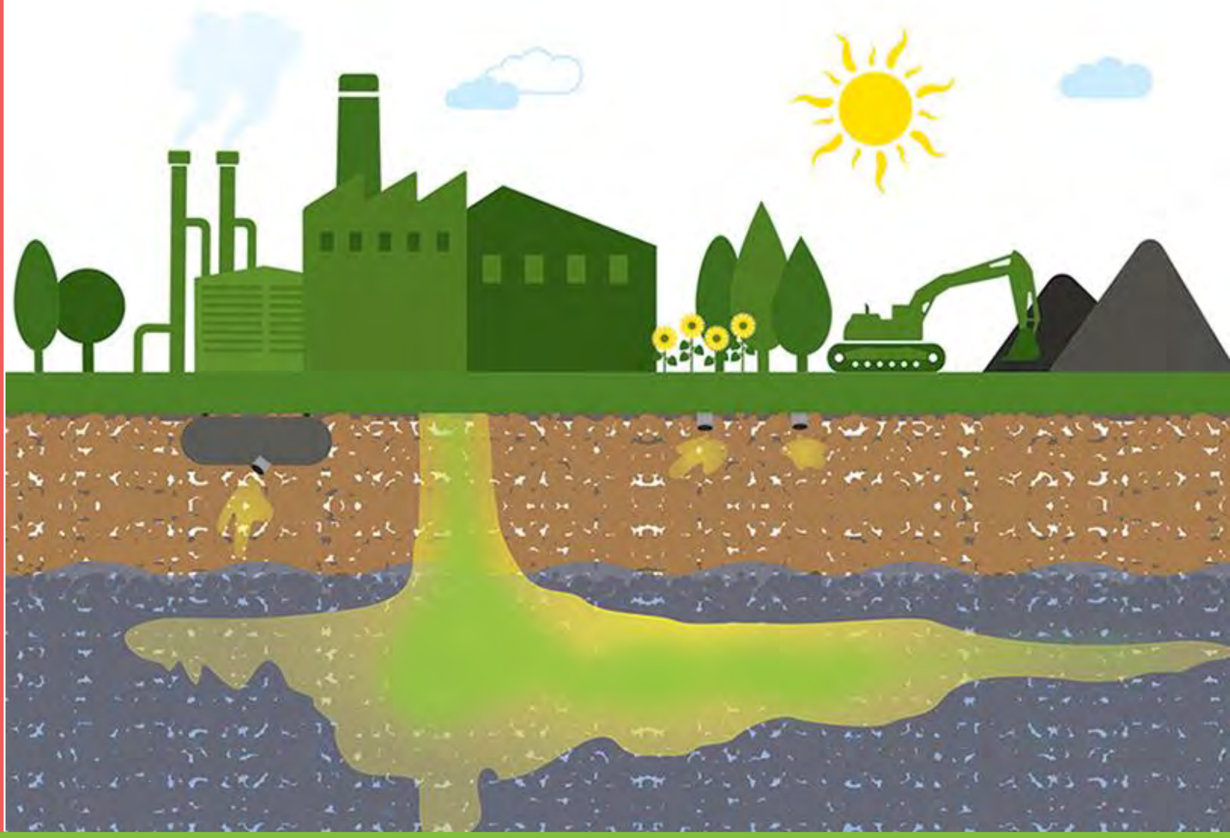
Aerobic Bioremediation
- Terramend® Reagent
- PermeOx® Ultra
- PermeOx® Ultra Granular

Metals Remediation
- MetaFix® Reagents

Chemical Reduction
- EHC ISCR Portfolio
  - EHC® Reagent
  - EHC® Liquid
  - EHC ® Plus
- Daramend® Reagent
- Zero Valent Iron

Enhanced Reductive Dechlorination
- ELS® Microemulsion
- ELS® Liquid Concentrate
- ELS® Dry Concentrate

BioGeoChemical
- GeoForm™ Reagents



Environmental Solutions

Previous ISCO-ISS Webinars

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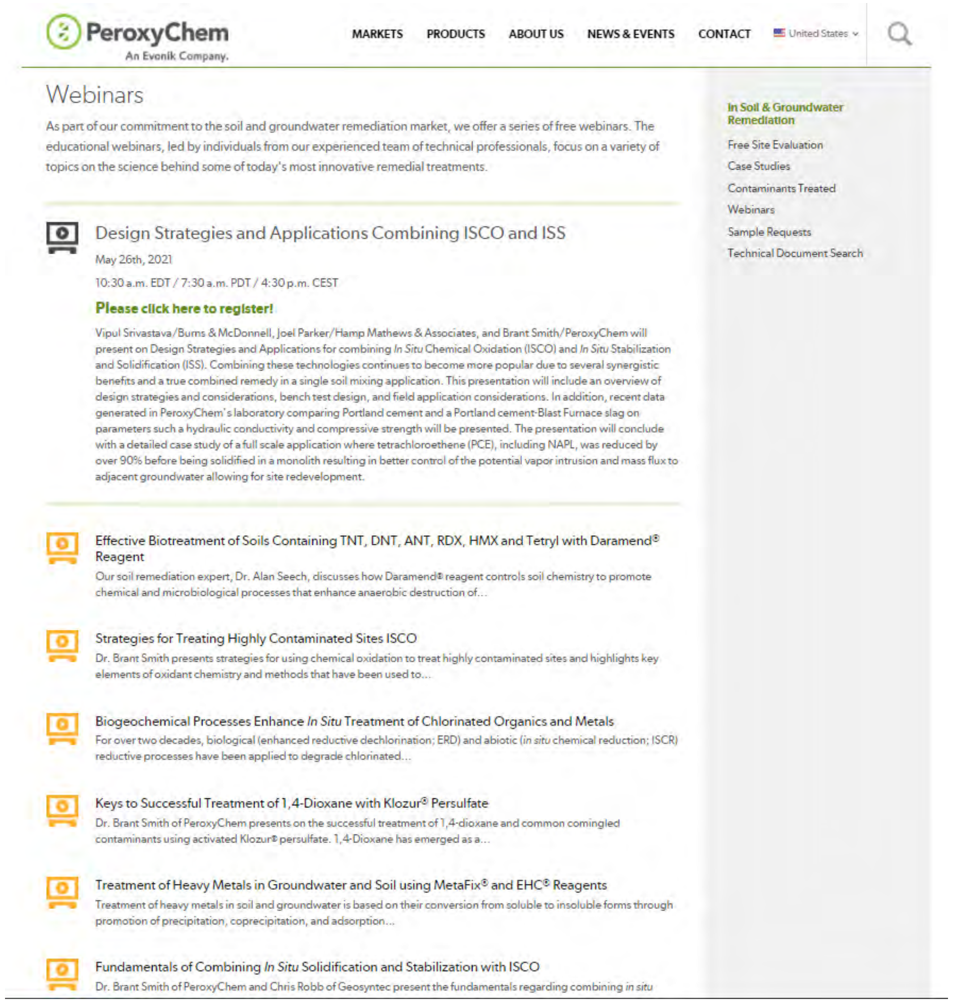
January 2017: Soil Mixing and *In Situ* Stabilization using Klozur Persulfate: Theories, Benefits, and Lessons Learned

Tom Simpkin, Ph.D., P.E./Jacobs
Mike Perlmutter, P.E./Jacobs
Dan Cassidy, Ph.D., P.E./Western Michigan University
Brant Smith, Ph.D., P.E./PeroxyChem

October 2019: Fundamentals of Combining *In Situ* Solidification and Stabilization (ISS) with ISCO

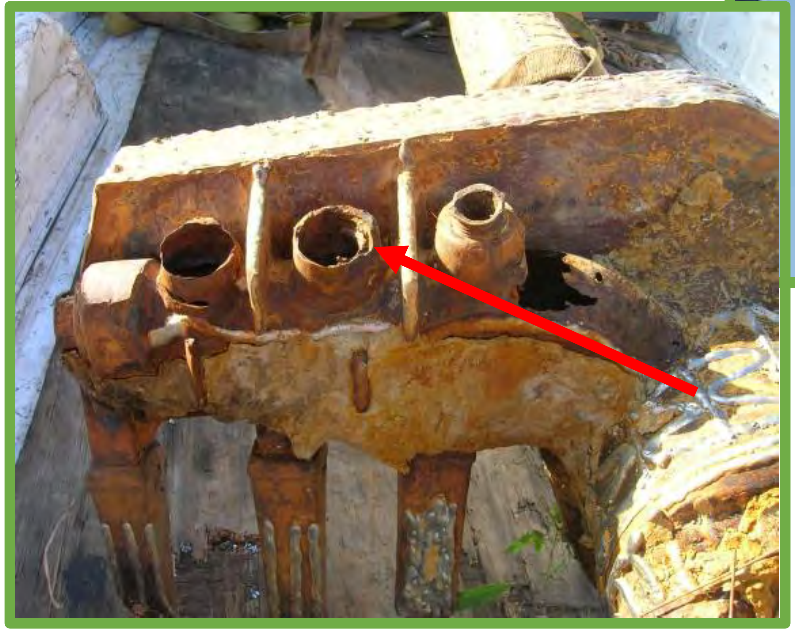
Chris Robb, P.E./Geosyntec
Brant Smith, Ph.D., P.E./PeroxyChem



http://www.peroxychem.com/remedationwebinars

Safety Share: Chemical Compatibility

- Neutral pH persulfate can be very corrosive to carbon steel
- Persulfate generates acid as it decomposes



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Safety Share: Compatible Materials

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Chemically compatible equipment needs to be used for all wetted equipment parts or parts that may come in contact with the reagents

- Compatible with persulfate:
  - 304 and 316 stainless steel, PVC, CPVC, polyethylene, Plexiglas®, glass, FRP (fiber reinforced plastic, e.g. Derakane©), Fiberglass – specifically vinyl ester resin, Polyester
  - Elastomers:
    - Long term duration: Teflon or PTFE, PVDF, or Gylon®
    - Short term duration: EPDM
    - Safety gear: butyl rubber, neoprene

- Corrosion rates increase at higher persulfate concentrations

Table 4: Results for Alkaline Activated Klozur Persulfate Solutions, 20 wt% and 40 g / L at Room Temperature After 1 Month Exposure Time

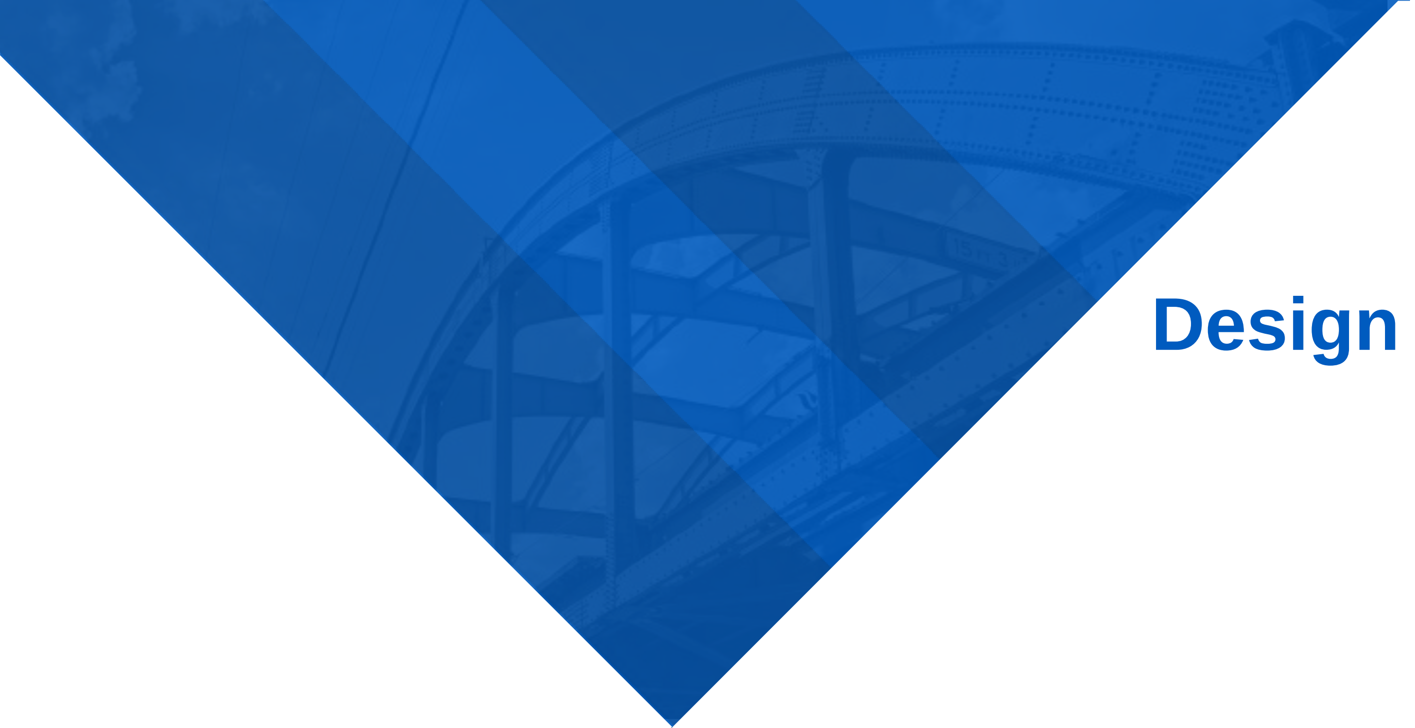
mpy – milli-inches per year; ✓- compatible material, ⊝ - non-compatible material

Material	20 wt% concentration	40 g / L	Comments
Stainless steels (304L, 316L)	✓	✓	< 1 mpy. No noticeable corrosion over 1 month
Copper Brass	✓	✓	Negligible general corrosion (< 2 mpy). Black film formation observed.
Carbon steel	✓	✓	Negligible general corrosion (< 2 mpy). Isolated rust spots observed

http://www.peroxychem.com/media/131599/peroxychem-klozur-compatible-materials.pdf

Webinar Agenda

- ISCO-ISS Fundamentals
  - Vipul Srivastava
- PeroxyChem Study Results
  - Brant Smith
- ISCO-ISS to Treat a Former Dry Cleaner Site: Kent Cleaners Case Study
  - Joel Parker



Design Strategies and Applications Combining ISCO and ISS: Background and Benefits

Vipul J Srivastava

May 26, 2021

Presentation Scope

- Combined ISCO/ISS Technology:
  - ISCO Technology
  - ISS Technology
  - Benefits of Combining ISCO/ISS Technology
    - Synergistic Value-added Effects of ISCO and ISS Technologies
    - Overcome Limitations of ISCO and ISS Technologies
    - Application can be Cost-Effective
- Path to a Successful Application
  - Thoughtful Treatability Testing
  - Strategic Remedial Design and Field Implementation
- Conclusions

ISCO Technology- Frequently Used Reagent Types- I

- **Sodium persulfate** ($Na_2S_2O_8$, $S_2O_8^{2-}$ $SO_4^{-\cdot}$), Solid
  - Sodium persulfate can be *activated* by one of the following methods to produce sulfate radical ($SO_4^{-\cdot}$):
    - Alkaline pH (> 10.5 pH)
    - Peroxide (H_2O_2) Addition
    - Chelated-iron Addition
    - Heat (>35 deg. C) Addition

- **Permanganate** (MnO_4); Solid
  - Sodium and Potassium Permanganate

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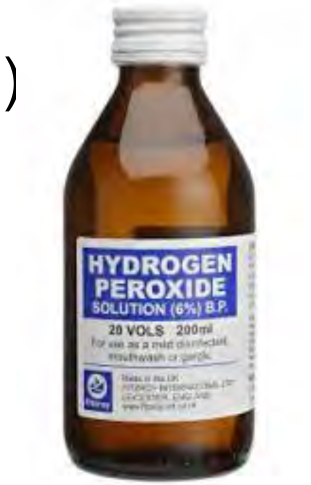
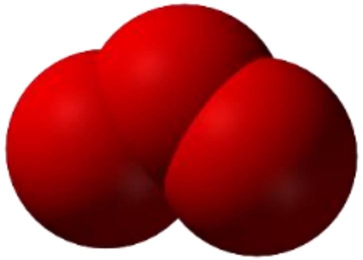
ISCO Technology- Frequently Used Reagent Types- II



- **CHP** (**c**atalyzed **h**ydrogen **p**eroxide, formerly called "modified Fenton's" , OH·)
  - **H_2O_2** (H_2O_2, Liquid)
  - **Iron** (including chelated iron)- **Iron** can activate to generate OH·
    - Iron in soil/GW if present in appropriate levels, or
    - Added iron



- **Ozone** (O_3, Gas)

- **Combination of Reagents such as**
  - **Persulfate and Peroxide**
  - **Persulfate and Permanganate**
  - **Peroxide and Ozone**

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ISCO Technology: Factors Affecting Success

- **Appropriate Reagent with Respect to Type of Contaminants**
- **Reagent Contact with Contaminants**
  - ✓ **Including contact duration**
- **Total Amount of Reagent Addition**

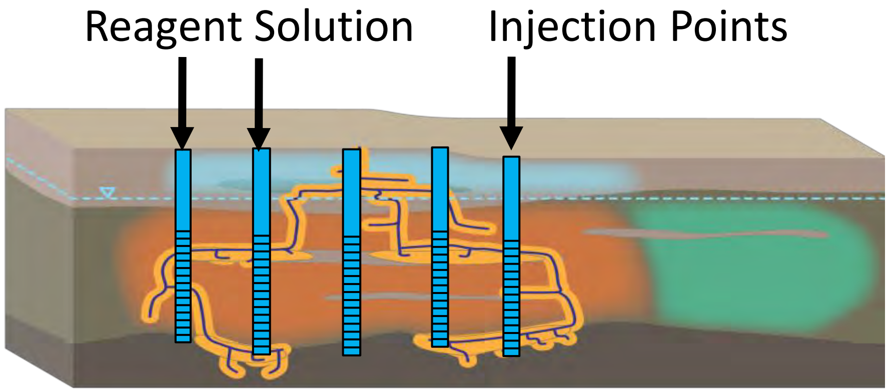
- **ISCO Reagents react and destroy/degrade soluble contaminants faster than those attached to soil or those in non-aqueous phase liquids (NAPL) phases**
  - ✓ **Due to limitation in rates of solubilization**
- **Measures of success for ISCO include-**
  - **Rate and Extent of Contaminant reductions, or**
  - **Reduction in Contaminant Concentration and Mass**

ISCO Technology: *Limitations* include

- Reagents are often applied as water-based (aqueous) solutions
- Contaminants (PAHs, TPHs, etc.) are often in NAPL phase
- Challenges in efficiently mixing reagents with contaminants
  - Short-lived Duration of Some Reagents/Oxidants (i.e., short half life)
  - Limitation of rates of Dissolution/desorption of contaminants from soil to groundwater
    - *Mass Transfer Challenges*
  - Excess Requirement of Reagents when Contaminants are not or less available
  - Contaminants rebounding- requiring multiple cycle of treatments
- Reagents can also be applied using soil mixing equipment
  - *Resulting in Swampy/Soupy Site*

ISCO Field Application Includes Reagent Injection Using Wells (w/ or w/o Groundwater Recirculation) or Using GeoProbe

- Reagents can be delivered in the subsurface through Injection Wells. Groundwater recirculation improves reagent distribution.



- Direct Push/GeoProbe can also be used to inject reagents in a targeted manner.
  - ✓ This can be effectively implemented to increase reagent contact with the contaminant mass

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ISCO Can be Implemented Using Soil Mixing Equipment to Improve Reagent Contact with Contaminants

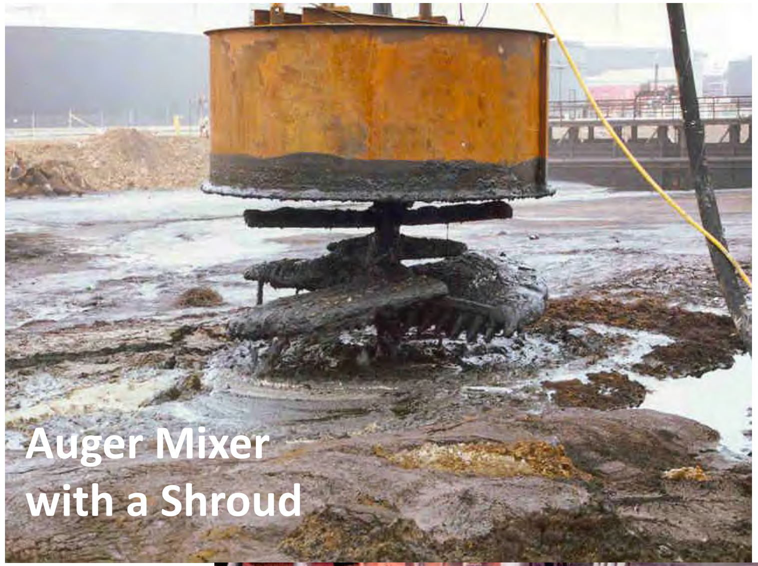
Leaving the Swampy Ground after ISCO with Soil Mixing

(See the Picture Above)

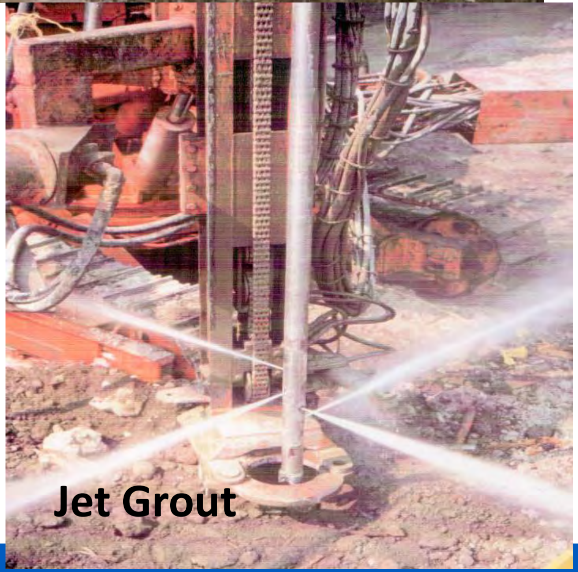
Disclaimer: Pictures in this presentation are taken from sources on Internet and/or presentations by others

ISS Technology: Frequently Used Reagents Include-

- Typical ISS reagents include-
  - Portland Cement
  - Slag Cement or Ground Granulated Blast Furnace Slag (GGBFS)
  - Bentonite
  - Hydrated Lime
  - Lime Kiln Dust



- ISS Application at DNAPL sites started primarily in early 1990s
  - ISS is one of the most utilized and successful treatments for Source Areas



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ISS Technology: Background

- ISS involves mixing of cementitious reagents with subsurface soil to *encapsulated* contaminants into a solidified mass or ***monolith***
  - ISS is not intended destroy contaminants
  - Addition of cementitious reagents to subsurface causes the soil volume to increase (swelling or bulking)
    - ✓ Necessitates excavation of significant soil (vadose and saturated)
- Deep soil-reagent mixing can be achieved with auger mixing in overlapping patterns
- Shallow soil-reagent mixing can be achieved with excavator mixing, rotary drum mixing, etc.

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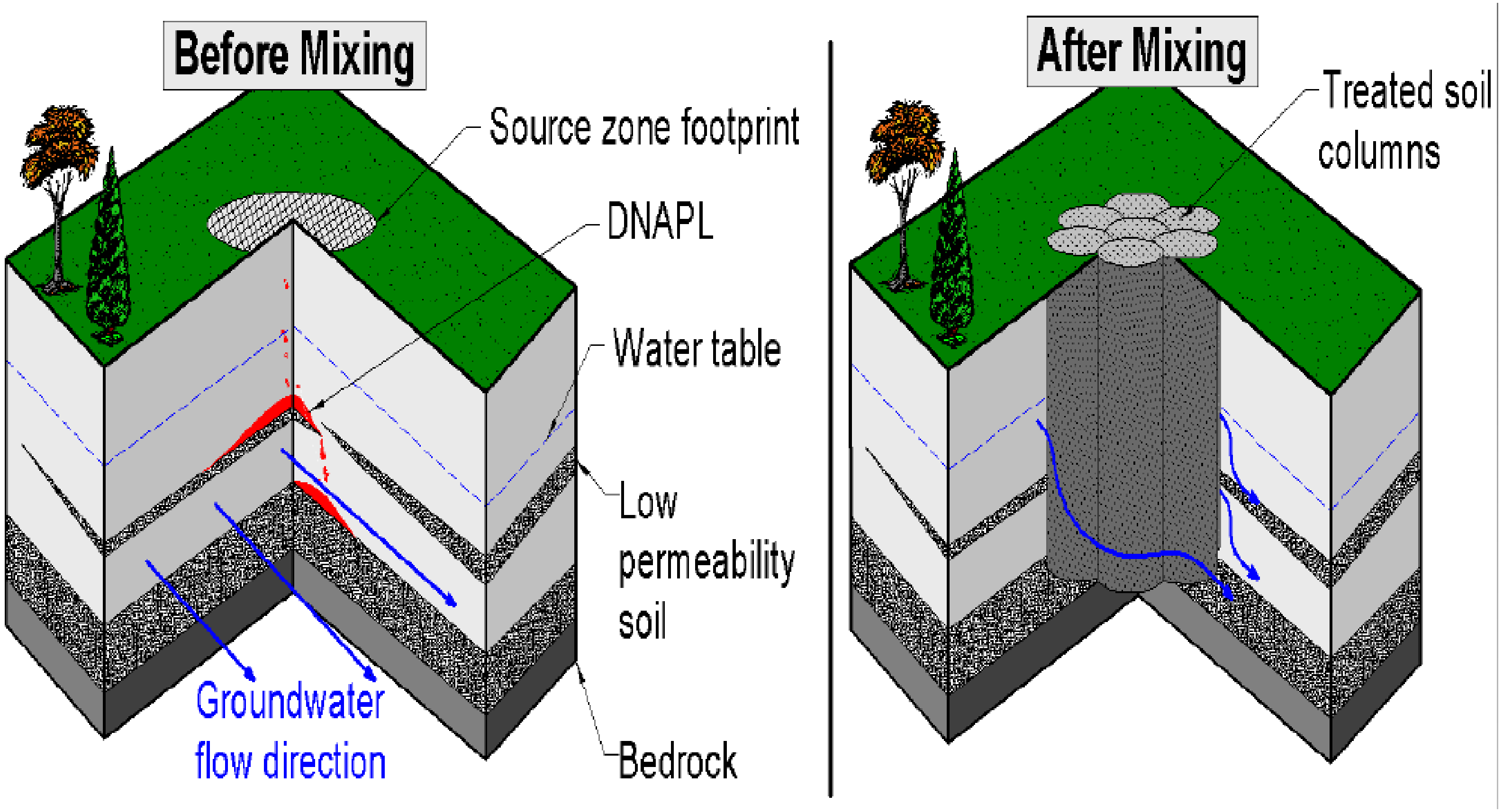
ISS Technology Background (contd.)

- Hydraulic conductivity) of treated soil (*monolith*) is much lower than the surrounding soil; thus, groundwater goes “around” the monolith, and <u>not</u> “through” the monolith
  - Contaminant leaching is significantly reduced or eliminated.
- Soil strength improves due to cement addition [as measured by Unconfined Compressive Strength (UCS)]
- Groundwater mounding is generally not a major issue because ISS treatment areas are small relative to large surrounding areas
- Excess sedimentation in groundwater has not been observed except during the initial phases of ISS treatment, but it resolves itself shortly thereafter.

Conceptual Depiction of Groundwater Flow *Before* and *After* ISS Treatment



Disclaimer: Picture Taken from 2011 ITRC Document on ISS Technology

ISS Technology: *Limitations include*

- Contaminants are not intended to be degraded
- Excess soil excavation (vadose and saturated) to compensate for the increase in volume due to ISS reagent additions
- Contaminants are encapsulated in monolith
  - Concerns about vapor if contaminants included volatile compounds
  - Concerns about long-term durability of monolith
    - Potential leaching of mobile/soluble contaminants

Combined ISCO/ISS Treatment

- **In-Situ Chemical Oxidation** (or ***ISCO***) using Sodium Persulfate

- **In-Situ Solidification/Stabilization** (***ISS*)-** using Portland cement or Slag cement, which *are alkaline (pH of ~12).*

  Cements-

  ✓ ***Activate*** sodium persulfate (alkaline activation) to **destroy** soluble and rapidly degradable contaminants

  ✓ **Encapsulate** remaining/residual contaminants

Key Publications:

1. EPRI. (2013). *Bench Scale Study of Integrated Chemical Oxidation Enhanced Bio-Stabilization of MGP Soils*
2. Cassidy et al. (2015). *Journal of Hazardous Materials*.
3. Srivastava et al. (2016). *Chemosphere*.
4. Srivastava et al. (2016). *Journal of Chemical Environmental Engineering*.

-

Combined ISCO/ISS Treatment (continued)

- **Combined ISCO/ISS Overcomes Limitations of ISCO and ISS and Highlights Strengths such as-**
  - **Degrades** mobile/soluble (i.e., low MW) contaminants prior to and during early phases of combined treatment
  - **Encapsulates** remaining contaminants
  - **Improves** soil strength (and no swampy land), and
  - **Reduces** hydraulic conductivity to force groundwater to go around the monolith

Advantages/Benefits of Combined ISCO/ISS Treatment

- Reduces contaminant mass by *chemical oxidation*, especially soluble/mobile/degradable contaminants,
- Encapsulates remaining, less mobile contaminants, and
- Combined ISCO/ISS treatment -
  - ✓Minimizes contaminant leaching potential
  - ✓Minimizes vapor intrusion potential after treatment
  - ✓Eliminates or minimizes contaminant rebound problem
- Increases soil strengths for Site Redevelopment (no swampy land)
- Reduces soil excavation requirement due to reductions in total ISS reagent additions (and hence reductions in Bulking or Swelling)

Combined ISCO/ISS Technology can be Implemented with Conventional ISS Equipment

- Combined ISCO/ISS treatment is another remediation approach for *certain types of sites, or for specific portions of sites*.
- This does not replace the conventional ISS or ISCO technology.

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When and Where Combined ISCO/ISS is Best Suited

- Remedial Goals include-
  - Reducing the Total Mass of Contaminants
  - Minimizing Long-term Leaching Potential of Saturated Zone
  - Minimizing the Vapor Intrusion Potential- Important when Redeveloping the Site
- Presence of Downstream Receptors such as a River or a Water Body
- Specific Areas with Abundance of Low-Molecular Contaminants (such as Mobile and/or Easily Water-Soluble Contaminants)

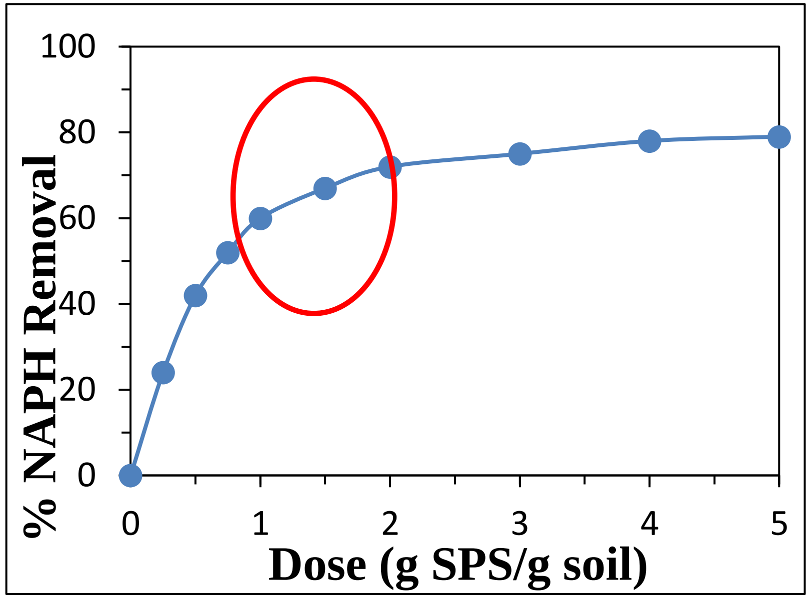
Approach to Evaluating and Implementing ISCO/ISS

- Conduct treatability studies with site soils
  - Combined ISCO/ISS using different combinations of ISCO and ISS reagents concentrations
  - ISCO alone (optional)
  - ISS alone (optional)
- Conduct pilot tests utilizing ISS field equipment
  - Small plots (e.g., 25’ x 25’)
  - Use full-scale equipment
- Implement full-scale remediation
  - Grid cell pattern (e.g., 50’x50’) across the contaminated site
  - Select reagent mixes for each cell

Treatability Studies/Tests

- What ratio of ISCO reagent to ISS reagents?
  - Ratios of ISCO:ISS reagents between 1:3 and 1:5 works well for most soils
  - Greater the ISCO reagent percentage, higher the overall reagent cost
    - Reagent cost for ISS and/or ISCO/ISS is a small percentage of total remediation costs
  - Treatability studies with over 12 MGP site soils found that between 1% to 2% ISCO reagent generally works well

ISCO/SPS Dose-Response



Example: Treatability Studies with MGP Soils

SITE BACKGROUND

- Former MGP site (WI), contaminated with BTEX, Naphthalene & PAHs
- Priorities: Reduction in contaminant mass & reduction in leaching of BTEX and Naphthalene
- Contamination Location- Approximately 20 feet bgs or higher.

Soil (former MGP site, Racine, WI)

Baseline Concentrations	Soil (mg/kg)	SPLP (µg/L)
BTEX	1,580	1,991
NAP	2,699	4,602
PAH*	4,057	6,253

* Includes NAP

Results of Treatability Studies with MGP Site Soils: Contaminant Mass Removal

Reaction	BTEX Removal (%)	PAH Removal (%)
Control	0.6	-0.3
SPS/ISS	64	70
SPS/NaOH	56	62
ISS	0.7	-1

ISCO destroys contaminants

Reduction in Leachability (SPLP) After 28 Days

Reaction	BTEX Reduction (%)	PAH Reduction (%)
Control	1	0
SPS/ISS	74	76
SPS/NaOH	12	14
ISS	26	22
SRB	3	4

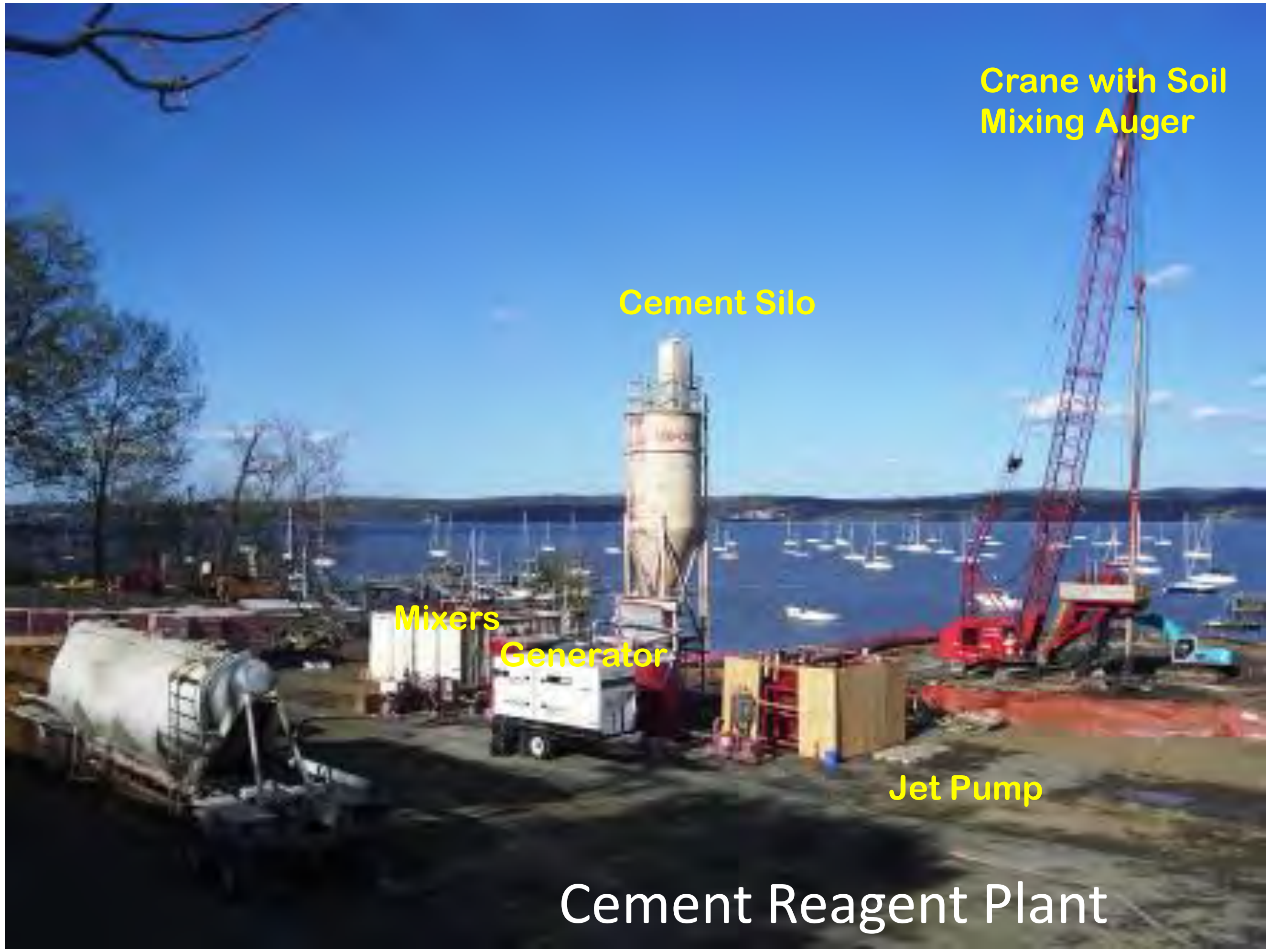
Combined ISCO/ISS reduced leaching more than either stand-alone

Full-Scale Implementations of Combined ISCO/ISS in the United States are Underway at Different MGP Sites

- Treatability studies were completed first
- Pilot tests were successfully completed at a MGP site with 1-4% sodium persulfate and 4-8% Portland cement
  - 25' x 25' pilot cells
- Remedial design completed
- Process of Full-scale remediation is underway

Combined ISCO/ISS can be Implemented with ISS Equipment

ISS Equipment in Full Operation



Mixing Equipment

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CREATE AMAZING.

Vipul J Srivastava
630-561-3396

Environmental Solutions

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PeroxyChem ISCO-ISS Study Results

Brant Smith, Ph.D., PE

PeroxyChem Studies

- PeroxyChem in-house studies
  - Alkaline activated persulfate*
- Evaluated
  - Oxidant dosage (Klozur® SP)
  - Portland cement (PC) vs blend of PC and Blast Furnace Slag (BFS)
  - Moisture content
- Soils: Clays and sands
- Binders Tested
  - Lafarge Type I/II Alpena Portland cement
  - Maxcem 70/30 (Lafarge PC and BFS)
- Assessing impacts on:
  - Unconfined compressive strength (UCS)
  - Hydraulic conductivity

* PeroxyChem LLC ("PeroxyChem") is the owner of U.S. Patents No: 7,576,254, US App 62/890,098 and their foreign equivalents. The purchase of PeroxyChem's Klozur® persulfate includes with it, the grant of a limited license under the foregoing patent at no additional cost to the buyer.

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Common Objectives of ISS

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

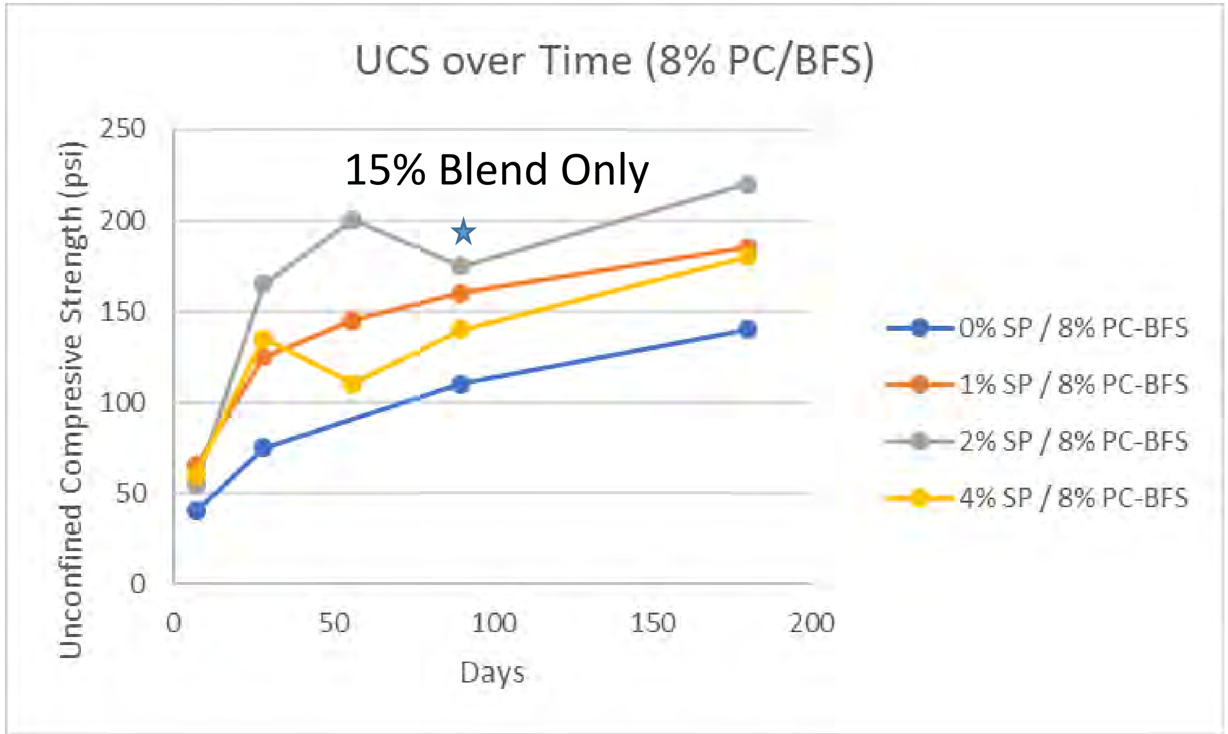
Typical target range for "workable" soils ~20-60 psi

Compressive Strength Over 180 Days

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

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

- Excess strength used to decrease reagents added = less soil bulking = less disposal



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Rate of Solidification

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- ISS often uses 7 and 28 day
  - Adding SP can lead to higher UCS
  - Rate of solidification can be slower
  - Day 7 UCS is not as predictive in ISCO-ISS as ISS only

Common ISS Targets

7 Day UCS less predictive

UCS as a Percent of Day 28: 8% PC/BFS

Day	0 % SP	1% SP	2% SP	4% SP
7	53%	52%	33%	44%
28	100%	100%	100%	100%
56		116%	121%	81%
90	147%	128%	106%	104%
180	187%	148%	133%	133%

UCS as a Percent of Day 180: 8% PC/BFS

Day	0 % SP	1% SP	2% SP	4% SP
7	29%	35%	25%	33%
28	54%	68%	75%	75%
56		78%	91%	61%
90	79%	86%	80%	78%
180	100%	100%	100%	100%

Day 7 UCS in this study was higher than usual. Often, Day 7 can be very low but UCS evolves to target levels over 28-90 days.
Longer bench studies recommended

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Moisture Content

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- Even vadose zone soils can have significant moisture
- Amount of moisture in soil mixing far exceeds classic concrete
- Many contractors use moisture to lubricate subsurface for equipment

% of PV	Water Weight (lbs)	Total Weight (lbs)	Moisture Content	
			% of Total Weight	% Dry Weight
10	2.2	112	2%	2%
25	5.5	115	5%	5%
50	10.9	121	9%	10%
75	16.4	126	13%	15%
100	21.8	132	17%	20%
125	27.3	127	20%	25%
Concrete			~7 to 8 %	

Assuming 35% porosity and 110 lbs/ft^3

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

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

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Water Content

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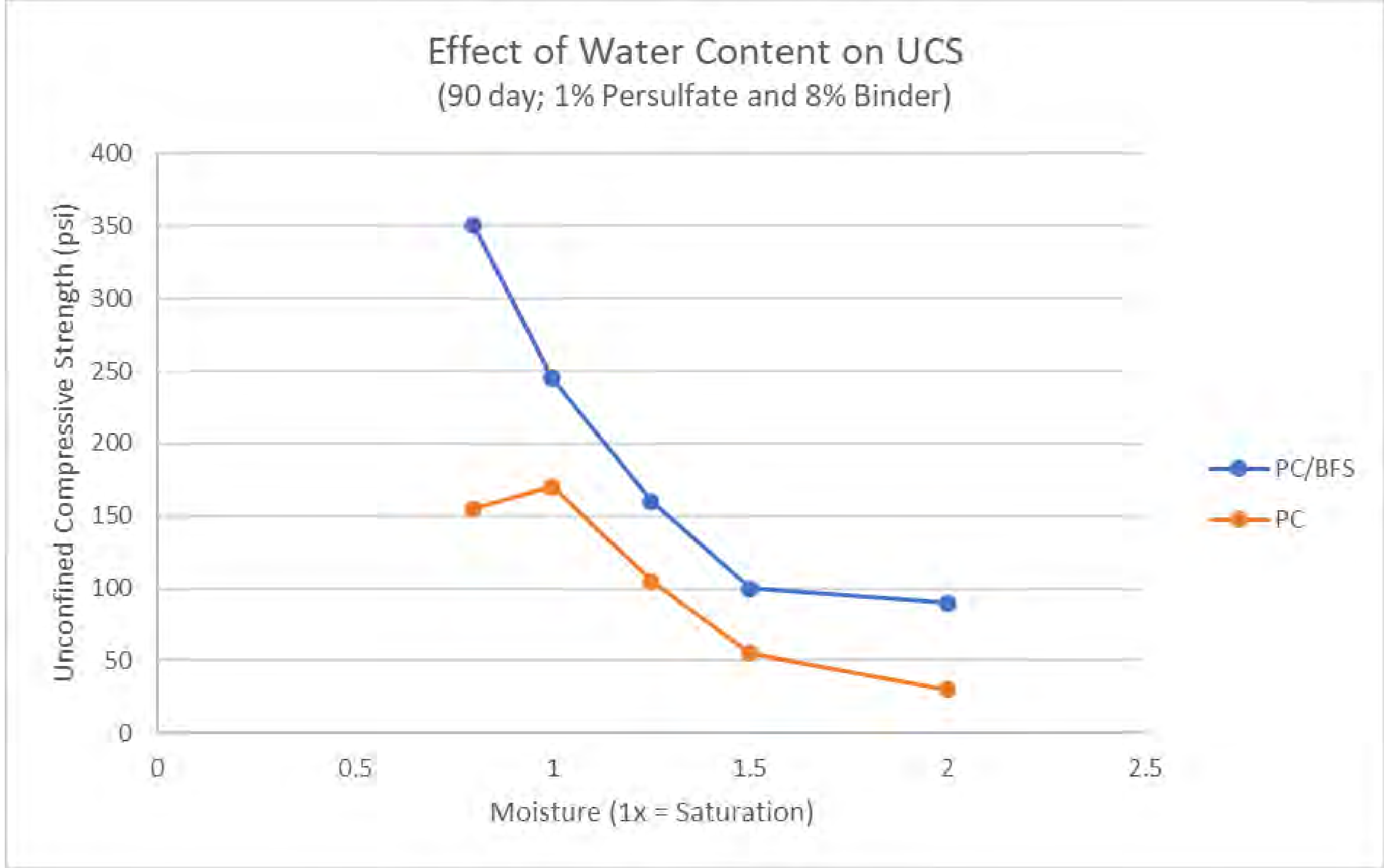
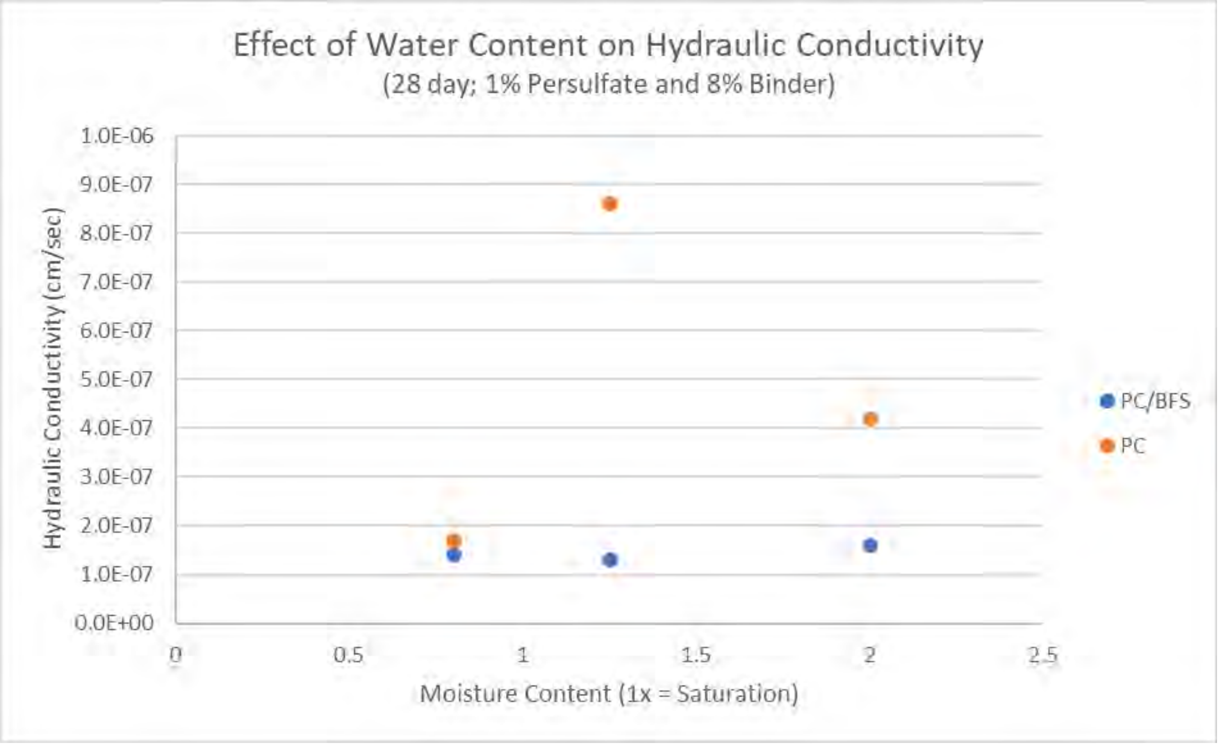
- Increasing water content resulted in decreased UCS
- BFS blend stronger than PC only
- PC only 0.8x and 1x very similar
- Most points above 50 psi
    - Had this been an actual site, <8% binder would have been used



Moisture on Hydraulic Conductivity

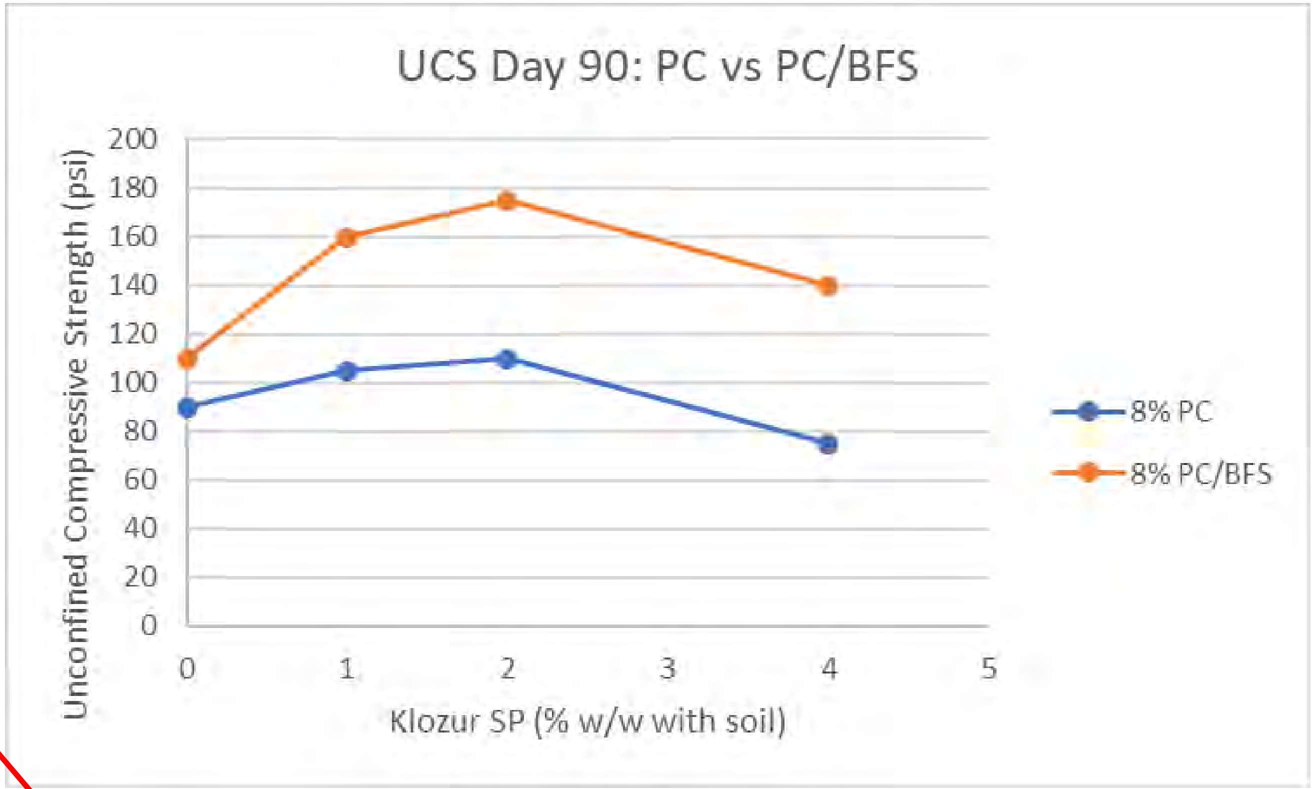
- Moisture had marginal to no impact on 28 Day hydraulic conductivity
  - Slight impact to Portland cement
  - PC/BFS very consistent
- Results may be soil specific



Addition of BFS on UCS

- Replace 30% of Portland with Blast Furnace Slag resulted in higher UCS for most test conditions

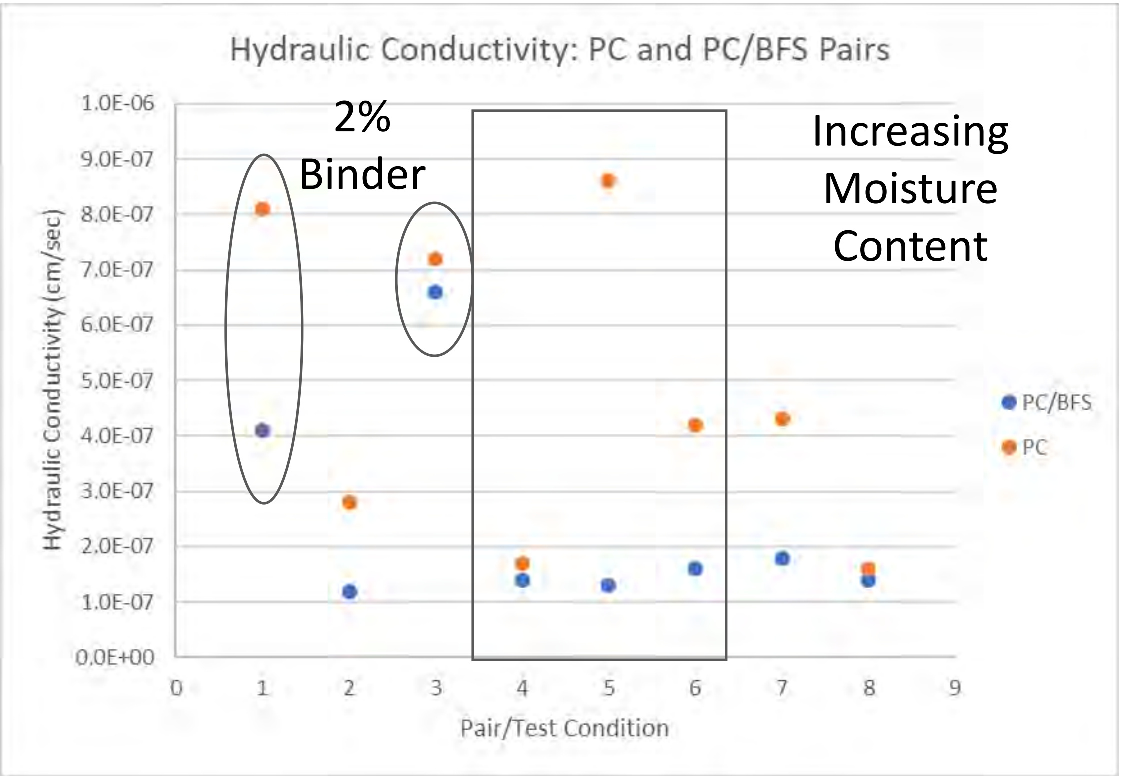
Klozur SP (% w/w soil)	8% PC		8% PC/BFS	
	Day 90 UCS (psi)	% of ISS only	Day 90 UCS (psi)	% of ISS only
0	90	100%	110	100%
1	105	117%	160	145%
2	110	122%	175	159%
4	75	83%	140	127%



Excess strength used to reduce total reagents which decreases bulking and associated handling/disposal costs

Addition of BFS: Hydraulic Conductivity

Pair	Klozur SP (%)	Binder (%)	Water (PV)	Binder	
				PC/BFS	PC
1	0	2	1.25	4.1E-07	8.1E-07
2	0	8	1.25	1.2E-07	2.8E-07
3	1	2	1.25	6.6E-07	7.2E-07
4	1	8	0.8	1.4E-07	1.7E-07
5	1	8	1.25	1.3E-07	8.6E-07
6	1	8	2	1.6E-07	4.2E-07
7	2	4	1.25	1.8E-07	4.3E-07
8	4	8	1.25	1.4E-07	1.6E-07
			Average	2.4E-07	4.8E-07
				Difference	50%



BFS Blend lower in every pair and more consistent

Study Summary

- Hydraulic conductivity
  - Minimal impact of varying binder ratios or Klozur SP
  - PC/BFS blend had lower HC for each test condition compared to PC only
- UCS
  - Day 7 less predictive with ISCO-ISS than ISS only
  - Lower UCS with increasing moisture content
  - Increasing UCS:
    - Increased binder concentration
    - Addition of BFS
    - Addition of Klozur® SP
      - Going above 2% Klozur® SP can sometimes result in lower UCS

Environmental Solutions

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ISS-ISCO OF PCE IN A RESIDENTIAL SETTING

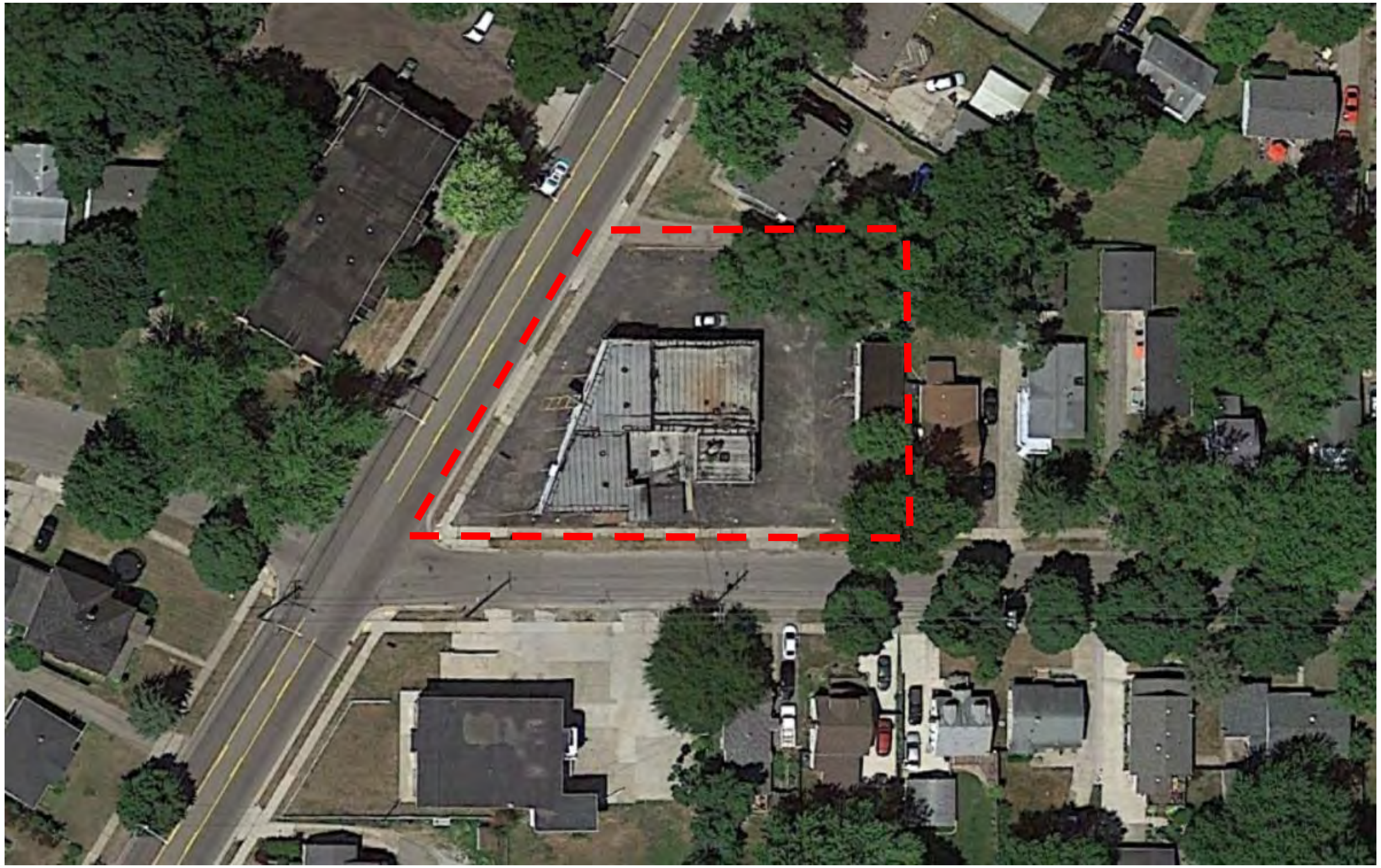
PRESENTED BY: JOEL PARKER

KENT CLEANERS, LANSING, MI

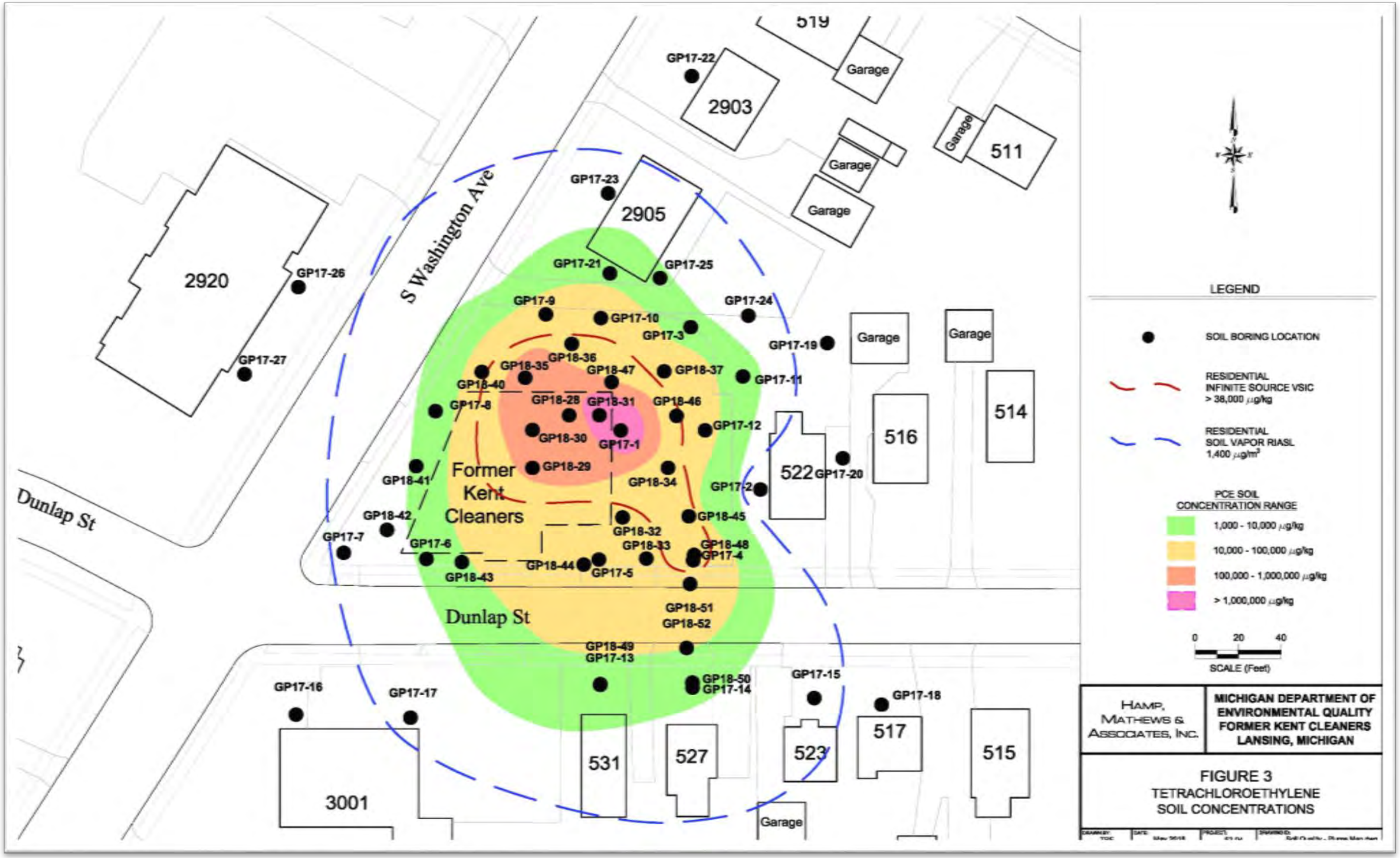
HAMP MATHEWS & ASSOCIATES, INC.

Kent Cleaners Overview

- Dry cleaner 1958-2015
- Orphan – State led site (EGLE)
- Surrounded by residential neighborhood
- Off-site Vapor Intrusion (VI) Assessment in 2017-2018
  - Soil gas > SLs off-site
  - SSDS in one home (527 South Dunlap)
- Significant soil impact: PCE > C_{sat} down to 22' bgs in center of site
- Groundwater typically encountered at 30-35' bgs
- Purpose of soil remediation is to reduce soil mass to lessen potential for further VI (hoping for 75-80% reduction)

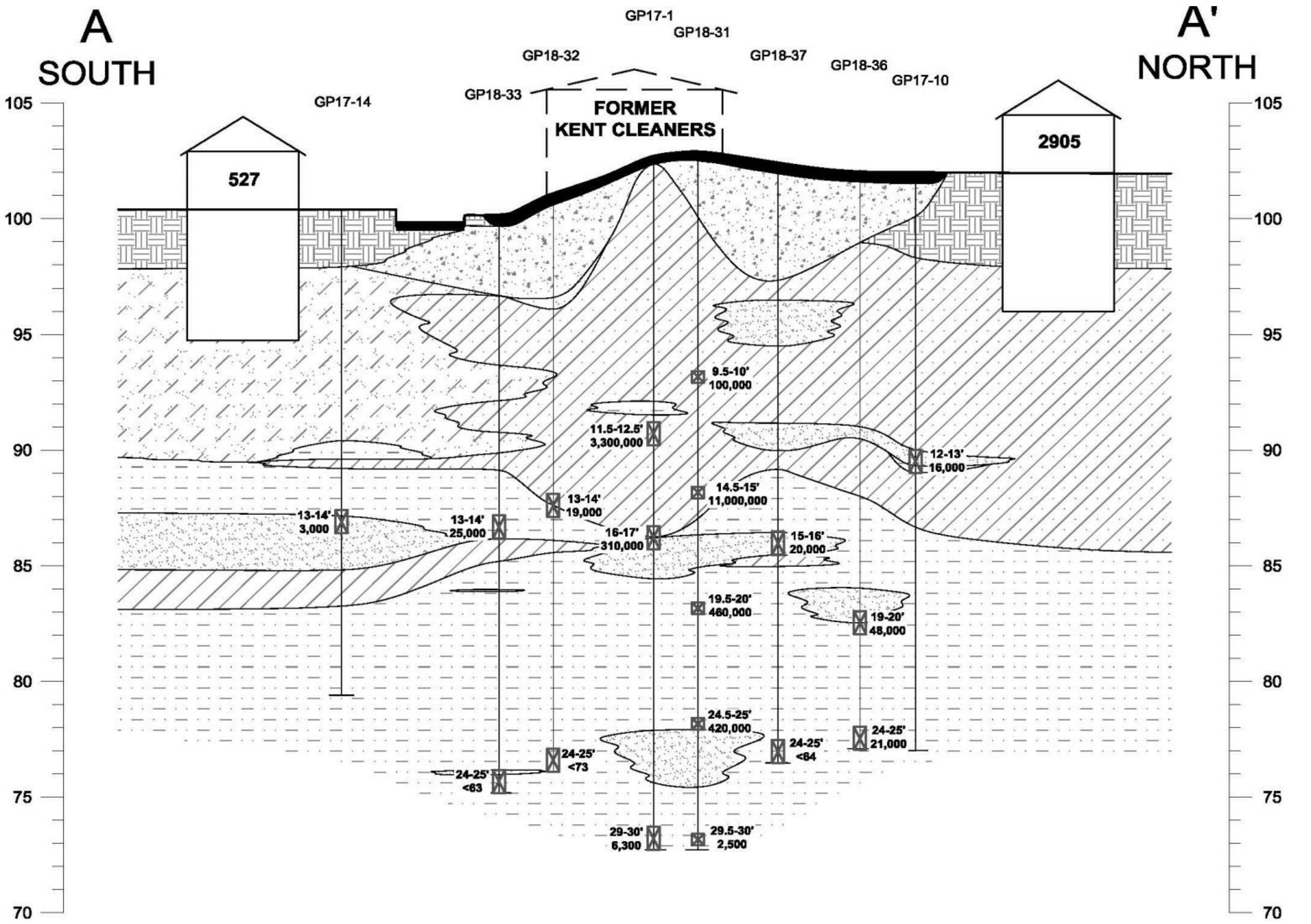


Extent of PCE in Soil



Kent Cleaners Overview

- Majority of the 0.4-acre site was impacted & long term off-site VI source
- Small size, tight spatial constraints with adjacent residential
- Residential neighborhood considerations – "intrusiveness"
- Challenges for conventional one technology strategies
    - Sheet piling for excavation & haz waste costs
    - Clay soils
- Let's explore potential to couple two technologies – ISCO & ISS



Combined Remedy

One single soil mixing application:

- Reduce contaminant mass with ISCO
- Stabilize/solidify the remaining contaminant mass with ISS
- Optimize treated soil characteristics for buildability

Key Logistics

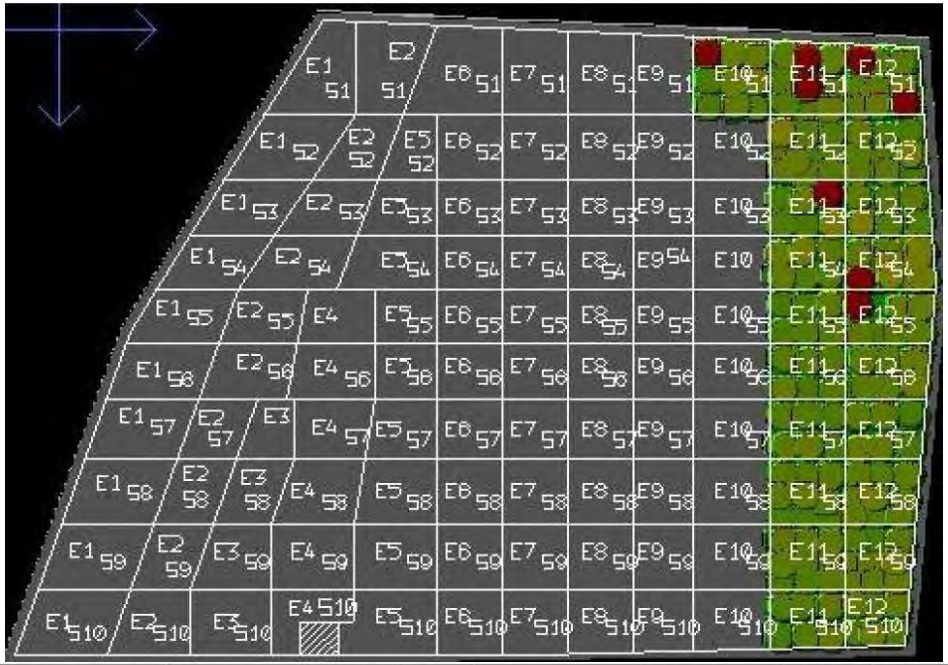
- Demo buildings
- Site Prep - Excavate & dispose of non-haz and surficial haz soils to make room for “swell”
- Berm
- Water

Lang Tool Company – Dual Axis Blender

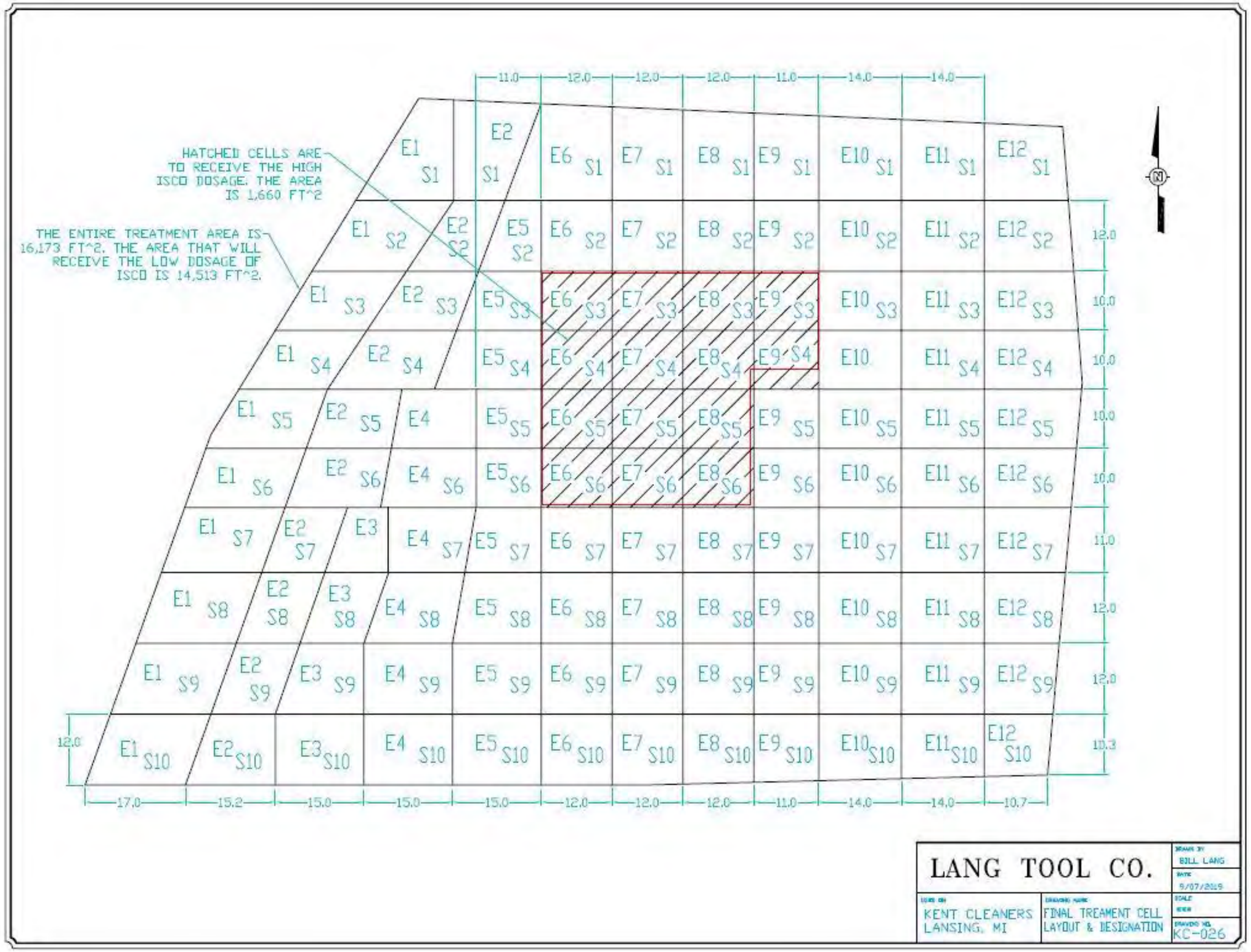
- Delivery and mixing in same tooling
- Contact between remediation additive and soil
- Measures quantity of reagent solution
- GPS system gives operator real time feedback on location

How do we do this?

- 10’ x 15’ cells
- Lower tier (7-23’) first
- Then upper tier



Easting	Northing	Elev	Dev	Easting	Northing	Elev	Dev
13071494.19	438270.85	832.40	-0.10	13071494.69	438244.71	832.49	-0.02
13071494.59	438265.41	832.44	-0.06	13071490.28	438250.62	832.52	0.02
13071489.64	438270.57	832.49	-0.01	13071490.49	438244.83	832.39	-0.11

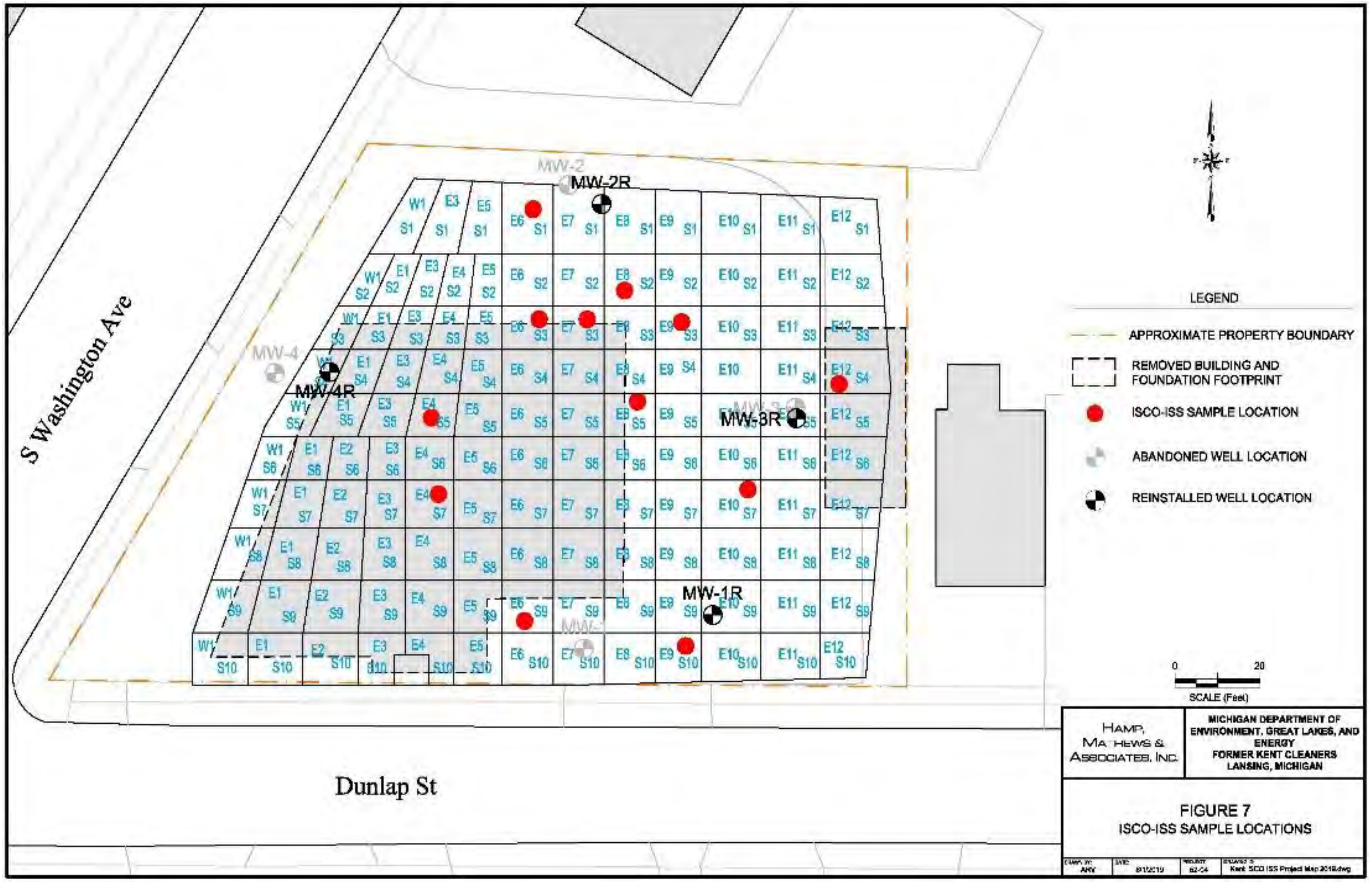


ISS – ISCO HIGHLIGHTS

- Sodium Persulfate (Klozur® SP) oxidation (alkaline activated) for destruction of contaminant mass
  - 440,000 pounds of Klozur® SP
  - 1% SP for all but center
  - 2% SP for center hot spot
  - Delivery and mixing accomplished via Lang Tool Company (LTC) Dual Axis Blender
  - 28 days of mixing – 500 CY/d
- Insitu stabilization (ISS) of mixed, blended soils with Portland cement to provide structural soil stability and binding potential
  - 4% PC, 1.6M pounds
- Bench tests to verify dosages
- Performed soil mixing in two tiers (upper and lower)
- Treated a total of 12,354 CY of soil

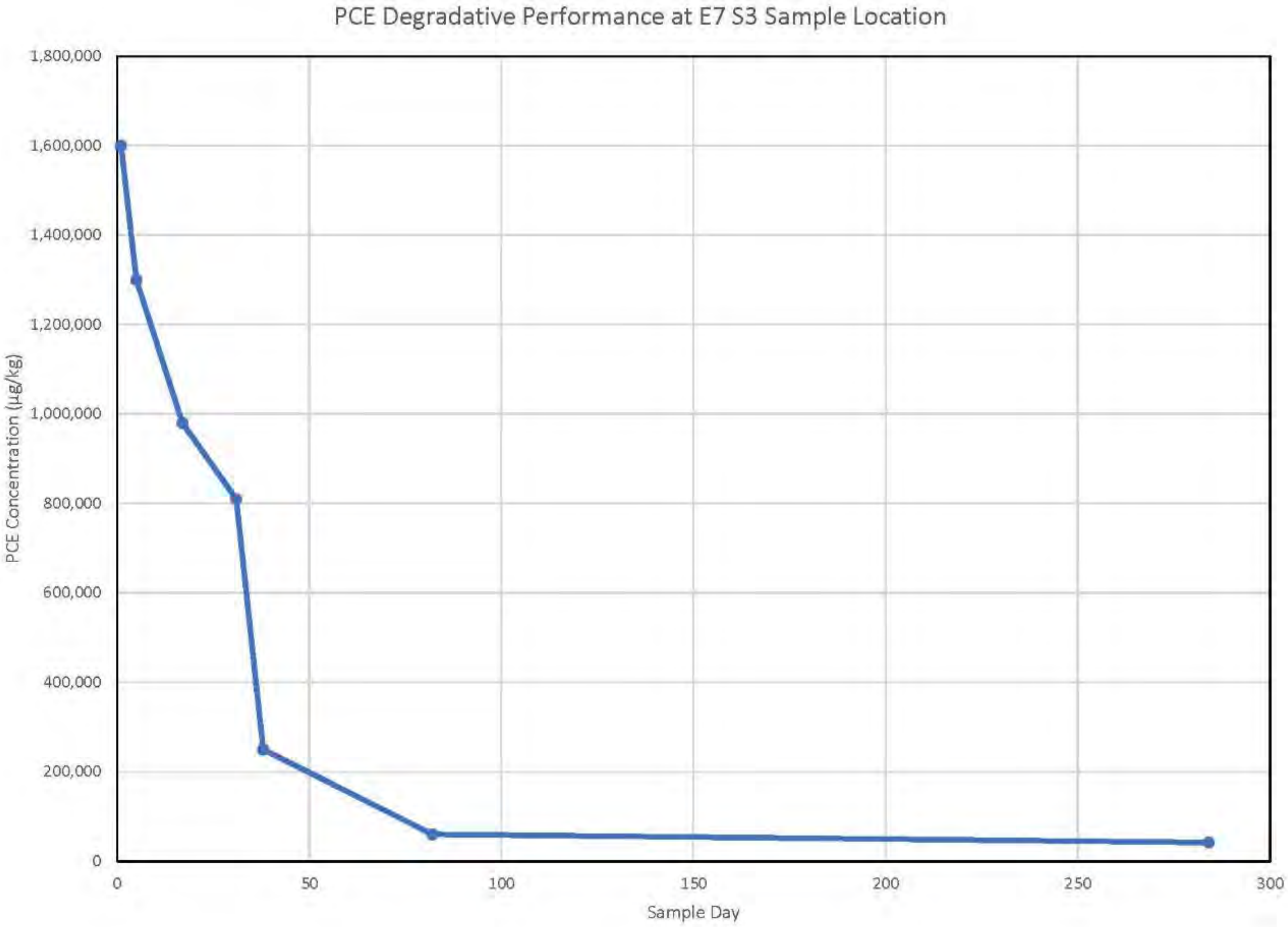
Verification of Remediation

- 36 discrete soil samples from 12 locations
- Total PCE concentration in soil
- Underlying groundwater from previous known locations "post" remediation



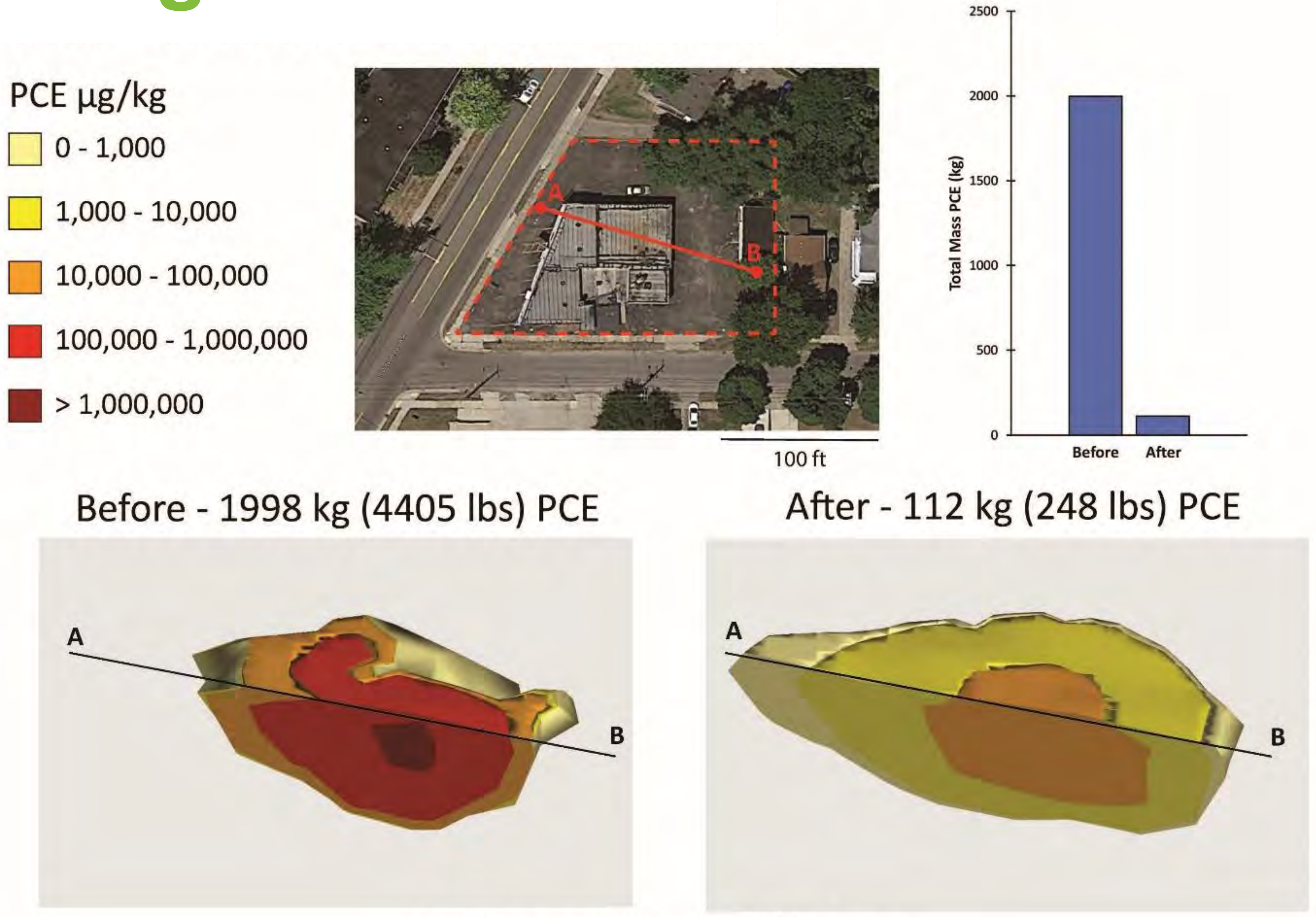
Tracking ISS – ISCO: Soil

- Avg. Pre-remediation PCE of 5,000,000 ug/kg in this area
- 1.6M on Day 1
- Continued degradation beyond Day 45
- Final concentration of 60,000 ug/kg



Tracking ISS – ISCO: Soil

- 90-94% reduction in mass
- UCS of 25-50 psi (Day 60)
- Underlying groundwater has reduced in concentration by 1-2 OOM
- Saved client > $2.5Million v. excavation
- Buildable site for property owner

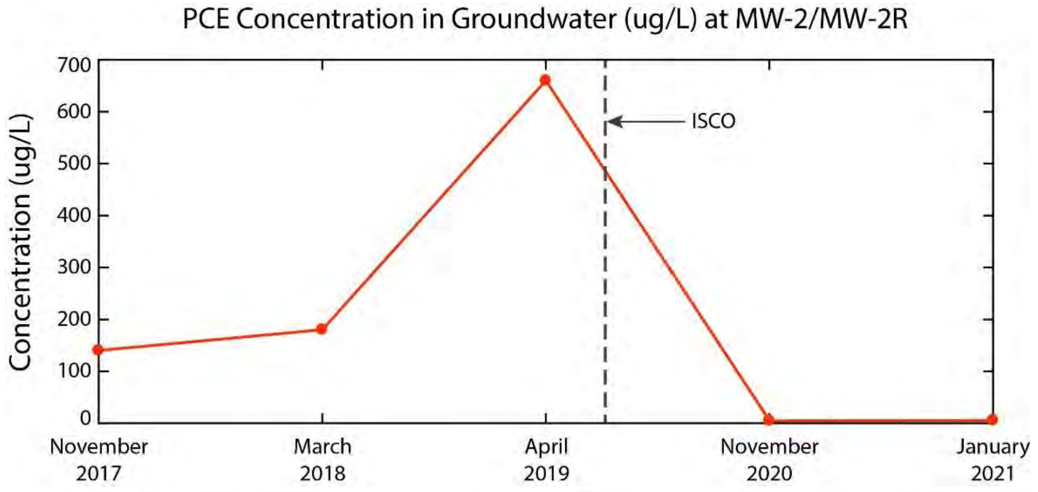


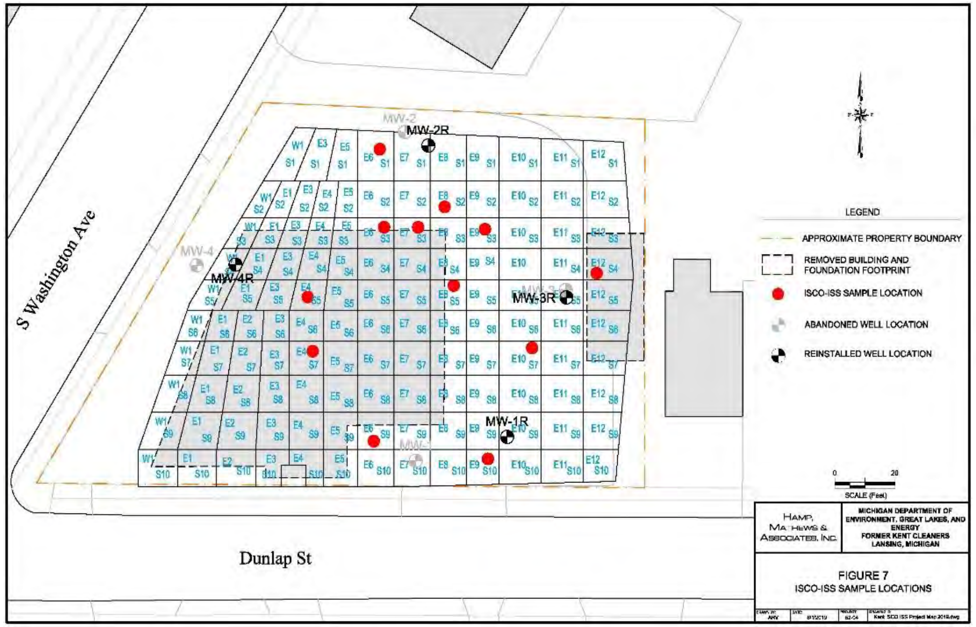
Looking north at a 30° plunge

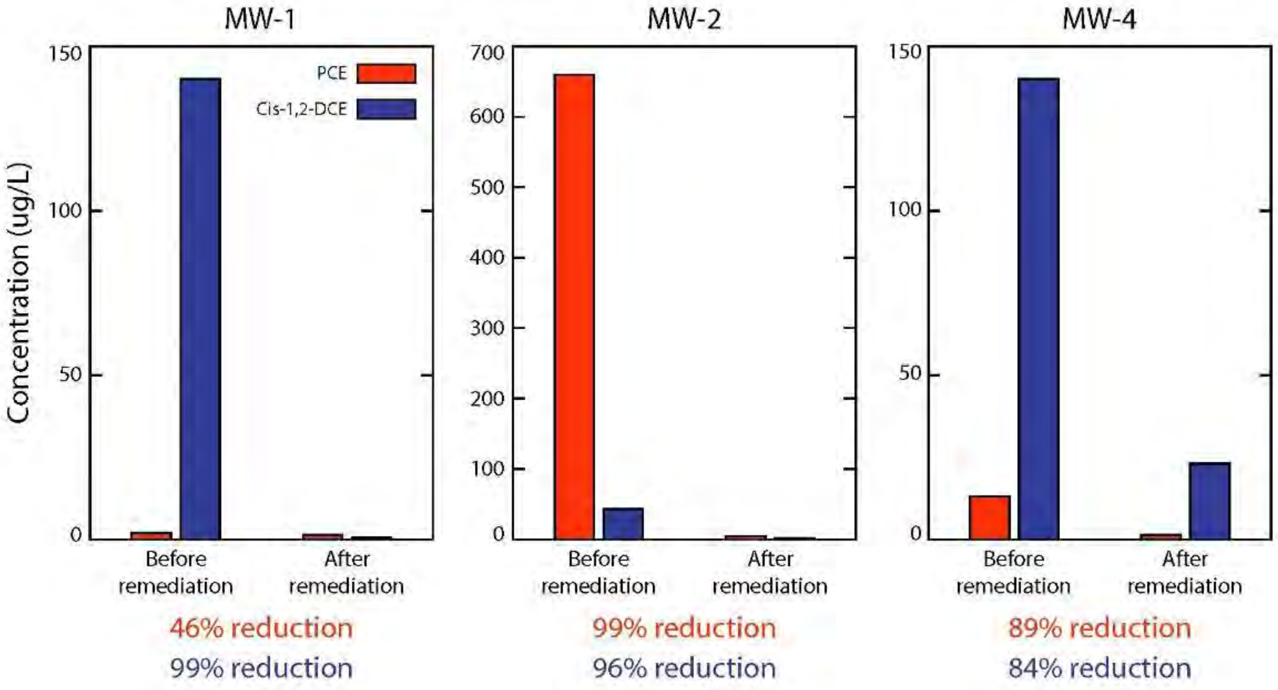
FIGURE 8

Tracking ISS – ISCO: Groundwater

- 660 ug/L PCE before remediation
- ISS – ISCO initialized September 2019
- < 5 ug/L PCE after ISS - ISCO








Final Site
Restoration

Lessons Learned…

- Technology works well for PCE in clay
- Site prep is a key consideration
- Choose verification parameters wisely, e.g., UCS, K, Totals, SPLP, soil gas, groundwater?
- ISCO destruction can continue out to 45-60 days
- More soil data always better

HAMP MATHEWS & ASSOCIATES, INC.

Summary

Environmental Solutions

Key Takeaways

PeroxyChem

- Combining ISS with ISCO:
  - Benefits ISCO soil mixing applications by solidifying soil post application
  - Benefits ISS applications by:
    - Reducing contaminant mass
      - Lower leachate concentrations
    - Higher UCS
    - Another input to allow better control over UCS
  - Cost Savings
    - Incorporating Klozur® Persulfate reduces the overall reagent dosing
    - Less reagents result in less swell/bulking and lower handling disposal costs of that material

Key Takeaways Continued

- Bench Tests are recommended
  - Control for key variables of binder, Klozur® SP, and moisture content
  - Evaluate lower reagent dosages that take advantage of additional strength provided by ISCO-ISS
  - Consider binders such as Portland cement and Portland cement blended with Blast Furnace Slag

- ISCO-ISS has been successfully applied in the field many times
  - Contaminant destruction
  - Solidify residual contaminants
  - Decrease groundwater concentrations
  - Mitigate vapor intrusion issues

Questions?

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