TEORI OM IN SITU STABILISERING SOM "STAND ALONE" METODE SAMT I KOMBINATION MED REAKTANTER. METODENS MODENHED OG EKSEMPLER FRA USA

Vintermøde 2019, Temadag om Soil Mixing som afværgemetode

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ISS as a "Stand Alone" Treatment Technology

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TREATMENT

- Mixing of contaminated materials with cementitious/pozzolanic reagents:
  - ***Reduces contaminant migration via Advection, Hydrodynamic Dispersion and Diffusion***

STABILIZATION

- Chemical reaction between reagents and contaminated materials - designed to reduce the leachability of targeted contaminants by:
  - ***Binding free liquids***
  - ***Immobilizing targeted contaminants***
  - ***Reducing solubility of the contaminated material***

SOLIDIFICATION

- Contaminated materials are encapsulated (physically trapped) to form a solid material that restricts contaminant migration by:
  - ***Reduction of permeability and effective porosity***
  - ***Increasing compressive strength and media durability***

In Situ Stabilization/Solidification (ISS) Conceptual Model

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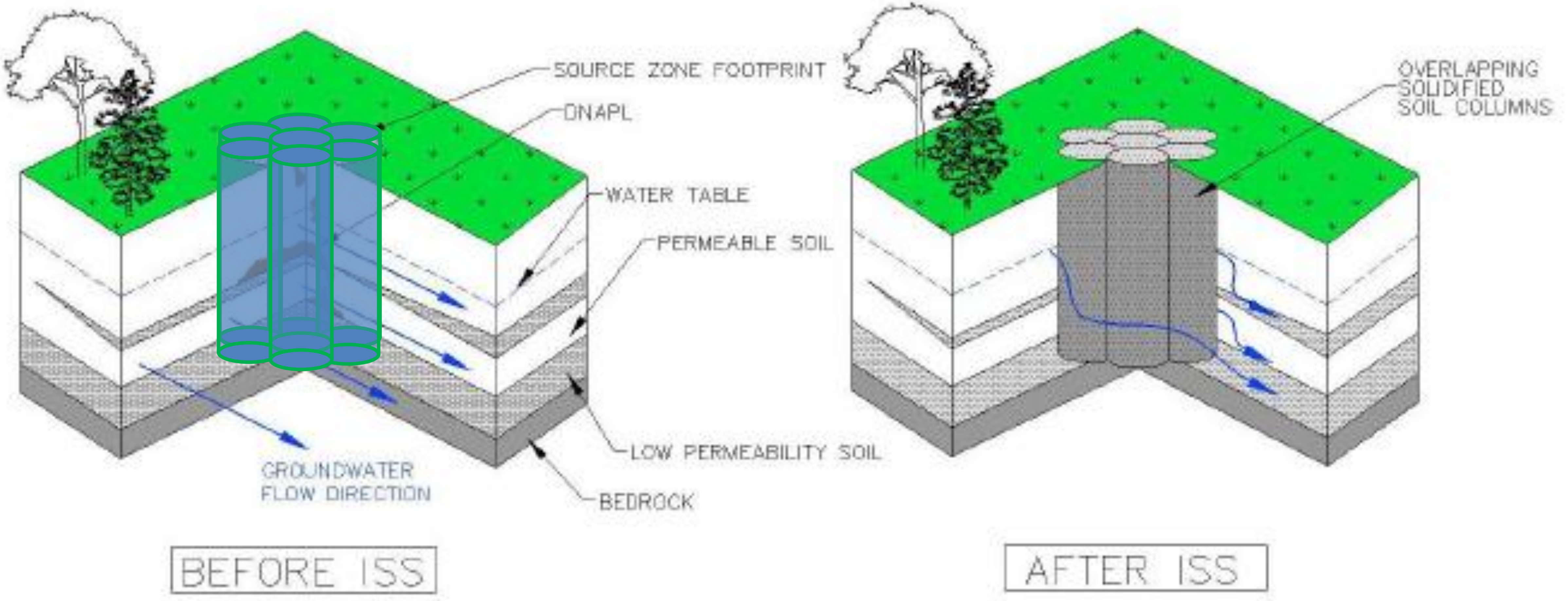

Source: *Development of Performance Specifications for Solidification/Stabilization*, Interstate Technology & Regulatory Council (ITRC), July 2011

ISS as a Treatment Technology

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ISS as a "Stand Alone" Treatment Technology

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STABILIZATION

- ➢ Metals
- ➢ Inorganics
  - ***Reducing solubility of the targeted contaminants***

SOLIDIFICATION

- ➢ Organics, NAPL
  - ***Reduction of permeability***

- Contaminants are not destroyed or removed
- Effectiveness for some contaminants (e.g., HVOCs) may require additional design measures
- Uncertainty in long term behavior / protection of sensitive receptors

In situ Treatment (IST) Fundamentals

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- What is IST? Remediation techniques utilizing treatment reagents to destroy and/or transform contaminants via oxidation, reduction, sorption, volatilization, enhanced biodegradation reactions
- Multiple reactants available:
  - Oxidants: Permanganate, persulfate, peroxides/Fenton's reagent, ozone/hydrogen peroxide
  - Reducers: Zero Valent Iron, Calcium polysulfide
  - Sorption: Organophilic clay, activated carbon
  - Volatilization: Steam, hot air
  - Enhanced Biodegradation: Nutrients, HRC, ORC

Typical implementation limitations:

- ***CONTACT and DISTRIBUTION***
- ***SOFT GROUND AFTER TREATMENT***

Illustration courtesy of EthicalChem

COMBINED ISS/IST TECHNOLOGY CONCEPTS

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Combining technologies to capitalize on attributes

- LDA Mixing Key Attributes
  - Overcomes heterogeneities
  - Complete mixing/contact
  - Overcomes contact/distribution challenge
- IST Key Attributes
  - In situ technology that results in contaminant destruction
  - Chemistry is proven - contaminants such as gasworks residuals and chlorinated solvents can be oxidized/reduced, etc.
- Combined ISS/IST Concept
  - Contaminant sequestration/destruction followed by solidification/stabilization
  - Useful **when contamination destruction and greater leaching reduction is needed**
  - Commingled plume applications
  - Overcomes soft ground challenges
  - ISS components can be used to heat / activate reactants (e.g., persulfate activated by cement heat of hydration and high pH)

Combining ISS With Reactants

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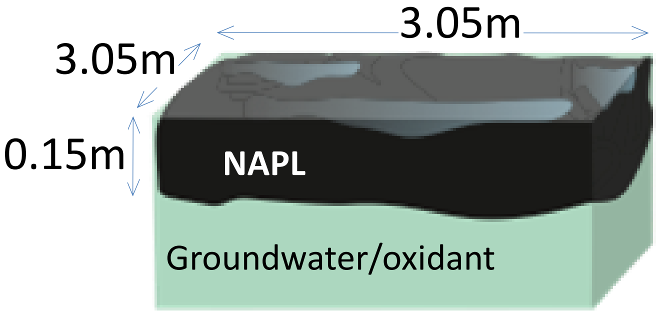
ISS or IST	Reagent	COCs Effectively Stabilized or Treated	Underlying Process
ISS	Portland cement	Numerous, MGP waste, gasoline and diesel range organics, metals	Binding
	Blast Furnace Slag	Numerous, MGP waste, gasoline and diesel range organics	Binding
	Flyash	Metals, organics and inorganics	Binding
	Cement Kiln Dust	Metals	Binding
	Activated Carbon	Organics, Phenolic Waste	Adsorption
	Bentonite Clay	Organics	Adsorption
	Organophillic Clay	Phenolic waste, organics	Adsorption
	Attapulgite Clay	Acids Waste, Metals	Adsorption
	Lime	Inorganics, Metals	Binding
IST	Zero Valent Iron	TCE, Arsenic	Reduction
	Potassium Permanganate	TCE, Acetone, Pesticides, VOCs	Oxidation
	Sodium Persulfate	TCE, Acetone, Pesticides, VOCs	Oxidation
	Ferrous Sulfate	TCE, Acetone, Pesticides, VOCs	Oxidation
	Calcium Polysulfide	Chromium	Reduction
	Biological Nutrients	Acetone, Pesticides	Enhanced Bio-Degradation
	Hot Air	VOCs	Volatilization

Sources: *Andromalos, K.B., Ruffing, D.G., and Peter, I.F., (2012) "In Situ Remediation and Stabilization of Contaminated Soils and Groundwater Using Soil Mixing Techniques With Various Reagents," SEFE7: 7th Seminar on Special Foundations Engineering and Geotechnics, Sao Paulo, Brazil, June 17-20.*

Enhancing Contact Through Emulsification

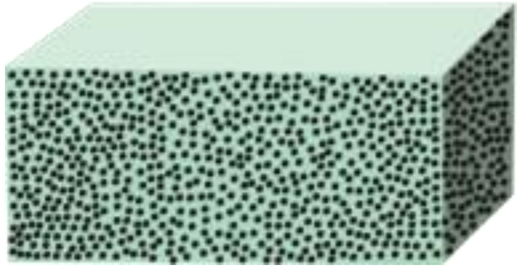
Emulsions increase interface area between oxidant and contaminant by several orders of magnitude



NAPL Volume: 1.4 m^3
1 NAPL mass
Surface Area: 20.4 m^2

With Surfactant

With Surfactant



NAPL Volume: 1.4 m^3
2.7×10^{18} Particles @ 1 µm diameter
Surface Area: 8,499,978 m^2

Illustration courtesy of EthicalChem

Enhancing Contact Through Emulsification

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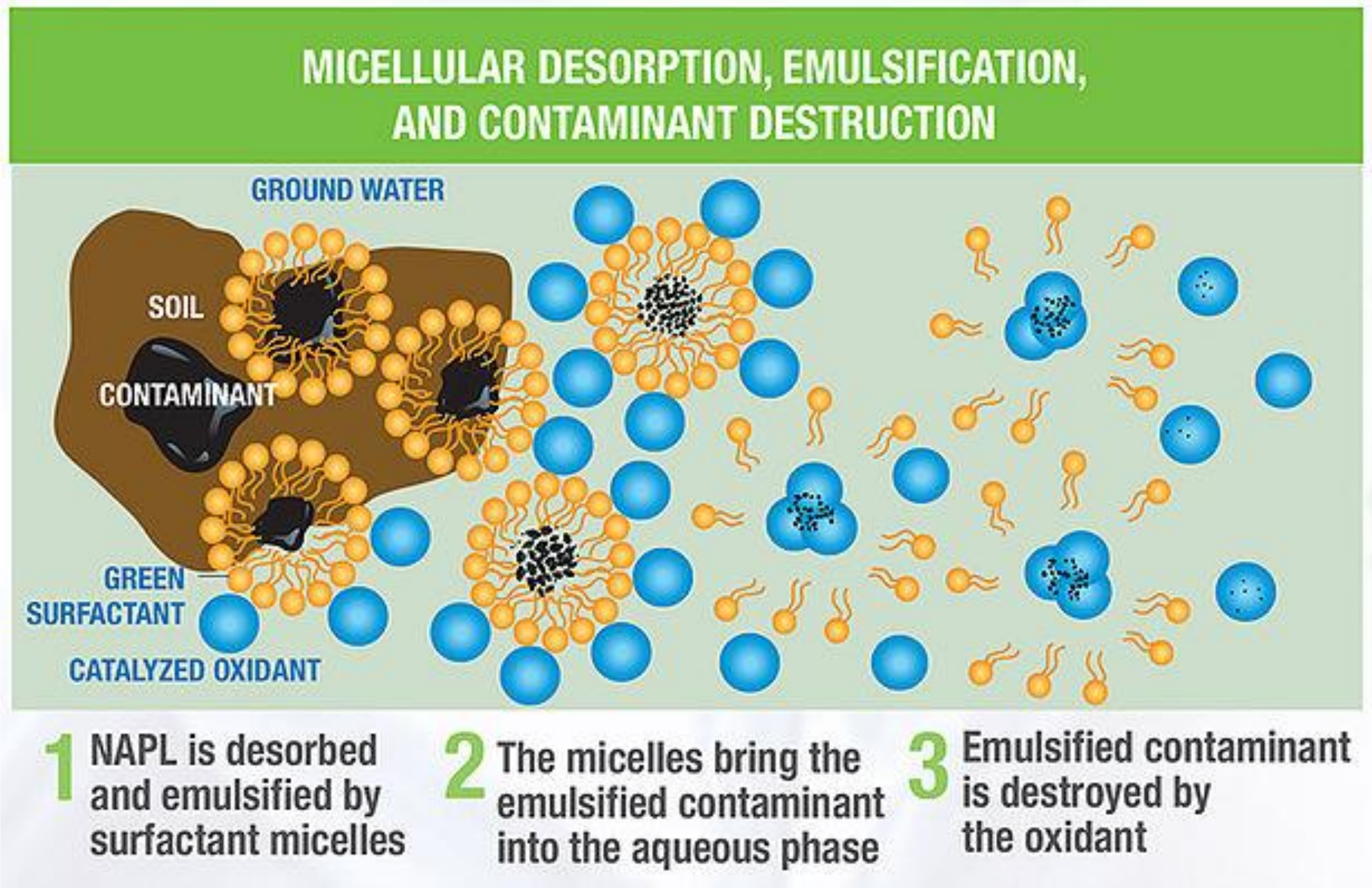

ISS Applications

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- Treatment
- Ground Improvement
- Containment

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ISS Equipment and Construction Techniques

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Auger Mixing – Crane Mounted Drill Table and Hydraulic Drill Rigs

Benefits:

- Deep treatment depths (up to 20 m)
- Highly homogeneous mixing
- Effective in both upland and sediment sites (does not require dewatering)
- Higher production rates (up to 600 m^3/day)

Challenges:

- Sensitive to debris, obstructions and stiff soils
- Requires stable work platform/heavy equipment
- Requires specialty Contractor/expertise
- Costly maintenance requirements

Source: *WRScompass. N.d. http://www.geoengineer.org/education/web-based-class-projects/geoenvironmental-remediation-technologies/stabilization-solidification?showall=1&limitstart=. Web. 27 Jan. 2016*

ISS Equipment and Construction Techniques

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Backhoe Mixing

Pros:

- Higher equipment mobility
- Uses conventional construction equipment
- Greater flexibility for working around debris and obstacles
- Lower mixing cost

Cons:

- Lower production rates (150 to 500 m^3/day)
- Lower quality of mixing in stiff soils (less homogeneous mixing)
- Reagents are not delivered in-situ
- Limited treatment depth (5 to 7 m)

Plant, T., Gustafson, A., Guay, M., Corradino, K. “Equipment and Scale-Up Considerations for In-Situ Solidification of MGP Sites.” MGP 2008 Conference in Dresden, Germany, March 4-6, 2008

ISS Equipment and Construction Techniques

Backhoe Mounted Specialty Mixing Tools

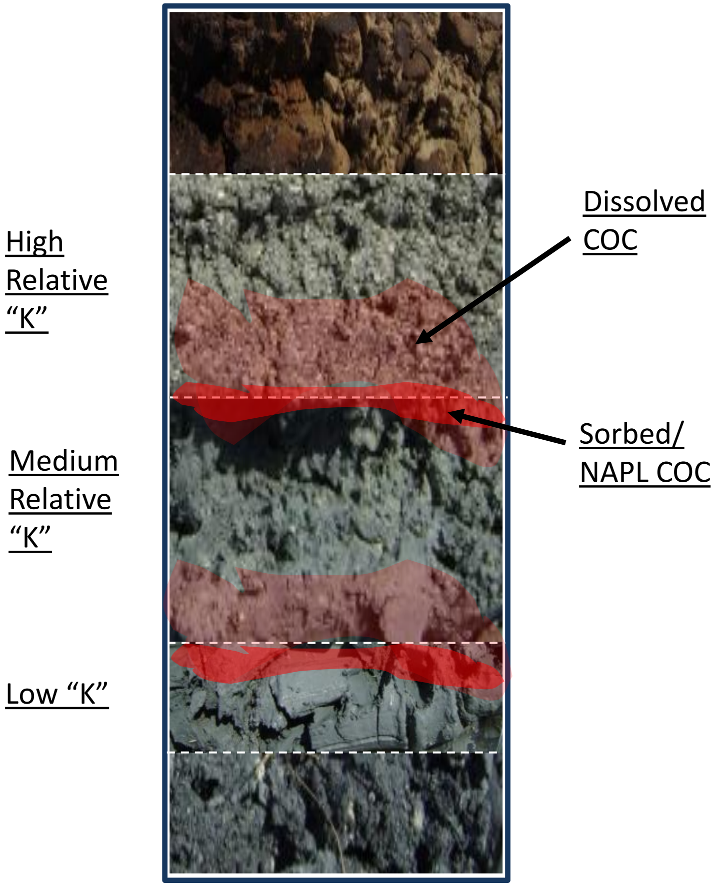
Pros:

- High-level of equipment mobility
- In-situ injection of reagents
- Greater flexibility for working around debris and obstacles
- Lower mixing cost
- Homogeneous mixing

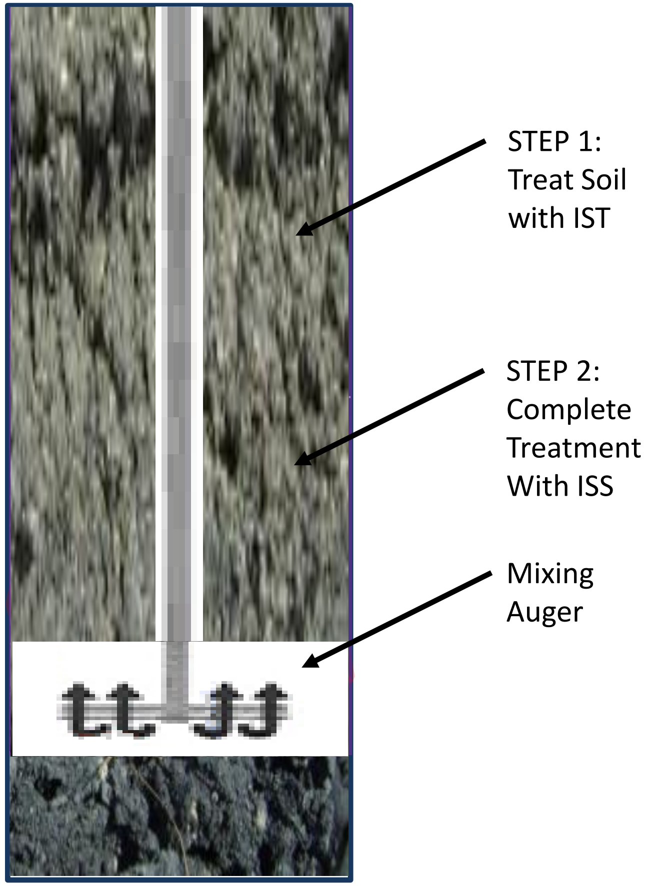
Cons:

- Lower production rates (150 to 500 m^3/day)
- Greater CQA limitations
- Limited treatment depth (5 to 10 m)
- Limitations for treating stiff soils – requires excavator support to pre-process soils

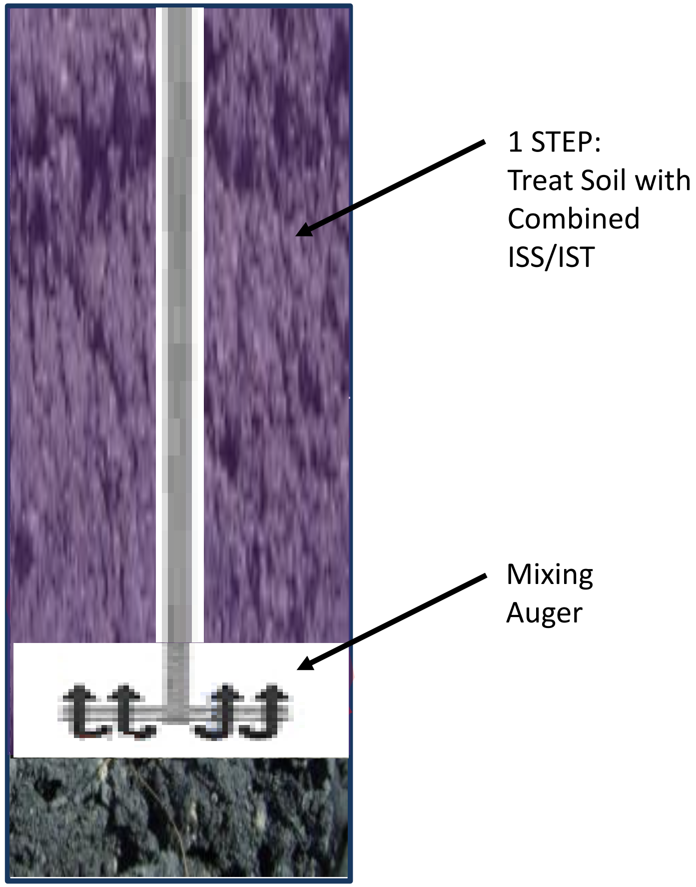
ISS/IST Combinations



Soil with NAPL diffused in heterogeneous matrix



Two Step Combined Remedy



One Step Combined Remedy

ISS/IST Design Considerations

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- Contaminants of Concern – Selection of Reactants
- Regulatory / Permits
- Future Site Use
- ISS/IST Treatment Limits:
  - Cut-line Approach
  - Long Term Monitoring Requirements
  - Administrative Boundaries (e.g., Railroad)
  - Depths
  - Geology / Hydrogeology – Key-in Stratigraphic Layer
  - Depth to Water Table
  - Debris

ISS/IST Environmental Stressors

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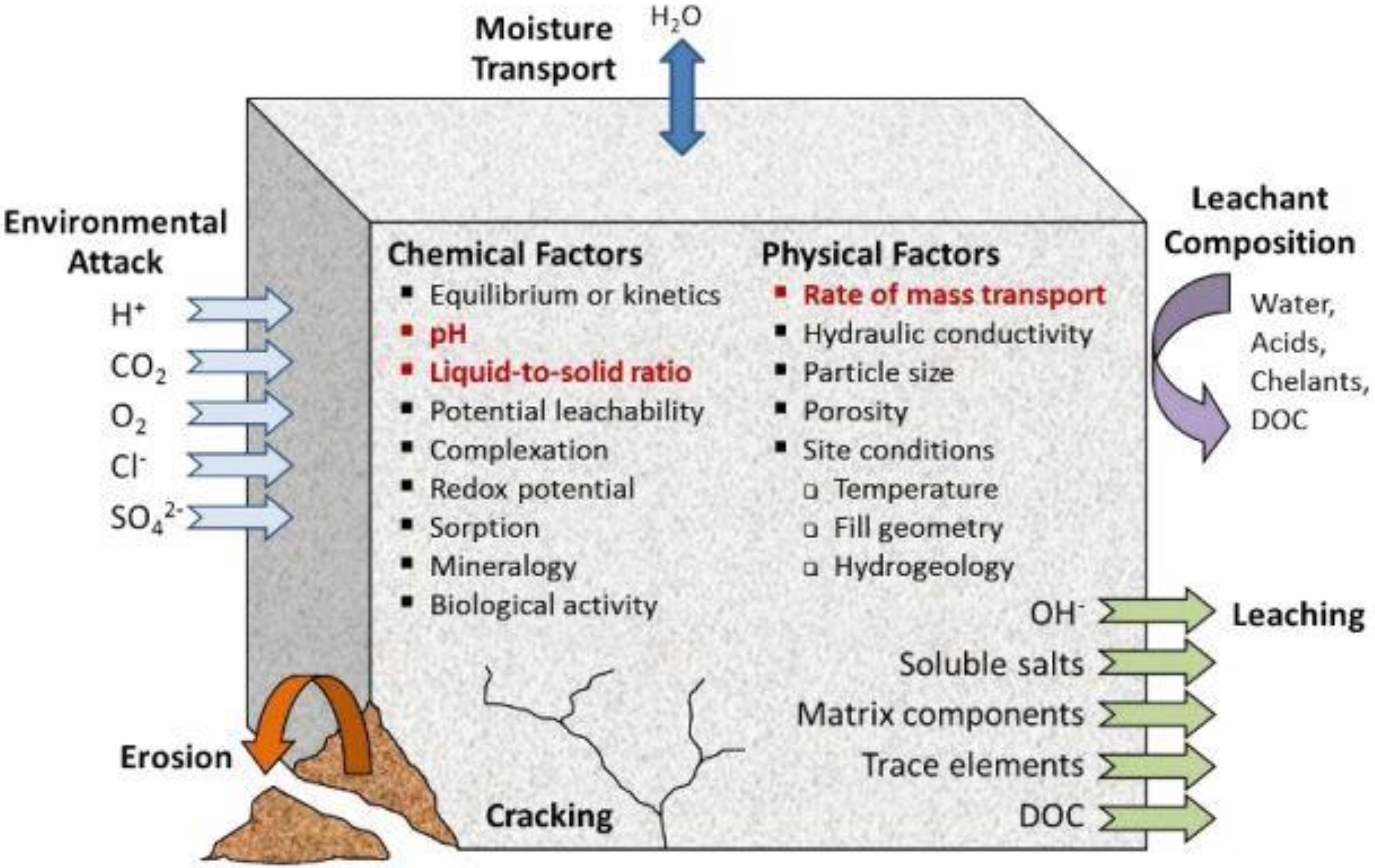

Source: *Modified from Garrabrants and Kosson, 2005.*

Selecting Treatment Performance Criteria

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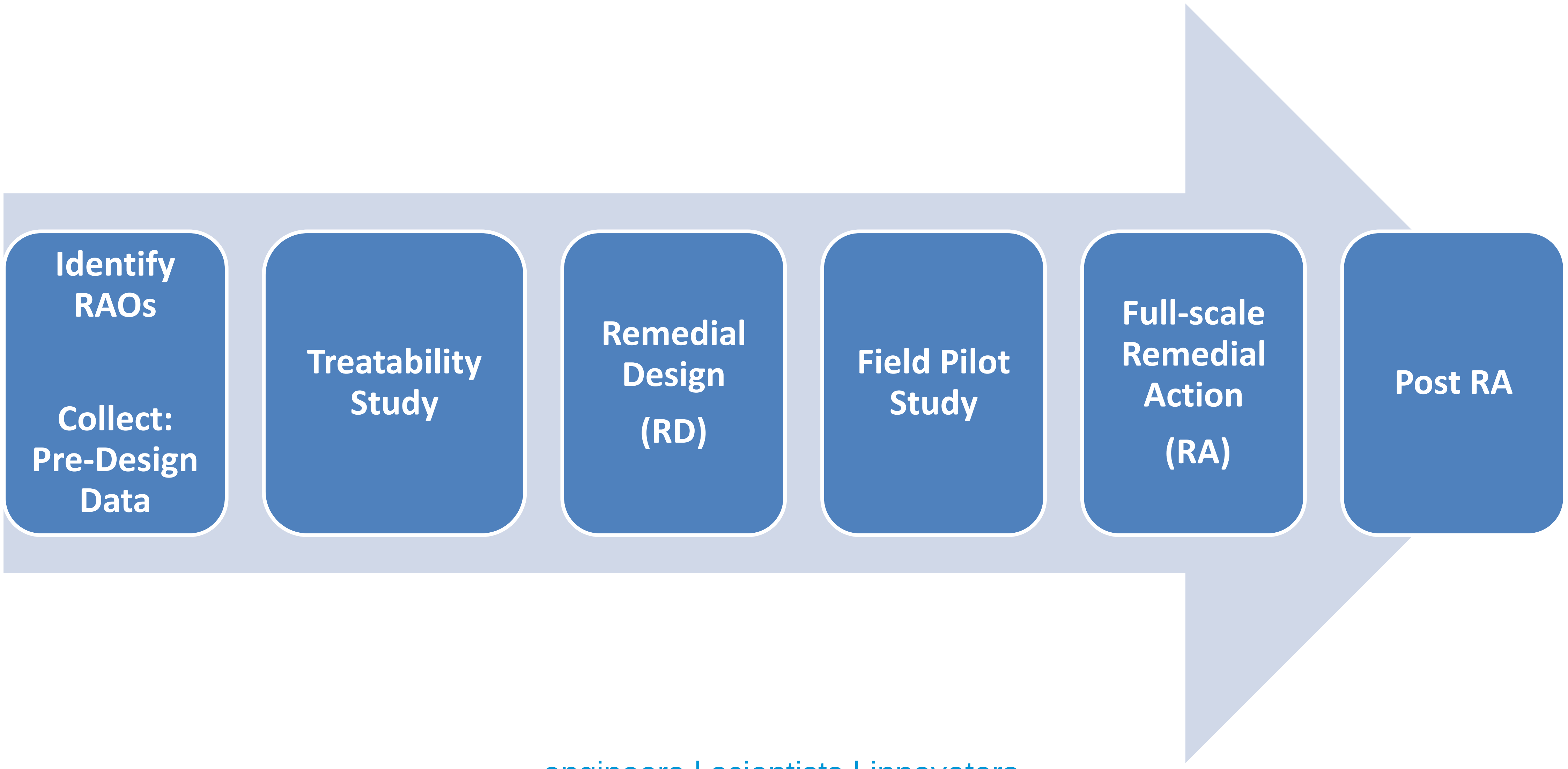
- Unconfined Compressive Strength (UCS) [ASTM D1633 or D2166]:
  - 50 psi [0.345 MPa] (common in USA)
  - Can design to increase/decrease UCS
- Hydraulic Conductivity (K) [ASTM D5084]:
  - < 1 x 10^{-6} cm/s to 1 x 10^{-7} cm/s
  - 1 to 2 orders of magnitude less than native material K is desired
- Leaching [SW-846 LEAF Method 1315]:
  - Determine interval flux; cumulative release to estimate mass transfer – What are your COCs / Receptors?
- Durability [ASTM D4843 and ASTM C1262]:
  - Wet/Dry – Freeze/Thaw < 10% to 15% degradation after 12 cycles
  - May not be necessary
- Contaminant Destruction

Source: *Development of Performance Specifications for Solidification/Stabilization*, Interstate Technology & Regulatory Council (ITRC), July 2011.

ISS/IST Design/Implementation Process



ISS: State of the Practice in USA

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- 1980s - Best Demonstrated Available Technology (BDAT) for a variety of CERCLA (Superfund) and RCRA remediation projects
  - ISS is one of the most common in situ technologies used at CERCLA sites for source control (USEPA, 2010)
  - 26 States reported implementation of S/S technologies (ITRC, 2011)
- Late 1990s – Preferred treatment technology for MGPs
  - Implemented in 13+ States
  - Currently being used to address impacted soil and groundwater across the USA
- Life expectancy of different S/S systems is predicted to extend from decades to thousands of years.[1]
- ISS typically implemented as a "Stand Alone" technology in USA
- Limited examples of combined ISS/IST applications

[1] : Bates, E., Hills, C. "Stabilization and Solidification of Contaminated Soil and Waste: A Manual of Practice" Hygge Media, 2015

ISS Selection – USEPA Superfund Program

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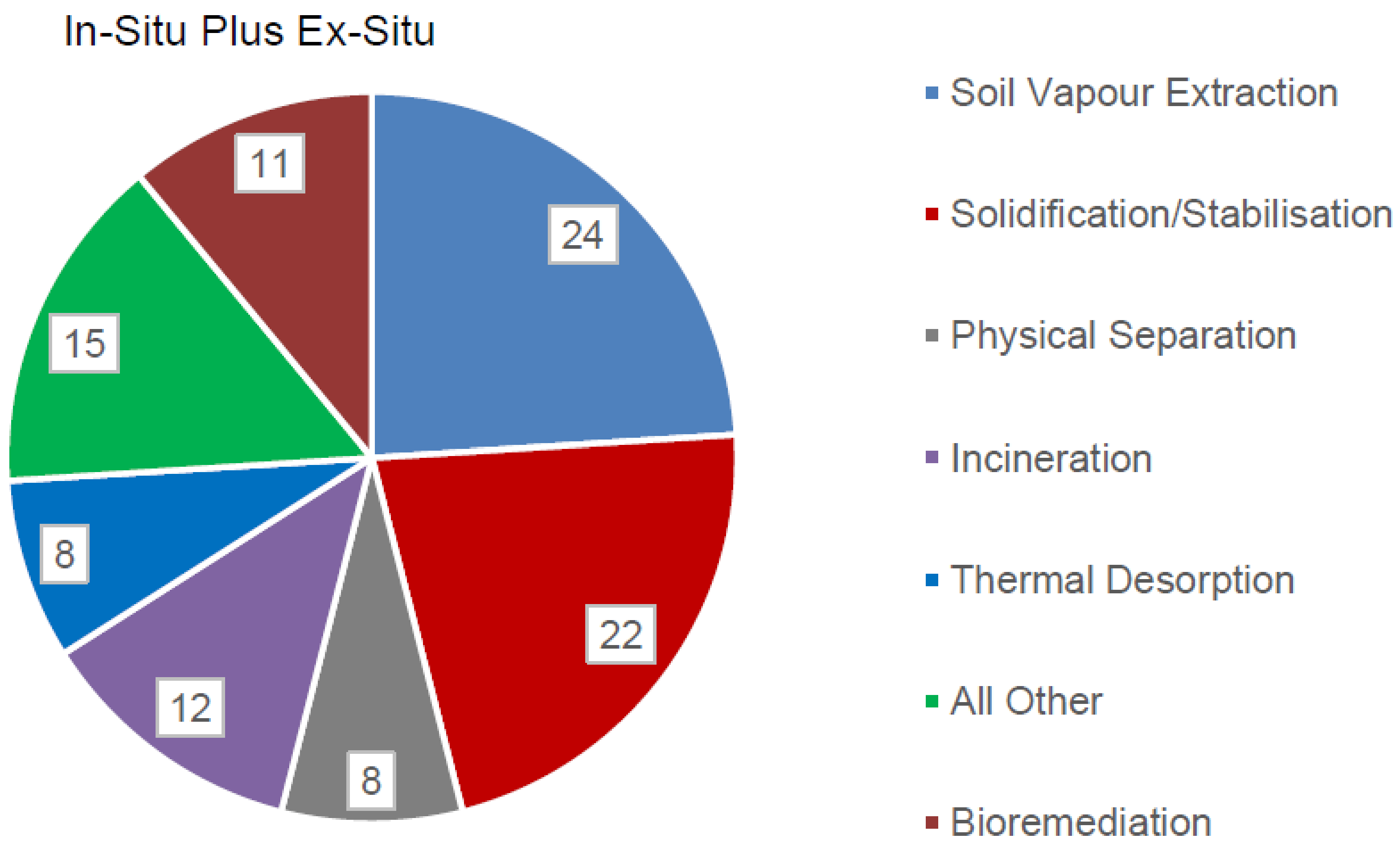

% of 1266 Treatment Technology selections (Excluding Groundwater)

Source: *Stabilization and Solidification of Contaminated Soil and Waste: A Manual of Practice, Figure 2.1: Cumulative source control technology selection from 1982-2011 After EPA-542-R-13-016, Appendix B), 2015*

Columbus MGP Site

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- Located in Columbus, Georgia USA
- First MGP Site Treated with ISS in USA – June 1992
- ISS Metrics:
  - 69,000 m^3 (90,000 yd^3)
  - 10% by weight Type I Portland cement and 25% addition for the western soil/cement wall
  - Up to 10.5 m (35 ft) depth
  - 1,800 overlapping 2.4 m (8 ft) diameter auger columns
  - 20 weeks including mobilization and demobilization

Conceptual Site Model

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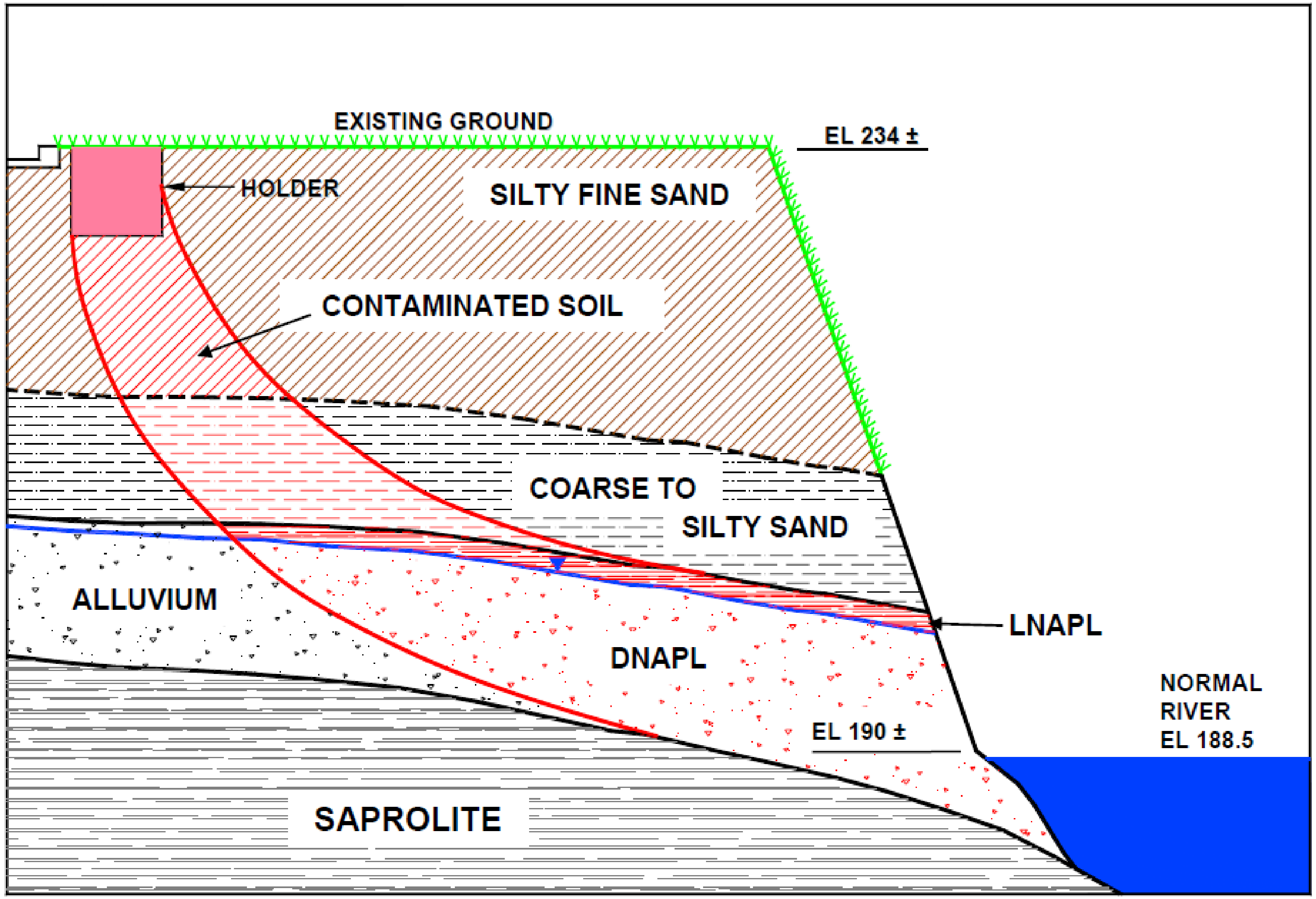

Source: *EVALUATION OF THE EFFECTIVENESS OF IN-SITU SOLIDIFICATION/STABILIZATION AT THE COLUMBUS MGP SITE, 2004*

ISS Results

138 m soil/cement wall

UCS @ 28-days

- 0.41 MPa

Hydraulic Conductivity

- General ISS: 1×10^{-5} cm/s
- Soil/Cement Wall: 1×10^{-6} cm/s

Comprehensive 10-year Evaluation

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- Drilled cores evaluated:
  - Permeability
  - moisture content
  - UCS
  - solid phase geochemistry
  - contaminant analysis
  - leachability testing
- K (10%): 1.2 x 10^{-6} cm/s to 2.8 x 10^{-8} cm/s with an average of 8.03 x 10^{-7} cm/s
- UCS: 1.95 MPa (283 psi) to 6.20 MPa (899 psi); site average of 3.25 Mpa (472 psi)
- Leachability: Naphthalene only PAH to exceed Federal Drinking Water Standards
- Mineralogy: ettringite and vaterite present, no breakdown products or physical degradation of any mineralogy observed

- Post-remediation groundwater monitoring:

Columbus MGP Groundwater Monitoring Parameters.

Analyte	Detection Limit (ug/L)	MCL (ug/L)
Benzene	1	5
Toluene	1	1,000
m,p, Zylene	2	10,000
Ethylbenzene	1	700
o, Zylene	1	10,000
Total Cyanide	1	200

Source: Evaluation of the Effectiveness of In-Situ Solidification/Stabilization at the Columbus, Georgia, Manufactured Gas Plant Site, EPRI, Palo Alto, CA: 2003. 1009095
https://www.epri.com/#/pages/product/000000000001009095/?lang=en-US

Challenging Site Logistics

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Source: Hennings, Wittenberg, R., Robb C., Luke, G. “*In Situ* Stabilization/Solidification (ISS) in the Power Industry and Applications for Coal Combustion Products (CCP).” World of Coal Ash Conference, Lexington, KY, April 22-25, 2013

Former Gasworks Site – Appleton, WI USA

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Remediation Stats:

- BTEX, PAHs, NAPL, As, CN^-
- Heterogenous glacial till; stiff lean clay
- 32,000 m^3 ISS
- 1,200 m^3 river bank sediment

- **Challenge:** River and Upland Impacts
- **Solution:** ISS Below Riverbank – Tie Upland to River Remediation
- **Result:** Cost Savings – "Whole Site" Integrated Remedy

of Contaminated

Reinforcement and Slope Stability – Highway Bridge Piers

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- **Challenge:** ISS around highway bridge piers, risk for pile cap destabilization
- **Design**: DOT stability analysis, assessment of ISS strength requirements and sequencing plan for ISS around piers
- **Construction**: Used combination of backhoe and auger mixing

Sanford Gasification Plant Site – Sanford, FL USA

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Remediation Stats:

- BTEX, PAHs, NAPL,
- 108,000 m^3 ISS

- **Challenge:** Creek Runs through ISS Area

Sanford Gasification Plant Site – Sanford, FL USA

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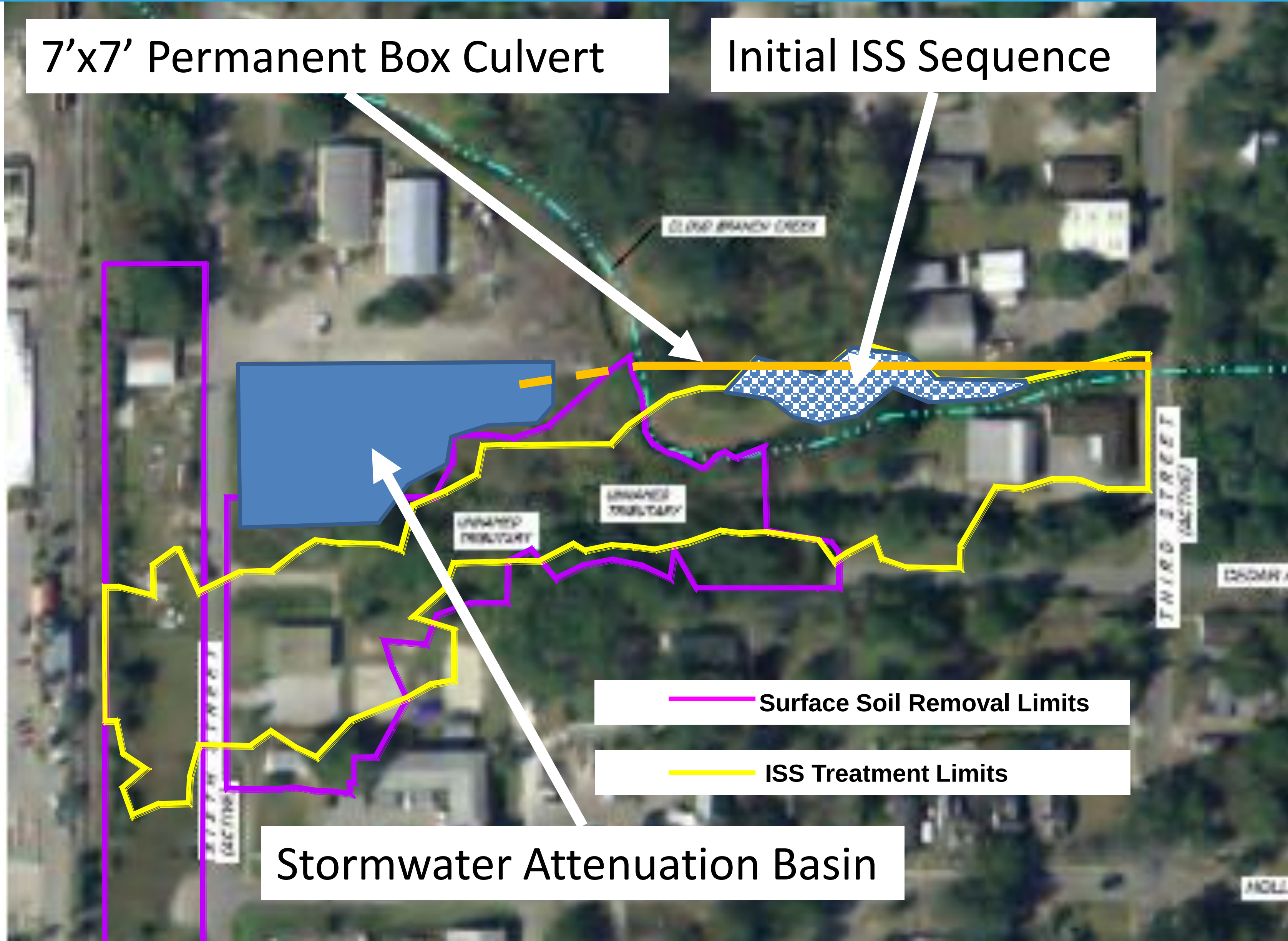
Remediation Stats:

- BTEX, PAHs, NAPL,
- 108,000 m^3 ISS

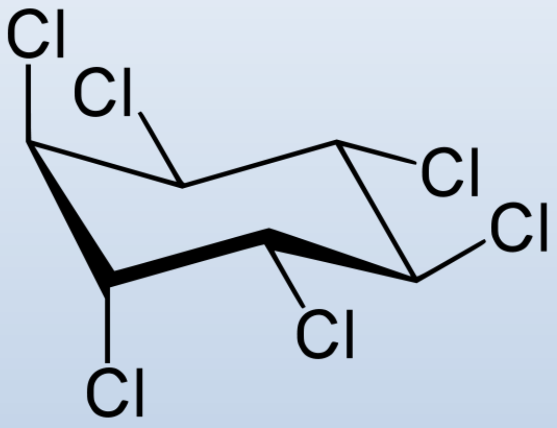
- **Challenge:** Creek Runs through ISS Area
- **Solution:** Permanent Surface Water Design Features Used to Eliminate Temporary Construction Elements
- **Result:** Successfully Completed ISS Construction through Florida's Wet Season

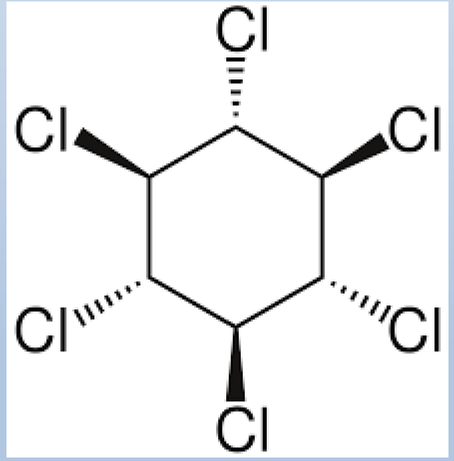


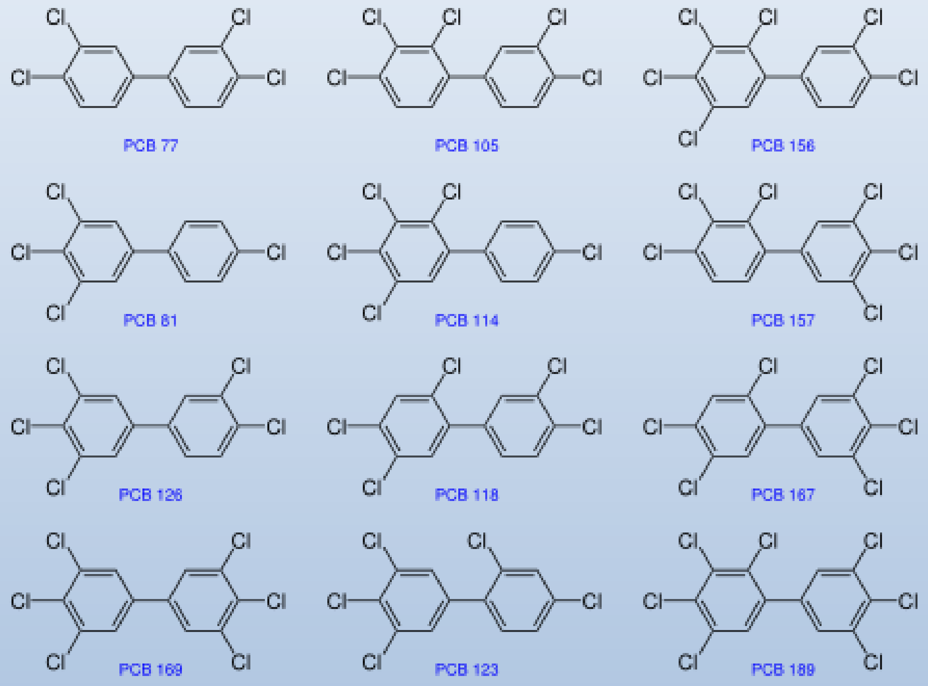
Hydraulic Control and Utility Installation

- **Challenge:** Shallow water table; unstable sand
- **Solution:** ISS Columns along box culvert alignment
- **Result:** No shoring or dewatering required

Recalcitrant Contaminants







Recalcitrant Contaminants

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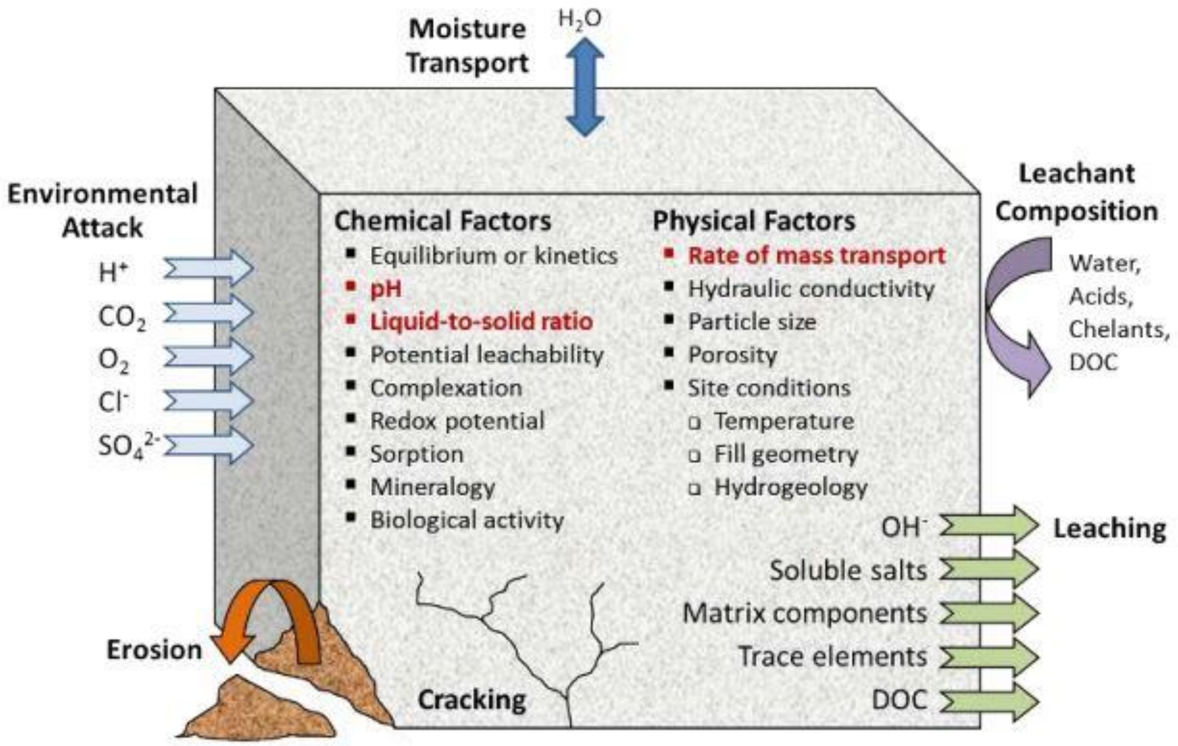
- **Site:**

  Confidential Superfund Site in Florida

- **Challenge:**
  - ❑ Pesticides (alpha BHC; beta BHC) and inorganics (arsenic)
  - ❑ Low pH environment (< 2 s.u.)
  - ❑ Peat/organic soils
  - ❑ Remedy near existing buildings
- **Solution:**
  - Tiered treatability testing to assess reagent performance and dosage
  - Mix designs targeted to different source areas



Source: *Modified from Garrabrants and Kosson, 2005.*

Treatability Study Method

COMPOSITE SOIL INDEX PROPERTY TESTING									
Sample ID	Boring Numbers [1]	Soil Content	Moisture Content (ASTM D2216)	pH (ASTM D4972)	USCS Soil Classification (ASTM D2487)	Grain Size Distribution (ASTM D422)	Atterberg Limits (ASTM D4318)	Organic Content (ASTM D2974)	Compaction Using Standard Effort (ASTM D698)
Mix-Peat	TBD	Peat	X	X	X	X	X	X	X [2]
Mix-Other	TBD	Peat/Other Soils	X	X	X	X	X	X	X [2]

PHASE 1A - CEMENT DOSAGE OPTIMIZATION - OTHER SOILS															
Design Mix [1,2]	Soil Type (%) [1]	Soil (%) [1]	Total Cementitious [3]	Reagents			Water : Reagents Ratio [1,4]	Volume Expansion Evaluation [5]	UCS (ASTM D2166/D1633) [6]			Hydraulic Conductivity [K] (ASTM D5084) [7]		SPLP Leaching (SW846 Method 1312) [8]	Leaching (SW846 Method 1315M) [8]
				Portland Cement Type I/II (%) [1]	Portland Cement Type V (%) [1]	GGBFS (%) [1]			7-Day	14-Day	28-Day	28-Day	Duplicate		
Mix-PC10	Other	100	16		16		1.0	X	X	X	X	X			
Mix-SC11	Other	100	16	4		12	1.0	X	X	X	X	X	X	X	X
Mix-SC12	Other	100	16		4	12	1.0	X	X	X	X	X			
Mix-SC4	Peat	100	16	4		12	1.0	X	X	X	X	X			
Mix-SC5	Peat	100	20	5		15	1.0	X	X	X	X	X	X		
Mix-SC6	Peat	100	24	6		18	1.0	X	X	X	X	X	X	X	X
Mix-SC7	Peat	100	16		4	12	1.0	X	X	X	X	X			
Mix-SC8	Peat	100	20		5	15	1.0	X	X	X	X	X	X		
Mix-SC9	Peat	100	24		6	18	1.0	X	X	X	X	X	X	X	X

Recalcitrant Contaminants

- **Results/Next Steps:**
  - Phase 1 mixes met and exceeded UCS and hydraulic conductivity performance goals
  - Currently optimizing dosage and reagents in Phase 1A
  - Best performing Phase 1 mixes will be assessed for leaching

Source: *Test America. Next Generation of Leaching Methods. Online Presentation. 2016.*

Recommended References

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- *Development of Performance Specifications for Solidification/Stabilization*, Interstate Technology & Regulatory Council (ITRC), July 2011

- *Stabilization and Solidification of Contaminated Soil and Waste: A Manual of Practice*, Edward Bates & Colin Hills, 2015

Questions?

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Thank you for your time!

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