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Current Overview of Groundwater Remediation Options for CCR Units

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Overview

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- Introduction and Problem Statement
- Applicable Groundwater Remedial Alternatives
  - Monitored natural attenuation (MNA)
  - Hydraulic control (in-situ and ex-situ)
  - In-situ redox approaches
  - Biogeochemical injections
  - Slurry walls
  - Permeable reactive barriers (PRBs)
  - In-situ stabilization/solidification (ISS)
- Remedial Alternative Selection Process and Costs

Environmental Challenges

- Mostly unlined ponds
- Hydraulic head created by wet disposal
- Type of constituents and concentrations dependent on:
  - Source of coal
  - Boiler operating conditions/air pollution control devices
  - Age of materials
  - Wet (active) versus dry (inactive)
  - Chemical makeup of CCR materials (bottom ash, fly ash, FGD, etc.)
  - Geochemical conditions in CCR unit and subsurface (ash below water table?)

Environmental Challenges

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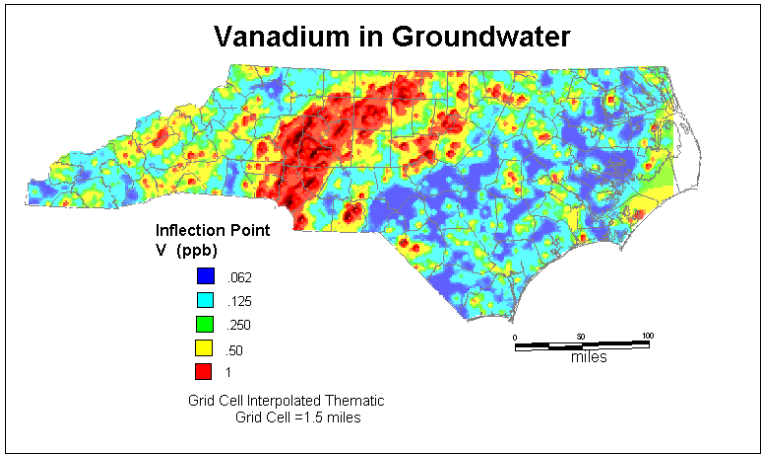
- Potential groundwater impacts limited to inorganics
  - Boron (B), arsenic (As), selenium (Se), iron (Fe), manganese (Mn)
  - Sulfate (SO_4), chloride (Cl), total dissolved solids (TDS), pH
  - Site-specific issues (e.g., mercury [Hg], vanadium [V], thallium [Tl], ammonia [NH_3-N])
- Natural background versus leaching versus geochemical changes
  - Fe, Mn, pH
  - V (e.g., NC)

Leaching Results for 34 Fly Ashes EPA-600/R-09/151, December 2009

	Hg	Sb	As	Ba	B	Cd	Cr	Co	Pb	Mo	Se	Tl
Total in Material (mg/kg)	0.01 – 1.5	3 – 14	17 – 510	590 – 7,000	NA	0.3 – 1.8	66 – 210	16 – 66	24 – 120	6.9 – 77	1.1 – 210	0.72 – 13
Leach results (µg/L)	<0.01 – 0.50	<0.3 – 11,000	0.32 – 18,000	50 – 670,000	210 – 270,000	<0.1 – 320	<0.3 – 7,300	<0.3 – 500	<0.2 – 35	<0.5 – 130,000	5.7 – 29,000	<0.3 – 790
TC (µg/L)	200	-	5,000	100,000	-	1,000	5,000	-	5,000	-	1,000	-
MCL (µg/L)	2	6	10	2,000	7,000 DWEL	5	100	-	15	200 DWEL	50	2



Groundwater Monitoring

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- Appendix III
  - Detection monitoring
  - "Indicator" parameters
  - First annual reports are published
    - Statistically significant increases (SSIs) are wide-spread throughout the industry
  - Alternate source demonstrations (ASDs) currently being implemented
    - Many unlined units do appear to have "fingerprint" of CCR management
    - If ASD is unsuccessful, assessment monitoring is required

Appendix III to Part 257—Constituents for Detection Monitoring

Common name [1]
Boron
Calcium
Chloride
Fluoride
pH
Sulfate
Total Dissolved Solids (TDS)

Groundwater Monitoring

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- Appendix IV
  - Assessment monitoring
  - Statistical significant levels (SSLs) above groundwater protection standards
    - MCL or background for constituents without MCL
  - Uncertainty related to timelines in the (revised) Rule, inclusion of B in App. IV, use of risk-based approaches
  - If App. IV ASDs are unsuccessful, assessment of corrective measures needed

Appendix IV to Part 257—Constituents for Assessment Monitoring

Common name [1]
Antimony
Arsenic
Barium
Beryllium
Cadmium
Chromium
Cobalt
Fluoride
Lead
Lithium
Mercury
Molybdenum
Selenium
Thallium
Radium 226 and 228 combined

Groundwater Remedial Alternatives

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- If groundwater impacts with Appendix IV constituents are attributable to a release from a CCR unit, active remediation beyond pond closure may need to be considered
- Inorganics cannot be destroyed or degraded, but only captured/contained or rendered immobile
  - Affects/limits potentially available remedial technologies
    - Monitored natural attenuation (MNA)
    - Hydraulic control (in-situ and ex-situ)
    - In-situ redox approaches
    - Biogeochemical injections
    - Permeable reactive barriers (PRBs)
    - Slurry walls
    - In-situ stabilization/solidification (ISS)

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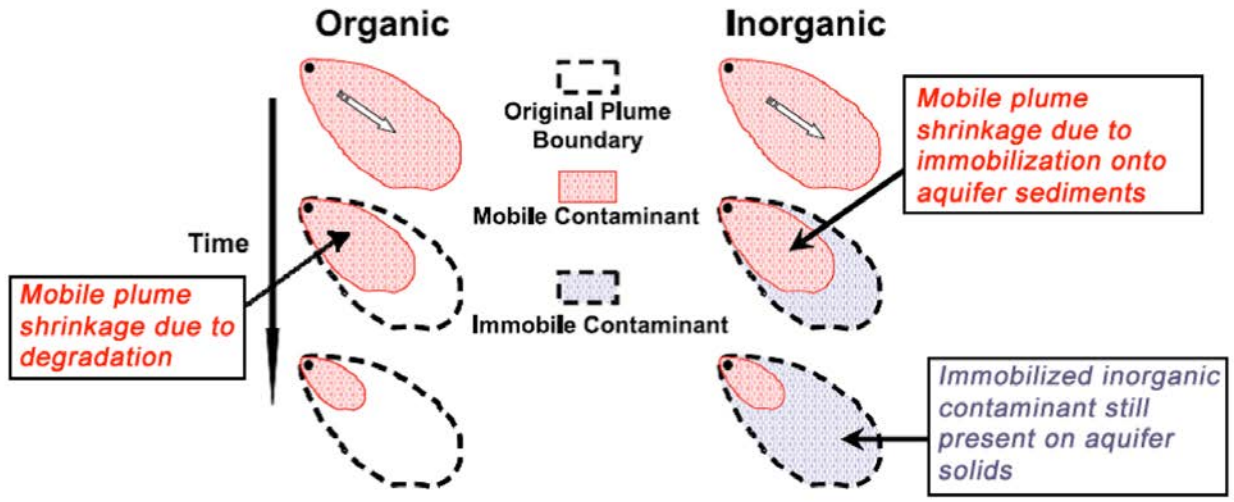
Monitored Natural Attenuation

Monitored Natural Attenuation

- Established protocol to implement MNA for inorganics
  - Reliance on natural attenuation processes to achieve site-specific remediation objectives within a reasonable time frame
  - Tiered approach/"lines of evidence"
    1. Clear and meaningful trend of decreasing contaminant mass/concentrations over time
    2. Hydrogeologic and geochemical data to (indirectly) demonstrate type(s) of natural attenuation process active
    3. Use of data from field or microcosm studies to directly demonstrate occurrence of a particular attenuation process



U.S. Environmental Protection Agency, Use of Monitored Natural Attenuation for Inorganic Contaminants in Groundwater at Superfund Sites, Office of Solid Waste and Emergency Response Directive 9283.1-36, August 2015.

MNA of CCR Leachate

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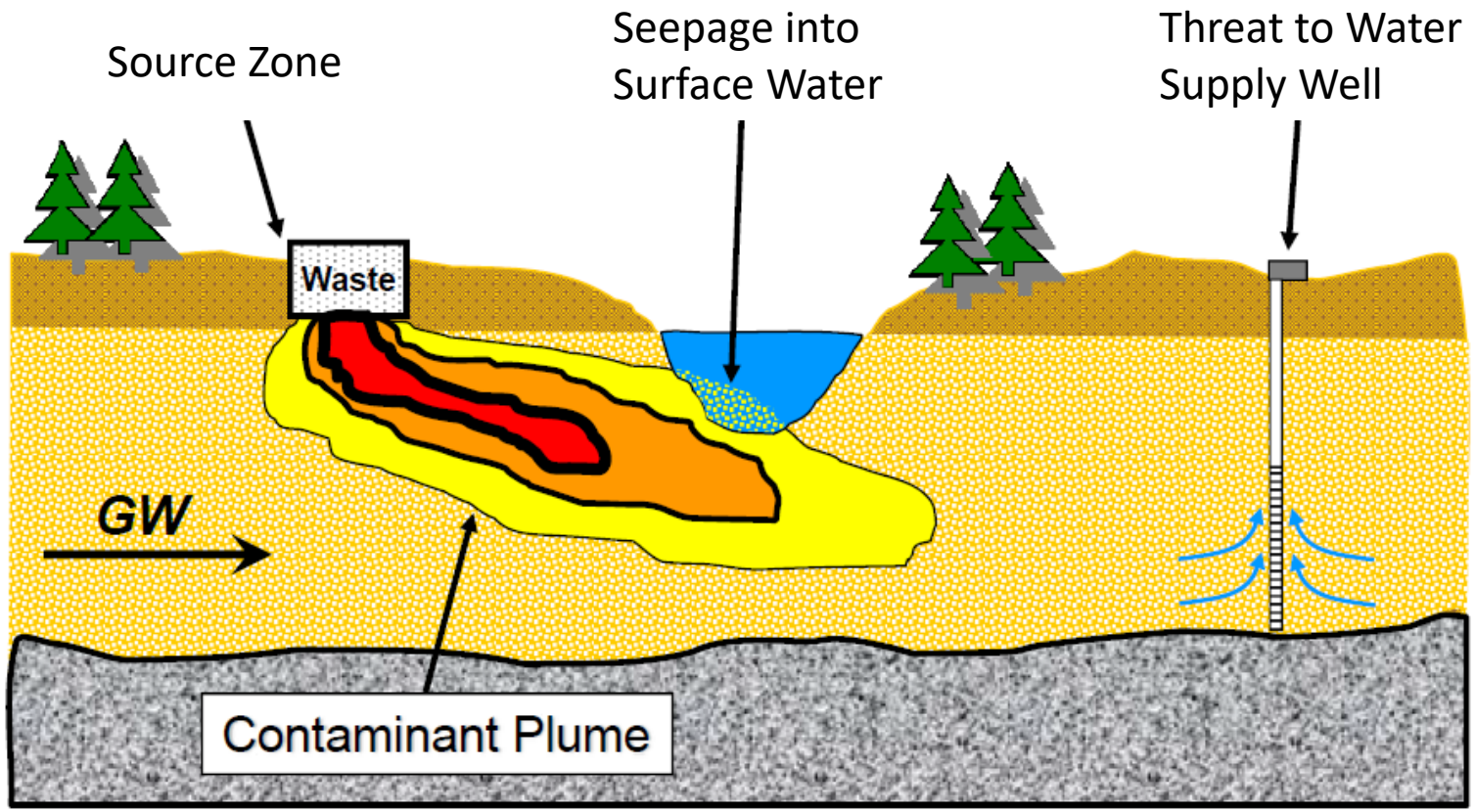
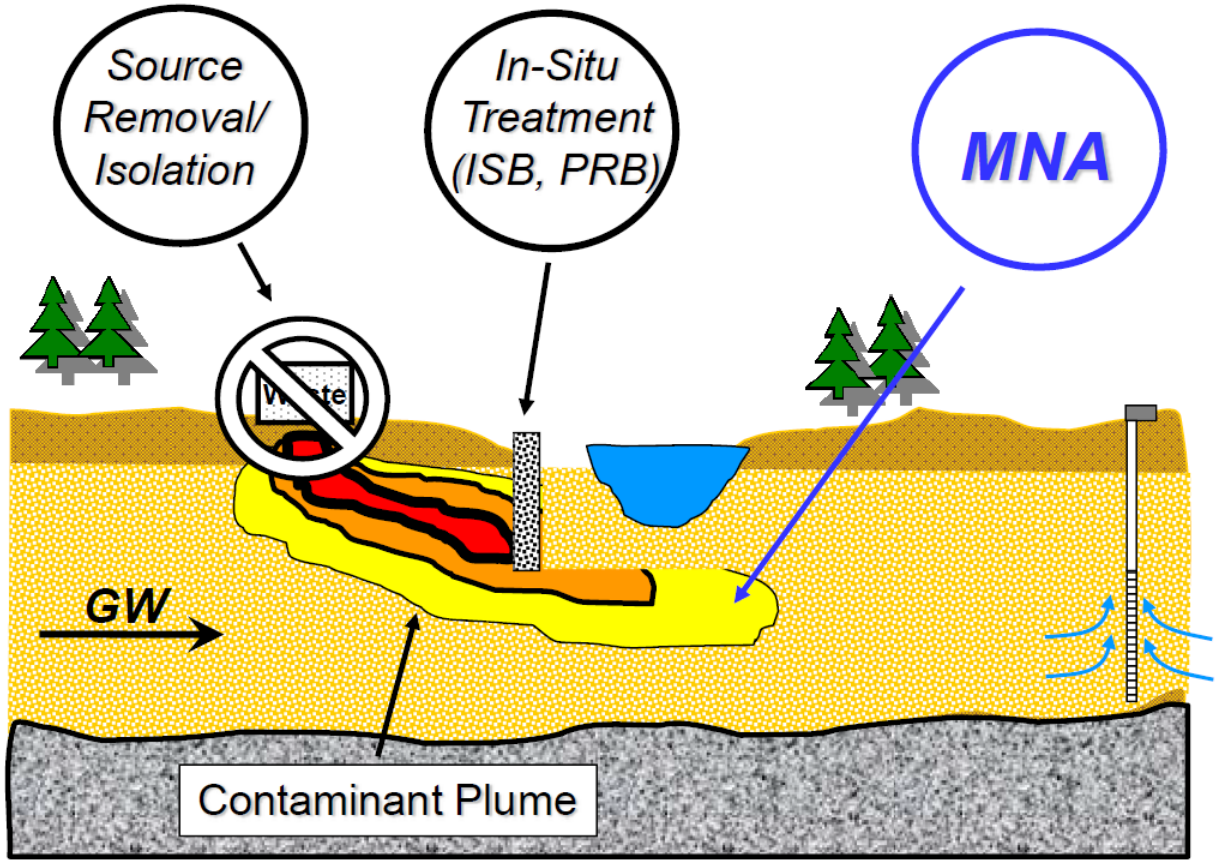


Generalized Site Scenario

MNA of CCR Leachate



Generalized MNA Application

- Plume stability through immobilization on aquifer solids
- These constituents will remain present on aquifer solids
- Thus, the need for demonstration of attenuation mechanism, stability of attenuation

MNA of CCR Leachate – Tiered Analysis

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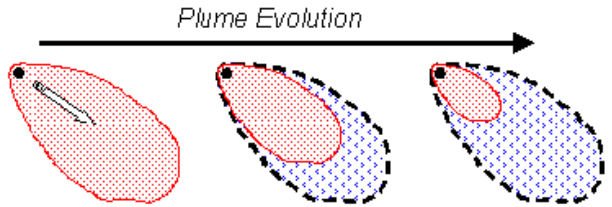
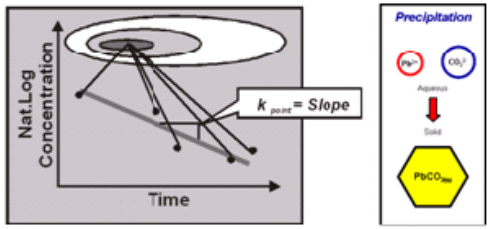
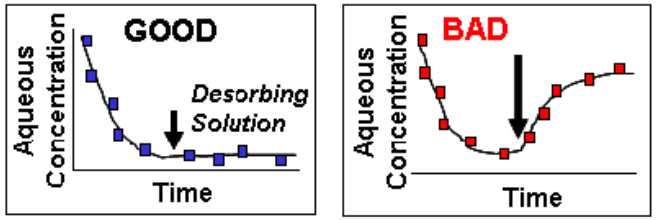
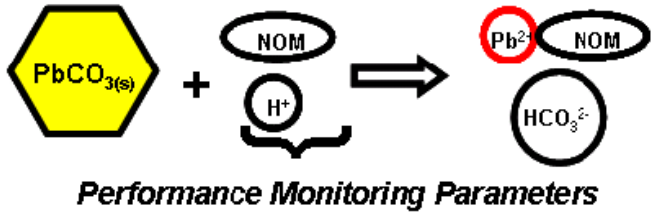
Tier 1 Evaluation of plume stability	
Tier 2 Evaluation of rate and mechanism	
Tier 3 Evaluation of capacity and stability	
Tier 4 Development of LTM plan; contingencies	

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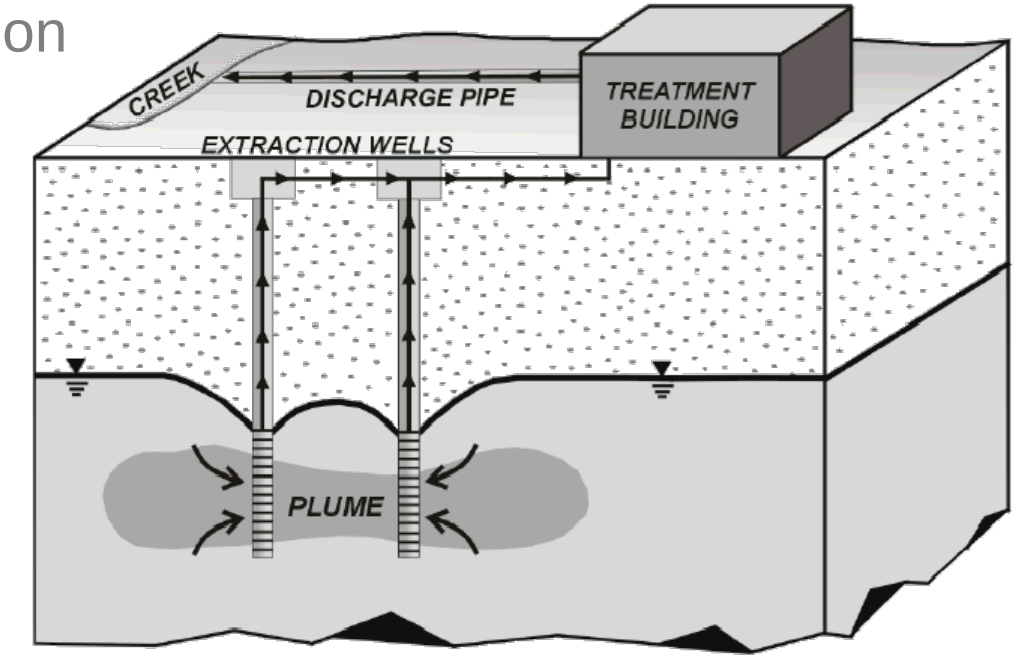
Hydraulic Control

Hydraulic Control (P&T)

- Objectives
  - Intercept migrating Contaminants of Concern (COCs)
  - Collect COCs from within a zone of influence
    - Extract with wells or collection trenches
  - Inject treated water to facilitate aquifer remediation
- Fundamental Concepts
  - Hydraulic containment of plume
    - Boundary control
  - Contaminant mass removal
  - Source control measures
  - Protect public drinking water wells



Hydraulic Control (P&T)

- Often considered “presumptive remedy” at many sites
- May require above-ground treatment to meet effluent discharge criteria
  - Surface water discharge (NPDES)
  - Groundwater injection (UIC)
  - Reuse potential
    - Dust suppression
    - CCR conditioning
    - Irrigation/land application
    - Process make-up water/cooling towers
- May effectively address the mix of constituents expected at CCR sites
- Many facilities have existing wastewater treatment capabilities (retention ponds, treatment plants, etc.)

Hydraulic Control (In-Situ Treatment)

- Hydraulic control without the need for above-ground water management/treatment
- TreeWell® system
  - Engineered phytoremediation system
  - LDA installation approach
  - Tree acts as solar-driven pump
  - Design based on GW flow velocity and cross-sectional area to be “intercepted”
  - Achieves design hydraulic control parameters after about 3 growing seasons

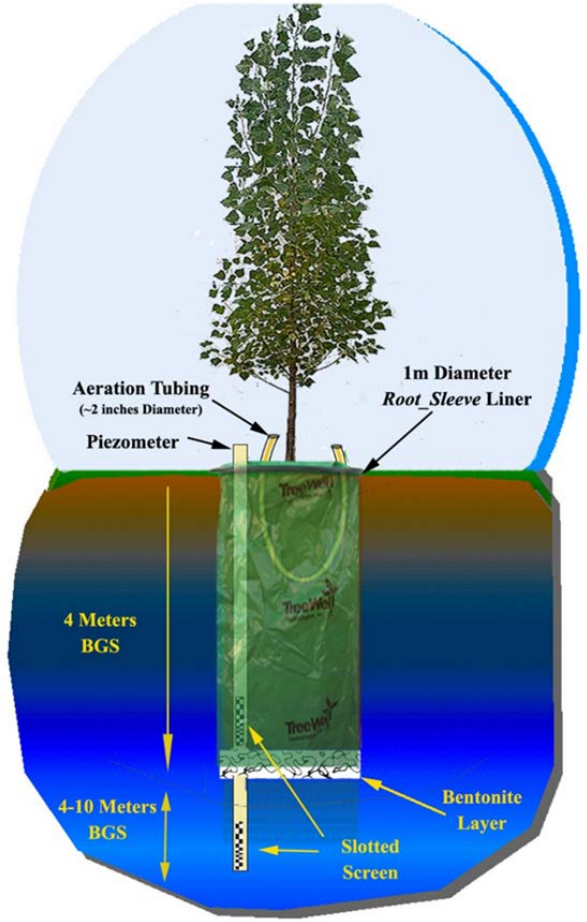


Image: Applied Natural Sciences, Inc.

Engineered Phytoremediation: The *TreeWell* System

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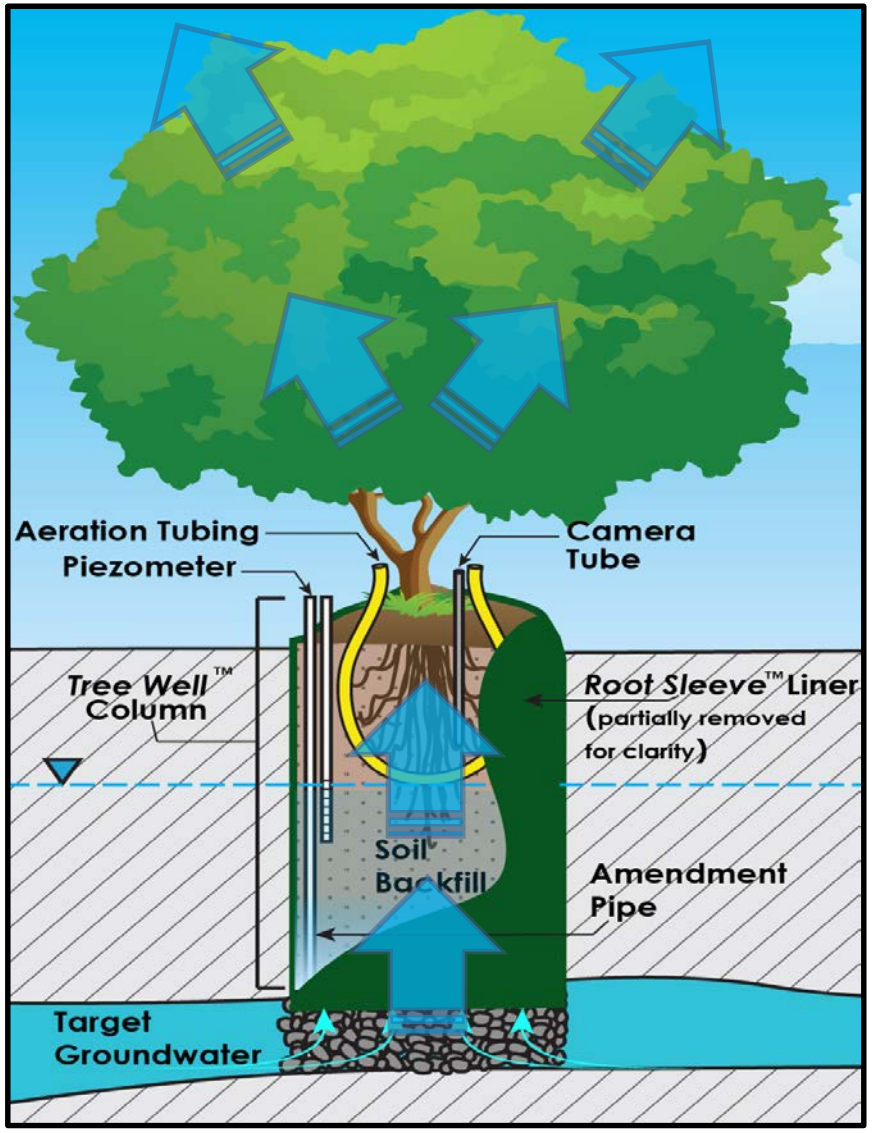

- Patented by Geosyntec's partner firm Applied Natural Sciences, Inc. (ANS)
- Targets specific groundwater by directing root growth downward to capillary fringe
- Groundwater is drawn upward through the soil column, then absorbed by plant roots
- Highly adaptable – can be tailored to specific site conditions
- Effectively target deep or confined aquifers
- Optimizes growing conditions for trees
- Bioreactor effect – both oxidizing and reducing zones in each unit
- Increases soil temps – enhances biodegradation rates in vadose zone
- Pre-treatment option (reactive treatment media)
- Active treatment – in a passive manner

Case Study: Central FL
1,4-Dioxane in Groundwater

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Site Background

- Fractured bedrock aquifer 5'-15' bgs; contaminant mass and flow in a thin fractured zone in the 10'-15' horizon
- Initial Remedy: Long-term pump & treat system with UV/Peroxide
  - >$300K/Year O&M costs
  - >10 Years to meet Remedial Goals

Phytoremediation Implemented

- Dense forest of low-quality non-native wetland species cleared for phytoremediation system
- Expedite permitting process by promoting wetland restoration

Remedial Goals

- Hydraulic Control
- Contaminant Treatment

Case Study:
System Installation

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2013 Installation

SYSTEM INSTALLATION DETAILS

- 154 Units Installed
- 48” Borehole Drilled to 15’ bgs
- Set liner system to top of impacted zone
- Plantings set 20 feet on center
- Native trees:
  - Slash Pine (*Pinus elliottii*)
  - Sycamore (*Platanus occidentalis*)
  - Willow (*Salix caroliniana*)
  - Pond Cypress (*Taxodium ascendens*)

Summer 2015

Case Study:
Impact on Groundwater Flow

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- *Yellow* indicates initial GW flow at time of Phyto System installation (away from source area towards site boundary)
- *Blue* indicates GW flow ***18 months after*** Phyto System installed (gradient reversal/hydraulic control; flow towards the Phyto System)
- Results have been very consistently positive:
  - Groundwater flow had been historically to the west-northwest
  - Some changes in flow were seen in the first season
  - By the end of the second season, groundwater flow had reversed

Demonstration of hydraulic capture enabled shutdown of the existing pump and treat system. The system has since been dismantled and removed.

Case Study:
Modeled vs Actual Groundwater Flow

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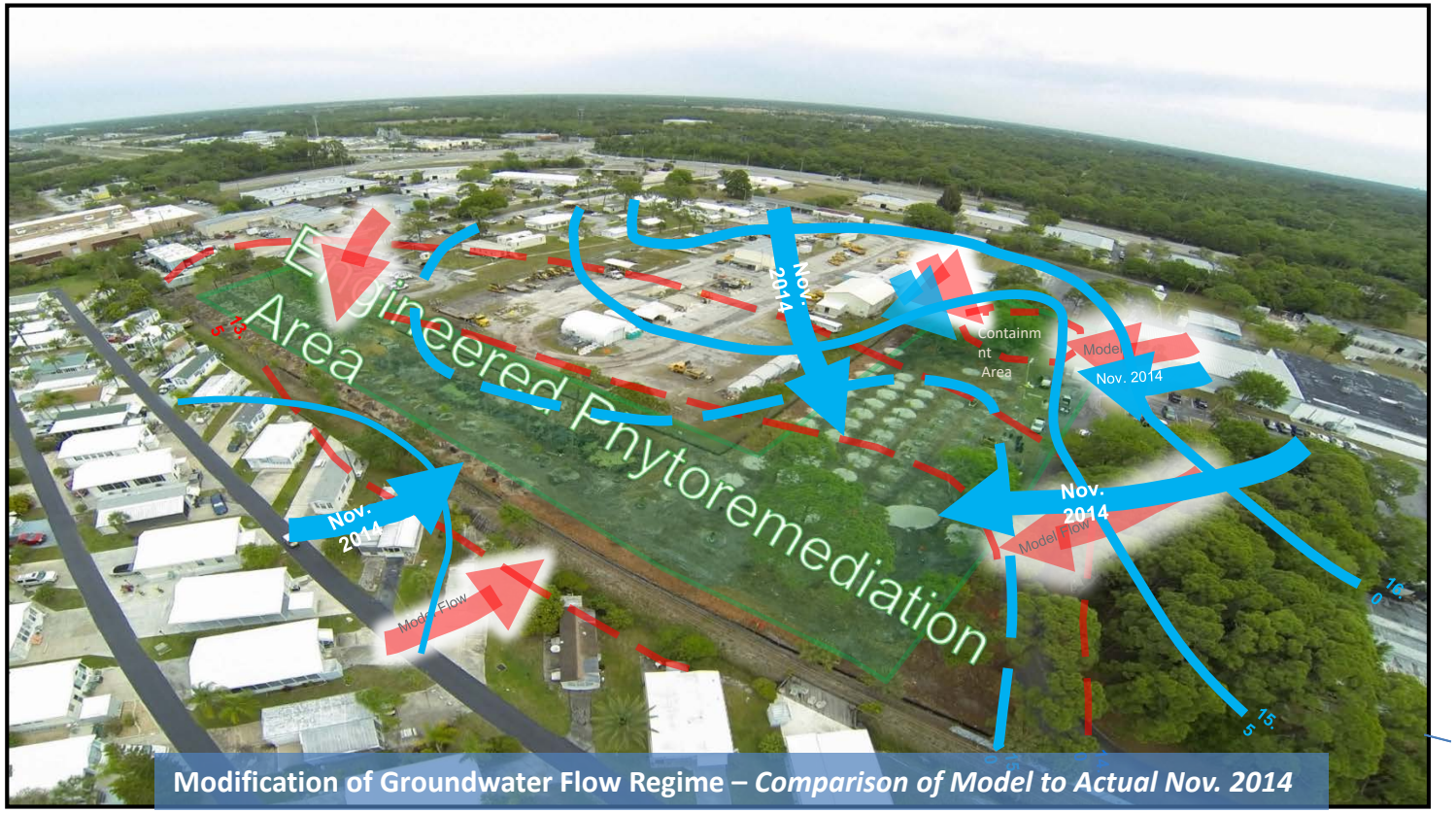

Modification of Groundwater Flow Regime – *Comparison of Model to Actual Nov. 2014*

Case Study:
Modeled vs Actual Groundwater Flow

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Modification of Groundwater Flow Regime – *Comparison of Model to Actual Feb. 2016*

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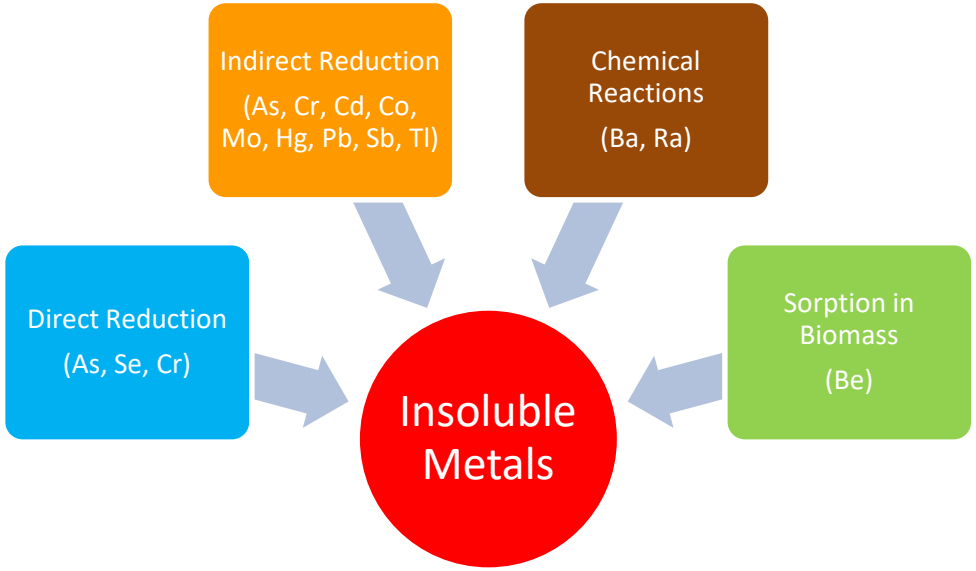
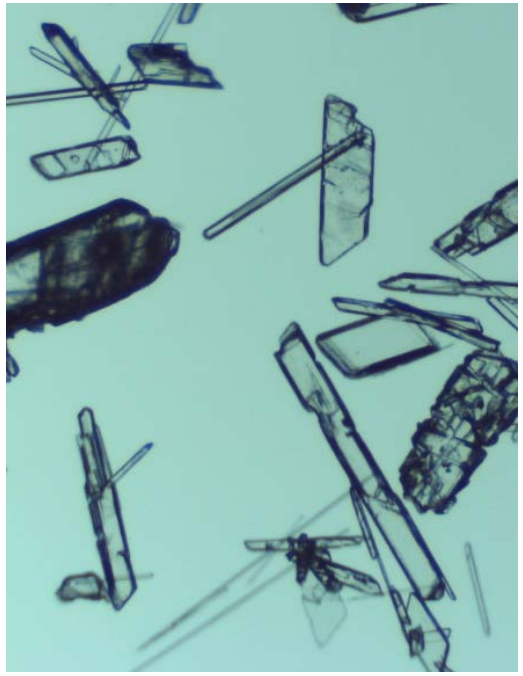
In-Situ Redox-Altering Approaches

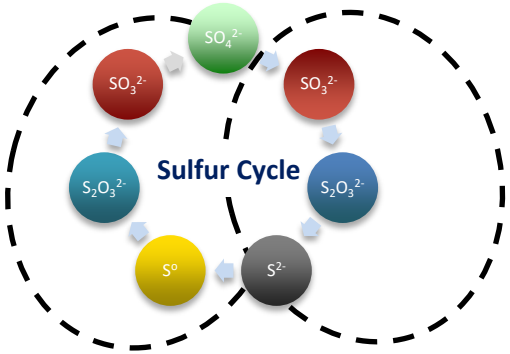
In-Situ Redox-Altering Approaches

- Chemical oxidants or reductants
  - ISCO and ISCR
    - Depending on mobility of compound
- Mechanical processes
  - Air sparging
    - Promote Fe precipitation and sorption/co-precipitation of As
- Biogeochemical processes

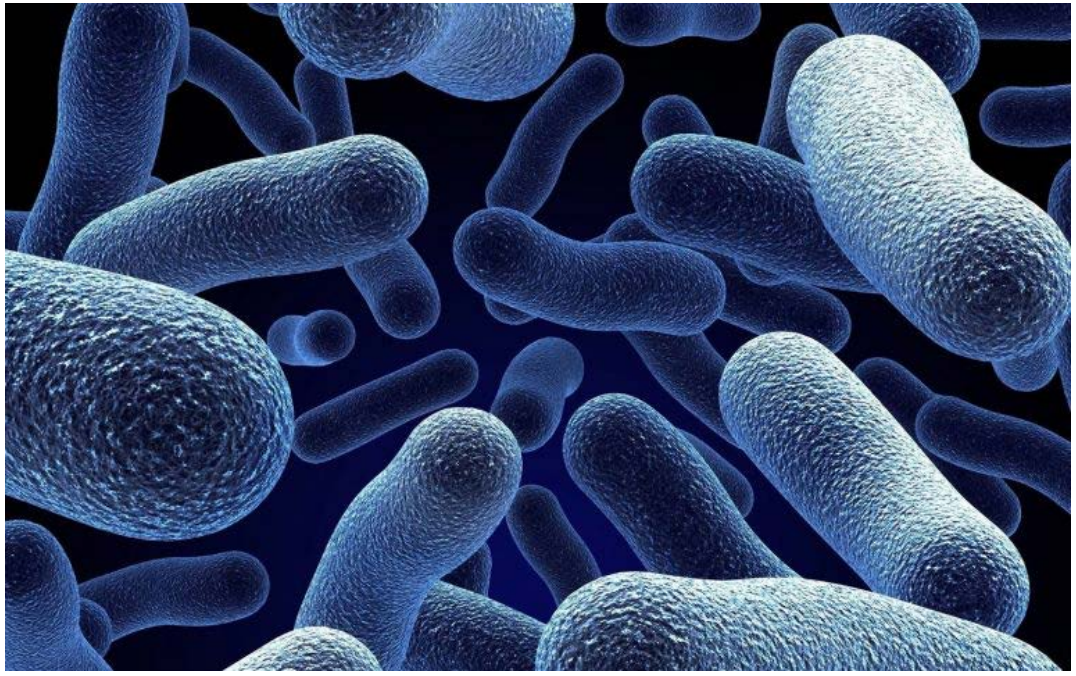




Oxidizer



Reducer



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Biogeochemistry

Biogeochemical Stabilization of CCR

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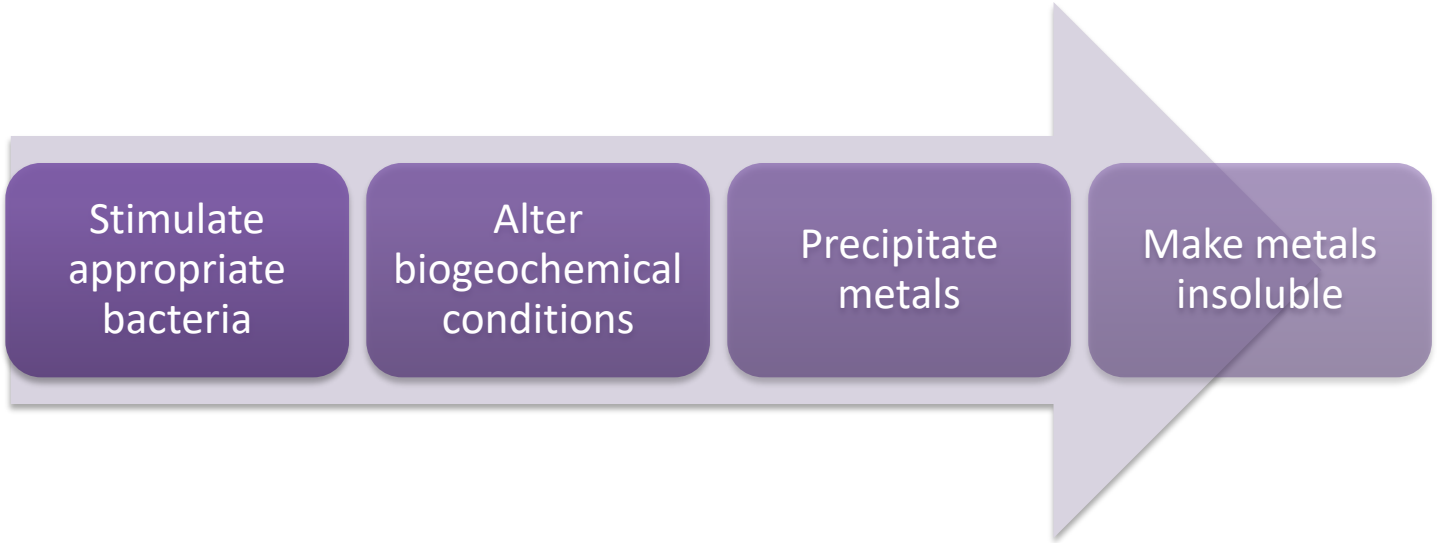
- Current approaches for stabilizing CCR focus predominately on physical technologies to manage ash
- Could we stabilize metals in CCR with biogeochemical reactions that target assessment metals?



Coal Ash Microbiology

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Little is known about the diversity of CCR microbial communities, but there is increasing effort to characterize these communities

Known Microbial Groups in Coal Ash
Denitrifying Bacteria
Nitrifying Bacteria*
Selenate Reducing Bacteria*
Sulfur Reducing Bacteria*
Sulfur Oxidizing Bacteria

* Relevant biogeochemical processes for immobilization of metals present in CCR Waste

Power and Process of Biogeochemistry

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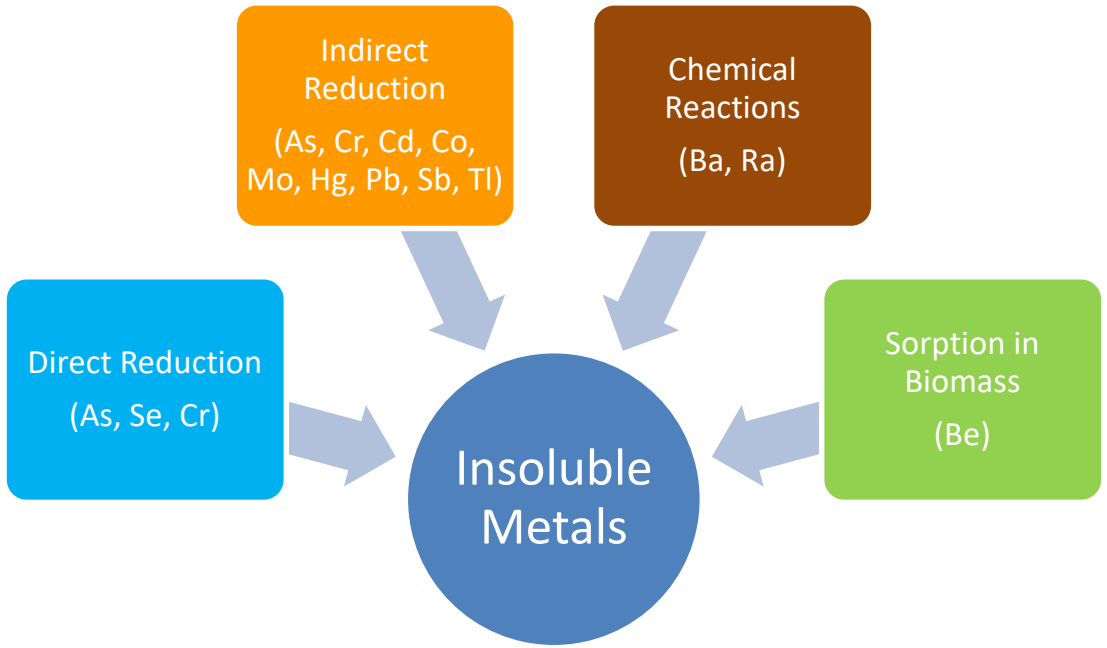
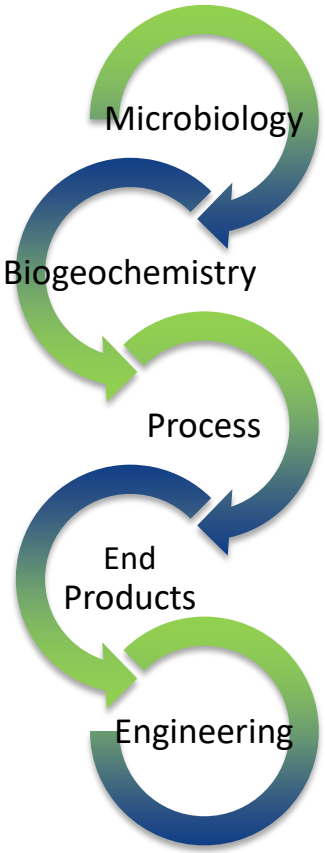


- Direct and indirect biogeochemical reactions affect CCR metals
- Naturally occurring microorganisms can be harnessed to drive helpful reactions
- Conditions can be engineered to favor specific microbial activities that produce desirable end products or environmentally stable forms of potential pollutants



Behavior of Metals in Storage Cells without Biogeochemical Controls

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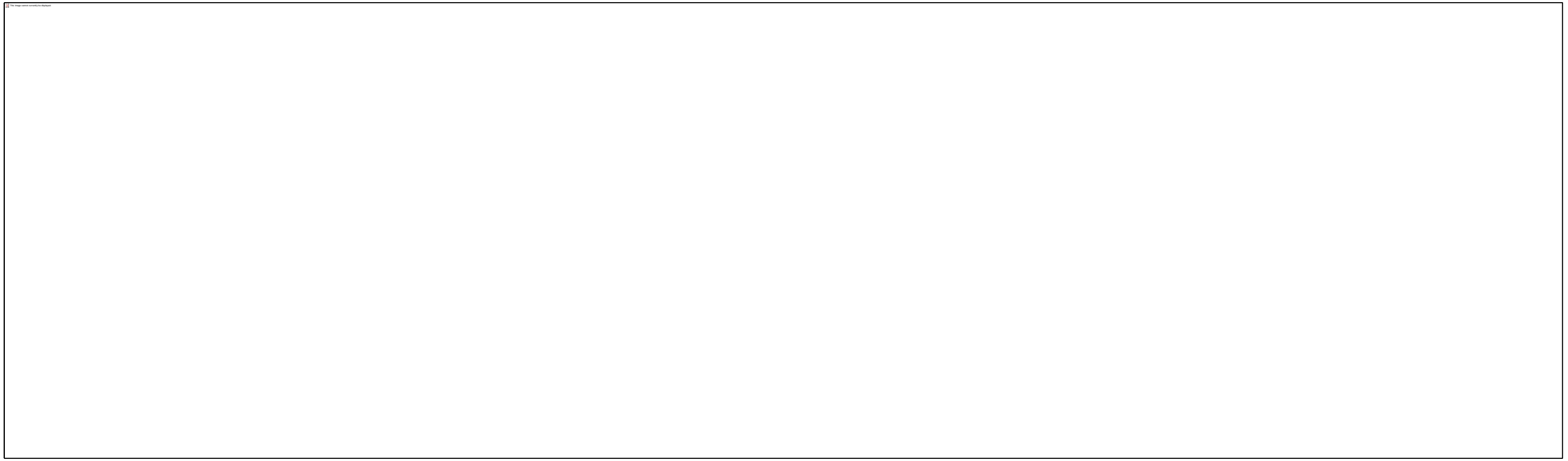

Options for Biogeochemical Control of Metals Migration

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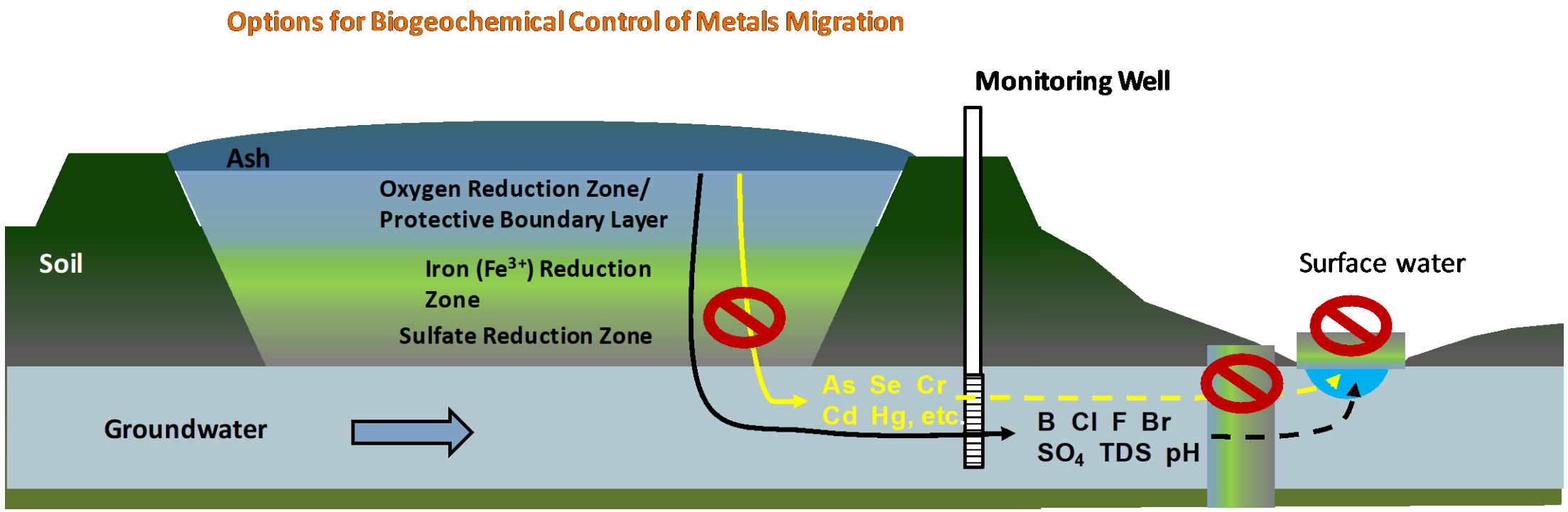

Engineered control points where metals migration can be biogeochemically arrested

Source: Provided by Geo-Solutions, Inc.

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Slurry Walls

Slurry Walls

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- Slurry Wall (a.k.a. “Barrier Wall”) - a physical, low permeability barrier to groundwater flow
- Design and Installation:
  - **Contain source area and prevent future migration of CCR constituents outside the “contained” area**
  - **Divert groundwater flow**
- Implemented for several decades and accepted by regulators
- Most effective when there is a lower “cut off” layer

Soil-Bentonite Slurry Wall Concept

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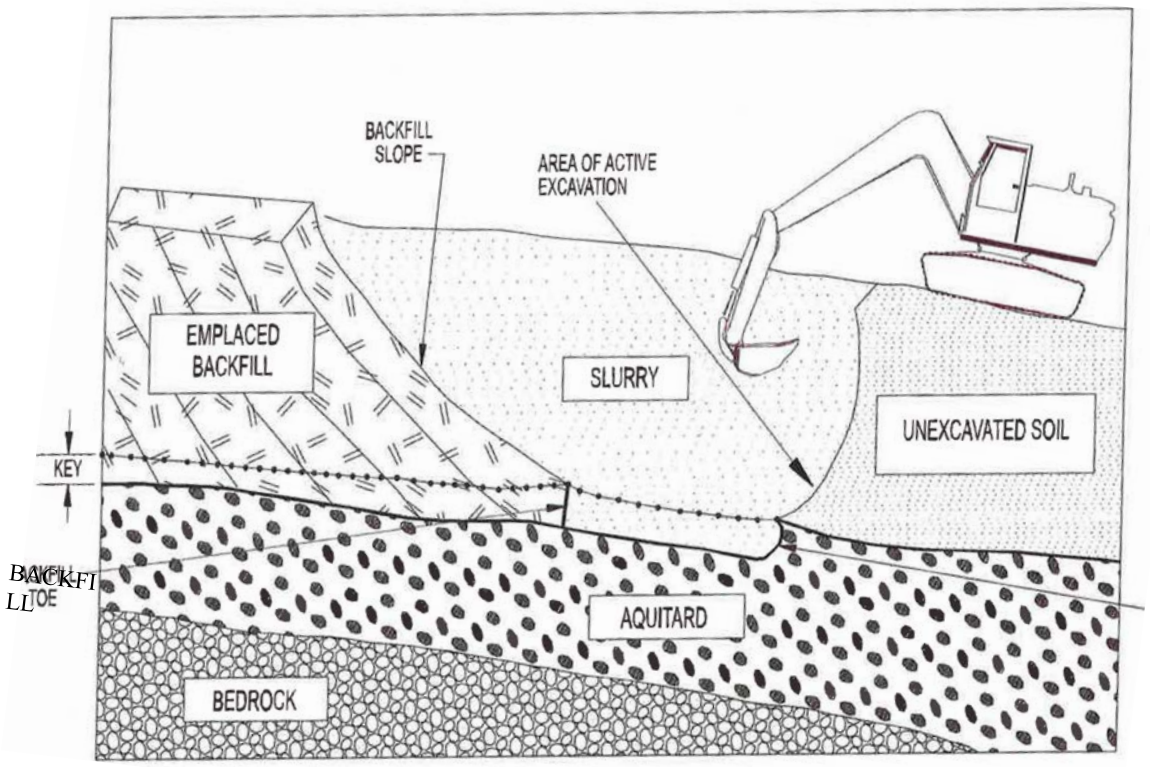

SB slurry wall concept

Track hoe excavation in slurry-filled trench

Types of Barrier Walls

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- Installed in a slurry trench and backfilled
  - Soil-bentonite (SB)
  - Cement-bentonite (CB)
  - Soil-cement-bentonite (SCB)
- Reagents mixed with soil *in-situ*
  - One pass trenching (OPT)
  - Deep soil mixing (DSM)
  - Cutter Soil Mixing (CSM)
- Special Applications
  - Vinyl sheet pile
  - Vibrating beam

One Pass Excavator

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(Courtesy DeWind)

Deep Soil Mixing

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Slurry Walls

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- **Advantages**
  - Can be implemented around an active facility
  - Lower cost source control
  - Effective for all CCR constituents
- **Limitations**
  - Gradient control systems
  - Source control combined with cap
  - Key for toe of slurry wall (e.g., lower cutoff layer)
- **Design Considerations**
  - Bench scale testing is typically performed to develop a mix design (e.g., hydraulic conductivity, geostructural)

Source: Provided by Geo-Solutions, Inc.

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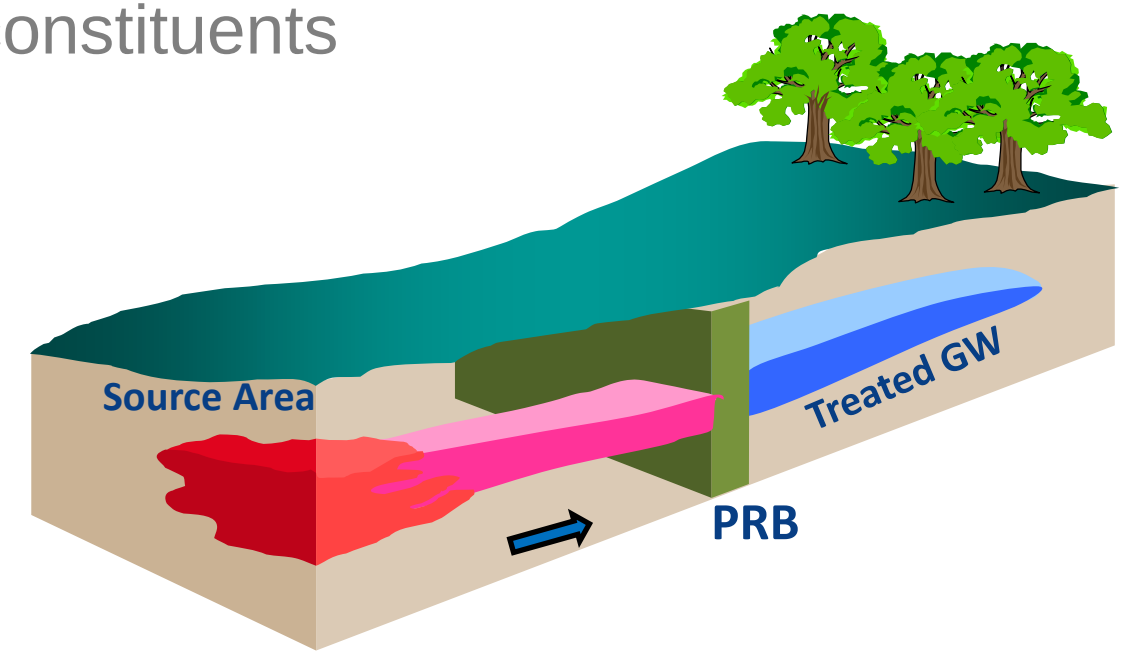
Permeable Reactive Barrier

PRB Application to CCR

- Permeable Reactive Barrier (PRB) is especially useful for controlling off-site migration
- Passive treatment: no energy or equipment required after installation
  - No operating costs during PRB lifetime (e.g., 10-20 years)
- Various reactive materials for CCR-constituents
- Long-term treatment
- Conserves water
- Allows productive use of site



PRB Design Considerations for CCR

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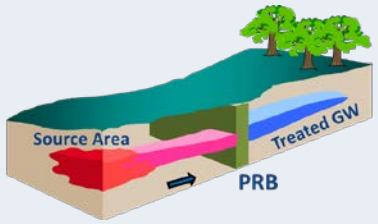
- Width of PRB depends on
  - Type and concentrations of COCs
  - Groundwater flow velocity
  - Type of reactive material/COC removal process (adsorption/reduction/precipitation for CCR impacts)
  - Rates of removal/required residence time
  - Construction limitations
- Long-term performance considerations
  - Reactivity loss with time
  - Permeability loss with time
  - Frequency of rejuvenation or reactive material change-out

 CCR COCs	ZVI	ZVI-carbon	Bio-barriers (solid carbon)	Apatite	Zeolite	Limestone/Alkali mat.
Fluoride						P
pH (acidity)						√
Sulfate		√	√			
Arsenic	√	√	√			
Lead		√	√	√	√	P
Molybdenum		√	√	√	√	P
Radium	√	√	P	P	P	P

PRB Construction Methods - Trenching

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Backhoe trenching (20 ft, 6 m)

Biopolymer trenching (70 ft, 21 m)

Cofferdam/trench box (30 ft, 9 m)

Continuous trenching (40 ft, 12 m)

Reagent Placement

PRB Construction Methods - Injection (Solids)

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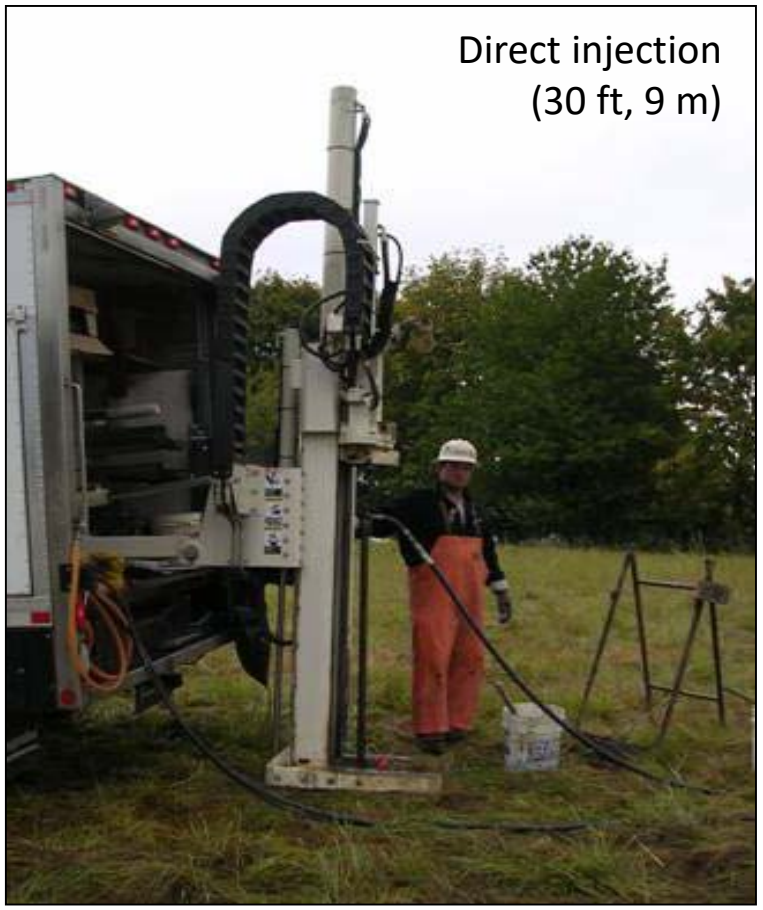
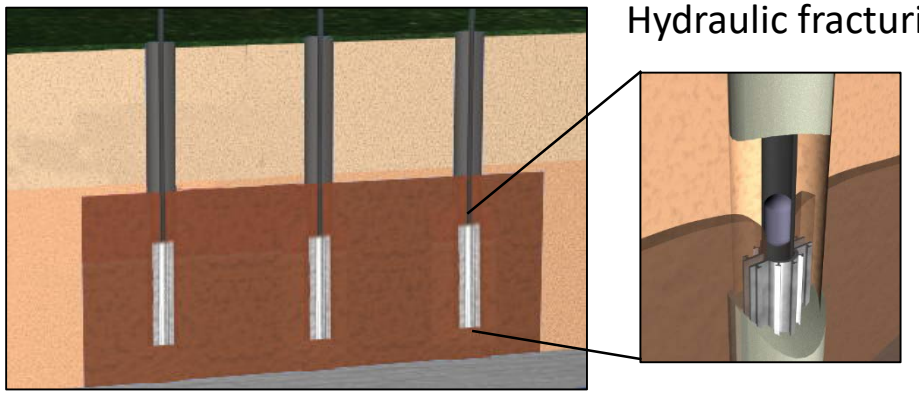
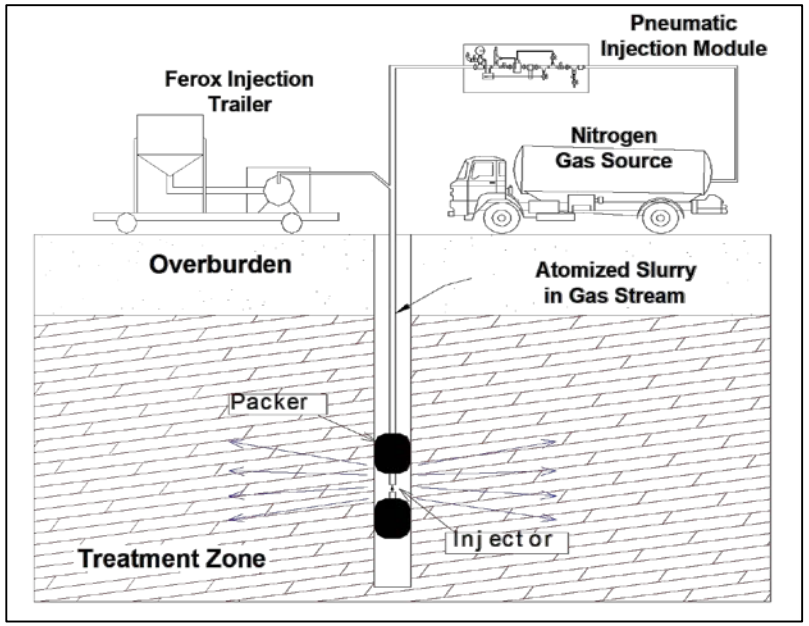
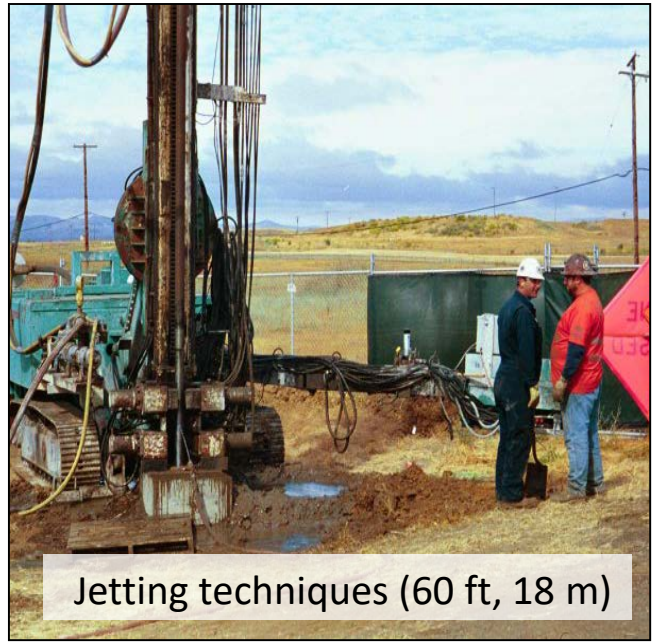




Hydraulic fracturing/Injection (300 ft, 91 m)



Pneumatic fracturing (90 ft, 27 m)



Jetting techniques (60 ft, 18 m)

Sulfate Reducing/Acid Neutralizing PRB

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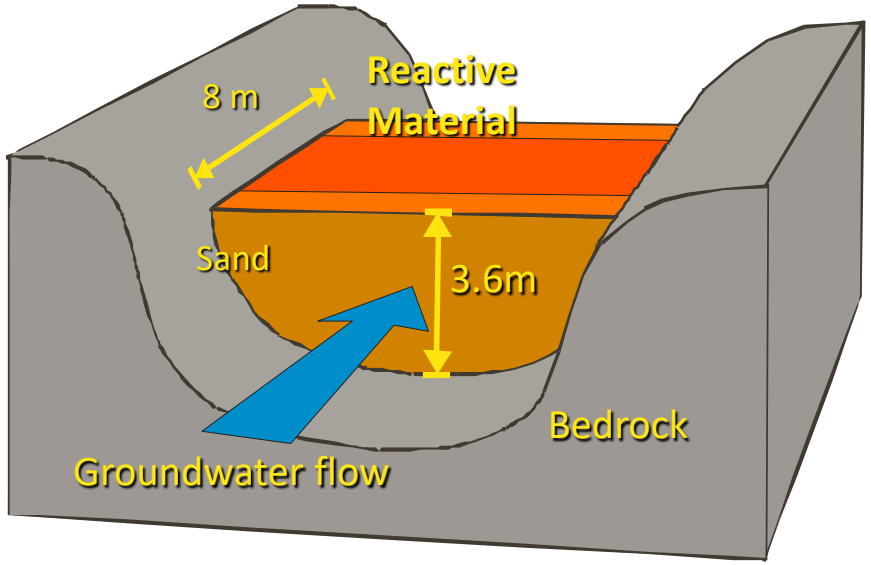

Benner et al., 1997

Sulfate Reducing/Acid Neutralizing PRB - Year 1

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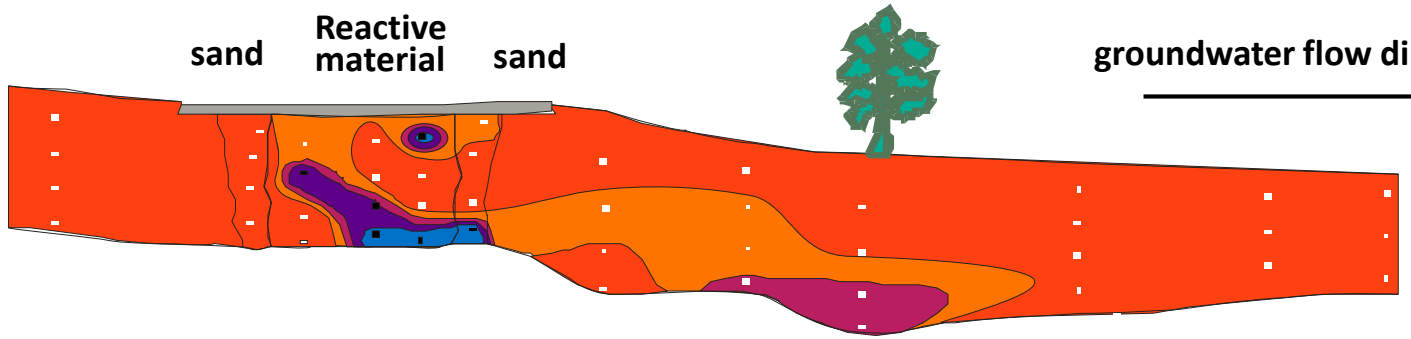
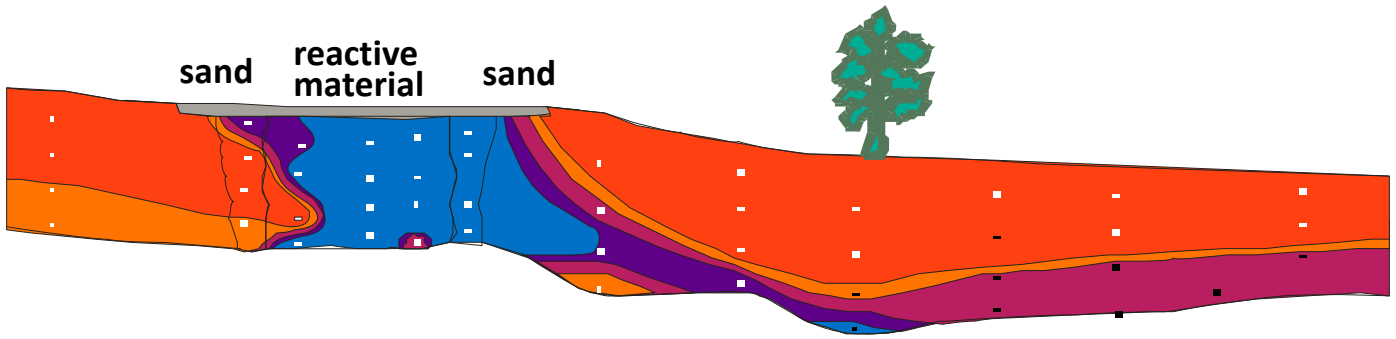
Sulfate (mg/L)

- >2000
- 1500-2000
- 1000-1499
- 500-999
- <500



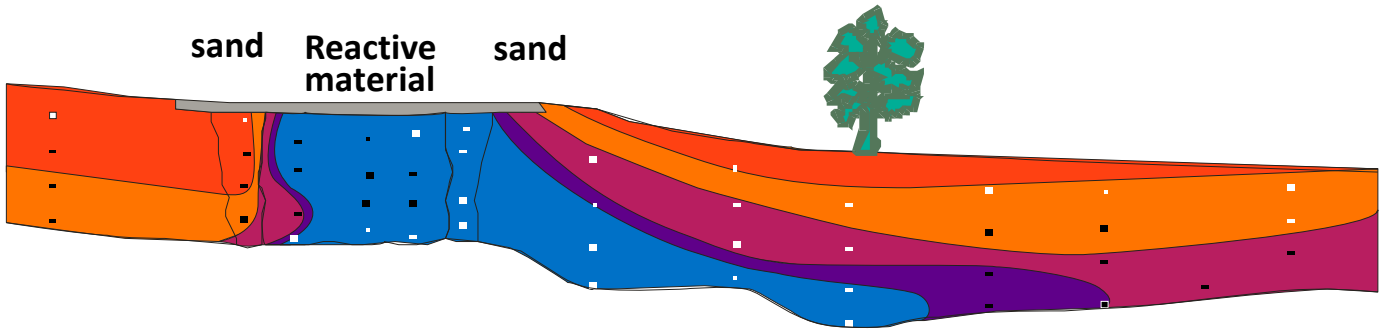
Iron (mg/L)

- >350
- 250-350
- 150-249
- 50-149
- <50



Acid Generating Potential (meq/L)

- >20
- 10 - 20
- 0.0 - 10
- -10 - 0.0
- <-10



0 m 5 m

Benner et al., 1997

Sulfate Reducing/Acid Neutralizing PRB - Year 6

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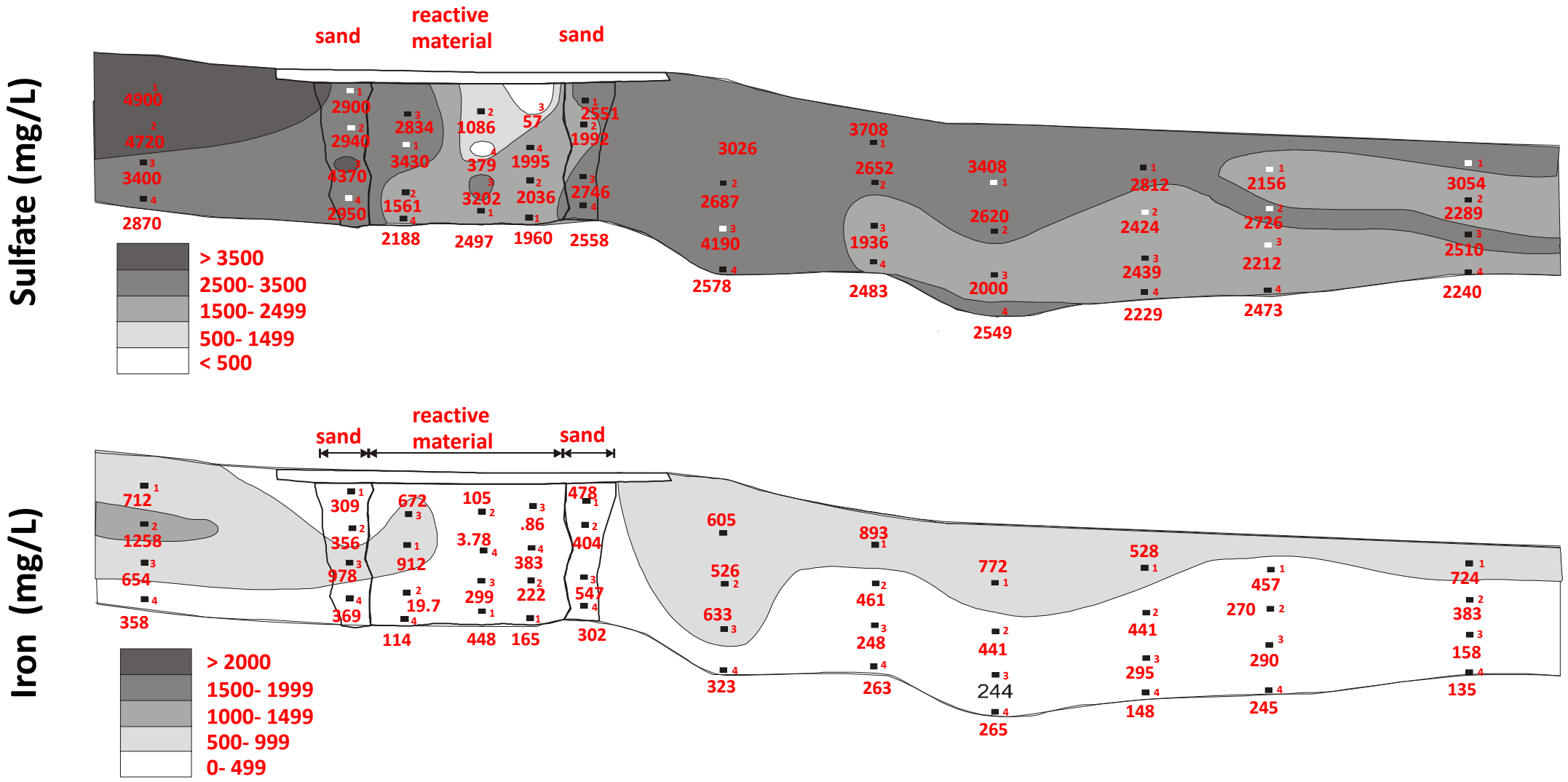

Blowes et al., 2000

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In situ Stabilization/Solidification (ISS)

What is ISS?

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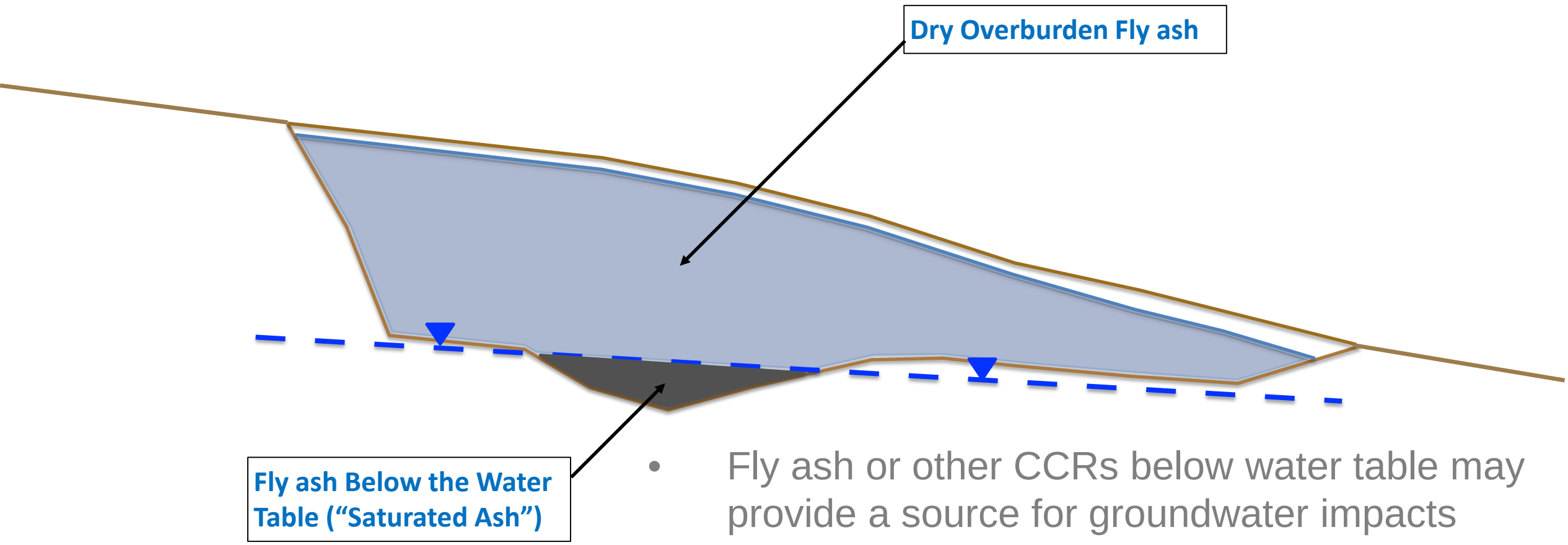
- **Solidification**: contaminated materials are encapsulated " physically trapped" to form a solid material that restricts contaminant leaching by:
  - *Reduction of permeability*
  - *Increasing compressive strength and media durability*

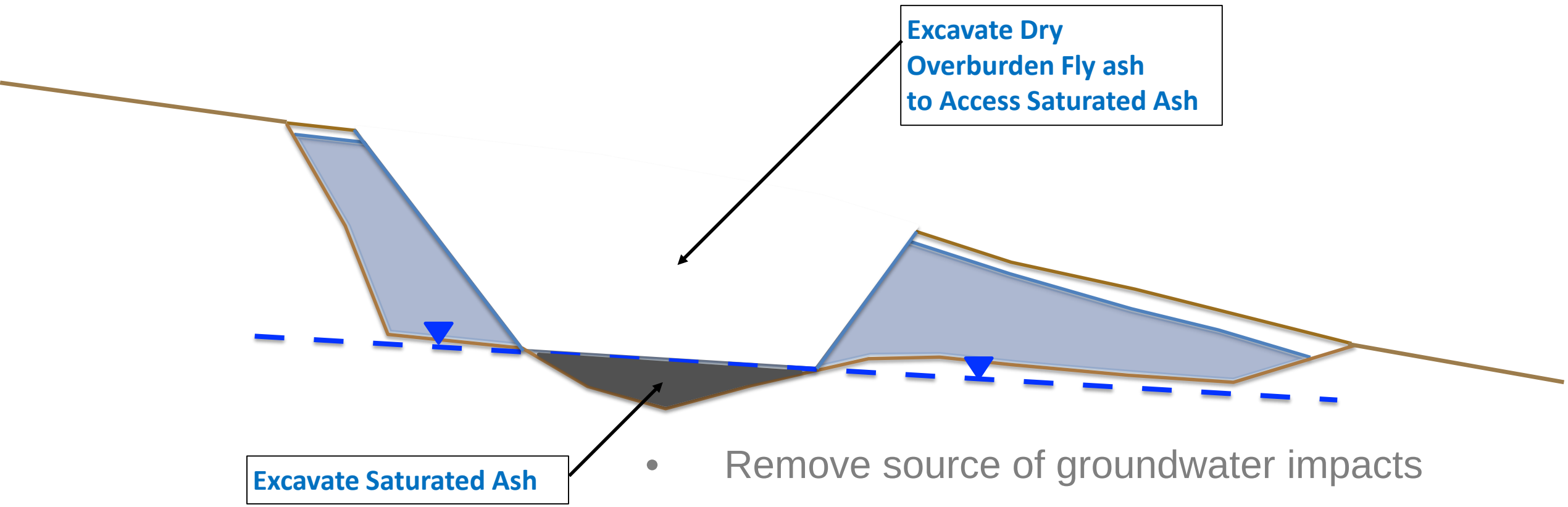
- **Stabilization**: Chemical reaction between reagents and contaminated materials - designed to reduce the leachability of targeted contaminants by:
  - *Binding free liquids*
  - *Immobilizing targeted contaminants*
  - *Reducing solubility of the contaminated material*

Why ISS – Conceptual Site Model



- Fly ash or other CCRs below water table may provide a source for groundwater impacts

Excavation Approach



- Remove source of groundwater impacts

Excavation Approach

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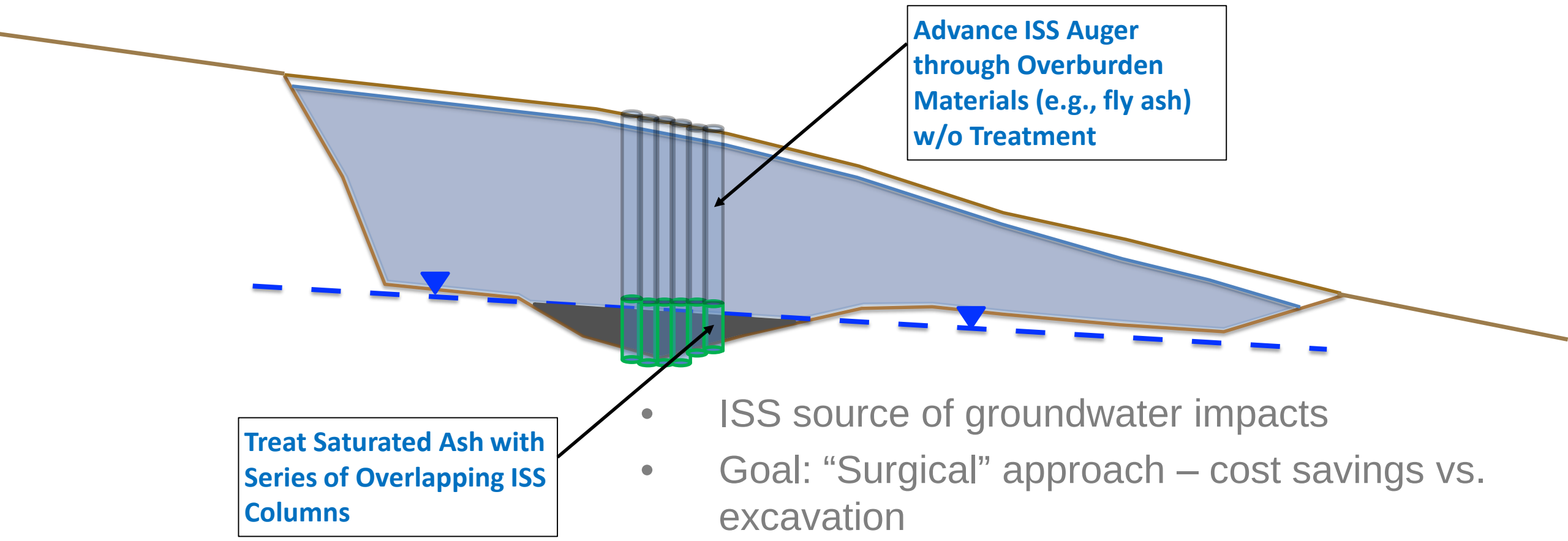
Why ISS? "Surgical" Alternative



- ISS source of groundwater impacts
- Goal: "Surgical" approach – cost savings vs. excavation

Key Considerations for CCR Units

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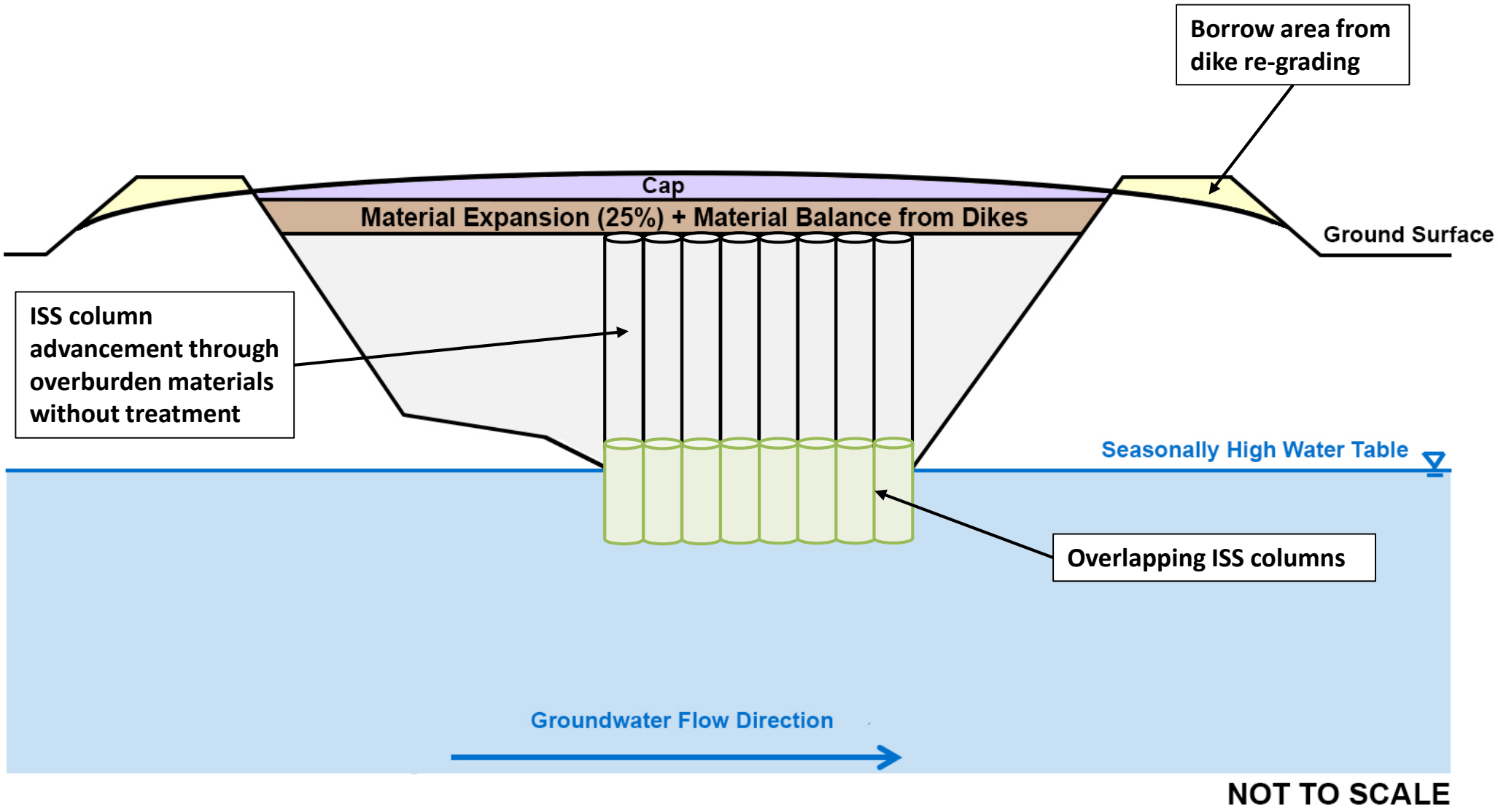
- Cost
  - Potential for cost savings vs. excavation
  - Range: $50 to $100 per cubic yard (application dependent)
  - May be cost prohibitive for large impoundments
- Geosyntec approach - niche applications:
  - **Small source areas**
  - When cost/benefit outweighs standard remedies (e.g., pump and treat; excavation)
- Geochemistry of COCs
  - Boron, sulfate, As, Se, Mo, etc.
  - Design application to address site specific COCs and geochemical conditions influenced by cement chemistry
  - Select reagents compatible high SO_4^{2-} conditions (e.g., GGBFS, PC V)
- Access!!!

Targeted Discrete Depth ISS



Vertical Barrier Source Control

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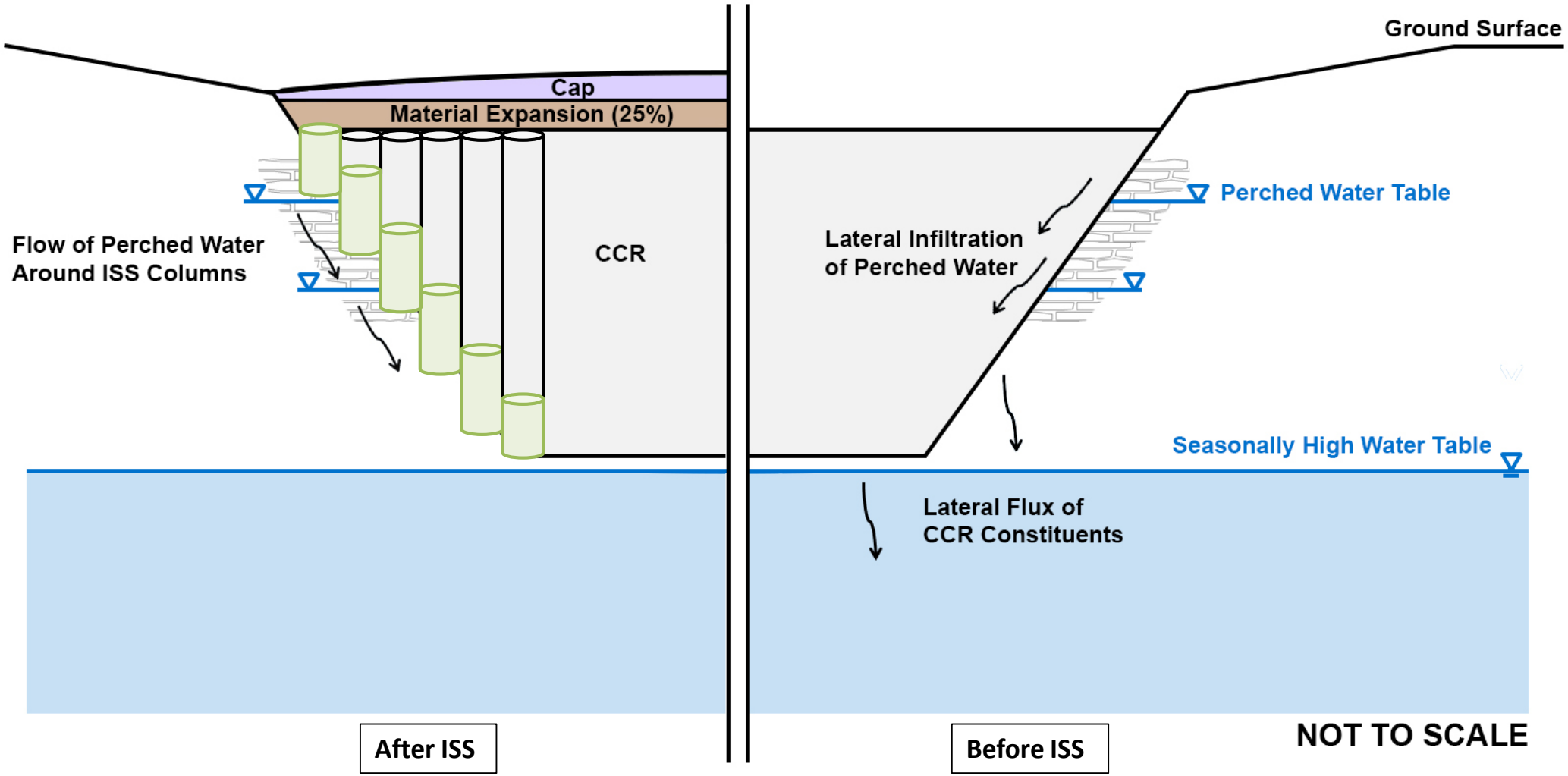
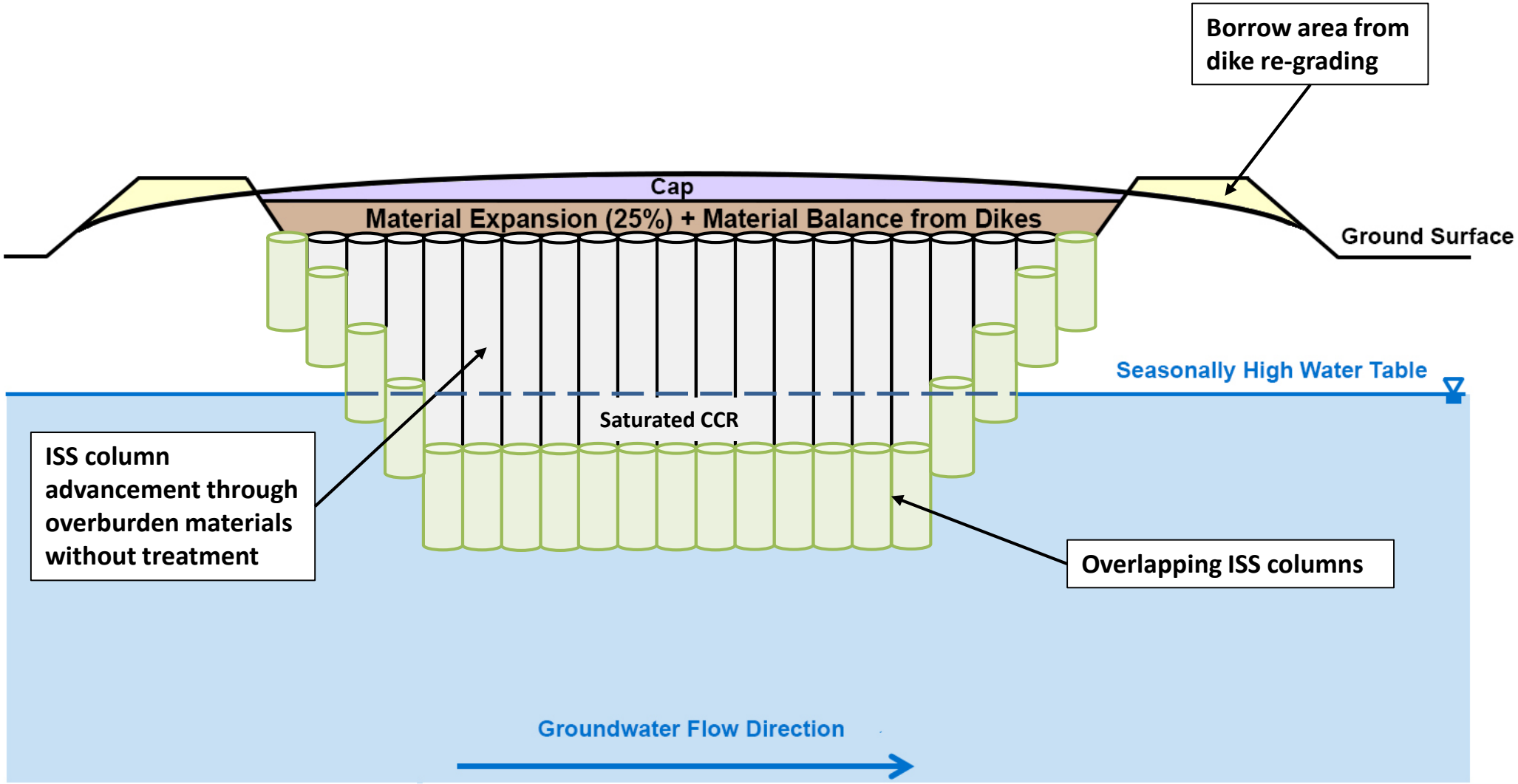


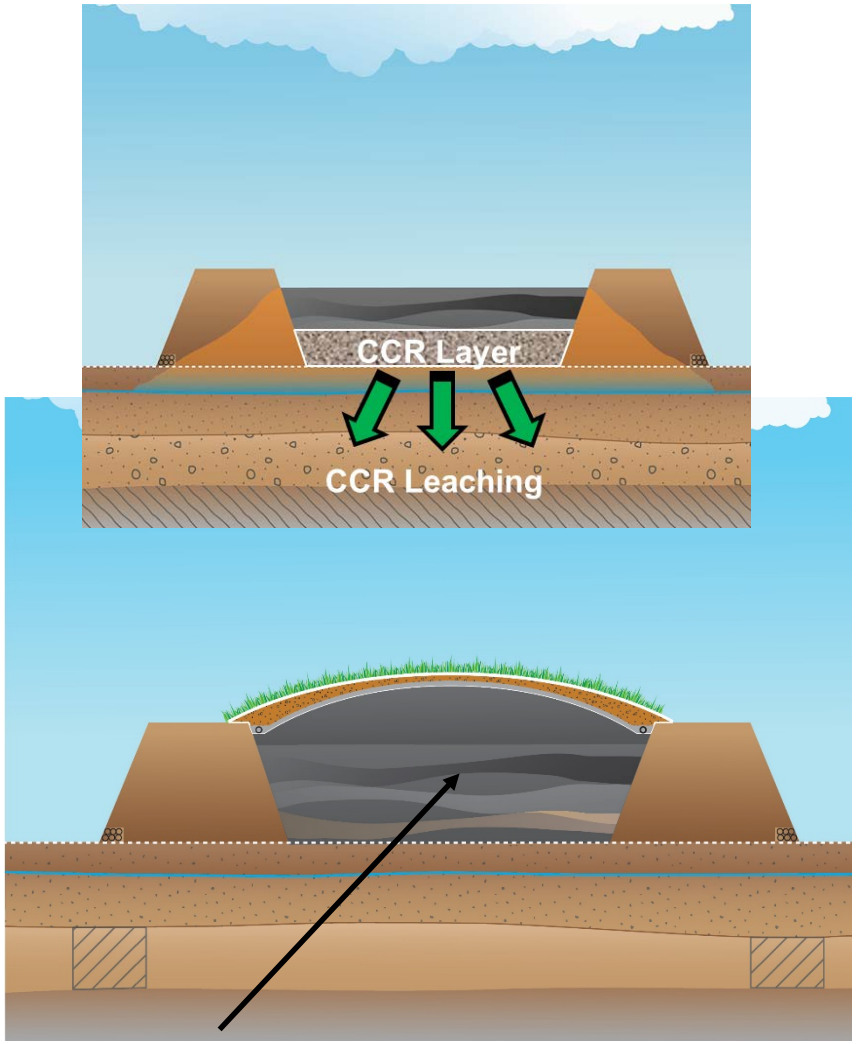
Discrete Depth ISS Containment



US Patent 9,909,277 B2 Mar. 6, 2018, *In situ* Waste Remediation Methods and Systems

Remedial Alternatives Selection Process

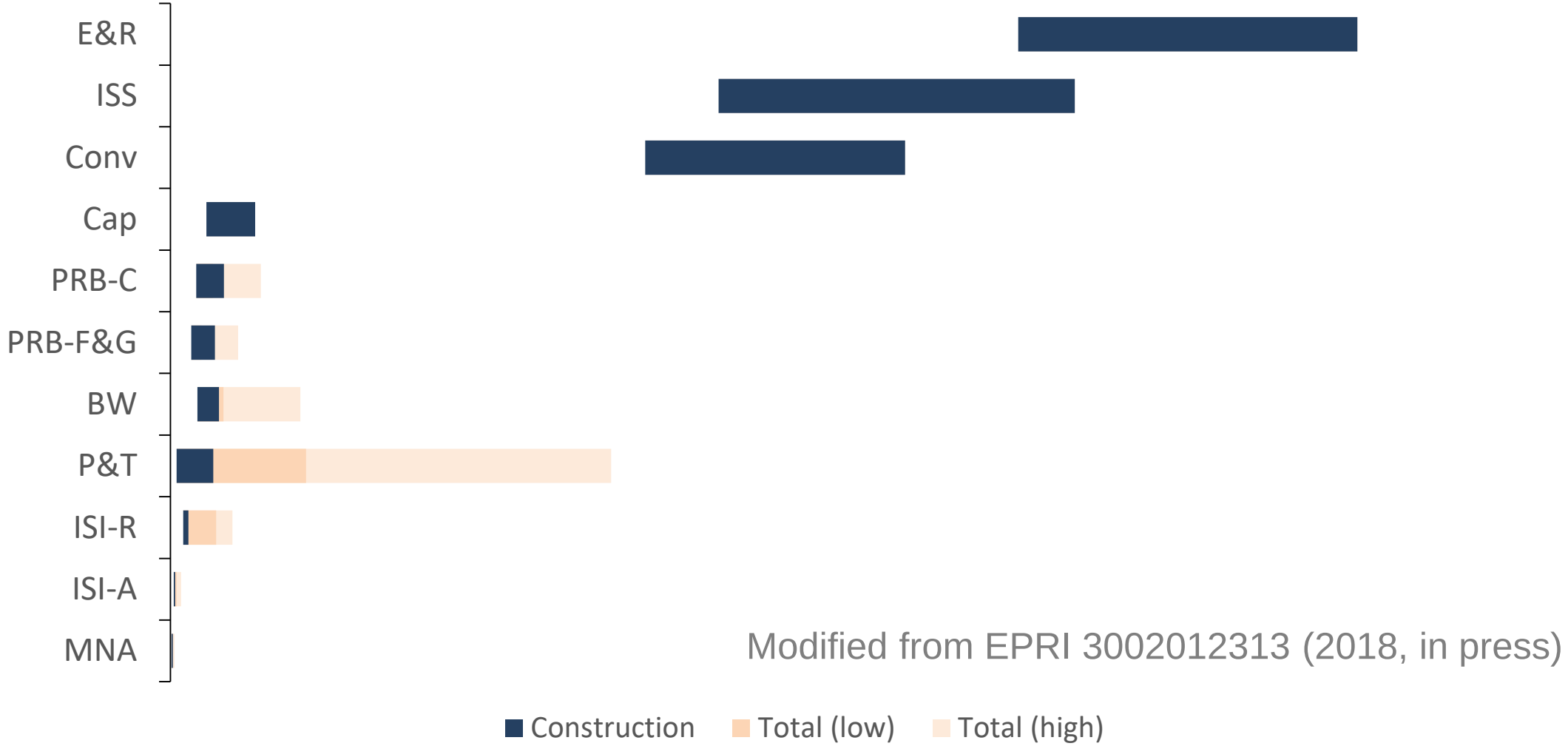
1. Exceedance attributable to CCR unit?
2. Alternate source demonstration (ASD)
3. Prioritize remedy implementation
   - Proximity to receptor, magnitude of release, toxicity/mobility of constituents, etc.
4. Evaluate MNA and IC after pond closure
5. Evaluate technologies likely to achieve stakeholder acceptance
   - Reliable, sustainable, and practicable
6. Take advantage of existing infrastructure
   - Retention ponds, treatment plants, connection to sewer, open (vegetated) spaces (irrigation)
7. Consider water reuse
   - Cooling towers, dust suppression, irrigation, ash conditioning, etc.



Note: CCR above groundwater table

Relative Cost

- Collaboration with EPRI *Groundwater Remediation Planning* – desktop reference



Modified from EPRI 3002012313 (2018, in press)

Solutions are Site-Specific

- Final selection of an active remedy, if necessary, should be:
  - Site-specific
  - Balance risks and the effectiveness in reducing these risks using a certain remedial approach
  - Implementability of a technology, and
  - Capital and long-term O&M costs.

Questions?

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Thank you for your time!

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engineers | scientists | innovators