


Reducing the Cost of Wastewater and Groundwater Treatment from Coal Ash Basin Using Closed Loop Zero Valent Iron (ZVI) Treatment Methods

World of Coal Ash 2022
May 18, 2022

ENERGY & ENVIRONMENT
INNOVATION FOUNDATION, LLC

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Agenda and Discussion Topics

- **Best Management Practices (BMPs) to reduce contact water** have been used on coal ash basin closure projects to reduce contact water and treatment cost;
- **Temporary covers and liner systems are an effective method** for reducing the cost of wastewater treatment from coal ash basin closure
- **Explain the use of lined contact water collection basins and ZV iron treatment systems** to create closed loop, on-site treatment systems;
- **Provide guidelines on the selection of the ZV iron treatment media** and how it can be used to achieve State regulatory requirements;
- **Cost considerations and case studies to develop a comparison** of coal combustion residual (CCR) wastewater treatment using conventional treatment methods.

CALM Initiative – History of Safety Awareness Training Focused on Solving Problems with Ash Basin Construction – September 2015

- Invited 10 Industry Partners and 4 electric power utilities.
- Discussion on Demonstration Projects and shared funding approach to applied research.
- Listened and learned about industry needs and concerns.
- Results and recommendations:
  - Focus on access road and excavation stability – excess porewater pressures.
  - SAFETY AWARENESS: Ash basin safety training defined as an urgent and important need.
  - NEED FOR BMPs: Need to close gap between ash basin closure design approach and means and methods.

UNC CHARLOTTE
Energy Production and Infrastructure Center (EPIC)

Coal Ash and Liquid Managements (CALM)
AGENDA - Kick-off Meeting

Purpose: To develop practical, technology based solutions for the energy production industry problems and challenges with coal ash and liquid management.

Objective: To have an interactive discussion with respected industry leaders about how to accomplish the purpose of the EPIC CALM Office. This discussion will include discovering the unique, applied research capabilities at EPIC, and develop a practical set of ground rules and bylaws that solve problems in a cost effective manner.

Monday Sessions – September 14, 2015

11:30 a.m. to 12:30 p.m. – Monday Early Session: Midday start accounts for variable travel schedule, initial tours of EPIC and casual meetings with UNC Charlotte "coal ash" professors and other Industry Partners.

12:30 p.m. to 2 p.m. - Working Lunch and Introduction of Industry Partners: This session will allow each Industry Partner to provide 5 to 10 minute presentation of the following:

- Brief Introduction and Welcome to EPIC – David Young
- Brief Introduction of the EPIC CALM Office by Chris Hardin and Milind Khire.
- Introduction of Your Company and its unique capabilities
- How, what, when and where can the EPIC CALM Office provide assistance, leadership and guidance to you and your company?
- What would make the EPIC CALM Office relative to your company and help it with solving problems or obtaining new projects?
- Assuming your company would be one of the Founding Industry Partners what are the "hot buttons" positive and negative that you would like to see the CALM Office "Do and Not Do"?

CALM Initiative is the Largest Industry Consortium Focused on Safety and Solutions.

- 10 Contractors
- 3 Engineering Consultants
- 10 Special Technology Companies
- 5 Utilities Involved as Key Stakeholders

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Background and Credentials of C. Hardin and the CALM Initiative

- Professional Engineer registered in six states including NC, SC, VA and GA.
- Former member of the American Coal Ash Association (ACAA) Executive Committee – Provided Industry Response Presentation – May 2009, Five months after TVA Kingston.
- Designed one of the first lined coal ash landfills in North Carolina – R.J. Reynolds Landfill in Rural Hall, NC and the first landfill after the TVA Kingston failure, Lee Steam Station in South Carolina. **Involved with coal ash remediation for over 25 years.**
- Designed and implemented one of the largest coal ash structural fills in North Carolina.
- Was present at the Dan River coal ash basin pipe repair to coach and guide contractors – Geotechnical & Safety
- Currently Managing Director of the Coal Ash and Liquid Management (CALM) Initiative at UNC Charlotte. Five of the largest Power Companies in the United States are members.
- Part-time sustainable, organic farmer who regularly interacts with environmental groups in the Carolinas. Over 70-percent "carbon neutral" and 70-percent recycle/reuse on our farm since 2012
- Purposely avoid litigation – periodically involved as a subject atter expert (SME) on several large coal ash projects.
- Currently involved with some of the largest, and most challenging ash basin closure design and construction projects in the United States.

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Best Management Practices (BMPs) to Reduce Contact Water and Treatment Cost

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Project Considerations for Closure Construction Costs – NC Sites

- **North Carolina Settlement, December 2020 requires that all the coal ash** on most of the North Carolina sites must be excavated, placed in a new landfill, and the wastewater collected and treated.
- **Removal of large volumes of coal ash requires that more expensive stability** and temporary containment structures.
- **All stormwater and contact water is considered wastewater** and must be treated prior to discharge.
- **Site constraints will require that large volumes of coal ash will need to be handled twice.**
- **Summary: Better and more cost effective methods for excavation, landfill construction and wastewater treatment are needed.**

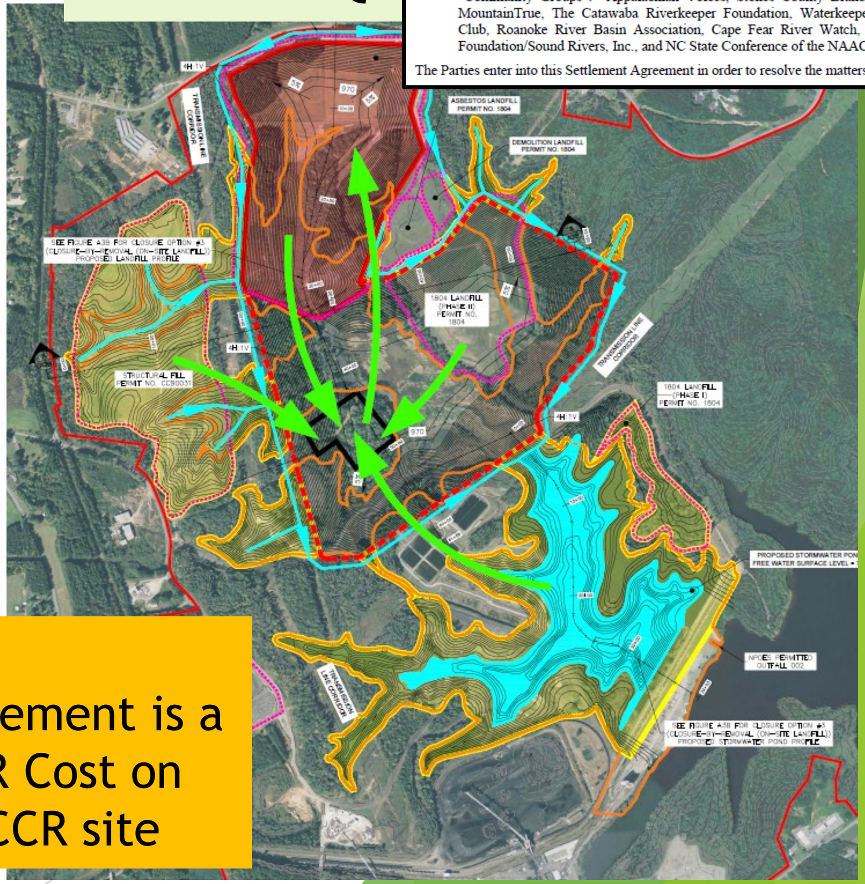
Excavation Option and On-site Landfill is required by North Carolina DEQ

DUKE ENERGY CAROLINAS, LLC, AND DUKE ENERGY PROGRESS, LLC, Petitioners, v. NORTH CAROLINA DEPARTMENT OF ENVIRONMENTAL QUALITY, Respondent, APPALACHIAN VOICES, THE STOKES COUNTY BRANCH OF THE NAACP, MOUNTAINTRUE, THE CATAWBA RIVERKEEPER FOUNDATION, THE SIERRA CLUB, THE WATERKEEPER ALLIANCE, and THE ROANOKE RIVER BASIN ASSOCIATION, Respondent-Intervenors.	SETTLEMENT AGREEMENT

THIS SETTLEMENT AGREEMENT (the "Agreement") is entered into on December 31st, 2019 ("Effective Date") between the Parties, defined as follows:

- "Duke Energy": Duke Energy Carolinas, LLC and Duke Energy Progress, LLC
- "DEQ": The North Carolina Department of Environmental Quality
- "Community Groups": Appalachian Voices, Stokes County Branch of the NAACP, MountainTrue, The Catawba Riverkeeper Foundation, Waterkeeper Alliance, Sierra Club, Roanoke River Basin Association, Cape Fear River Watch, Inc., Neuse River Foundation/Sound Rivers, Inc., and NC State Conference of the NAACP.[1]

The Parties enter into this Settlement Agreement in order to resolve the matters referenced herein.



Water Management is a MAJOR Cost on most CCR site

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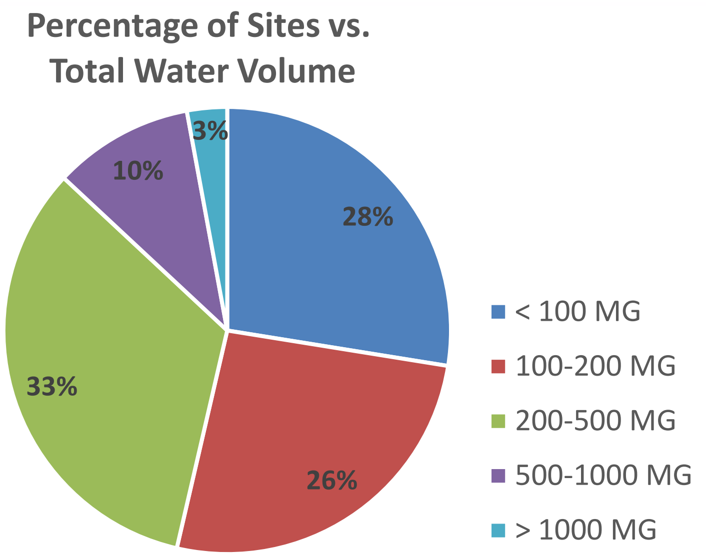
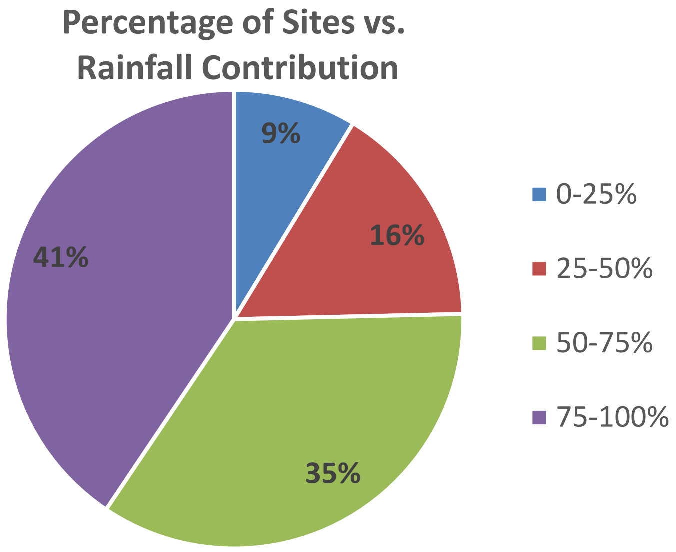
Technical Info from CALM Meeting December 2016

Volume of Water for Management & Treatment

- 54% of sites have less than 200 MG total water
- 13% of sites have more than 500 MG total water





- > 50% Rainfall Contribution at 76% of sites
  - Diversion Water – Conveyance/TSS
  - Contact Water – Site Specific Storage/Treatment Requirements

Contact: Greg Hebeler of Golder
Ghebeler@Golder.com

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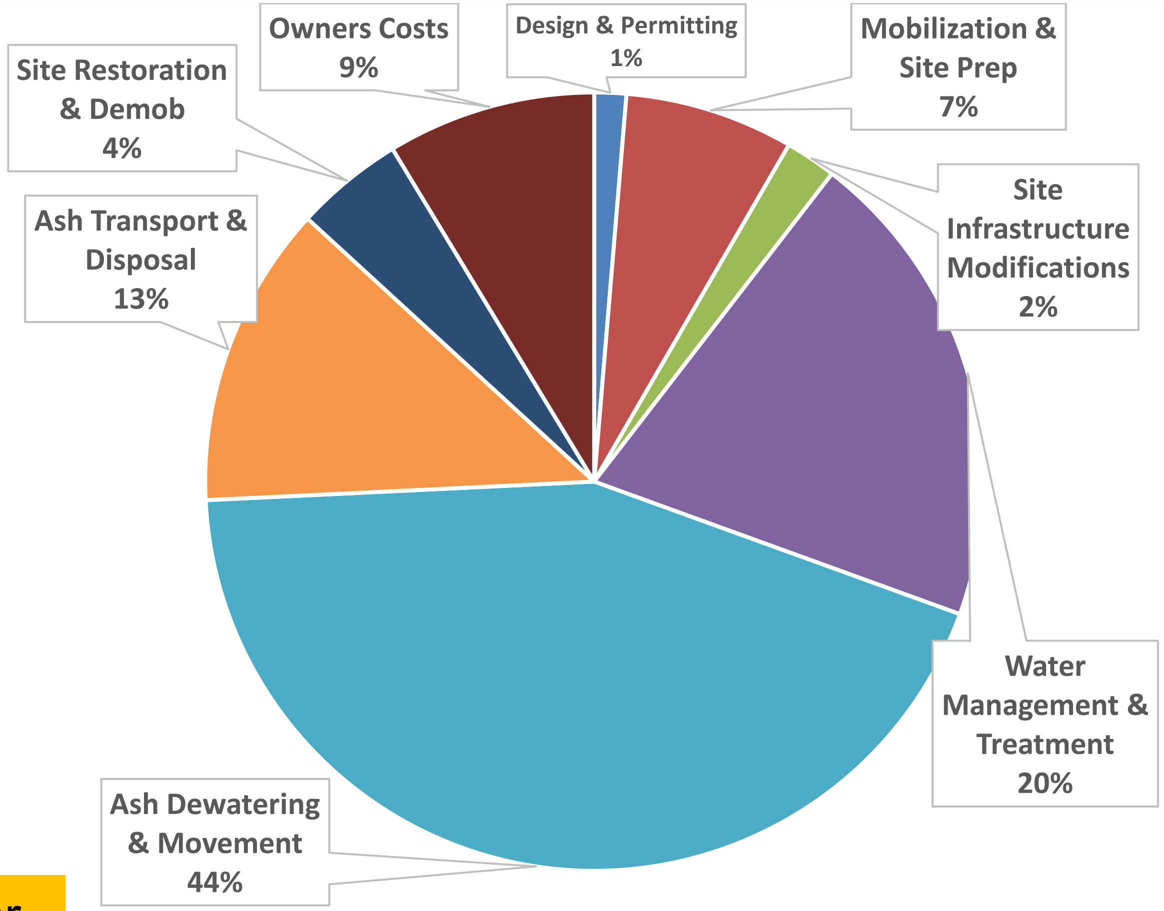
Ref: Project Information from Golder Associates

Technical Info from CALM Meeting December 2016

Relative Basin Closure Cost Impact

- Closure Scenarios
  - Clean Close
  - Cap In Place
  - Combination

- Water Management & Treatment ~ 20%
  - Water Storage
  - Water Movement
  - Water Treatment



Contact: Greg Hebeler of Golder
Ghebeler@Golder.com

Ref: Confidential Project Information Golder Associates,

Temporary Geomembrane Covers

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WASTEWATER

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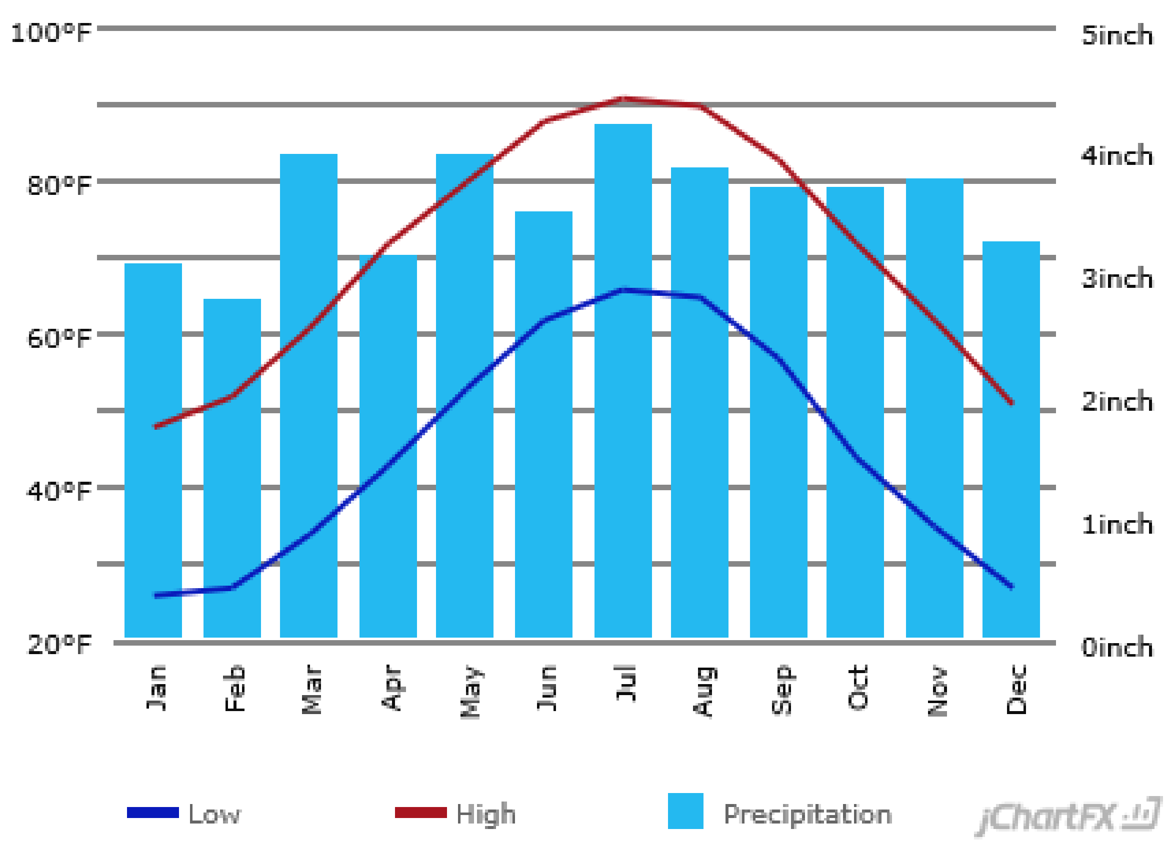
CHESAPEAKE CONTAINMENT SYSTEMS, INC.

1. **Begin with the End in Mind** – Water management is a significant part of the cost associated with ash basin closure.
2. **The best and most cost effective way to “treat” wastewater from ash basin is to not create it.**
3. Temporary covers substantially reduce the amount of water that infiltrates into an ash basin
   a. This reduces the wastewater volume
   b. Allow dewatering to control and provide pre-treatment of groundwater
   c. Part of the system that can prevent migration to on-site or off-site receptors.

Contact: Ryan Kamp
Chesapeake Containment Systems: rkamp@ccsliners.com

TEMPORARY COVERS

- Avg. Annual Rainfall Volume - ~79.3M gal
  - Area - ~68-acres (Lined Area) x 43,560 SF/acre
  - Avg. Annual Rainfall – (43-in/yr)/12-in/ft) = 3.58-ft/yr*
- Average Disposal Cost = $0.10/gallon**
- Annual Estimated Treatment Cost – ~$7.9M/yr. **
  - Avg. Annual Rainfall - ~79.3M gal
  - Avg. Disposal Cost - $0.10/gal**
- Temp Cover System Supply & Install= ~$1.5M**



* Per U.S. Climate data

** Theoretical value for comparison purpose only.

Power Project- Mid-Atlantic USA

4,000,000 SF Ash Basin Temp Cover

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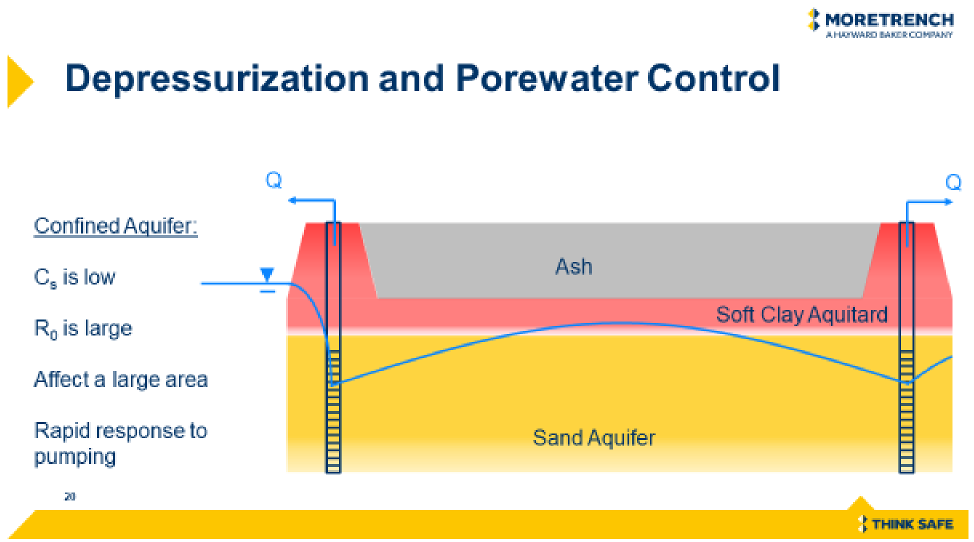
Power Project- Southeast USA

2,000,000 SF Ash Stockpile Cover

Wellpoint Dewatering Reduces Oxidation of CCRs and Surface Metals Release

- Dewatering wells reduce exposure of surface CCRs to oxidation.
- Properly installed dewatering wells increase stability and reduce wastewater treatment cost.



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Lined Contact Water Collection Basins and ZV Iron (ZVI) Treatment Systems

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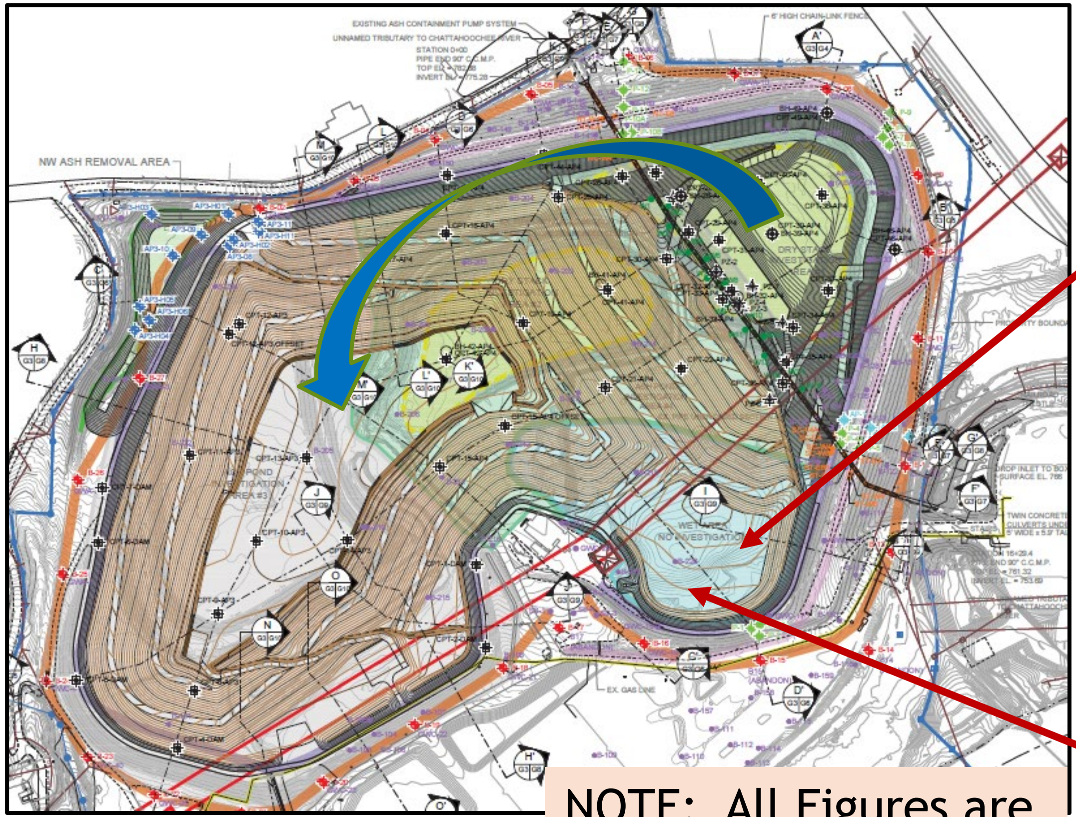
Southeast Site – Hybrid Closure, Lined Stormwater Collection Channels and Basins



Perimeter channels and lined stormwater basins collected contact and non-contact water and allow separation and treatment.

Wastewater was controlled and contained on-site, rain covers and incremental geotechnical investigations

Phys-Chem On-site Wastewater Treatment

NOTE: All Figures are from Public Record

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Typical Coal Ash Basin Closure with Lined Stormwater Collection Channels

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Guidelines for Alternative Treatment and ZVI Media Selection for Wastewater or Groundwater Treatment

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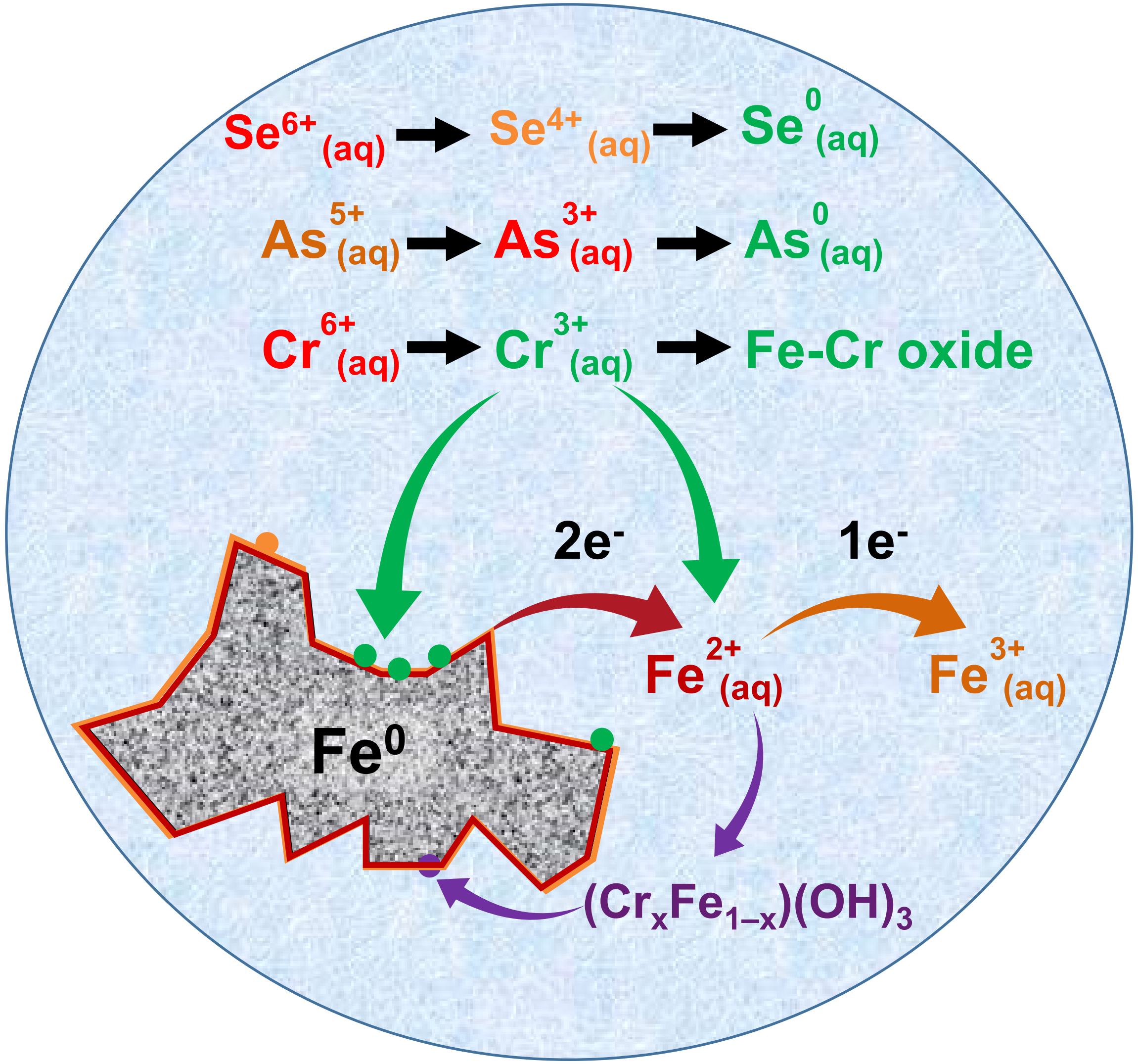
Water Treatment System and Discharge: Phys Chem System or Hoganas ZVI Media

Phys-Chem WW Treatment Package Plant

Hoganas – Clean-IT Treatment Package Plant

ZVI Iron Chemistry for Metals Removal



1) Oxidation of Zero Valent Iron → Reduction of Contaminants

$$M^{X+}_{(aq)} \rightarrow M^{x-y}_{(aq)}$$

2) Adsorption → Strong surface binding with high affinity

3) Complex formation and precipitation

Contaminants to Target:

- Metals/metalloids
  - Se, Cr, As, Pb, U, Cd, Ni, Zn, Cu, Mo, Tl

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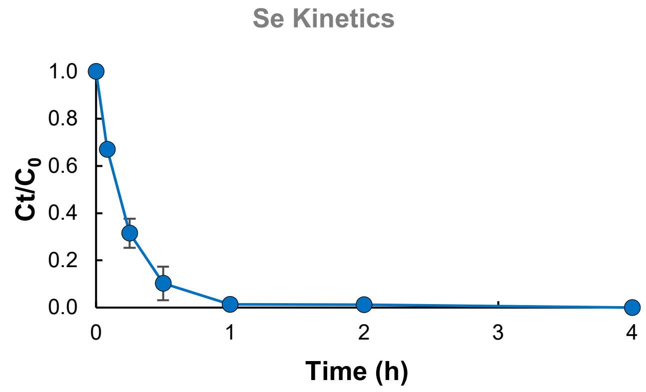
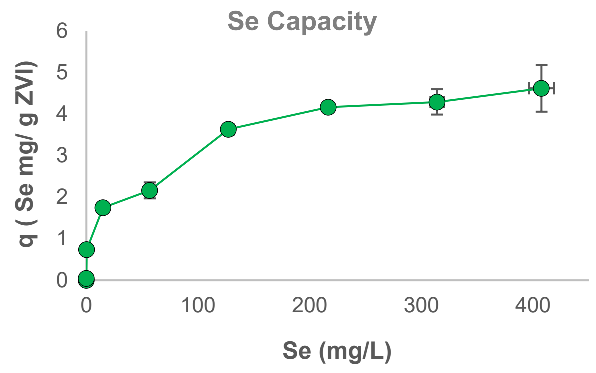
Cleanit®-LC Reactions & Kinetics

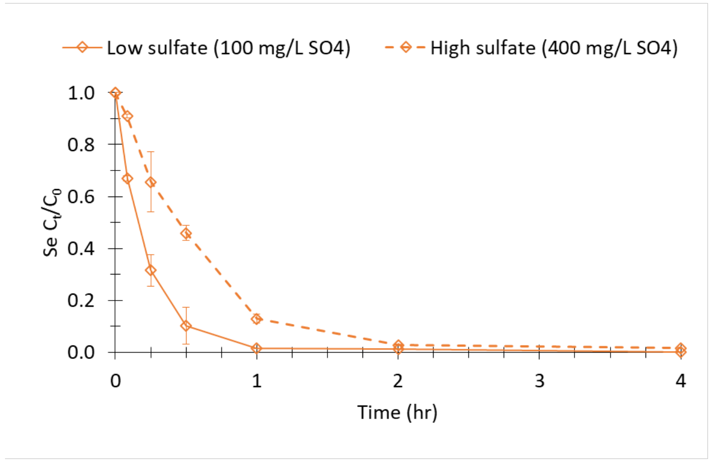
- Self-Buffering Capacity lowers Eh to maintain neutral pH and reduce passivation
- Minimal Influent Concentration Effects
- 100% removal (<1 ppb) across a wide range of influent concentrations 1-10 mg/l or higher
- High media adsorption capacity / Long Life:
  - Selenate:
    - >4 - 5 mg Se/g ZVI
  - Selenite / Selenosulfate /Selenocyanate:
    - >4.9 - 5.0 mg Se/g ZVI
- ***Minimal sulfate (SO_4) kinetic interference***
- Insignificant nitrate (NO_3) interference
- No capacity reduction

Selenate Kinetics and Capacity

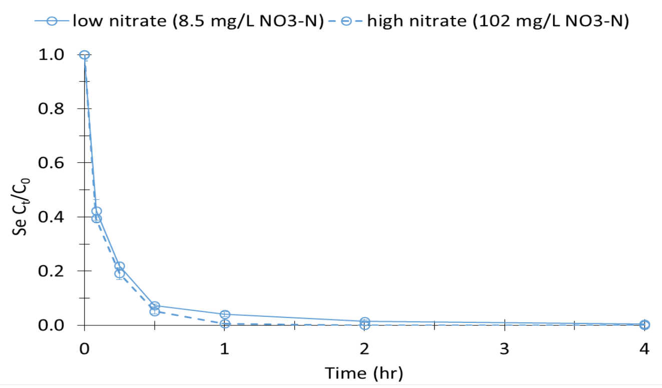




Minimal Sulfate Interference

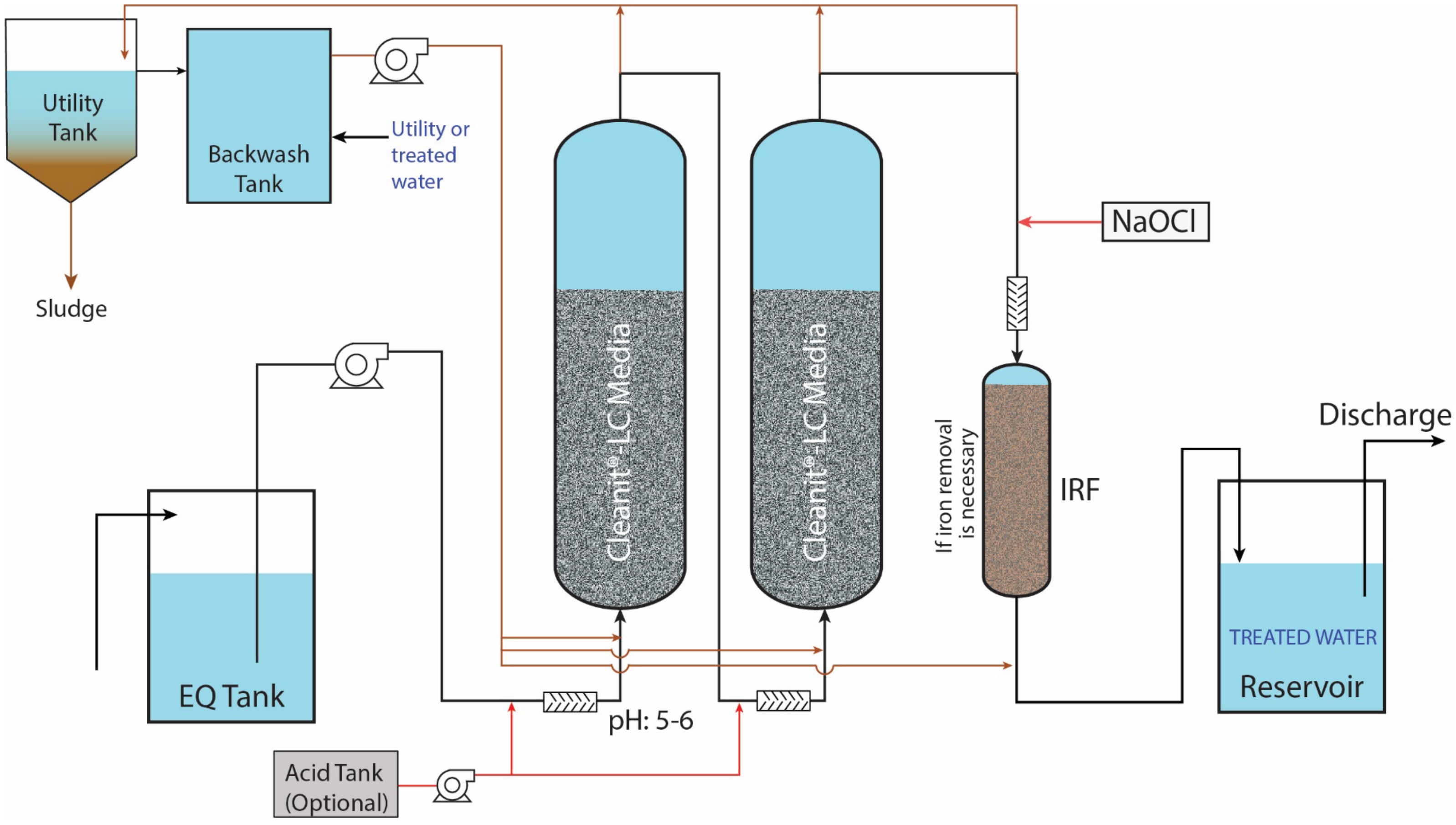


No Nitrate Interference



Cleanit®-LC Process Overview

- Single-pass (SP) or multiple-pass (MP) up-flow, direct contact design
- Rapid kinetics / Relatively Low HRT
- Periodic bed expansion cycle to maintain efficiency. Minimal waste (2-8%, typ)
- Simple media exchange (media only or complete vessels)
- 100% Standard “Off-The-Shelf” system components
- Process conditions can easily be adjusted to match influent flow & concentration
- Extremely simple process design, control, automation, and performance monitoring
- Simple / Rapid Startup / Shutdown
- Low Total Cost of Ownership (NPV)



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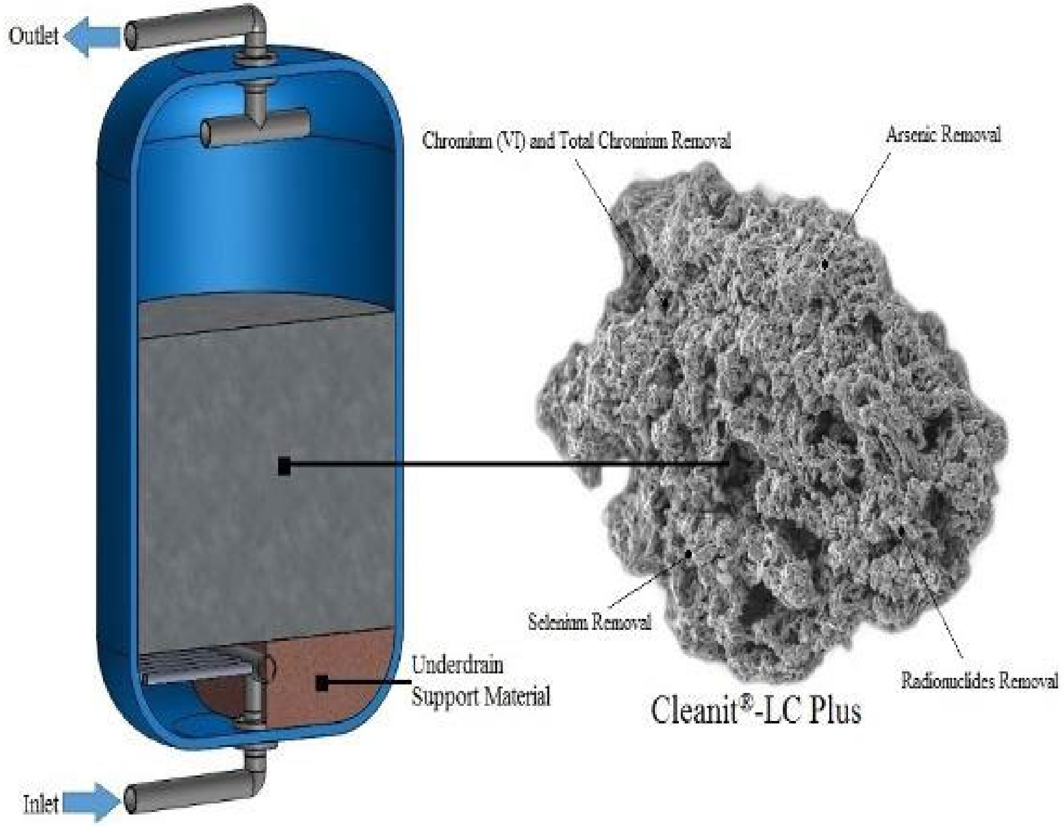
CleanIT®-LC Process & Advantages

PROCESS PARAMETER

- EBCT: 10 – 30 min (based on water quality)
- HLR: 6-9 gpm/ft^2
- Fill Volume: 60-75%
- Bed Expansion: 12-18 gpm/ft2 for 5-10 min @1-21 days
- Bed Regeneration: Lo pH Rinse @ 1-21 days
- Media Life: 1-6 months (based on application)

PROCESS ADVANTAGES

- CleanIT-LC / LC+ ZVI media *rapidly and irreversibly* reacts with metals for permanently removal.
- Fast reacting with *minimal process interference*.
- Flexible / Scalable Designs (<1 to >3,000 gpm)
- Simple process design, control and automation
- Very high water recovery (90-98%) with minimal backwash waste.



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Cost Considerations for CCR Wastewater and Groundwater Treatment with ZVI Media

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Explanation of the US EPA Regulatory Update from January 11, 2022

- The Federal CCR Rule 2015 provides information that was focused on State Enforcement for coal ash basin remediation and closure, AND allows the Citizen Lawsuit provision for unclear areas of groundwater protection.
- See Pages 87, 153 and 154 in the Federal CCR Rule for information about the State Enforcement and Citizen Lawsuit provision.
- **Bottom Line:** The Majority of coal ash basin do not have off-site groundwater contamination, BUT longterm protection of groundwater is NOT guaranteed.

or are undergoing remediation with federal/state oversight. These commenters also said that 12 of the 70 EIP-alleged damage cases were previously addressed in EPA's 2007 Damage Case report, and of these, five sites had been rejected by the EPA due to lack of evidence of damage or lack of evidence of damage uniquely associated with CCR, and seven sites had been characterized as indeterminate due to insufficient information. According to these commenters, no new information regarding these 12 sites was contained in the two EIP reports that warrants their designation as proven damage cases.[202]

2. Individual State Comments

EPA also received a significant number of comments from individual states. In their comments, many of the states addressed selected damage cases that occurred within their jurisdiction, subject to their authority. Several states agreed with EPA's assessment of the damage cases; for instance, Wisconsin and Michigan complimented EPA's database of damage cases. Other commenters agreed with some of the newly alleged damage cases' reports of groundwater contamination exceeding regulatory standards, but disagreed with EIP's conclusions that enforcement was inadequate, tardy, or absent. According to some state commenters, enforcement was not necessary or appropriate in those instances. For example, some states (*e.g.*, North Carolina, Oklahoma, Tennessee, and Florida) argued that the contamination did not pose public health risks because the contaminants were confined to state-established Compliance Boundaries (known also as Groundwater Mixing Zones)[203] and/or because there was no evidence the contamination had migrated off-site. Several other states (*e.g.*, Maryland, Virginia, and Texas) confirmed EPA's established damage cases as well as some of the newly alleged damage cases, but claimed that these cases were associated with presently outdated practices, and that regulatory requirements have since been revised to prohibit such practices. Two states (South Dakota and Pennsylvania) confirmed that contamination above federal or state regulatory standards had occurred, but attributed the contaminant(s) to sources other than CCR units, *e.g.*, coal mining pits associated with coal refuse; and/or nearby, up-gradient unlined MSWLFs, cooling water evaporation ponds, or natural background soil compositions. For certain cases, the states explained that required assessment monitoring was still ongoing to establish the sourc scope, and extent of the contamination and so had reached no conclusions about the specific allegations (North Carolina, North Dakota, and Tennessee Finally Ohio acknowledged that the extent of groundwater contamination risk within the state is poorly-documented due to the scarcity of monitoring wells down gradient from unlined disposal units.

3. State Association Comments

The Association of State and Territorial Solid Waste Management Officials (ASTSWMO) argued that the 24 proven damage cases reported in EPA's 2007 Damage Case report do not reflect current land disposal practices, and so are irrelevant to the proposed rule. For example, disposal "units" involved in several damage cases included five sand and gravel pits, two quarries, and one lake impoundment. ASTSWMO commented that half of these sites began operating in 1970 or earlier, including at least six sites that began operating in the early 1950s. ASTSWMO claimed that much of the information cited in the two EIP 2010 alleged damage case reports is incomplete, incorrect and/or misleading. For example, their comments alleged that EIP failed to provide pertinent information on specific monitoring wells, sample/analytical dates, and hydrogeological data. ASTSWMO also claimed that many of the assumptions about groundwater flow were based on a topographic maps rather than on potentiometric maps that are based on subsurface groundwater flow data. They also claim that data in state files contradicted claims in the reports, and that EIP's reports contained numerous technical errors, such as reporting values for naturally occurring constituents as contamination, reported data without distinguishing between down-gradient and up-gradient wells, ignoring the potential contribution from sources other than CCR-related units (*e.g.*, coal mining legacy), and claims that information provided by state program staff was misconstrued/misrepresented.

was performed voluntarily by the utilities and was not reported to state regulators. These commenters also claimed that although less than half of EPA's damage cases preceding the 2010 EIP reports involve active landfills, almost three-quarters of the newly alleged damage cases (EIP's 2010 reports) involve active landfills. They further alleged that a large majority of EPA's surface impoundment damage cases preceding the 2010 EIP reports are active sites, indicating that the absence of liners is contributing to the contamination problems. They noted that one quarter of the damage cases in EIP's 2010 reports involved units with liners, indicating that the mere presence of any liner provides no assurance that migration of contaminated groundwater from a waste unit is not occurring. Overall, they claimed that surface impoundments remain "woefully unregulated" when compared to landfills. Over one third of EIP's alleged groundwater damage cases show migration of contamination off-site. Also, a quarter of EPA's damage cases preceding the 2010 EIP reports involve contamination of surface water, and 15 percent of these damage cases show ecologic damage. Finally, these commenters note that several of the Secondary Contaminant Maximum Levels (SMCLs) constituents still might

[202] EPA–HQ–RCRA–2011–0392–0211, ibid.

[203] A Zone of Discharge or Zone of Mixing is a three dimensional region containing groundwater being managed to mitigate impairment caused by the release of contaminants from a waste disposal site; by definition, it is inside the detection boundary area, hence it is exempt from compliance with MCL and SMCL standards (*e.g.*, in Florida, Illinois, South Carolina, Tennessee, North Carolina, and Pennsylvania).

EPA Takes Key Steps to Protect Groundwater from Coal Ash Contamination

January 11, 2022

Contact Information

EPA Press Office (press@epa.gov)

Today, the U.S. Environmental Protection Agency (EPA) is taking several actions to protect communities and hold facilities accountable for controlling and cleaning up the contamination created by decades of coal ash disposal. Coal combustion residuals (CCR or coal ash), a byproduct of burning coal in coal-fired power plants, contains contaminants like mercury, cadmium, and arsenic that without proper management can pollute waterways, groundwater, drinking water, and the air.

Today's actions advance the agency's commitment to protecting groundwater from coal ash contamination and include (1) proposing decisions on requests for extensions to the current deadline for initiating closure of unlined CCR surface impoundments; (2) putting several facilities on notice regarding their obligations to comply with CCR

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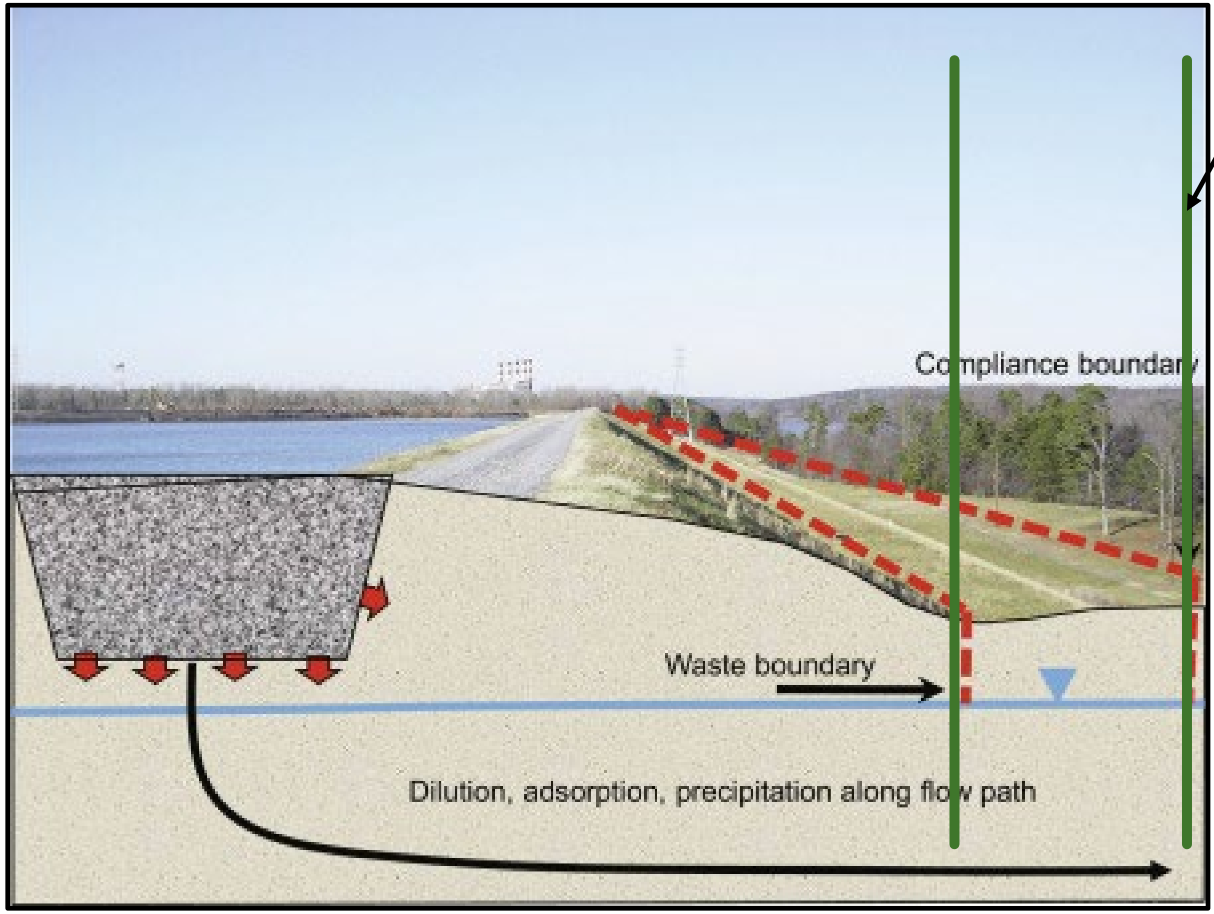
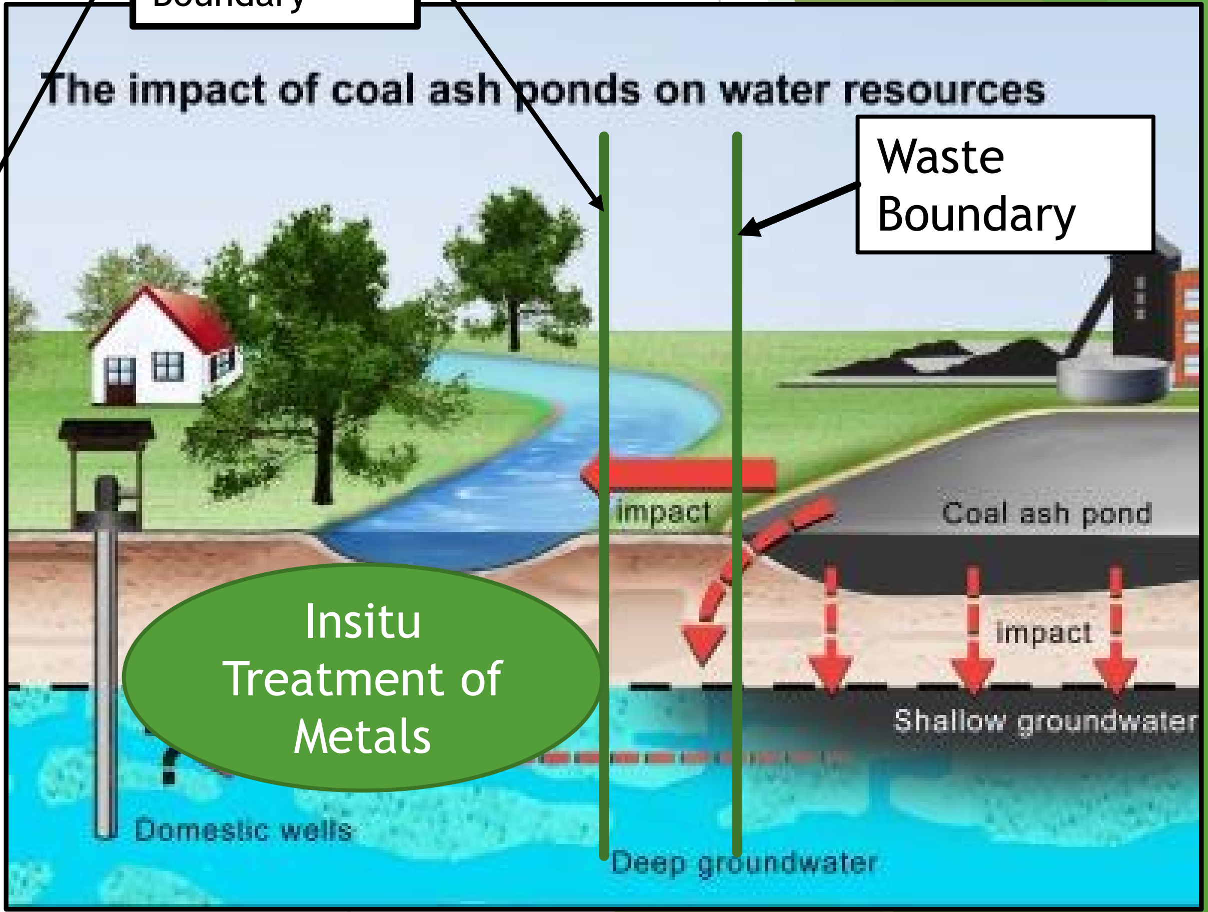
Compliance Versus Waste Boundary
Groundwater Impacts Versus Porewater

BIG QUESTION: How to Address the Treatment of Porewater to Protect Groundwater?

Monitoring Wells at the Compliance Boundary





Closed Loop Treatment Can be Used for Wastewater or Groundwater Treatment

1. **Bench Scale Study** using on-site wastewater or impacted groundwater.
2. **Field Demonstration Project** to confirm or adjust bench scale results, and to develop field equipment installation methods.
3. **Check cost and utilization of ZVI Media** for a variety of conditions.
4. **Upsize to Full Scale and Implement** to develop cost optimization.

COMBINE TECHNOLOGIES

Hoganas ZVI Injection

AST Environmental In-situ Treatment and Injection Methods

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Cleanit® Case Study: CCR Landfill Leachate (Lab Pilot)

Application:

Coal ash landfill in the Northeastern US

- Se influent 390 µg/L
- Mo – 2.4 mg/l
- Se treatment target of 12 µg/L

Solution:

CleanIT®-LC PLUS pilot system – 6 Columns

- Flow rate – 321 mL/min (5.09 gal/hr)
- Hydraulic Loading Rate (HLR) – 6 gpm/ft^2
- Empty Bed Contact Time (EBCT) – 60 min total
    - Maximize data points
- pH adjustment investigation

Result:

Non-detect Se in the final effluent at all times!

- Operated for 1600 BVs
- Se generally below 12 ppb through 1400 BVs
    - pH control complications

Cleanit® Case Study: Heavy metals and metalloids

Application

Mixed waste stream from a site in the Midwest with high concentrations of metals and metalloids that limit treatment options.

- **Se target was 0.09 mg/L**

Solution:

Cleanit-LC Plus pilot system – 2 columns

- Flow rate – 0.4 gpm
- Hydraulic Loading Rate (HLR) – 2 gpm/ft^2
- Empty Bed Contact Time (EBCT) – 30 min total
- pH was adjusted to 5.5

Result:

- Selenium (Selenate) was removed with a 30 minute EBCT to well below the target (0.09 mg/L)
- Large reduction in all metal or metalloids
- Flexible HLR design could yield better effluent and/or lower OPEX

Analyte	Target (mg/L)	Infulent (mg/L)	After C1	Removal (%)	After C2	Removal (%)
Al		11 ± 13.9	4.6 ± 8.2	58.2%	2 ± 6.2	81.8%
As	4.36	0.07 ± 0.1	0.7 ± 0.1	85.7%	0 ± 0.01	100.0%
CN-	0.33	0.27 ± 0.33	0.17 ± 0.2	37.0%	0.11 ± 0.15	59.3%
Co		1.2 ± 0.77	0.6 ± 0.52	50.0%	0.39 ± 0.39	68.0%
Cr	1.479	0.1 ± 0.03	0 ± 0.01	100.0%	0 ± 0	100.0%
Cu	0.362	0.13 ± 0.19	0.01 ± 0.02	92.3%	0.02 ± 0.03	85.0%
Mo		21.2 ± 32.2	6.7 ± 6.9	68.4%	4.7 ± 6.5	77.8%
Ni	6.883	2.4 ± 2.6	0.5 ± 0.7	79.2%	0.16 ± 0.25	93.0%
Se	0.18	0.22 ± 0.2	0.06 ± 0.06	72.7%	**0.03 ± 0.03**	86.4%
Zn	8.348	0.1 ± 0.13	0.07 ± 0.09	30.0%	0.05 ± 0.04	50.0%

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Cleanit® Case Study: Groundwater Selenium Removal

Application

Groundwater (dewatering) treatment application
Mountain US

Solution:

Cleanit-LC Plus Treatment Process – 3 columns

- Flow rate – 5 gpm (nominal)
- Hydraulic Loading Rate (HLR) ~ 2 gpm/ft^2
- Empty Bed Contact Time (EBCT) ~15 min total
- pH was adjusted to 5.0
- Iron removal post-treatment required

Result:

- Selenium (Selenate) was removed from 15 ug/l to <4.6 ug/l
- Easily accommodated seasonal flow variations (<1-5 gpm)

Cleanit® Case Study: High Sulfate Industrial Wastewater

Problem:
- Highly acidic industrial wastewater with high sulfate content (**~ 20 g/L**)
- Influent Se (selenate) concentration: **~ 3 mg/L** Treatment target: 1 mg/L
- Contains multiple heavy metals

Result:
- Selenium reduced to less than 1 mg/L in 15 min
- Successful removal of all heavy metals (see table)
- No impact of sulfate

Solution:
- Cleanit-LC process without pH adjustment

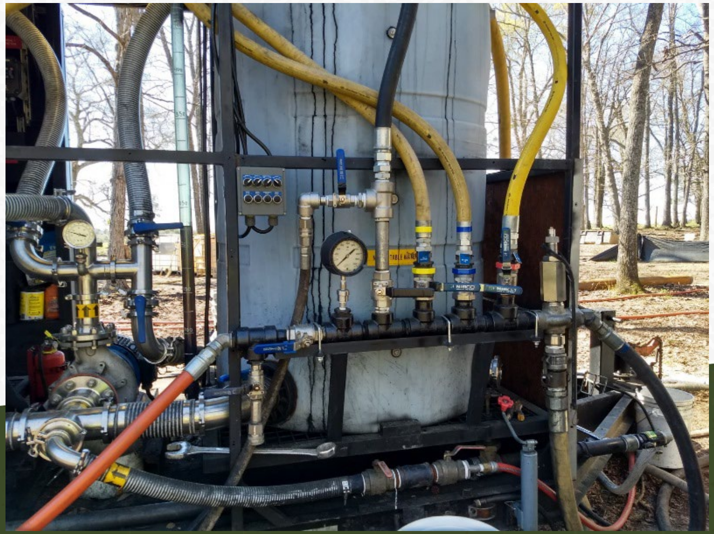
Analyte	Influent Concentration (mg/L)	C1A Concentration (mg/L)	C2A Concentration (mg/L)	C3A Concentration (mg/L)	C1B Concentration (mg/L)	C2B Concentration (mg/L)	C3B Concentration (mg/L)
Arsenic	1.7 ± 1.46	1.8 ± 1.26	1.0 ± 0.58	0.9 ± 0.48	0.9 ± 0.52	0.7 ± 0.43	0.4 ± 0.46
Cadmium	6.9 ± 12.75	8.9 ± 7.51	3.3 ± 6.25	2.6 ± 4.67	2.1 ± 2.78	1.4 ± 1.88	1.5 ± 1.80
Iron	16 ± 8.9	297 ± 231.3	528 ± 145.9	572 ± 156.6	840 ± 193.2	837 ± 181.1	831 ± 185.0
Lead	133 ± 141.8	79 ± 81.9	18 ± 21.3	20 ± 24.0	18 ± 23.0	13 ± 17.5	14 ± 15.9
SO_4^{2-} - S	19372 ± 4079	19183 ± 3865	19184 ± 3820	19092 ± 3691	19203 ± 3812	19136 ± 3740	18906 ± 3621
Selenium	**3.1 ± 0.96**	**3.1 ± 1.27**	**1.6 ± 0.79**	**1.5 ± 0.69**	**1.0 ± 0.56**	**0.9 ± 0.47**	**0.9 ± 0.53**
Zinc	0.32 ± 0.08	0.52 ± 0.205	0.24 ± 0.21	0.24 ± 0.213	0.23 ± 0.199	0.19 ± 0.145	0.19 ± 0.134
pH	2.9 ± 0.16	5.0 ± 1.87	6.7 ± 0.55	6.9 ± 0.36	6.4 ± 0.34	6.8 ± 0.29	6.8 ± 0.32

Höganäs

Overburden Injection System

- Flow rate – 2 to 70 gpm
- Maximum Pressure – 1,200 psi
- 2 - Pumps in Parallel
- 2 - 30 hp Electric Motors
- VFD Controls
- Safety Bypass Valves
- 4000- gallon mix tank

Triplex Injection System (Bedrock, etc.)



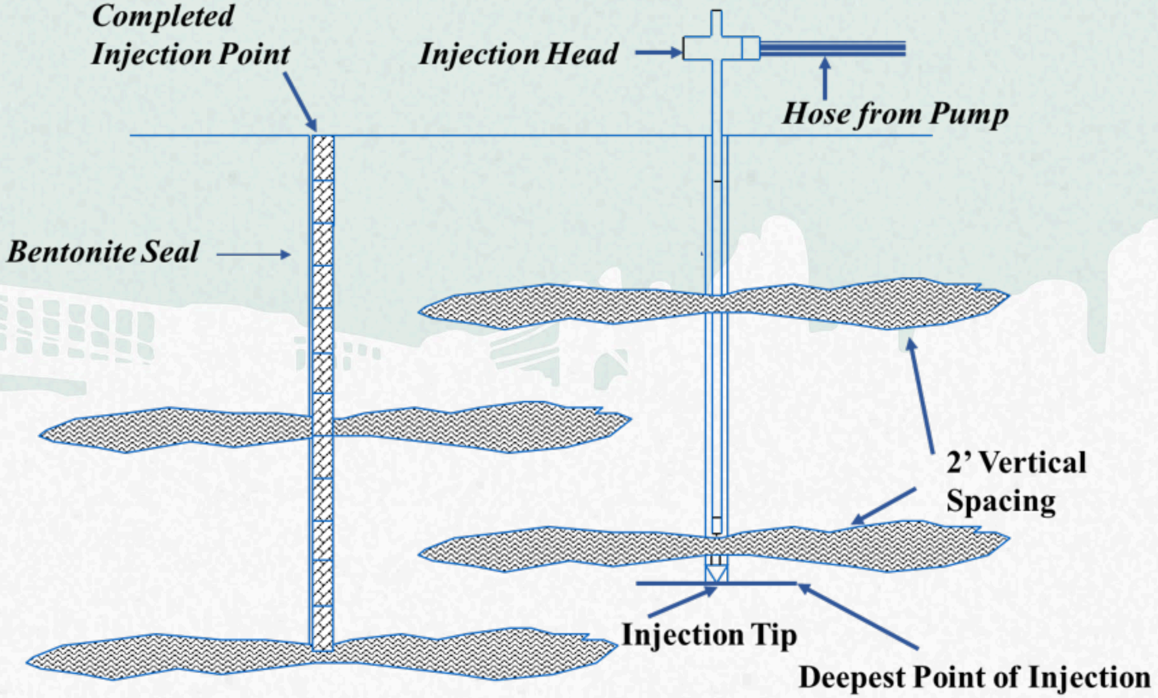
- 165 HP Triplex Pump
- 8 gpm to 250 gpm
- Max Press. - 2,500 psi
- 2 - 1,000 gallon slurry tanks

Triplex (Varied Flow Rates)

Various Flow Rate

20 gpm, 60 gpm
120 gpm, 250 gpr

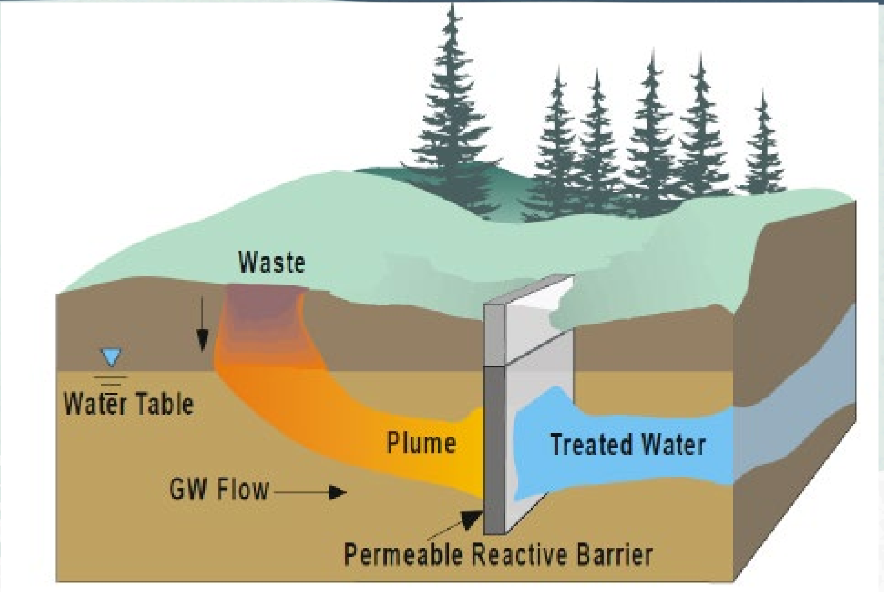
Overburden Slurry Application Best Practices



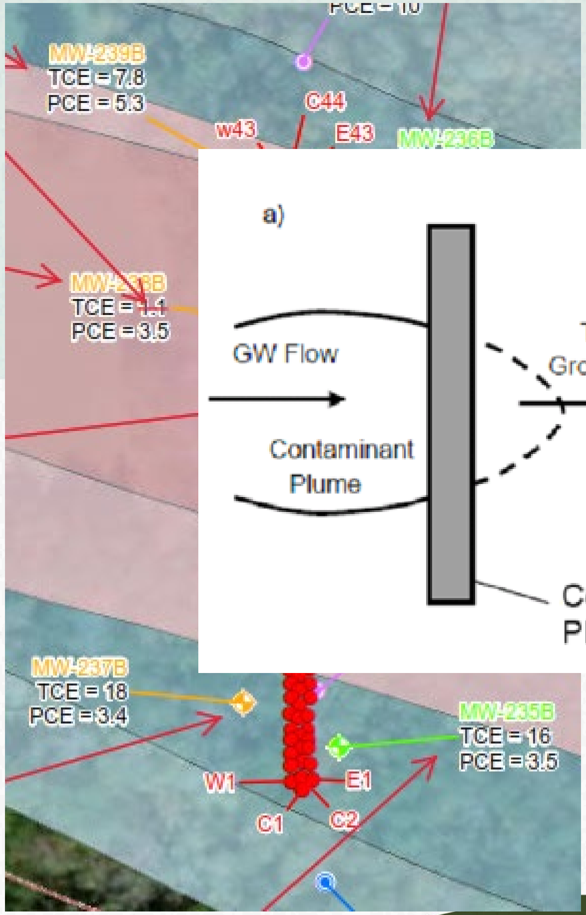
Typical "Top-Down" Injection

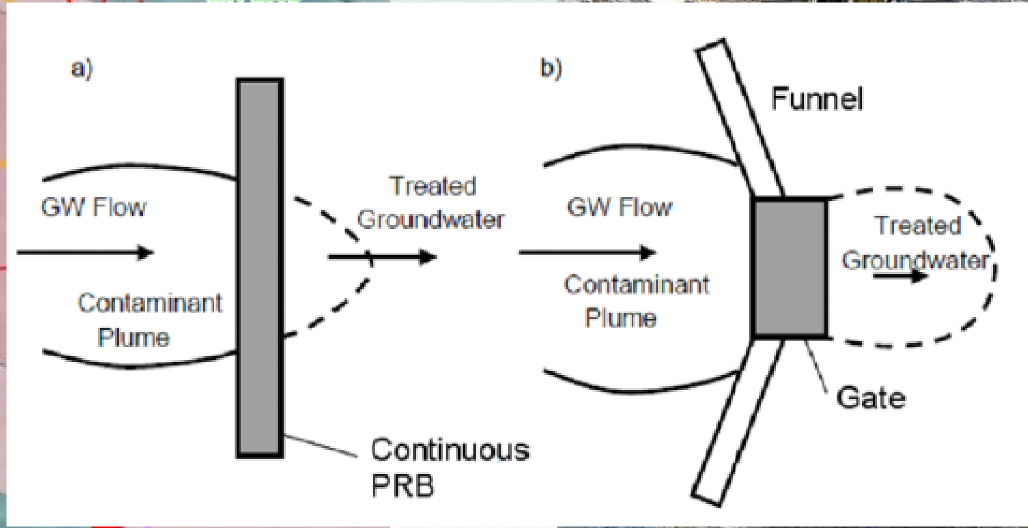
- Proper method of installation depends on the product and delivery method
  - Slurries = high flow rate and relatively small injection volumes
  - Emplacement into formation
  - Top-down = path of least resistance horizontal
  - Dedicated temporary points

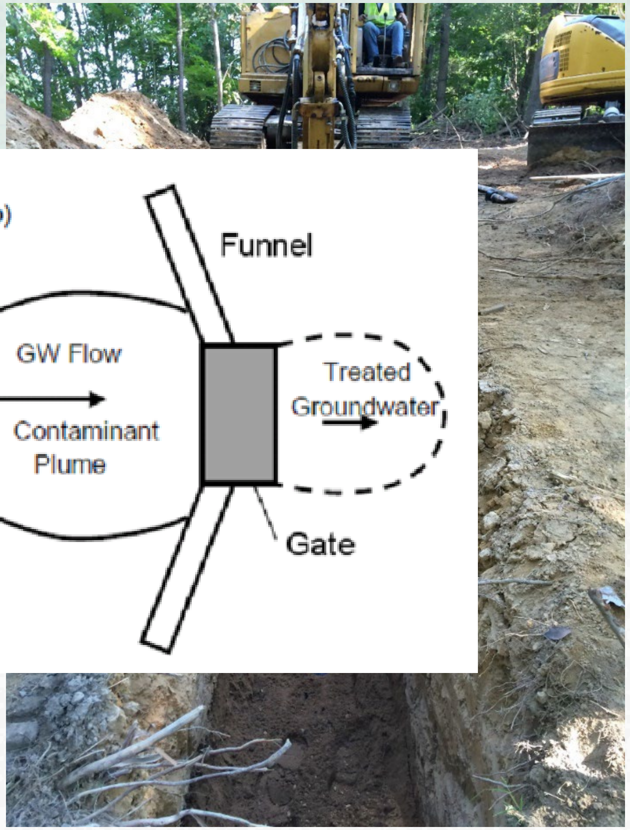
A Solution – Permeable Reactive Barriers



- PRB is an in situ, permeable treatment zone designed to intercept and remediate a contaminant plume. (ITRC, 2011)
- Treatment zone created:
    - Directly (e.g. ZVI)
    - Indirectly (e.g. bio*)







QUESTIONS?