Strategic Approaches to Address the Unique Challenges of Groundwater Remediation at Coal Ash Facilities

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ABSTRACT: The need to evaluate groundwater remediation options in conjunction with closure of coal ash impoundments is becoming more important as Coal Combustion Residuals (CCR) Rule corrective action deadlines approach. While traditional technologies, including barrier walls, grout curtains, pump and treat, and permeable reactive barriers are being considered, the nature of coal ash impoundments requires modification of typical approaches for these technologies to be technically feasible and cost effective. Specifically, coal ash impoundments often have large surface areas and long perimeters. They are typically located adjacent to space-constraining surface water bodies, where discharge of groundwater may also need to be addressed. Also, groundwater impacts may include a mix of inorganic constituents that require different treatment approaches.

Here, characterization and design concepts adapted to address these technical and logistical challenges are explored. The scale of groundwater impacts might render typical designs for pump and treat and permeable reactive barrier approaches infeasible or cost prohibitive. Strategies to improve efficiency and feasibility of these approaches include mass flux-based characterization and design, segregation of clean and impacted water, and passive water collection and treatment techniques. Case studies from other industries are used to demonstrate how a focus on mass flux was used to improve efficiency and how approaches for segregating, managing and treating water via techniques such as groundwater diversions, drainage swales, covers, and permeable reactive barriers were used to address sites with COCs such as arsenic. Finally, the use of an innovative passive monitoring device (Min-Trap™) to quantify the potential for natural and enhanced in situ mineral precipitation and/or transformation will be discussed.

INTRODUCTION

The United States Environmental Protection Agency (USEPA) Coal Combustion Residuals (CCR) Rule codifies a program and schedule for the identification of groundwater impacts originating from CCR impoundments. Section § 257.96 of the CCR Rule requires an Assessment of Corrective Measures (ACM) when any constituents listed in Appendix IV of the Rule have been detected at a statistically
significant level (SSL) exceeding groundwater protection standards (GWPS), and the owner or operator has been unable to demonstrate that the exceedance was caused by a source other than the CCR unit (Figure 1). Based on the timeframes written into the CCR Rule, the identification of Appendix IV SSLs has been completed, and site owners are completing the assessment of corrective measures.

Figure 1. CCR Rule Process

An ACM for CCR impoundments must consider several logistical and technical challenges inherent in these sites (Figure 2), including:

- A large aerial extent (typically tens to hundreds of acres)
- Long perimeters
- Proximity to surface water bodies, limiting access for remediation
- Dynamic hydraulic conditions
- Mix of inorganic constituents
- Security and health and safety factors associated with active operations
In order to develop feasible and cost-effective solutions to address the challenges that CCR impoundments represent, the implementation of traditional technologies must be strategically adapted.

The following presents actual and conceptual examples where innovative adaptations have been applied to create feasible and cost-effective remedial approaches, including:

- strategic water management
- refined conceptual site model (CSM) and stratigraphic flux-based design
- an innovative new monitoring device for cost-effective collection of solid phase mineral samples

**STRATEGIC WATER MANAGEMENT**

Given the scale of coal ash impoundments, the volumes of impacted water that may require management with corrective measures is large. In addition, the treatment intensity of some constituents of concern is high. For example, treatment of boron (required in some states) may require use of highly specialized resins, while treatment of constituents like lithium may be cumbersome due to the presence of high concentrations of other cations in the water like magnesium and calcium that compete with lithium in removal processes. Strategies that reduce the flux of contaminant mass from entering groundwater and therefore reduce the volume of impacted groundwater requiring management can reduce this treatment burden. One such strategy is to “keep clean water clean” by diverting clean water coming onto the site; on the surface, in groundwater, or both; to reduce the flux of groundwater flowing through waste material and requiring downgradient treatment.

The potential feasibility and cost-benefit of a “keep clean water clean” approach is based on several factors of the conceptual site model, including:

- **Geologic setting:**
  - Accessibility and permeability of water bearing units
  - Presence/depth of an underlying low permeability bottom

- **Groundwater flow conditions:**
  - Understanding of the primary recharge and discharge pathways
  - Variability in groundwater flow conditions and the factors that affect variability (precipitation, surface water levels, pumping, etc)

- **How the coal ash impoundment interacts with underlying groundwater:**
  - Are point locations of high mass flux identified?
To what extent will source control (i.e. capping, dewatering, etc.) impact water levels within CCR waste?

- Facility infrastructure and access:
  - Can the target locations be accessed?
  - Can diverted water be utilized in facility operations?

Application of the “keep clean water clan” design concept could build off of the facility closure plan and combine strategies for water management at the surface with diversion of clean groundwater coming into the system. Drainage systems can be used to strategically manage storm water run off and subsequent infiltration to groundwater. In combination with closure plans (i.e. low permeability cover systems, dewatering), the surface water management can be designed to physically isolate waste material from the surrounding environment. In addition, the collection and diversion of groundwater flow from upgradient of the CCR impoundment can be used to minimize the flux of groundwater through CCR waste material and the downgradient flow requiring treatment. This approach has the highest potential to be a cost-effective management solution for units where groundwater is relatively shallow, and the combination of upgradient diversion and a final cover system result in a decline in water levels to below the bottom of the waste material.

Two examples are presented where a strategic water management approach could have the potential to significantly reduce the flux of impacted groundwater requiring treatment through management of groundwater and surface water upgradient of CCR waste material.

Figures 3, 4, and 5 illustrate how the keeping clean water clean approach was employed at a site impacted with arsenic.

Figure 3. Arsenic Case Study: Original Remedy Design
Figure 4. Arsenic Case Study Water Management Plan: Reduce arsenic flux to river
At sites where flow conditions are highly variable and a significant component of flow occurs following major precipitation events, such as the example presented here, this strategy could significantly reduce the flux of impacted groundwater that would potentially require active treatment.

In a second conceptual example, CCR impoundments are located adjacent to the active facility area, which is located in a topographically elevated area. Prior to construction, the natural topography was consistent with the surface of shallow bedrock, which slopes downward under the CCR impoundments away from the facility. Recharge occurs within the facility area, and groundwater flow conditions are controlled by the slope of the bedrock surface, through and under the CCR units, and ultimately discharge to surface water downgradient.
In this conceptual example, strategic management of infiltration and shallow groundwater could be implemented by:

- Diversion of clean groundwater upgradient of the CCR impoundments using a slurry wall and/or pumping wells
- Channelized management of precipitation falling onto the cap using lined ditches

This potential approach is particularly feasible at locations where bedrock (or an unconsolidated low permeability underlying unit) is shallow and there is adequate access upgradient of the CCR unit.

**REFINED CONCEPTUAL SITE MODEL AND STRATIGRAPHIC FLUX FOCUSED CORRECTIVE MEASURES**

Conceptual site models (CSMs) are used for different purposes throughout the lifecycle of a CCR project. During the detection and assessment phases of a CCR project, CSMs are used to site compliance monitoring wells and interpret the results. At this stage of the project, it is a common approach to develop CSMs at a high level, describing the general geologic deposits, groundwater flow conditions (groundwater flow direction, flow of water through the impoundment, potential discharge to surface water), and contaminant distribution. Permanent monitoring wells with fixed screen intervals are used to produce reproducible data during the monitoring phase.
As the project progresses from the monitoring phase into remedy selection and design, a shift in thinking toward a deeper understanding of the role of heterogeneity in the subsurface can lead to improved efficiency in the design and implementation of remedial systems. When characterizing at a high level using only monitoring wells, our picture of the system is out of focus, glossing over the orders-of-magnitude variation in permeability and contaminant concentrations that may occur at the scale of an aquifer, as shown in Figure 7. A sharper focus shows us that there is significant variation in the mass that we were missing.

![Figure 7. Resolution of a monitoring well (left) versus what’s really in the aquifer (right)](image)

Higher resolution characterization enables a refined understanding of where the contaminant mass is moving and provides a basis to determine where to focus remedial efforts. Instead of relying only on generalized data produced by a monitoring well network, a high-resolution approach can create a flux-based CSM to distinguish the contaminant mass that moves from the mass that does not move. Our experience with high resolution characterization shows that, for the vast majority of sites, groundwater plume mass moves in less than 20% of the aquifer volume. Armed with a refined delineation of the mass flux, remedial strategies can be streamlined to target the mass that matters most.

Arcadis applied this approach at a wood treatment processing facility that was impacted with creosote dense nonaqueous-phase liquid and associated volatile and semi-volatile organic compounds. Contaminant concentrations and aquifer permeability were mapped along the property boundary using a high-resolution characterization program to determine whether impacts were migrating off site and needed to be addressed. The
relative permeability and groundwater concentrations were combined to produce a measure of plume strength: mass flux.

A remedial approach based on concentration alone, the conventional measure of contaminant extent, would suggest that the entire perimeter would require a slurry wall (Figure 8). However, the results of the investigation show that 90% of the contaminant mass was moving across the property boundary within small areas. The resulting remediation strategy optimized pumping in a small area, rather than the entire perimeter. This evaluation also showed that construction of a slurry wall was not needed. The remedy was significantly reduced in level of effort from the initial design, while still effectively managing the advective contaminant flux, resulting in a significant economic return on investigation.

Figure 8. Example of stratigraphic flux characterization at a wood treatment facility.
MONITORING MINERALOGICAL PROCESSES USING Min-Traps™

Potential in-situ groundwater treatment approaches for inorganic constituents typical of CCR impoundments could include enhanced or passive formation, dissolution, and/or transformation of solid-phase minerals to sequester groundwater contaminants. However, confirmation of these in situ processes is often only inferred from aqueous phase conditions (i.e., groundwater sampling) because of the significant challenges and costs associated with the collection of solid phase samples. Traditional approaches for the collection of solid-phase samples include the use of high cost drilling/coring techniques, and sub-sampling of discrete zones within the core material for analysis. In addition to the high costs and health and safety risks, drilling/soil sampling examines discrete points/depths within the subsurface, often requiring a relatively large sample number to adequately characterize the subsurface area of interest and account for natural heterogeneity observed across very small scales. The Min-Trap™ (available commercially from Microbial Insights, Inc.) is an innovative sampling device designed to overcome these technical and logistical challenges. The Min-Trap™ is a new, cost-effective in-situ monitoring tool that offers distinct advantages over traditional approaches for collecting mineralogical data to manage in-situ groundwater programs. Min-Traps™ solve many challenges inherent to the direct evaluation of mineral processes of interest for a variety of in-situ remedial approaches, including: (1) lack of direct feedback from the subsurface regarding the mineral or activity of interest, (2) costs, time, data quality, and health and safety risks associated with drilling for samples, (3) lack of a technical basis to support estimates of mineral stability and/or long term reactivity and implications for transition from active to passive treatment, and (4) confirmation of ongoing effectiveness during passive treatment, monitoring natural attenuation, or long-term monitoring programs.

- Provides direct evidence of mineralogical processes occurring within the aquifer
- Porous medium inside mesh acts as a carrier for target minerals
- Medium is customizable
- Inexpensive

![Min-Trap™ sampling device](from Ulrich et al, 2019 and Martin Tilton et al, 2019).
The Min-Trap™ is a passive sampling device that is deployed within a conventional monitoring well and allowed to incubate over time (Figure 9). It consists of a non-reactive medium (e.g., silica sand), a reactive medium (e.g. iron oxide sand or site soil), or a combination of both, contained within a water-permeable mesh. The non-reactive medium within the Min-Trap provides a carrier substrate upon which target minerals can form passively. The use of reactive media within the Min-Trap™ provides a substrate for transformation processes that reflect the natural and/or engineered geochemical conditions within the aquifer. Minerals that form in a Min-Trap™ represent the minerals forming in the subsurface. Consequently, for both non-reactive and reactive media versions, analysis of the solid phase media within the Min-Trap through chemical, microscopic, or spectroscopic means gives direct evidence of the formation, dissolution, and/or transformation of target minerals in-situ while avoiding the challenges associated with traditional solid-phase sampling techniques.

The Min-Trap™ approach has the potential to provide mineralogical data beneficial to the characterization of the nature and extent, assessment of corrective measures, and remediation of groundwater impacts at CCR impoundments. In a CCR impoundment setting, Min-Traps™ data collected from multiple locations can provide additional insight into the geochemistry CSM. Min-Traps™ containing non-reactive media can be used to identify natural precipitation processes ongoing in different areas of the site, validating or contradicting hypotheses drawn from aqueous data based on traditional approaches such as eh-pH diagrams or Piper diagrams. Min-Traps™ created with reactive media can be used to evaluate the potential effectiveness of an in situ corrective measure. For instance, chemical reagents can be applied to engineer the geochemical environment and enhance mineral precipitation by increasing or decreasing pH or through modification of redox conditions. Reactive media contained within Min-Traps can be engineered to mimic these conditions and provide in situ field data to validate and optimize the process without investment in costly drilling programs.

While the adaptation of traditional remedial approaches for the mix of inorganic constituents present at CCR impoundments will continue to evolve, Min-Traps™ can provide a cost-effective approach for the collection of mineralogical samples throughout corrective measures assessment, design, and implementation.

CONCLUSIONS

Coal ash impoundments represent significant technical, logistical, and financial challenges for remediation. As coal ash impoundments regulated under the CCR Rule move from Assessment Monitoring to Assessment of Corrective Measures and Implementation of Corrective Measures, the industry must adapt traditional remedial technologies and approaches originally developed for sites in other industries in order to design cost effective corrective measures. Strategic approaches to water management, refined CSMs, stratigraphic flux focused remedies, and innovative monitoring approaches are several examples of adaptations that can be implemented to address
the challenges associated with the remediation of groundwater impacts at coal ash impoundments.

![Diagram](image)

*Figure 10. Strategic implementation of traditional technologies results in cost effective corrective measures.*

**REFERENCES**

