WHITE PAPER / **COAL COMBUSTION RESIDUALS**

ENHANCING SURFACE IMPOUNDMENT CLOSURES TO SUPPORT GROUNDWATER COMPLIANCE

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The federal rule regulating the disposal of coal combustion residuals (CCRs) generated at coal-fired power plants also governs groundwater quality at these sites. Careful consideration of groundwater issues during impoundment closure planning and design can significantly benefit groundwater quality and reduce long-term risk.

The Disposal of Coal Combustion Residuals (CCR) from Electric Utilities final rule promulgated by the U.S. Environmental Protection Agency requires surface impoundments and landfills at the coal-fired power plants it regulates to undergo groundwater monitoring.

When groundwater monitoring results show any constituents of potential concern listed in the CCR rule at statistically significant levels that exceed groundwater protection standards (GWPS), the unit's owner or operator is obligated to take action. Unless the excess GWPS levels can be attributed to an alternate source or sampling, analysis or evaluation error, nearby property owners and the general public must be notified and the nature and extent of contaminants that exceed GWPS must be characterized. A corrective measures assessment and groundwater remedy selection must also be completed. These can come at potentially high legal risk and financial costs.

Groundwater compliance requirements should be considered early in the planning and design process, typically during a feasibility study or impoundment closure alternative evaluation. From alternative cover systems and grading designs to waste consolidation and in situ treatment, the options that emerge can be screened for feasibility, cost, effectiveness and overall value. In some cases, the potential cost and risk of groundwater contamination and associated corrective actions justify substantive modifications or enhancements to impoundment closure methods.

While early consideration of groundwater impacts can reduce future risks and cost, the converse is also true. If groundwater issues are not considered during planning and design, project costs and risks can grow — particularly if corrective actions are required after closure is complete. Coal ash removal from a saturated zone, groundwater extraction, in situ water treatment and other corrective actions may, for example, require the costly removal or penetration of cover systems and double-handling of waste.

Addressing groundwater issues from the beginning, in other words, can be far less costly than retrofitting a closure or implementing active groundwater remedies in the future.

IMPOUNDMENT CLOSURE ENHANCEMENT EVALUATIONS

Impoundment closure enhancement evaluations can be of great value to CCR unit owners and operators wishing to mitigate the potential costs and risks associated with GWPS exceedances and other groundwater compliance issues. These evaluations provide a way to assess the short- and long-term effects of impoundment closure activities on groundwater quality.

While the objectives vary from project to project, these evaluations are typically designed to:

- Limit or eliminate direct CCR contact with the uppermost aquifer, as defined in the CCR rule.
- Minimize the potential need for post-closure groundwater corrective action.
- Promote a decrease in CCR constituent concentrations in groundwater.
- Preclude or eliminate pathways for potential contaminant transportation and receptor exposure.

Impoundment closure enhancement evaluations typically involve the following steps.

1. DATA REVIEW

The process begins with a comprehensive review of currently available site data. This can include reviews of data related:

- Groundwater quality
- Site hydrology, groundwater analytical and geochemical parameter data
- Hydrogeological data such as groundwater elevation measurements, hydraulic conductivity estimates and potentiometric surface depictions for multiple aquifer units over multiple seasons and/or years
- Subsurface lithology
- Stream/surface water stage data
- Water supply data
- Geotechnical data and reports
- General site conditions
- Impoundment construction drawings
- Preliminary closure plans
- Historical operational data and future operational plans

2. DEVELOPMENT OR REFINEMENT OF THE CONCEPTUAL SITE MODEL

Data and literature review results are used to develop a conceptual site model (CSM) for the site. A CSM reflects all the factors that impact groundwater movement, as well as the nature, extent and transport of potential contaminants.

Consisting of site maps, cross sections, three-dimensional models and other data presentations, a CSM assimilates information concerning site-specific subsurface conditions and the nature, extent, fate and transport concepts of potential contaminants, along with potential receptors and exposure pathways.

Most CCR sites are located in sedimentary depositional environments, which are often characterized by relatively young and dynamic alluvial systems. An Environmental Sequence Stratigraphy (ESS) analysis can often add considerable value to the CSM by identifying hydrostratigraphic units (HSUs) that constitute preferential groundwater flow paths.

Because HSUs can significantly impact the fate and transport of contaminants, they can be critical in maximizing the performance and cost-effectiveness of impoundment closure enhancement and groundwater corrective measures.

Enhancement Categories	Enhancement Alternatives	Description	Effectiveness	Implementability	Relative Cost
Potential Cover System Enhancements	Impoundment Grading Modifications	Modifications to the current grading design to decrease potential infiltration (and subsequent leachate generation). This includes modifying surfaces slopes to increase surface water runoff.	Modifying slopes do not appreciably impact leachate production.	Feasible; however, may require importing additional fill material.	Low
	Drainage System Enhancements	Modifications to the current drainage system design to decrease potential infiltration (and subsequent leachate generation). This includes modifying surface slopes to increase surface water runoff.	Modifying slopes do not appreciably impact leachate production.	Feasible; however, may require importing additional fill material or adding additional culverts.	Low
	Impoundment Cap Enhancements	Modifications to the current cover system design to decrease potential infiltration (and subsequent leachate generation). This includes use of geomembrane liner. This also includes addition of a geocomposite drainage layer to further reduce potential infiltration.	Adding a geomembrane liner or geomembrane liner with geocomposite drainage layer can significantly reduce leachate production.	Feasible; also requires additional cover system materials.	Moderate
Potential Source Mitigation Measures	CCR Consolidation	Excavation and removal of saturated CCR material located below the water table). This includes consolidating CCR material over portions of the Surface Impoundments with no CCR and groundwater interaction.	Effective and reliable method for the removal of contaminated material acting as the source for groundwater impacts; however, may not effectively reduce down gradient plume concentrations.	Feasible, although a large amount of material may require removal. Engineering design likely needed.	High
	Pump & Treat	Active pump, treat and recirculation for aggressive in situ remediation of submerged CCR source material. Also prevents contaminations from migrating further down gradient.	Dependent on subsurface geology (reduced effectiveness in low permeability material).	Pilot studies are needed to assess effectiveness. Will require design and permitting.	High
	In Situ Immobilization	Prevents or slows the mobility of contaminants through physical and chemical means by trapping contaminants in their host material, rather than destroying them.	Dependent on COPC characteristics, geochemistry and site geology.	Feasibility is limited due to the amount of material requiring immobilization.	High
	In Situ Solidification/ Stabilization (ISS)	Prevents or slows the mobility of contaminants through physical and chemical means by trapping contaminants in their host material, rather than destroying them. Stabilization utilizes chemical reactions to prevent contaminants from migrating. Can be performed in situ or ex situ.	Dependent on COPC characteristics, geochemistry and site geology.	Feasibility is limited due to the amount of material requiring solidification/ stabilization.	High

Figure 1: *Results from initial screening of impoundment closure enhancement alternatives, including potential cover system enhancements and potential source mitigation measures.*

Enhancement Categories	Enhancement Alternatives	Description	Effectiveness	Implementability	Relative Cost
Hydraulic Containment Measures	Capture via Perimeter Extraction Well System	Prevents the majority of contaminated groundwater from migrating down gradient by recovering groundwater through vertical extraction wells. Extracted groundwater is treated and released to an appropriate discharge point or made available for beneficial reuse.	Dependent on geology (reduced effectiveness in low permeability) and groundwater gradient. In addition to preventing lateral migration, hydraulic control removes concentrations within the capture zone.	Pilot studies are needed to assess effectiveness. Will require design and permitting.	High
	Capture via Extraction Trench or Horizontal Well System	Prevents the majority of contaminated groundwater from migrating down gradient by recovering groundwater through horizontal extraction wells, or interceptor trenches. Extracted groundwater is treated and released to an appropriate discharge point or made available for beneficial reuse.	Dependent on geology (reduced effectiveness in low permeability), groundwater gradient and depth. In addition to preventing lateral migration, hydraulic control removes contaminants and reduces overall plume concentrations within the capture zone.	Pilot studies are needed to assess effectiveness. Will require design and permitting. Feasibility is limited due to the depth.	High
	Cut-Off Wall	Physical barriers or slurry walls used to contain, divert, or block groundwater flow. Typically used to direct groundwater flow towards treatment zones or to prevent groundwater plumes from migrating towards receptors.	Used as a containment measure only. No remediation occurs within or up gradient of the barrier.	Requires additional design and permitting. May require specialized equipment to implement.	High
In Situ Treatment Measures	Permeable Reactive Barrier	Subsurface emplacement of reactive materials (zero-valent iron, chelators, sorbents, bioremediation amendments, etc.) to intercept and treat groundwater plume as it flows under natural gradient. Treated groundwater exits the treatment barrier and continues along the natural flow path.	Dependent on COPC present, aquifer chemis-try/geochemistry, geology and groundwater gradient. Treatment media/processes may lose reactive capacity over time.	Pilot studies are needed to determine reactive material effectiveness and compatibility with site-specific aquifer conditions. Will require design and permitting.	High
	Phytoremediation	In situ process utilizing green plants and their associated microorganisms to stabilize/ reduce contaminants in soil, sediment surface water and groundwater. Plant roots supply nutrients to microorganisms to support biological treatment process. Also consists of contaminant uptake by plant roots and transference to plant and leaves.	Dependent on COPC present, their concentrations and depth. Also dependent on climate, length of growing season and soil conditions. Native plants used to limit need for care/fertilization.	Ideal for large cleanup areas with shallow contamination. Low-risk, requires less equipment and labor. This use of native plants will minimize the need for care/fertilizations.	Low

Figure 2: *Results from initial screening of impoundment closure enhancement alternatives, including hydraulic containment measures and in situ treatment measures.*

A site's CSM and groundwater compliance objectives can be further refined by identifying potential receptors and evaluating potential exposure pathways, including any potential groundwater-to-surface water interaction.

3. IDENTIFICATION OF POTENTIALLY VIABLE ENHANCEMENT MEASURES

Given its expansive content, the CSM provides an ideal basis for identifying potentially viable impoundment closure enhancement measures.

The identification and development of enhancement measures typically requires a multidisciplinary team of solid waste engineers, groundwater characterization and remediation professionals, regulatory specialists and professionals from other disciplines, such as geotechnical engineers, risk assessors and permitting specialists. This team identifies and conceptualizes the initial closure enhancement options so they can be screened and evaluated for feasibility and compatibility with site conditions and project objectives (see step 4). This process typically results in a shortlist of a dozen or more closure enhancement alternatives.

4. SCREENING EVALUATION PROCESS

Enhancement measures are site-specific but may include alternative cover systems, alternative grading designs, waste consolidation, in situ solidification/stabilization, in situ treatment, flood protection modifications and hydraulic containment, with or without pretreatment and/or beneficial reuse options (see Figure 1 and Figure 2).

After identifying enhancement measures, the project team conducts an initial screening process, reviewing alternatives on the basis of relative cost, constructability, effectiveness, certainty of performance and other site- or owner-specific criteria. The screening typically results in three to seven or more viable closure enhancement alternatives that, after securing of owner and stakeholder agreement, are carried forward for detailed evaluation.

5. DETAILED EVALUATION PROCESS

For each of the impoundment closure enhancement options selected for detailed evaluation, designers develop preliminary concepts and scopes of work. These concepts are presented in conceptual site plans and other drawings, process line diagrams and tabulated presentations of basic design parameters and criteria.

Design, construction, operation and maintenance, monitoring, compliance and reporting requirements

	Relative Cost	Effectiveness	Constructability	Long-Term Risk	Overall Score (0-50)	Remarks
	20	40	10	30		
Option 1 - CCR Closure by Removal	High	Moderate-High	Moderate	Low-Moderate	33	• High certainty that targeted CCR is removed. • Excavation depths or management of potentially saturated and unstable CCR material can present safety challenges. • Moderately safe. Contractors have experience at this and similar sites. Excavation and management of potentially saturated and unstable CCR material can present safety challenge. • Low impacts to future operations. Site can be restored to serve as dry detention basin with little maintenance. • Unpredictable conditions associated with unstable CCR may present scheduling certainty challenges. • Provides the most horizontal separation from the river.
	1	4	3	4		
Option 2 - CCR Consolidation	Moderate-High	Moderate-High	High	Low-Moderate	37	• Moderate-high certainty that targeted CCR is removed. • Excavation depths are manageable given contactor experience at this and similar sites. • Moderately safe. Contractors have experience at this and similar sites. Excavation and management of potentially saturated and unstable CCR material can present safety challenges. • Low to moderate impacts to future operations. Maintenance of a cover system within Impoundment 1 would be required. • Unpredictable conditions associated with unstable CCR may present scheduling certain challenges. • Provides horizontal separation from the river.
	2	4	5	4		
Option 3 - In Situ Stabilization	Moderate	Moderate-High	Moderate-High	Moderate	35	• Moderate-high certainty that CCR is stabilized as required. Vertical and lateral CCR grain size variability may present challenges to amendment delivery and distribution using jet grouting resulting in performance and cost uncertainty. • ISS depths are achievable using typical ISS delivery equipment. • ISS requires management of excess stabilized material (i.e., "fluff"). • Potentially safer than excavation as less equipment may be required. Additionally, limited saturated CCR management will be required. • Low impacts to future operations. Site can be restored to existing grades and conditions.
	3	4	4	3		

	Low	Low-Moderate	Moderate	Moderate-High	High
Score	1	2	3	4	5
Effectiveness	Least effective				Most effective
Constructability	Least constructible				Most constructable
Score	5	4	3	2	1
Relative cost	Lowest cost				Highest cost
Long Term Risk	Least risk				Most risk

Figure 3: *Comparative closure enhancement alternatives evaluation summary.*

over the 30-year post-closure care period are also developed for each option, as defined in the CCR rule.

Impoundment closure enhancements considered during detailed evaluation process include:

- Cover system enhancements have been constructed to reduce subsurface infiltration under close-in-place scenarios.
- In situ treatments have been implemented using permeable reactive barriers or other delivery techniques.
- Monitored natural attenuation includes closure features and enhancements that support this groundwater management approach.
- Relief wells and levee toe drains used for flood protection have been modified to minimize or eliminate the discharge of potentially impacted groundwater-to-surface water bodies.
- Slurry walls and groundwater extraction have been employed to provide hydraulic containment. Groundwater extraction strategies may also include pretreatment and beneficial reuse options, or an evaluation of hydraulic capture via existing facility production wells.
- Surface grading and drainage modifications have been used to increase stormwater conveyance efficiency and reduce subsurface infiltration.
- Waste consolidation and in situ solidification/stabilization have been implemented to remove or stabilize CCR below or near the upper limit of the uppermost aquifer, as defined in the CCR rule.

In addition to evaluating these alternatives using typical feasibility study criteria, detailed evaluations compare the cost/benefit of implementing these measures during impoundment closure, with that of implementing them later when groundwater corrective action may be mandated by regulation. Delaying implementation could also result in the need to penetrate, retrofit and/or remove the surface cover for investigation, remedial actions or cap improvement, resulting in the rehandling of CCR and fill material.

The CSM serves as the basis for these detailed closure enhancement evaluations and can also be used for data gap analysis and future design and planning tasks. A data gap analysis can identify information needs and the relative cost/benefit of obtaining the data. A data gap analysis effort, for example, could recommend subsurface investigations for the collection of physical, chemical and/or geochemical data, risk assessment studies and/or treatability studies. Hydrologic and groundwater modeling tools may also be used to help improve understanding of potential contamination fate and transport concepts, as well as to predict the performance of closure enhancement measures over time.

Newly acquired data can then be assimilated into the CSM and used as the basis for impoundment closure enhancement selection and design, as well as any required future groundwater monitoring and corrective action.

Life cycle costs are also estimated for each alternative that undergoes detailed evaluation. Cost estimates should be comprehensive and include anticipated engineering design, procurement and construction, project and construction management, engineering during construction, O&M, monitoring and reporting requirements, as well as costs related to general conditions, escalation, contingency and other indirect costs.

Following a detailed evaluation, it is often instructive to conduct a comparative analysis of alternatives (see Figure 3).

CONCLUSION

To identify and mitigate future corrective action risks and costs associated with the federal CCR rule, groundwater quality and compliance issues should be considered during impoundment closure planning and design.

Studies that evaluate closure options and assess the long-term financial liabilities associated with potential groundwater impacts play an important role in the planning process. By assessing risk, identifying corrective measure concepts and forecasting potential costs, these studies provide a framework for evaluating future groundwater monitoring data and the potential need for corrective measures.

In addition, closure enhancement studies allow the project team to reconsider potential groundwater impacts and associated risks before proceeding to detailed design and implementation. Enhancement evaluations at sites where groundwater protection standards are exceeded or are presumed to occur can also be helpful in developing a closure approach. In some cases, closure design features or enhancements that improve groundwater quality and mitigate risk can be incorporated at little or no cost.

BIOGRAPHIES

JOHN R. HESEMANN, PE, is an environmental remediation engineer with more than 20 years of professional experience in remediation and environmental engineering. His experience includes the selection, design, evaluation and safe implementation of environmental remediation technologies to address a wide variety of contaminants, including petroleum hydrocarbons, chlorinated ethenes and methanes, radionuclides, energetics, metals and inorganics. As the remediation technical service leader for Burns & McDonnell, he supports nationwide remediation field implementation, optimization and operation and maintenance efforts. John specializes in rapid remedial progress through effective remedy selection, pilot testing, design, field application and optimization. He serves on the Interstate Technology & Regulatory Council (ITRC) Optimizing In Situ Remediation Performance & Injection Strategies Team and has authored, presented and published several technical papers on in situ remediation and other topics.

WAYNE A. WEBER, PE, PG is a geological and environmental engineer with more than 20 years of experience working with clients to investigate and clean up complex contaminated sites, evaluate environmental liability and risk associated with potential transactions, and achieve and maintain compliance with environmental laws and regulations. He has planned and implemented site investigations to characterize soil, groundwater, surface water and sediment conditions at multiple facilities including several Superfund sites. Wayne has also designed, overseen construction of and managed the operation, monitoring and maintenance of remediation systems consisting of permeable reactive barrier, soil vapor extraction, in situ chemical reduction/oxidation and other technologies. Wayne served on the Interstate Technology & Regulatory Council (ITRC) Remediation Management of Complex Sites team and his recent experience includes assisting utility clients as they assess regulatory, legal, and financial risk associated with potential groundwater contamination associated with coal combustion residuals (CCR) units.

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10503-ICE-0820