ELECTRIC POWER RESEARCH INSTITUTE

Guidance for Coal Combustion Residuals Pond Closure and Overfills

Technical Brief — Coal Combustion Products, Environmental Issues

Introduction

This Technical Brief summarizes key information on coal combustion residual (CCR) pond closure and construction of landfills and other structures over closed ponds. This document is intended to provide a brief overview of some key topics addressed in the two EPRI companion reports *Coal Combustion Residuals Pond Closure: Guidance for Dewatering and Capping* [1] and *Coal Combustion Residuals Pond Closure: Guidance for Construction Over Closed or Closing Ponds* [2]. The reader is referred to those two guidance documents for more detailed information on project planning, conducting field and laboratory site investigations, geotechnical evaluation, hydrologic and hydrogeologic evaluations, site design, permitting, site construction and operations, monitoring, and long-term care. The reports also contain extensive lists of references for further information.

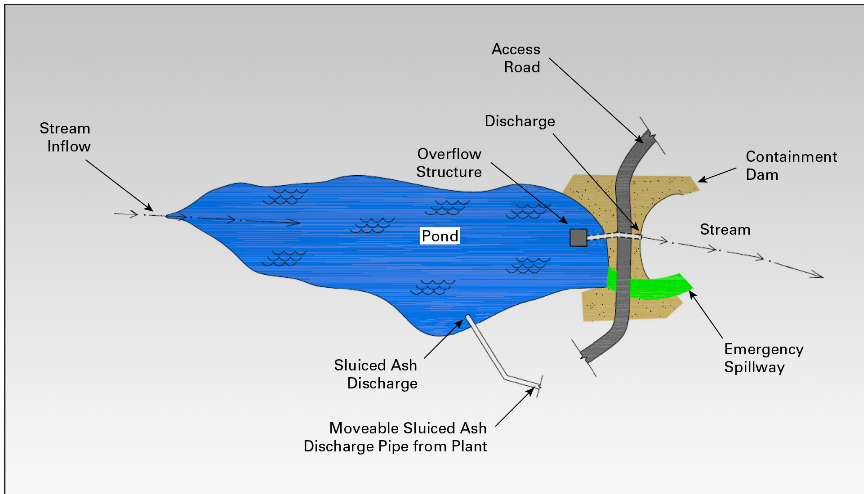

Figure 1. Fly ash pond constructed in stream valley fill

CCR Ponds

Closure of CCR ponds requires extensive engineering analysis to develop safe and effective designs. Significant factors such as the size of the ponds and the potential for material variability complicate the design and construction of the pond closures. The size of ponds varies considerably, with surface area ranging from a few acres to hundreds of acres. The engineering properties of the materials contained within the ponds vary based on the type of coal combusted, type of boiler, type of air pollution control technology, and manner of CCR placement, all of which may also vary over the operational lifetime of the pond.

CCR ponds are a common primary treatment facility for management of fly ash, bottom ash, and flue gas desulfurization (FGD) residuals. The CCRs are transferred hydraulically (i.e., sluiced) from the point of origin within the power generating facility to the pond, where the mixture of water and solids is retained for sufficient time to permit settling of solids to meet discharge criteria. Chemicals may be added to facilitate settling, and effluent from the pond may directed to a secondary or polishing pond to allow for mixing, normalization, additional flocculation, and/or settling.

CCR ponds are created using four primary methods: (i) retention dam; (ii) perimeter embankment; (iii) rim ditch; and (iv) incised pond. Components of CCR ponds may include (i) containment structures; (ii) bottom liners; (iii) underdrains; (iv) spillways; (v) interior containment berms; and (vi) monitoring instrumentation.

A *retention dam* pond is constructed in a relatively steep-sided stream valley, most commonly in the eastern United States (Figure 1). The retention dam is constructed across the stream valley to impound sluiced CCRs as well as stream drainage. The dam is often regulated by the state government.

A *perimeter embankment* pond is constructed on relatively flat terrain near the power plant (Figure 2). This type of pond receives sluiced CCRs and direct rainfall. It

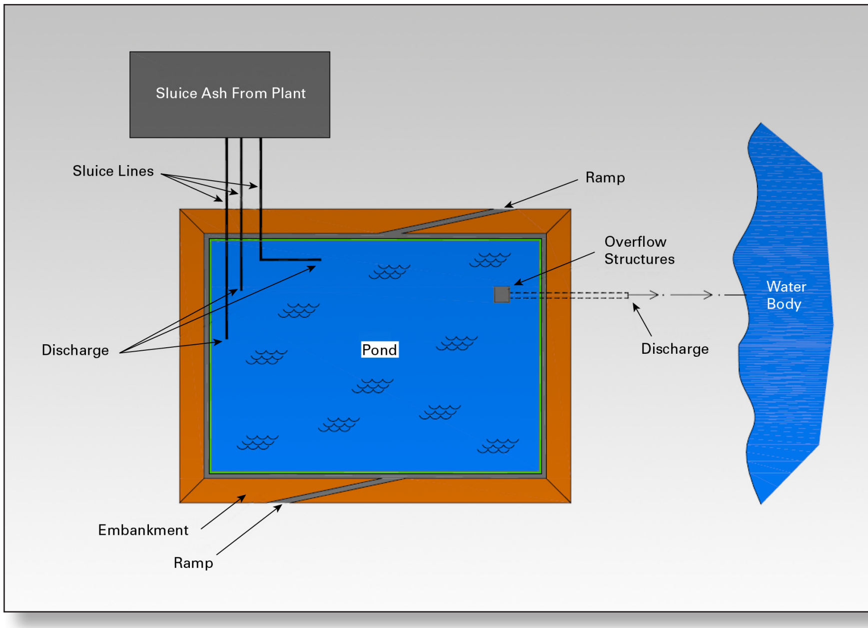

Figure 2. Fly ash pond constructed using perimeter berms

may or may not have a separate state dam permit.

A *rim ditch pond* is created by sluicing CCRs around the inside perimeter of a containment embankment. The rim ditch is extended to a length that allows settling of particulates that are periodically removed from the ditch and either placed along the ditch or hauled to an interior location. The embankment may be raised using either CCRs or earth materials, which allows additional vertical height for storage of more CCRs.

An *incised pond* is created by excavating to a sufficient depth to achieve the required storage volume. As the volume of the CCRs in the pond increases, it becomes more difficult to achieve adequate settling of particulates because the water volume and available retention time decrease. In some cases, this type of pond is periodically cleaned out to reestablish the water volume for settling. The CCRs removed from the pond are placed in a "dry stack" or another storage facility. Ponds are often a combination of incised and embankment pond types.

Overfills and Other Structures

The area over closed ponds has been increasingly used for new landfill facilities (overfills) or other structures. The use of the area over the ponds for new landfill facilities to replace the closing pond avoids the need to obtain separate property that would have to meet siting criteria, and also utilizes a "brownfield" property instead of developing a new "greenfield" property. Other advantages of overfills include the following:

- The engineered bottom liner of the overfill also acts as the final cover over the pond.
- The haul route for transporting CCRs is shorter, compared to hauling to a new site farther from the plant.
- One combined site has less total land area requiring long-term maintenance and monitoring, compared to two separate sites.
- There is reduced potential for ground water releases, due to the smaller footprint and integrated cap/liner.
- Other structures that have been built on, or considered for, closed ponds include athletic fields and parks, solar power systems, wastewater treatment systems, industrial buildings, and storage and staging areas. Considerations for each of these are provided in the overfill guidance report [2].

Closure Timeframes

Construction schedules can be very long for closure of ponds, especially large retention dam ponds. Specific items that will affect the duration of a construction project include the following.

Complexity of pond dewatering. For example, if the dewatering of the pond is going to be conducted using existing pond structures, the duration of dewatering will be controlled by the operational limitations of such structures. If the dewatering is going to be augmented by pumping, trenches, or wick drains, the dewatering rate will be limited by the rate of water release from the CCRs and the design of the enhanced dewatering system. Because there are potential safety concerns associated with operating construction equipment in and around pond materials that are near saturation (and close to open water), dewatering must be sufficient to support construction equipment and personnel.

Size of the project. It is common to phase the closure project on large sites so that specific areas can achieve subgrade and liner system grades as quickly as possible. Large open areas pose a risk for erosion and impacted stormwater discharges.

Availability of soil materials. Additional schedule time may be required to (i) temporarily stockpile fill materials for drying; (ii) process materials to meet gradation requirements and/or amend soils (e.g., add bentonite) to achieve permeability requirements for low-permeability soil cover and liner layers; and (iii) raise surface topography with contouring fill to achieve positive slopes.

Depending on the percentage of capacity that remains in a site, for a large CCR pond it can take several years to reshape the CCR deposits and import and place sufficient grading fill material to raise the existing topography and facilitate appropriate CCR stability and final slopes for the closure.

Geotechnical Evaluation

Designs for CCR pond and overfill projects require collection of geotechnical data for the impounded CCRs and the surrounding embankments. Geotechnical investigations include preliminary site evaluation and reconnaissance, subsurface exploration, and laboratory testing for design. Some of this evaluation is similar to that for more typical soil investigations, but some methods of correlating field data to lab data are different due to the unique characteristics of ponded CCRs.

Site Investigations

Exploration and testing of the in situ CCRs is performed to (i) estimate in situ CCR stiffness and strength; (ii) obtain undisturbed and disturbed samples of soil and CCRs for laboratory index testing; and (iii) obtain subsurface profile information including thicknesses of soils and CCRs, and piezometric level. Implementation of an exploration and testing plan may include typical field testing technologies, such as standard penetration test (SPT) borings and sampling, cone penetration testing, field load testing, and geophysical methods.

The cone penetration test (CPT; ASTM D-5778) is a type of in situ test that is popular because it is fast and economical and provides continuous profiling of stratigraphy. The penetrometer is deployed from a rig that may be tailored for overland work (see Figure 3) or overwater work from a barge.

Figure 3. Tracked CPT rig (photo courtesy of Conetec)

The primary advantages of the CPT are that a continuous vertical profile of stress, pore pressures, and other measurements can be obtained without a borehole, cuttings, or spoils. Because a soil sample is not obtained using a CPT, it is typical for CPTs to be conducted as a complement to a boring and sampling program.

The costs of field investigations for site closure can vary significantly depending on the amount of existing information that is available for the site. A subsurface investigation in support of a design can range from $100,000 to $200,000. An additional cost in the $50,000 to $200,000 range is required if overwater work is necessary (if the pond is still in service or not drained). Conventional laboratory testing programs are on the order of $20,000 to $40,000. Specialized laboratory investigations are in addition to the conventional program and are on the order of $15,000 to $25,000. It is not uncommon to conduct an initial site investigation during the planning (feasibility study) phase, a full site investigation after a site has been selected, and a follow-up investigation to fill data gaps that are identified during design.

Accounting for the Unique Properties of Ponded CCRs

The process of planning the pond closure or construction of a landfill over a closed pond requires knowledge of the material properties of CCRs because they are considerably different from soil materials for some parameters, such as specific gravity. Fly ash typically has a lower specific gravity than soils, due to vesicles (air voids) in the spheroidal particles created during combustion of the coal and cooling of the fly ash (Figure 4).

Considering that the physical and chemical compositions of soil and CCRs are quite different, the use of empirical correlations and estimation based on past experience with soils to derive design parameters for CCR materials can result in overestimation or underestimation of design parameters and performance. EPRI is performing research designed to help develop CCR-specific geotechnical correlations.

In most cases, an investigation including field and laboratory testing should be con-

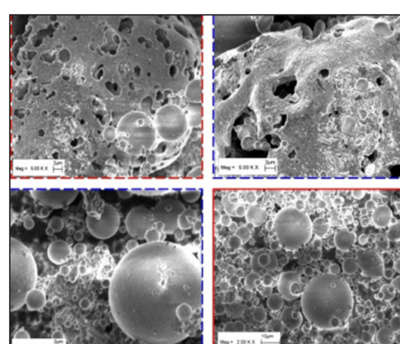

Figure 4. Fly ash morphology

Table 1. Comparison of fly ash material parameters to conventional soil types

Characteristic	Fly ash behaves like ...
Grain size distribution	Well-graded silt
Specific surface	Silt composed of spherical particles
Plasticity	Low-plasticity silt
Specific gravity	No typical soil – but typically low
Porosity	Very loose granular material (with internal pores like a volcanic rock)
Permeability	Coarse-grained material (not consistent with particle size; depositional-induced anisotropy)
Shear strength	Granular material
Compressibility	Sand to low-plasticity clays
Shear wave velocity	Soft clays/loose sands to dense sands/medium-stiff clays

ducted to identify the extent of the CCRs in the pond and their geotechnical properties. A comparison of fly ash in a pond to more conventional "textbook" soils such as sand and clay is provided in Table 1.

Further, CCRs are commonly placed in ponds using a sluice method that deposits them in an underwater environment where there is no drying, limited consolidation, and consequently, limited strength gain. Therefore, the materials can be susceptible to settlement and slope instability. Countering this, however, the sluice deposition method also creates an anisotropic hydraulic conductivity regime, creating layers of larger and smaller particle size. This layering causes the horizontal hydraulic conductivity to be greater than the vertical hydraulic conductivity, which improves the ability of fly ash to drain horizontally during dewatering and when loads are applied.

During the planning process, consideration must be given to the time period necessary to safely manage the ponded CCRs. The CCRs often require some degree of dewatering and surface stabilization before closure can begin. Additional time is also necessary for management/relocation of CCRs during construction, and to increase grades and facilitate post-closure runoff management. If the construction process is accelerated, potential safety issues can arise from shallow liquefaction due to equipment vibrations, lateral slippage of the drier crust over saturated CCRs, slope stability due to rapid loading, or ash movement due to steep excavation faces at or near open water.

Related EPRI research further addresses the unique geotechnical characteristics of fly ash [3,4,5,6].

Liquefaction

There are specific technical challenges to designing and constructing overfills and other structures over closed ponds. First, the CCRs that form the subgrade are usually saturated, thick, and compressible and can result in large settlements, which must be accounted for in facility design. Second, following the TVA Kingston Plant Dredge Cell failure in 2008 there is a heightened concern that static liquefaction could occur if the pond surface is loaded too quickly.

Static liquefaction is a phenomenon in which the granular skeleton of a saturated, loose soil matrix collapses during an undrained shear loading, resulting in a significant reduction in effective stress that then leads to the flow of the soil mass. However, field and laboratory studies have found that fly ash drains relatively quickly. If the pore pressures are rapidly reduced, it significantly reduces or eliminates the potential for static liquefaction.

Seismic liquefaction is a similar phenomenon, where dynamic loads are induced by earthquake activity. Seismic liquefaction has been documented for over 70 years and came to prominence in geotechnical engineering in the 1960s with earthquake-induced liquefaction in Japan and Alaska. It has been observed in saturated, loose, uniformly graded, sandy soils.

The original analytical method used to assess seismic liquefaction for soils has proven to be just the first analytical step. In situ shear wave velocity measurements using the piezocone and laboratory cyclic triaxial or cyclic direct simple shear tests on ponded material have been shown to better indicate the liquefaction potential. Methods to mitigate seismic liquefaction potential include foundation subgrade improvement, improved containment of the perimeter using shear keys, and construction of berms at the toe of the slope to improve resistance from sliding.

Settlement

Large settlements, especially differential settlements, can occur with the loading of saturated, loose CCRs. When considering a cover system, the load imparted by the cover system may not be significant, but installing contouring or grading fill to

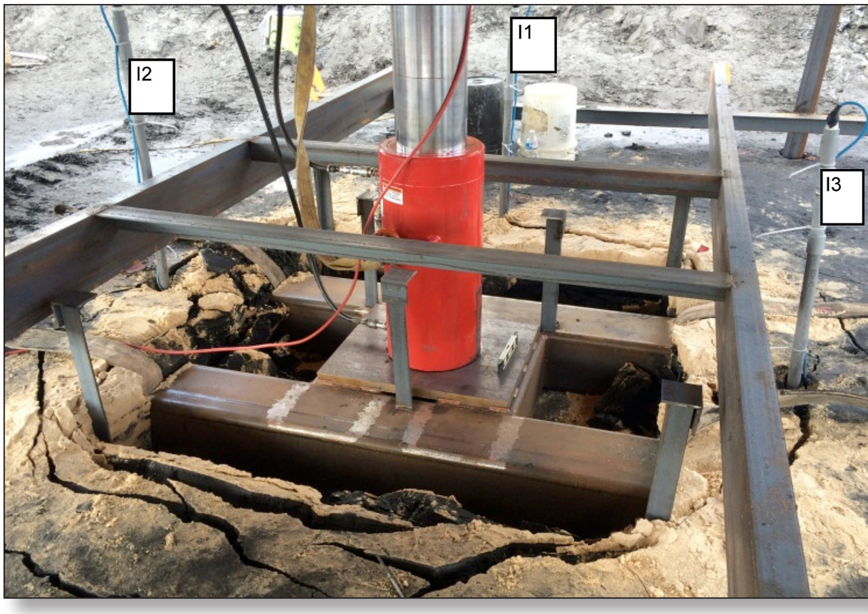

Figure 5. Field plate load test for estimating fly ash response to loading (I1-I3 are inclinometers)

achieve positive drainage over the final cover can be significant. Similarly, the load induced by an overfill or other structure will be significant.

For valley-fill CCR ponds, the original bottom of the pond is irregular in elevation and shape, creating a greater potential for differential settlements. An evaluation of the effect that total settlement and differential settlement may have on capping system components such as soil barriers, geomembranes, geosynthetic clay liners (GCLs), or drainage piping can be performed to facilitate cap or overfill design. In addition, the post-settlement grade of the cap or overfill bottom liner system should be evaluated to demonstrate that surface grades and leachate management systems will maintain positive drainage (i.e., no calculated grade reversals) for the long-term condition.

If excessive settlements are predicted, the CCRs can be preloaded with soil or CCRs from another nearby source to induce settlements to occur before construction of a cap or overfill. For example, a 35-ft-high preload was constructed at an overfill over a 100-ft depth of fly ash that removed approximately 3 ft of settlement prior to construction [7]. This removed on the order of one-third of the predicted settlement, thereby reducing the strain on the subsequently constructed geomembrane liners and reducing the slopes of the leachate collection system. However, preloading can add significantly to the closure timeframe and cost.

Free Water Removal and CCR Dewatering

The free water (or supernatant) on the CCR pond must be removed before the placement of fill or a cap begins. The need to meet any site discharge permit requirements throughout CCR pond closure must be taken into account in the planning and design process. For example, removal of free water may reduce the ability of the site to settle solids. Meeting discharge criteria during CCR pond closure is especially challenging for retention dam ponds because runoff from the original stream watershed, which is much larger than the pond drainage area, continues to flow during construction and can cause sediment loading that must be reduced prior to discharge.

In addition to free water removal, the near-surface CCRs are typically dewatered (i.e., porewater is removed) in order to have a stable platform for closure cap construction. Current pond conditions, operating history, and geotechnical characteristics of the ponded CCRs are important factors to understand in preparing a dewatering plan. Among all aspects to be considered, the geotechnical characteristics of particle size and hydraulic conductivity will most directly influence the effectiveness of the selected dewatering method.

CCR dewatering using physical methods, including vacuum extraction (e.g., well points), enhanced gravity dewatering (e.g., drainage trench/French drain systems), and filtration dewatering (e.g., geotextile tube), may be used to remove further porewater. A piezocone can be used to estimate horizontal hydraulic conductivity in the field. Laboratory testing provides more accurate measurement of vertical hydraulic conductivity. It has been observed that the horizontal hydraulic conductivity measured in the field is greater than the vertical hydraulic conductivity measured in the laboratory because of the layering of the ponded CCRs. It is important to consider the anisotropy in hydraulic conductivity when designing dewatering systems.

Surface and Subsurface Stabilization

Stabilization of the CCRs is done to provide a suitable foundation for cap construction, an overfill, or other post-closure uses. The methods include (i) mechanical ground improvement techniques; (ii) bridging of the CCRs using a suitable fill material with or without geosynthetic reinforcing; (iii) blending the CCRs with other materials; and (iv) vegetation. While mechanical ground improvement methods can be used to stabilize CCRs at depth, bridging, blending, and vegetation are primarily used to stabilize CCRs at the surface of a pond.

Several bridging techniques can be used for surface stabilization to facilitate cap construction. Options for bridging include the placement of a nominal thickness of suitable fill material, such as soil, bottom ash, or fly ash, over the pond surface. Using geosynthetic reinforcement (e.g., geotextile or geogrid) increases the effectiveness of the bridging layer.

Worker safety is an important consideration due to the nature of the surface of the ponded CCRs. Construction of a bridging layer will proceed at a slower pace than if the work was performed on stable subgrade.

Design of bridging layers requires an understanding of the geotechnical properties of the CCRs, primarily unit weight and shear strength, as well as an understanding of the subsurface profile and piezometric conditions within the CCR pond. After the geotechnical and subsurface information is obtained, bearing capacity analysis is performed to analyze stability of the bridging fill layer under both self-weight and anticipated construction loads. Although working on a CCR pond surface can be challenging, there are design methodologies for construction of geotextile reinforced bridging layers over weak soils and many examples of highly specialized designs used successfully to construct bridging layers over extremely soft industrial sludges.

Additional stabilization of the subgrade may be necessary for construction of other structures, especially overfills. The surface stabilization methods used for construction of closure caps described above are generally applicable to construction of additional structures. But to carry larger loads associated with overfills, additional analysis and methodologies are required.

One approach to improving the subgrade is to dewater the CCRs to a greater depth, to improve strength and promote settlement. A lateral underdrain layer may be constructed at the base of the overfill. The underdrain is used to remove the porewater expressed from the underlying CCRs during loading.

If more aggressive dewatering methods are necessary, wick drains in combination with an underdrain may be used. Wick drains are strips of geotextile fabrics inserted vertically into the subgrade to be dewatered. They are spaced according to the hydraulic conductivity of the subgrade. In most cases, wick drains should not be needed to support the construction of a landfill over the CCR pond. However, consolidation test and CPT pore pressure dissipation test data and grain size data need to be reviewed before making a final decision. Consolidation testing in the laboratory, CPT pore pressure dissipation testing in the field, and additional instrumented field test fills may be needed to evaluate the need for wick drains for unoxidized FGD products (i.e., calcium sulfite) that behave like thixotropic sludges.

Pond Capping Systems

Capping systems include soil caps, soil-geosynthetic caps, and alternative caps (e.g., evapotranspirative caps, or exposed geomembranes). Each of these has advantages and disadvantages, depending on the site and availability of materials. Materials that are commonly used for cap construction include vegetative support soil, granular drainage material or a geosynthetic drainage layer, geomembrane, GCL, low-permeability clay, and foundation layer/contouring fills. If a landfill will be constructed on top of the closed pond, the pond cover system will be modified to also serve as the landfill bottom liner.

The design of the cap for a pond closure addresses settlement, capping system veneer stability, geotextile and granular drainage layer filter design, geomembrane puncture protection, hydraulic performance, soil barrier frost protection, static embankment stability, seismic embankment stability, static liquefaction, seismic liquefaction, and stormwater management/erosion control. As part of a closure, it may be beneficial to relocate ponded materials to achieve specific design grades and/or promote a cut/fill balance for a phase of the project. Open excavations in materials such as fly ash may become less stable with time due to water infiltration; analyses to evaluate safe cut slopes should be conducted prior to excavating into the ash.

GCLs offer a significant advantage at sites without a source of liner-grade clay, or with vertical space limitations. GCLs consist of a layer of granular or powdered sodium bentonite clay sandwiched between two geotextiles (Figure 6), and are only a few inches thick. The bentonite in the GCL swells on contact with water, providing an effective seal. However, there is a concern that CCR leachate may negatively impact GCL performance by increasing hydraulic conductivity of the bentonite if the leachate is rich in polyvalent cations (such as magnesium and calcium) or has high ionic strength. To address the issue, some GCL manufacturers have developed specialized GCLs that can resist the detrimental effects of different classes of chemi-

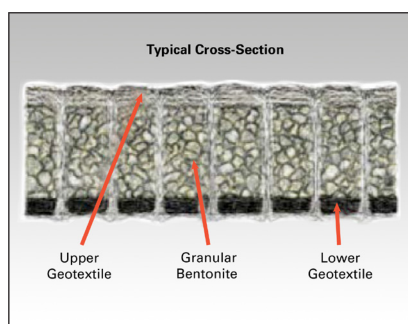

Figure 6. Typical geosynthetic clay liner

cals. EPRI is evaluating the impact of various CCR leachate types on the performance of both standard and resistant GCLs [6].

Overfill Leachate Management Systems

A dry landfill constructed over a closed pond may require a leachate management system (LMS) above the bottom liner (pond cap). Components of the LMS are the same as those for any landfill, including leachate collection layers, collection pipes, sumps, pumps, and riser pipes. However, there are unique challenges with designing these systems for CCR landfills located over closed ponds. In particular, the potential for large differential settlements and associated strains on the LMS components is a concern that needs to be carefully addressed in the overfill design.

Specifications for geocomposites that can withstand large strains and differential settlements are available. The geomembrane component of the liner system will have a lower tolerance for tensile strains and differential settlements than the LMS components, and will consequently govern the design. However, it should be verified that leachate collection pipes can withstand the anticipated strains and differential settlements, and steps should be taken to maintain the required minimum positive slopes to promote drainage.

As with all CCR landfills, the potential for clogging of geotextiles and geocomposite drainage layers and collection piping by fine-grained fly ash and FGD solids should be accounted for in the design. Calculations for filter design can be verified by specific laboratory tests to support the selection of geotextiles and geocomposites with CCRs. Use of sand or gravel drainage layers in lieu of geocomposites may be warranted in some cases.

Monitoring

A hydrogeologic investigation may be required prior to construction of an overfill. This can involve borings and wells, geologic logs, groundwater flow directions and rates, groundwater quality, and modeling. Some information will likely be available from previous investigations of the closed pond.

Many older CCR ponds have natural bottoms (no liners), and may have impacted groundwater during their operational life. Closing the pond reduces the hydraulic head, which is the driving force for downward migration of leachate. One function of the overfill is to further limit the potential for leakage from the closed pond by limiting infiltration.

An important component of the hydrogeologic investigation for an overfill site is documentation of both background natural groundwater quality and existing groundwater quality that may have been impacted by the historical pond operation. This information is used to develop a monitoring plan that can account for existing groundwater quality, and for selection of appropriate constituents and criteria for evaluating performance of the overfill.

Post-Closure Care

Post-closure care (PCC) activities typically include visual inspection, environmental monitoring (e.g., groundwater, surface water), geotechnical monitoring (e.g., porewater pressures, settlement), and maintenance activities (e.g., cover system, leachate and stormwater control systems, monitoring wells, and access controls). PCC periods are not universally established for ponds. Traditionally, 30 years has been considered the period for PCC following capping system installation at municipal solid waste landfill facilities. There are no specific criteria for ending PCC; however, many state solid waste rules allow either a decrease or an increase in the traditional 30-year PCC period based on site conditions.

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