Work Area Quantification Processes to Guide CCR Construction Programs

Dale W. Evans, P.E.[1], Kathleen Whysner[1], Joseph Scalia, Ph.D.[2], Christoper Bareither, Ph.D., P.E.[2]

[1]Remedial Construction Services, L.P., 9977 W. Sam Houston Parkway N., Suite 100, Houston, TX 77064
[2]Civil & Environmental Engineering, Colorado State University, 1372 Campus Delivery, Fort Collins, CO 80513

CONFERENCE: 2017 World of Coal Ash – (www.worldofcoalash.org)

KEYWORDS: coal combustion residuals (CCRs), geotechnical engineering, materials characteristics, laboratory testing, field-pilot testing, moisture-shear strength relationship, dewatering, corrective action, construction

ABSTRACT

Conventional geotechnical engineering practice provides the analytical tools necessary to address a host of civil construction issues. Most commonly, physical relationships are embodied within calculation methods used for defining the performance of foundations, embankments, and related behavioristic responses to various soil and rock mechanics applications. While many of these tools have evolved to the point that they are relatively routine, few methodologies have been developed specific to predicting and understanding long term behaviors of soft waste materials such as coal combustion residuals (CCRs).

Specific to CCR management, typically adopted methods for predictive analysis of field-based responses in soft soils may have little application to predicting long-term behavior or importantly, planning construction processes as part of impoundment closure programs. As a consequence of the lack of functional relationships defining field behaviors, a number of CCR construction planning efforts have relied on approaches tied not to tangible facts, but instead on the extent that someone is willing to gamble on the outcome. Obviously, this represents a dangerous precedent with regard to field-based safety as well as reasonably defining the means and methods necessary to meet design constraints on a cost-effective basis. Therefore, this paper has been prepared to define a Work Area Quantification Process (WAQP) to define materials testing and behavioristic analytical tools capable of providing simplified predictions of construction-based field behavior.

OVERVIEW OF ISSUE

Many coal combustion residual (CCR) impoundments were constructed to contain wet fly ash materials which, for economic reasons, were often hydraulically conveyed and discharged at the impoundment using a sluice-based process. Such processes used large volumes of water to provide rheological reliability due to the conveyance distances that resulted in very low solids content delivery at the point of discharge. Discharge of low solids content material resulted in entropic deposition processes with typically no defined drainage pathways across the deposited section of CCR materials. This depositional environment has led to most wet impoundments having significant retained moisture contents with very little internal shear strength. These high moisture content, low shear strength materials create a host of issues for closure due to the direct implications on equipment access for removal or capping activities as well as the longer-term behaviors due to the post-closure time-rate of drainage and consolidation.

A means to effectively predict CCR behavior is absent, and the capacity to define optimized materials handling technologies and the associated means and methods required to optimize the cost-effectiveness of the work performed is limited. In particular, the lack of tangible input to planning leads directly to uncertainty of output with respect to the applicability of means and methods selected and importantly, the accuracy of cost and schedule predictions for construction. Further, the lack of tangible input also limits the accuracy of predicted long-term field conditions, such as the ultimate post-consolidation contours due to porewater drainage and consolidation. Importantly, these same porewater drainage relationships may have a profound effect on the cost of potential corrective action efforts as the fate of the remaining porewater inventory within an impoundment may directly influence the extent of corrective action liabilities.

If he considerations noted are left unquantified, the conditions within many wet CCR impoundments have the potential for both dangerous as well as costly field operations. Therefore, to understand field conditions and predictively assess the efficacy of construction actions to improve safety and optimize production, a pragmatic field quantification method is needed to define field conditions and related construction activities. The Work Area Quantification Process (WAQP) outlined herein supports baseline characterization, field-based efforts, field-pilot validation, and analytical methods necessary to define construction means and methods based on relationships between moisture, effective stress, shear strength, and permeability. Specifically, the geotechnical process described can be used to establish a functional link between the field conditions present and the construction means and methods appropriate to support safe and cost-effective impoundment closure.

KEY TAKEAWAY: The WAQP applies geotechnical engineering to avoid and mitigate risks related to:

- ***Field-based health and safety of construction activities;***
- ***Expected production rates;***
- ***Project cost and schedule;***
- ***Environmental liabilities;***
- ***Long-term site stability; and***
- ***Life-cycle costs.***

PROVIDING SURETY OF OUTCOMES

While conventional geotechnical practice has had limited focus on linking the specific mechanics of various waste materials to regulation-based closure mandates, the mechanics-based prerogatives prescribed by closure designs have for many years been implemented in some active mine waste management projects. The multitude of factors affecting field-based performance of these mine tailings materials share many commonalities with CCR materials, including the following, among others:

- Fine-grained matrices;
- Initially high degree of saturation (i.e., low solids content).
- Limited stress history;
- Moisture - bulk density - shear strength - permeability dependencies.

While the design of many CCR closure efforts may not define the required means and methods for construction, to meet the requirements established by the design, the construction means and methods selected must directly address such conditions as they will directly affect pricing. Specifically, because the cost of any project depends on both the cost of the resources allocated as well as the production rate recognized, these variables must both be understood with respect to materials characteristics to provide reliable pricing. Thus, the accuracy of any competitive bid for a CCR wet impoundment closure may be profoundly compromised if the production rate varies appreciably. Therefore, optimized surety of pricing must consider the linkage between materials behavior, the available materials handling methods, resource costs (i.e. labor, equipment, and materials), and production rate.

CCR-SPECIFIC ISSUES

Although CCR materials emulate the behaviors of fine-grained mine tailings materials, effective consideration of their behaviors in wet impoundments depends on holistic consideration of the myriad of factors affecting their development, placement, and at-rest conditions within disposal impoundments, including the following, among others:

- Coal source;
- Combustion process;
- Scrubber process;
- Bottom ash presence and distribution;
- Transport rheology;
- Discharge process;
- Beach development;
- Uniformity;
- Thixotropic conditions;
- Porewater chemistry;
- Vibration;
- Drainage (surface water as well as groundwater);
- Environmental conditions (e.g. precipitation and evaporation); and
- Piezometric surface.

These factors each affect definition of the means and methods required for a host of CCR-related closure activities, including construction of capping systems, recovery for relocation, regrading, environmental isolation, and other potential actions required for closure or corrective action.

With respect to corrective action, these conditions may directly influence the long-term consolidation-derived drainage of porewater, potentially effecting long-term environmental liabilities. In effect, even after closure, the fate of the remaining inventory of porewater requires consideration and an understanding of the characteristics affecting such drainage.

UNDERSTANDING CCR MATERIAL PROPERTIES

Due to the limited bearing capacity within most wet ash impoundments, a systematic process for quantification of field behaviors is appropriate as can be defined using a process that includes four discrete components, including:

1. Baseline materials characterization;
2. Field-based materials characterization;
3. Field-pilot performance verification; and
4. Full-scale monitoring and modification.

This process should be organized and orchestrated to support obtaining the information required to develop a site-specific understanding of material behavior that govern the construction processes required to meet specified design prerogatives. Accordingly, the data developed must be carefully considered such that site conditions are understood based on the premise that what is known is important but that what is not known may be the most detrimental to the accuracy of any predictive analysis and the resulting costing effort. Therefore, a focus should be placed on cause and effect relationships governing the analyses planned such that only data necessary for the evaluation processes and the defining of uncertainties is developed. .

Importantly, the goal of the WAQP detailed herein is to support rapid, cost-effective development of the information necessary to support the analysis required to predict material behavior. Behavior will be defined by fundamental baseline relationships such as those associated with moisture content and shear strength and the resulting impact on bearing capacity.

These baseline relationships may lack precision due to the multitude of boundary conditions and the variabilities inherent within most wet ash impoundments, but are necessary as the foundation for decision-making related to means, methods, and costing. Accordingly, the WAQP noted in the following sections supports the capacity to verify the likely operating range of conditions, predict field-based behaviors, and as needed, adjust field efforts to respond to encountered field conditions.

BASELINE MATERIALS CHARACTERIZATION

Any baseline characterization of site conditions should first consider the conditions present within ash impoundments with respect to placement methods and the existing conditions. These factors will directly affect the number of samples required to develop an effective baseline. The baseline should be encapsulated through creation of an Interpretive Site Model (ISM) that can be used to evaluate the likely range of cause and effect relationships associated with various construction means and methods. Therefore, the ISM should broadly be configured using all available and appropriate elements associated with site physiography, CCR characteristics, hydrologic conditions, and other conditions that will control long-term behavior and prediction of field performance subject to potential construction means and methods. The ISM should include all data required to evaluate the physical, chemical, and coupled interactions likely to define and control behavior relevant to required closure and/or corrective action efforts.

Although the discrete data needs may vary based on site conditions, the baseline geotechnical data appropriate to develop should include consideration of each of the following tests:

- Specific gravity;
- In-place moisture content;
- In-place bulk density;
- Atterberg limits;

- Particle size analysis;
- Saturated permeability;
- CCR-water characteristic relationship (capillary head behavior);
- Unsaturated permeability (capillary permeability);
- Large strain consolidation; and
- Shear strength via various methods (e.g. direct shear, triaxial, lab vane, etc.).

Each of these tests may offer valuable information specific to the needs associated with a given site and the construction methods required to implement the required design. Of primary interest for many wet CCR impoundments will be data that supports understanding CCR shear strength as a function of moisture content, bulk density, and void ratio in relation to changes in pore pressure and the resulting effective stress.

The data developed from a laboratory program should be accumulated with the goal of defining a generalized understanding of behavior for each material represented within the body of CCRs within an impoundment. However, to limit costly and potentially ineffective distinctions that cannot be verified, this process should be focused on defining the generalized conditions across relatively broad material characterizations, such as the following:

- Bottom ash;
- Fly ash;
- Mixed ash (based on deposition history); and
- Thixotropic ash.

Specific to CCR materials, understanding behavior must also consider behavior affected by variations in porewater chemistry and the time-dependent conditions impacting conventional analysis of effective stress. As shown on Figure 1, the calculated effective stress based on static conditions may not represent what is present. Factors such as time, depositional history, capillarity, drainage rate, surface disturbance, and vibration, among other factors may each contribute to deviations from what would be expected through conventional calculation or long-term measured values. The degree of any such variances is important to consider as part of any characterization effort to fully understand and predict field behaviors.

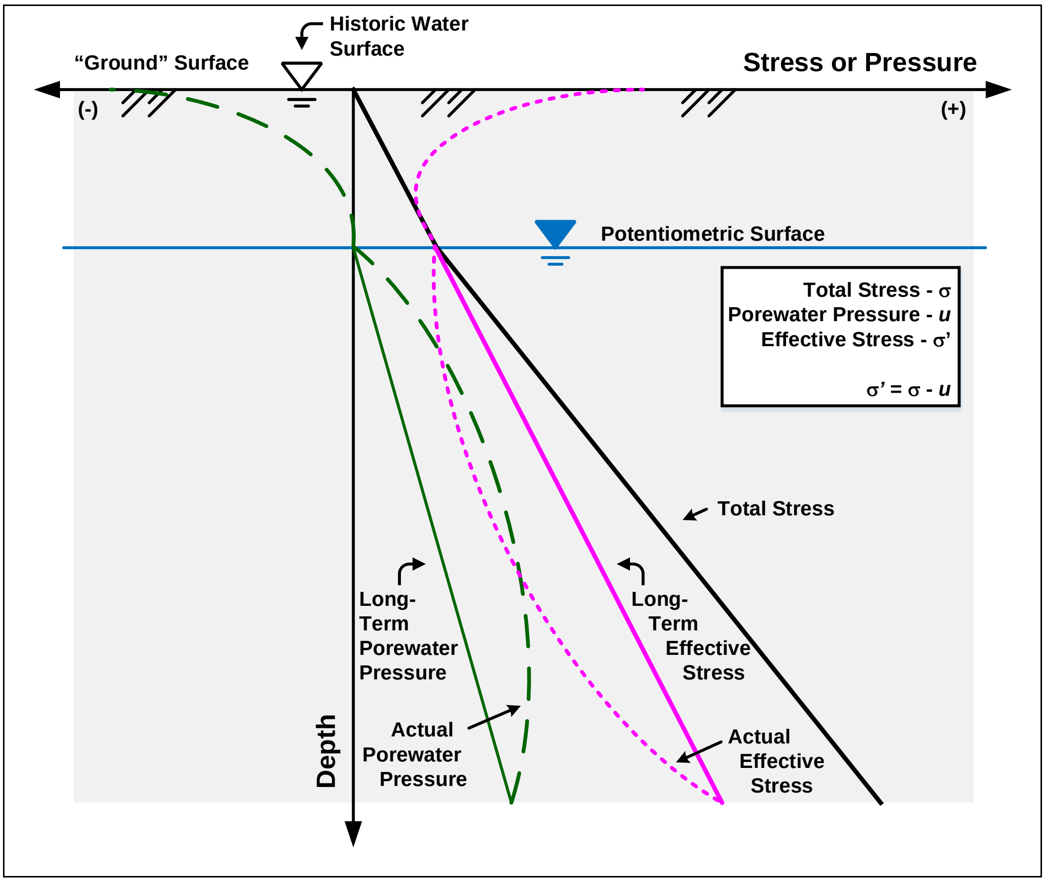

FIGURE 1: Effective Stress Relationships: Calculated Steady State vs. Actual

As noted, due to the inherent variabilities represented in most wet ash impoundments, such data should be developed with an emphasis on defining a relatively broad basis for selection of applicable construction technologies. Specifically, these efforts should define the degree of accuracy and the expected range of variability in the resulting field performance. As an example, laboratory-based shear strength processes should generally define the anticipated range of values and degree of correlation expected using confirmatory field methods such as vane shear or cone penetrometer testing.

Once the material characterization data has been accumulated, key index parameters should be evaluated across the materials to define any behavioral relationships or commonalities that exist. Quantitative data should be used wherever possible to demonstrate potential interrelationships such as through direct analogs or key ratio analyses. As an example, development of relationships between moisture content reduction and shear strength increases provide valuable data for predicting the effectiveness of field construction efforts. The schematic depicted in Figure 2 details the functional representation of data showing the degree of shear strength improvements required to provide the bearing capacity necessary for equipment operation.

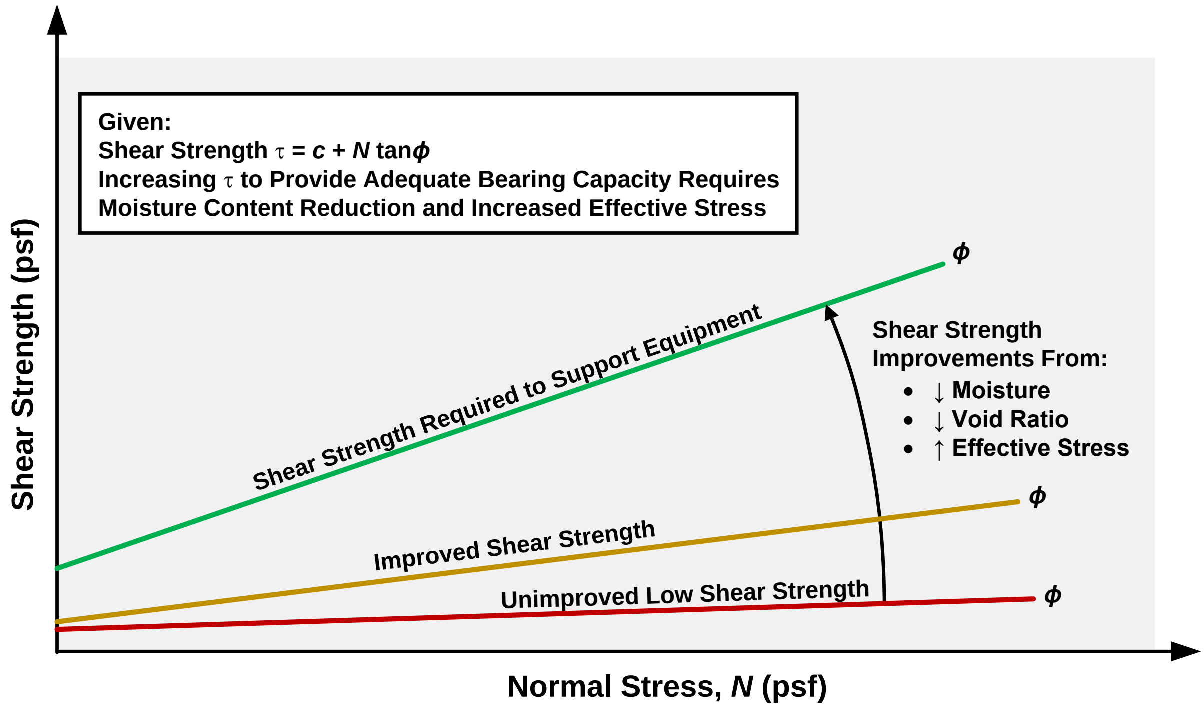

FIGURE 2: Idealized Moisture-Shear Strength Relationship for Site Operations

KEY TAKEAWAY: The WAQP employs geotechnical engineering theories to understand likely field behaviors related to:

- ***Moisture-shear strength relationships;***
- ***Time-rate relationships for dewatering;***
- ***Shear strength required for field actions;***
- ***Selection of materials handling methods, and***
- ***Prediction of field performance.***

FIELD-BASED QUANTIFICATION

Once baseline laboratory data has been accumulated and evaluated, a field-based quantification program can then be used where appropriate to establish or verify the relationship between the materials tested and those likely to be encountered in the field. This type of program can be costly and over-extensive if not carefully planned and should focus on establishing linkages between the developed laboratory data and the field performance expected. Such linkages provide valuable information related to definition of the critical factors driving field performance, monitoring, and scalability as may be appropriate to guide field operations.

The field-based quantification efforts anticipated to generate the greatest value include a simplified series of tests to identify the followng:

- Moisture content;
- Bulk density;
- Phreatic surface; and
- In-place shear strength with depth.

Using this data, analyses can be performed to define the generalized actionable relationships between shear strength and moisture content. These relationships, the degree of agreement between laboratory and field quantification data, and the ISM can then be used to predict full-scale field behavior during construction. In some instances, the data developed may support a need to define a field-pilot program as the basis to understand field operations parameters such as the following, among others:

- Dewatering effectiveness;
- Surface stability and bearing capacity based on incremental water lowering;
- CCR material handling methods;
- Factors of similitude affecting scalability; and
- Production rate related to means and methods defined.

FIELD-PILOT PERFORMANCE VERIFICATION

On projects where performance-based decisions strongly influence costs, a field-pilot program may be appropriate to validate or establish the linkage between projected and actual performance such that costs can be reasonably predicted. Understanding the linkages between laboratory and field quantification efforts that support predictions of performance and definition of the scalability factors required to define full-scale field operations and associated production rates can often be accomplished through use of a well-planned field-pilot program.

As an example, where a wet ash impoundment may have limited bearing capacity, development of a prediction of the extent of lowering in the phreatic surface necessary to provide adequate bearing capacity can be accomplished using the WAQP. Using the WAQP, planning the capping efforts would thus discretely consider each of the following factors:

- Time-rate of dewatering to obtain the required shear strength;
- Means and methods required to accomplish such dewatering;
- Projected productivity and cost (i.e. ft/day of lowering, $/acre-foot of water removed, and overall $/ft of lowering);
- Field monitoring required to assess performance and performance metrics to be used; and
- Decision-making criteria to support field adjustments as may be appropriate.

Each of these factors is linked to a variety of analytical performance elements. As an example, the time-rate of dewatering will be important as a cost-related determinant but will be uniquely dependent upon the geotechnical performance associated with the effect on shear strength from drawdown-induced negative pore pressures (capillary forces). Such a relationship establishes the need for prediction and the real-time monitoring processes noted. While the inherent variabilities present across most CCR facilities will affect the accuracy of such predictions, the fixed costs represented by the resources required to accomplish the work cannot be avoided and without the predictive analysis and field validation, an accurate prediction of construction costs will be based more on probability than fact.

Using the data developed from a field-pilot program, as an extension of the ISM, an Interpretive Pro Forma (IPF) can be developed to define the projected range of performance criteria for field actions such as dewatering and bearing capacity based system responses. This IPF can be instrumental in predicting and measuring "worst case", "best case", and most importantly "expected case" field performance with respect to cost and schedule, especially with respect to defining key performance relationships, such as:

- Cubic yards managed/day;
- $/cubic yard managed;
- $/acre-foot of water recovered; and
- $/foot of water lowering accomplished;

Having reasonable accuracy across these key relationships can be important as part of construction contracting efforts and provide a reasonable boundary for contract-based financial obligations. Using this type of process provides the ability to provide an unambiguous demarcation between client and contractor obligations, largely based on production-based operational targets.

KEY TAKEAWAY: The WAQP supports performance-based predictions as can be validated by field-pilot programs to evaluate:

- ***Effectiveness of selected field technologies;***
- ***Assessment of predicted production rates;***
- ***Scalability factors for full-scale programs;***
- ***Basis for cost and schedule assumptions; and***
- ***Likely cost metrics for contracting.***

FULL-SCALE MONITORING AND MODIFICATION

Using the data accumulated as part of the WAQP, field-based monitoring can be performed to understand full-scale performance and define potential actions that could increase productivity or effectiveness. As an example, the schematic shown in Figure 3 illustrates an "expected case" response to dewatering an impoundment using a combined slurry wall-based isolation and recovery system.

While a host of predictive elements are represented in Figure 3, the primary takeaways of interest gained by the monitoring efforts would be related to the following:

- Degree of phreatic surface lowering required to provide adequate bearing capacity for equipment access;
- Time required to provide the required lowering;
- Resources and cost associated with such efforts; and
- Productivity enabled once access to work areas is available.

Collectively, these elements can be used to assess field performance in relation to the bid-level estimates for the project and where necessary, the actions required to improve productivity to control or reduce costs.

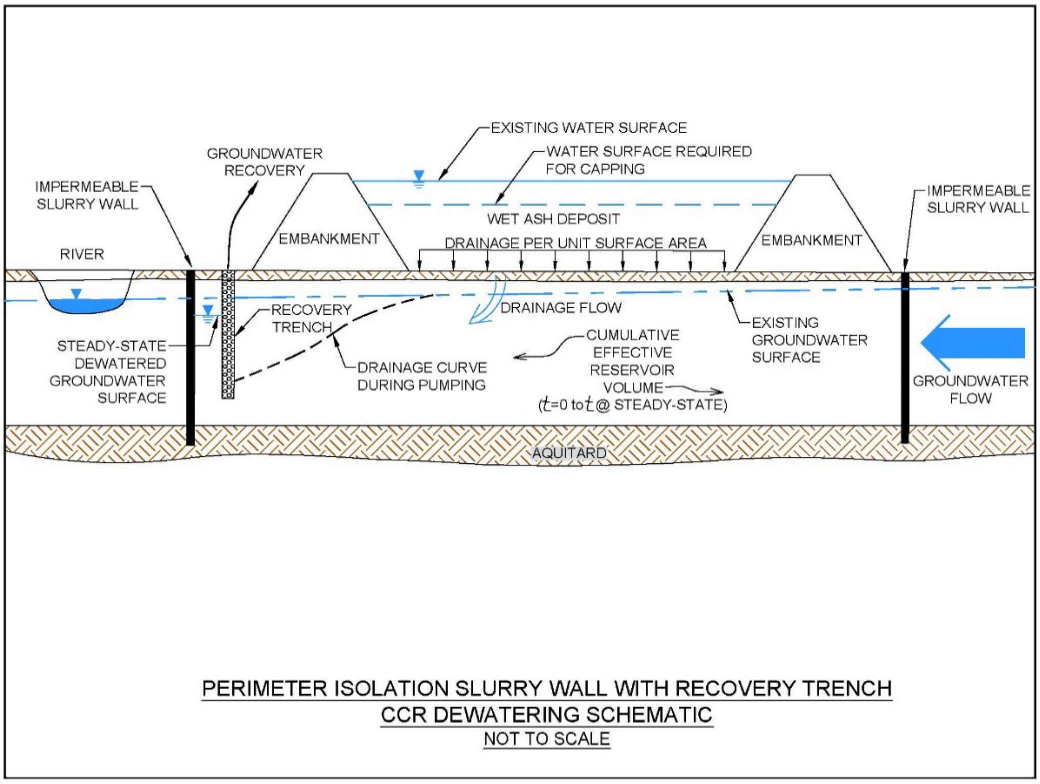

FIGURE 3: Use of Field Monitoring to Evaluate Predicted Performance

CLOSING REMARKS

The Work Area Quantification Process (WAQP) outlined herein has been developed to provide a cost-effective, geotechnical engineering-based process to support prediction of likely materials behavior for defining appropriate field construction processes and "expected case" cost and schedule elements. Through thoughtful application, this process is intended to support field management in relation to "expected case" performance criteria as can be monitored and adjusted where needed to meet the

KEY TAKEAWAY: The WAQP represents an important tool to understand, predict, and manage field construction efforts associated with CCR closure programs to support:

- ***Accuracy of predicted costs and schedule.***
- ***Reduction of life-cycle costs and liabilities.***
- ***Optimal project-level risk avoidance, mitigation, and reduction.***
- ***Surety of outcome.***

prerogatives established by the coal combustion residual (CCR) impoundment closure design developed.