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July 21, 2009

The Honorable Eddie Bernice Johnson, M.C.
U.S. House of Representatives
Chairwoman, Committee on Transportation and Infrastructure
Washington, DC 20515

Re: Testimony of William S. Almes, P.E.
Marshall Miller & Associates, Inc. Peer Review of
AECOM's "Root Cause Analysis of TVA Kingston
Dredge Pond Failure on December 22, 2008"
Tennessee Valley Authority - Office of the Inspector General

Dear Representative Johnson:

Per your request and on behalf of **Marshall Miller & Associates, Inc. (*MM&A*),** I am pleased to provide written testimony related to the MM&A Peer Review of the "*Root Cause Analysis of TVA Kingston Dredge Pond Failure on December 22, 2008*" report prepared by **AECOM Technologies Corporation (*AECOM*)**. The written testimony contained herein is derived from the content of the reports completed by MM&A on July 9 and July 12, 2009. Copies of these reports are available upon request.

1.0 Introduction and Background

Marshall Miller & Associates, Inc. (*MM&A*) is an employee-owned Engineering News-Record Magazine (*ENR*) Top 500 company that began offering geologic services to the mining industry in 1975 and for 33 years has provided a full range of related services to the mining, utility, financial, governmental, and legal industries. Today, MM&A employs nearly 200 engineers, geologists, scientists and other professionals working from regional offices in ten states.

Members of MM&A's Project Team have been intimately involved with the development of the two engineering design manuals prepared by the **Mine Safety and Health Administration (*MSHA*)**, which specifically address the procedures that should be followed for designing and operating coal refuse impoundments and embankments. The first manual was published in 1975, and an updated version is scheduled to be released in 2009. Although these manuals were written to address the design and operation of coal refuse disposal facilities, the key chapters, which include material characterization, hazard classification, planning, staging, foundation considerations, surface drainage and storm water control, instrumentation monitoring, geotechnical engineering and design, seismic hazard assessment, seismic stability and deformation, environmental considerations, and emergency action plans, are directly applicable to the disposal of fly ash and bottom ash materials.

MM&A has also been involved with forensic studies of major waste impoundments that have experienced uncontrolled releases of fine slurry, as well as slope instability within the embankment portions of both coal ash embankments and impoundments and coarse coal refuse dams.

2.0 Summary of MM&A's "Peer Review of the AECOM Root Cause Analysis of TVA Kingston Dredge Pond Failure on December 22, 2008," dated July 9, 2009

The **Tennessee Valley Authority (*TVA*) Office of the Inspector General (*OIG*)** engaged MM&A to conduct a peer review of the Root Cause Analysis (*RCA*) prepared by AECOM relating to the ash dredge cell failure which occurred at the TVA Kingston Fossil Plant (*Kingston*) near Harriman, Tennessee, on December 22, 2008. On June 25, 2009, AECOM publicized the results of its comprehensive six-month study entitled "*Root Cause Analysis of TVA Kingston Dredge Pond Failure on December 22, 2008*." According to AECOM, the root cause of the failure was a long-evolving set of conditions, including a combination of the high water content of the wet ash, the increasing height of ash, the construction of the sloping dikes over the wet ash, and the existence of an unusual foundation layer consisting of sensitive slimes and silts.

MM&A initially visited the Kingston facility on February 4, 2009, and met with various representatives of the OIG, TVA, AECOM, **Tennessee Department of Environment and Conservation (*TDEC*)**, and **Environmental Protection Agency** (***EPA***), among others, during the course of the engagement. Subsequently, MM&A was provided access to various documents including engineering design drawings, photographs, aerial maps and other relevant materials which were reviewed in the context of the engagement.

MM&A did not conduct a parallel investigation to AECOM's. MM&A's professional opinions are based principally on the review of various documents regarding Dredge Cell 2, a meeting with AECOM personnel at their Vernon Hills, Illinois, office location on June 2, 2009, briefings provided by AECOM during presentation and conference call meetings, and a review of the final RCA report dated June 25, 2009.

On July 9, 2009, MM&A published a report entitled "*Peer Review of the AECOM Root Cause Analysis of TVA Kingston Dredge Pond Failure on December 22, 2008,*" in which it concluded that: (1) the scope of the RCA, as presented by AECOM, was sufficiently thorough for the RCA, and AECOM applied appropriate methodologies, investigative methods, in-situ testing techniques, and sampling practices; (2) the characteristics of the loose, wet ash indicate the wet ash as a probable root cause of equal or greater significance to the soft foundation soils; and (3) that, because the failure was not strictly associated with the "thin, weak slimes" layer and more associated with the ash dike (or "fill") geometry and relatively low strength of the sluiced ash foundation and impounded material, other similarly constructed ash (or gypsum and/or other byproducts) impoundments could be at risk of failure and should be properly investigated.

3.0 Summary of MM&A's "Historical TVA Documentation Review Summary, Opinions and Recommendations Related to the TVA Kingston Dredge Pond Failure on December 22, 2008" dated July 12, 2009

In addition to its July 9, 2009, peer review report, MM&A was also engaged to discuss design practices and the historical development of the disposal facility as it relates to the siting, design and construction of the containment dikes at Kingston up to the time of failure on December 22, 2008. Also discussed were overall opinions and recommendations related to the TVA Kingston dredge pond failure.

MM&A met with various representatives of the OIG, TVA, AECOM, TDEC and EPA, among others, during the course of its engagement, and was provided access to multiple documents including engineering design drawings, photographs, aerial maps, internal TVA memoranda and various reports produced by TVA's consultants, as well as other documents which were reviewed in the course of the engagement.

On July 12, 2009, MM&A published a report entitled "*Historical TVA Documentation Review Summary, Opinions and Recommendations Related to the TVA Kingston Dredge Pond Failure on December 22, 2008*" concerning appropriate design philosophy, design standards, and construction and operations procedures that are applicable to coal ash disposal facilities. MM&A's opinions were based on extensive experience with a variety of ash ponds, mine waste embankments and slurry impoundments that have been operating throughout the United States for several decades. MM&A also commented on salient aspects of the evolution of the facility.

4.0 General Background on Historical Ash Disposal Practices

AECOM documented the history of development of coal ash disposal at Kingston, including the depositional and construction history of Dredge Cell 2 and of Dike C surrounding Dredge Cell 2 (See *Section 1.2* of the AECOM's RCA report dated June 25, 2009). Several important factors are observed from this history:

- The coal ash storage facility was built over portions of the former Swan Pond Creek flood plain. Clayey sediments found below Dike C and Dredge Cell 2 are "lacustrine," a term which refers to sediments deposited in lake environments. The type of sediment deposited in lakes can vary widely and locally depends upon the size of the lake, the climate, and the nature of the surrounding soils and environment.

- Prior to the construction of the initial ash containment dike, fly ash from the plant was sluiced directly into the Watts Bar Reservoir.

- In 1958, Dike C was completed creating the Ash Pond.

- Since the passage of the Clean Water Act in 1972, many industries in the United States, including the power industry, implemented new waste handling and disposal

practices in an effort to prevent pollution of surface water and groundwater features. As a result of the operational changes, containment dikes for the ash disposal ponds were required. The upstream construction method, as depicted in **Figure 1** of MM&A's July 12, 2009, report, consists of raising the crest of the impounding dike by constructing each successive dike, or stage, above previously placed/sluiced ash, which then becomes the foundation material.

- While employing the upstream construction method during the vertical expansion of the existing dredge pond, TVA's use of this practice at the site resulted in Dredge Cell 2 having a series of ash dikes built with 3 horizontal to 1 vertical (3H:1V) slopes and 15-foot wide benches founded on 35 to 40 feet of hydraulically placed or sluiced ash, with a 200-foot setback from the original Perimeter Dike C. The ash used for dike construction was dredged from an adjacent ash collection/settling pond which was allowed to dewater over time.

- As the height of the dikes was increased, the dredge cell footprint area decreased as new lifts of material were placed. Consequently, more height was necessary to provide adequate storage for the same annual production of ash at the fossil plant. This process increased the total load and rate of loading imposed on the sluiced ash.

- Samples of the sluiced ash indicate that it has a high void ratio and does not show signs of consolidation or densification under the weight of new ash placed over older ash. As a result, the wet ash remains very loose and susceptible to liquefaction under rapid loading or rapid displacement.

- Laboratory test results also indicate that the wet ash is prone to experience static liquefaction due to its highly sensitive structure, which shows a rapid decrease in its shear strength when it changes from a drained to an undrained behavior.

5.0 Potential Failure Modes, "Triggers," and Most Probable Factors/Root Causes of Failure

In simplistic terms, the failure of Dredge Cell 2 and Dike C was the result of the hydraulically placed/sluiced ash assuming undrained behavior, resembling a liquid, and flowing into the Swan Creek flood plain and surrounding acreage. A technical review of the fly ash material identified several factors that indicate the conversion from a stable to unstable condition, which occurs rapidly as a result of the material's placement into undrained shear failure. In a technical letter report dated June 25, 2009, prepared for Mr. Ralph E. Rodgers, Assistant General Counsel for TVA, Dr. Gonzalo Castro, Ph.D., P.E., a Geotechnical Consultant from Lexington, Massachusetts, presented his conclusions regarding AECOM's analyses of the failure at Kingston. Castro succinctly explains the physical conversion from stable (drained) strength to the substantially lower (undrained) strength of the ash material[1]. The physical process involved in the liquefaction conversion is well documented in the literature for soils or

[1] Dr. Gonzalo Castro, Ph.D., P.E., Geotechnical Consultant, to Mr. Ralph E. Rodgers, TVA, June 25, 2009, Page 3.

materials with properties similar to the ash analyzed and tested by AECOM. Castro further observes that "Liquefaction caused by non-seismic triggering is referred to as static liquefaction… and [is] caused by a) slippage elsewhere in the soil [ash] mass… b) an increase in the rate of loading… and c) local relatively rapid erosion at the toe of slopes…"[2] AECOM concludes that increases in the rate of loading and localized failure at the toe of slopes or other surface/outslope areas are lesser possibilities of triggering the failure that occurred.

In the course of its analysis, AECOM identified the following probable root causes of the Kingston ash pond failure:

1. Fill geometry (upstream-constructed dike configuration on sluiced ash foundation);
2. Increased fill rates (increased loads and loading rates due to higher fill levels and shrinking footprint);
3. Soft foundation soils (weak, sensitive silt and slimes foundation layer); and
4. Loose, wet ash (hydraulically placed/sluiced ash).

AECOM discussed the thin layer of slimes beneath the dikes of Dredge Cell 2, per item 3 above, which was discovered during its subsurface investigation. Slimes do not exist beneath Dike C. Although the properties of this slime layer suggest it as a potential slippage surface based upon mathematical modeling, it is MM&A's opinion that it is not the only possible slippage surface. AECOM documented that slimes were not found in some locations, were not of consistent thickness, and had properties very close to those of the ash material itself.

It is MM&A's professional opinion that the characteristics of the loose, wet ash, such as the rounded particle shape, weakly fused and loose particle structure, sensitivity, consistently high void ratios with increasing depth (lack of consolidation behavior), along with the contractive undrained behavior and very low undrained steady-state shear strength evidenced in the laboratory tests, pose the wet ash as a probable root cause in the failure of Dredge Cell 2.

6.0 Conclusion and Observations

The following outlines MM&A's conclusions and observations based on its review of AECOM's June 25, 2009, RCA report as well as its review of various documents regarding Dredge Cell 2, a meeting with AECOM personnel at their Vernon Hills, Illinois, office on June 2, 2009, and briefings provided by AECOM during presentation and conference call meetings.

6.1 AECOM's RCA

In summary, MM&A found the following with regard to AECOM's root cause study and culminating RCA report dated June 25, 2009:

[2] Ibid, Page 4

1. The scope of the RCA, as presented by AECOM, was sufficiently thorough for the RCA, and AECOM applied appropriate methodologies, investigative methods, in-situ testing techniques, and sampling practices.

2. The laboratory geotechnical testing program was sufficiently thorough and applied appropriate and complementary suites of tests to characterize the native soils and non-native site materials (e.g., ash and slimes) in the primary areas of interest for the RCA. However, MM&A understands that AECOM was not able to recover and extrude undisturbed samples of the hydraulically placed ash for laboratory testing. This situation adds uncertainty to AECOM's characterization of the hydraulically placed ash at Kingston; thus, the role of the loose, wet ash as a root cause of the failure can not be discounted.

3. AECOM discussed the thin layer of slimes beneath the dikes of Dredge Cell 2, which was discovered during its subsurface investigation. Slimes do not exist beneath Dike C. Although the properties of this slime layer suggest it as a potential slippage surface based upon mathematical modeling, it is not the only possible slippage surface. AECOM documented (*Sections 1.3.4.2* and *1.7.11* of the RCA report dated June 25, 2009) that slimes were not found in some locations, were not of consistent thickness, and had properties very close to those of the ash material itself.

4. The characteristics of the loose, wet ash (hydraulically placed/sluiced ash) such as the rounded particle shape, weakly fused and loose particle structure, sensitivity, consistently high void ratios with increasing depth (lack of consolidation behavior), along with the contractive undrained behavior and very low undrained steady-state shear strength evidenced in the laboratory tests, pose the wet ash as a probable root cause of equal or greater significance to the soft foundation soils (weak, sensitive silt and slimes foundation layer).

5. The fundamental conclusions of AECOM's RCA with regard to the four most probable root causes or factors contributing to the Kingston ash pond failure are technically plausible and reasonably supported by the study data. MM&A concurs with AECOM that some or all of these four factors discussed contributed significantly to the failure.

6. MM&A concludes that, because the failure was not strictly associated with the "thin, weak slimes" layer and more associated with the ash dike (or "fill") geometry and relatively low strength of the sluiced ash foundation and impounded material, other similarly constructed ash (or gypsum and/or other byproducts) impoundments could be at risk of failure and should be properly investigated.

7. MM&A notes that the stated objectives of the AECOM RCA do not encompass the task of identifying necessary changes in design philosophy, design standards, construction documentation, inspection and instrumentation to prevent another Kingston-type failure. Consequently, the root cause study and culminating report by AECOM defines the problem but does not provide clear direction to TVA in

the form of technical guidance for evaluating, designing, and constructing reliable containments for "wet" ash disposal now or in the future.

8. MM&A believes that the AECOM RCA focused disproportionately on the significance of the thin, discontinuous, soft foundation layer (sensitive silt and slimes) as one of the most probable factors/root causes. The significance of the "Fill Geometry" factor/root cause should be equally emphasized. In the Kingston case, the specific complexities and uncertainties associated with the ash dikes/embankments constructed over the hydraulically placed or sluiced ash deposits (i.e., upstream-constructed containment) is an important component of the "Fill Geometry" factor and, in MM&A's professional opinion, is of equal or greater significance relative to the "Soft Foundation Soils" factor.
9. Other factors evaluated by AECOM as probable root causes should be strongly considered by TVA and the power generation industry as a whole in evaluating the condition and structural integrity of wet ash disposal facilities. Each one of these factors is critical and should be closely examined at all of the existing TVA ash handling and disposal facilities. These concerns and findings could have a significant effect on the requirements and standards of care for facilities throughout the industry.

6.2 General

During its historical record review, meetings and observations, MM&A determined the following:

1. As early as 1985, intrinsic problems related to the stability of Dike C were mentioned, specifically in a TVA memorandum (see **Exhibit 1** of MM&A's July 12, 2009, report) which indicates that the calculated factor of safety was less than the minimum acceptable value of 1.5 and close monitoring was recommended to detect any potential signs of failure–in lieu of changing TVA policies and procedures that would require that the ash pond be designed to the higher "dam safety" standard. No specific action by TVA appears to have been taken as per the reviewed documents to improve the stability of the earthen Dike C embankment.
2. The construction of successive upstream stages to elevation 820 (approximate crest elevation of Dredge Cell No. 2 at the time of failure) above the original containment dike may have contributed to an additional decrease in the factor of safety of the containment dike system. In essence, at the time of failure on December 22, 2008, this increase in constructed height equated to an approximate 70-foot increase in the height of the ash pond above the crest elevation of the original Perimeter Dike C.
3. In MM&A's opinion, if TVA had included its ash ponds in the Dam Safety Program as discussed in December 1988 when TVA decided against this policy,

the probability of identifying some or all of the conditions that led to the Kingston failure would have increased significantly.

4. The design of the Kingston coal ash dredge cells should have included a thorough engineering evaluation of all potential failure modes.

5. It is considered sound engineering practice to design such facilities with features that provide a reasonable degree of redundancy or "second line of defense" in the event that one or more of the systems become inoperable. To some extent, establishing higher factors of safety provide this protection. However, other considerations are appropriate such as specifying a sufficient number of internal drains in the event one or more become clogged or compromised in some fashion. The same applies to specifying the degree of compaction of the dike materials since weather conditions, the level of experience of the equipment operators and other variables can affect the final condition and ultimate behavior of the structure. In MM&A's opinion, it is important that this design philosophy be applied to all of TVA's ash disposal facilities.

6. The recommendations made by **Geosyntec Consultants, Inc. (*Geosyntec*)** following its peer review of the 2004 TVA document entitled "Operations Manual–Dredge Cell Lateral Expansion" were appropriate, and the failure of TVA to respond to such warnings and affect necessary revisions to the design shows that conservative engineering design principles were not being followed within TVA. Furthermore, had corrective measures been completed in a timely manner, it is possible that TVA could have potentially prevented the occurrence of the failure.

7. With regard to the TVA reaction to the 2003 ash slope failure along Swan Pond Road, buttress construction was a reasonable immediate response. However, use of riprap material alone without proper filter materials between the existing ash dikes and riprap buttress, whether 50 feet or 250 feet wide, was not a technically acceptable longer term solution. Rather than adopting a "wait and see" approach with the 50-foot wide buttress, the problems and potential longer term solutions warranted prompt evaluation by a qualified geotechnical/dam engineer. If the ash ponds had been included in the Dam Safety Program, this closer evaluation and a more sound "engineered" solution probably would have occurred.

8. It is evident from findings and recommendations in the Geosyntec report that, in addition to consideration for liquefaction, modifications to the expansion design should have been made to require compliance with a more stringent design configuration. Upon completion of the proposed Phase 2/3 expansion, which had not occurred at the time of the failure, more height and weight would have been added to what is now the failed ash pond. TVA's concurrence with the recommendations would have resulted in additional extensive analyses and modeling.

9. It is not prudent to presume that if the slimes layer observed in the failed section at Kingston does not exist at other plant sites, there is adequate stability of these structures. On the contrary, the information developed from the extensive studies

conducted by both **Stantec Inc.** and AECOM indicates that there is a reasonable risk of other dike failures if changes are not made in the design construction, oversight, and operation of the wet ash disposal sites throughout TVA.

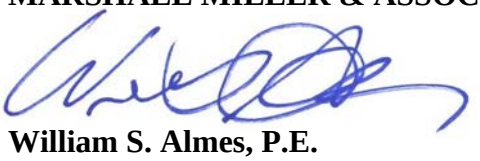
7.0 Closing

In preparing this testimony, the professional services of MM&A have been utilized, findings obtained, and conclusions made in accordance with generally accepted engineering principles and practices. MM&A reserves the right to amend and supplement this testimony based on new or additional information that might be obtained or become known. If OIG, TVA, TVA's consultants, or others discover additional information pertinent to the Kingston ash pond failure or related studies, MM&A requests the opportunity to review the information for significance relative to MM&A's findings and conclusions as presented herein.

Should you have additional questions, please call me at (919) 786-1414. Thank you very much.

Sincerely,

MARSHALL MILLER & ASSOCIATES, INC.



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