# CONDITIONS OF COAL ASH EMBANKMENTS

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ABSTRACT

There are nearly 500 coal ash disposal/treatment ponds contained by earthen and coal ash embankments up to 400 ft high in the United States.  They are not consistently regulated among states and many are not regulated under dam safety programs, instead relying on treatment pond (National Pollutant Discharge Elimination System) or disposal area (solid waste) regulatory programs.  In the wake of the dredge cell failure at the Tennessee Valley Authority (TVA) Kingston Fossil Generating Plant in 2008, the United States Environmental Protection Agency (USEPA) inspected 180 power plant facilities and more than 429 impoundments from 2009 through 2011.

This paper presents a statistical summary of the findings of the inspections for the following eight key characteristics: embankment hazard classification, height, downstream slope, evidence of failure, construction materials, evidence of seepage or sloughing, presence of woody vegetation, and major erosion or slope deterioration.

A summary of past failures is presented with an assessment of whether the key characteristics observed during the inspections are sufficient indicators of future failure.  The statistical data and the evaluation of past failures indicate that while embankment inspections are standard practice, they should not be solely relied upon to assess embankment safety.  Further, the Potential Failure Mode Assessment (PFMA) is offered as an additional method to assess the safety of embankments.

## INTRODUCTION

After the dredge cell failure at the TVA Kingston Fossil Generating Plant, the USEPA mandated inspections of disposal unit embankments at power plants between 2009 and 2011 as a part of their national effort to assess the management of CCRs.  Findings were summarized in USEPA Coal Combustion

Residuals Impoundment Assessment Reports (Reports). The Reports include a checklist for one or more disposal units at each facility.

The Reports for 180 facilities available on the USEPA website were reviewed.Footnote 1 The Reports contained 429 ash disposal unit inspection checklists. The number of disposal units in the data base is slightly more than 429 checklists because some disposal units shared an embankment and were therefore assessed in a single checklist. The checklists were completed by contractors with expertise in the area of embankment integrity and are stamped by a professional engineer.

This paper presents a statistical summary and discussion of checklist responses to key characteristics that are generally considered to be good indicators of embankment conditions and therefore potential failure of the disposal unit. In total, the inspection checklists requested information on 25 topics. Eight key characteristics of embankments were selected for use in this study because they are most likely to indicate potential for failure. The characteristics have discrete (e.g. a simple “yes” or “no”) or numeric responses.

This paper then provides a summary of six previous disposal unit failures, which are then compared to the key characteristics to evaluate whether the characteristics can be used as predictors of future failure. Finally, the paper addresses the ability of key characteristics and other inspection data to adequately assess the safety of CCR embankments.

*This paper was presented to the U.S. Society on Dams (USSD) for inclusion into their April 2015 conference in Louisville, KY. The audience for the USSD conference is primarily for design, maintenance and operation of water retention dams and not wastewater dams that is the focus of WOCA and its attendees. Therefore, the paper is being presented to a largely different audience at WOCA and is expected to provide both WOCA and USSD attendees significant informational value.*

## METHOD

The checklists enabled extraction of CCR disposal unit information in a consistent method despite a number of different authors and diverse facility site settings. Additionally, aerial imagery was acquired to aid in the review of facility layout and design characteristics. General information on facility location provided in the Reports was used to obtain accurate aerial imagery.

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[1] The electronic USEPA Coal Combustion Residuals Impoundment Assessment Reports repository used for this evaluation can be found at the following internet address: http://www.USEPA.gov/osw/nonhaz/industrial/special/fossil/surveys2/.

## Key Characteristics

A brief discussion of the eight key characteristics extracted from the inspection checklist follows.

Hazard potential classification.

The hazard potential classification is reported as one of the following four categories in the inspection checklist: high, significant, low or less than low. Embankments assigned a high hazard potential classification will likely cause the loss of human life in the event of a failure or misoperation. A significant potential classification describes embankments that are unlikely to cause the loss of human life in the event of a failure or misoperation but may result in economic loss, environmental damage, or disruption of lifeline facilities. Embankments whose failure or misoperation will not result in the loss of human life and have low economic or environmental losses are classified as having a low hazard potential. A less than low hazard potential classification rating is assigned to embankments resulting in no loss of human life, or economic or environmental losses in the event of failure or misoperation. Note that the hazard potential classification does not provide an indication of the potential for failure.

What is the dike/embankment height (feet)?

The maximum dike/embankment height for the embankment was typically provided in the inspection checklist or in the text of the Report. For facilities that contained two or more tiers, the total height of the disposal unit's dike/embankment was entered measured from the downstream toe to the crest at the highest point.

What is the dike/embankment downstream/outboard slope?

The downstream slope of the dike/embankment was obtained from text descriptions of the facilities or from review of drawings. In instances where a range was provided for the slope, the steepest slope was reported.

Is there evidence of failures (Y/N/Minor)?

The inspection checklist contains a section to discuss failures. If this section contained a discussion of past failures (generally defined as a slope stability failure on the outside slope or a failure resulting in the release of CCR materials through the embankment or overtopping the embankment to outside of the containment area) the question was answered “Yes”. An answer of “Minor” indicated that failures were not discussed in the inspection checklist but the report identified minor historic or current failures.

<u>What are the construction materials?</u>

Descriptions of the dike/embankment construction materials are recorded in the questionnaires as described in the Report. Responses to the dike/embankment construction materials query were reduced to two possible categories: "Ash" or "Other" during data processing. Materials classified as "Ash" include bottom ash, fly ash or flue gas desulphurization (FGD) waste. Embankments constructed with a mixture of ash and other materials were classified as "Ash". Embankments that did not include ash as a construction material were classified as "Other."

<u>Is there evidence of seepage and/or sloughing (Y/N)?</u>

Information on seepage and sloughing was obtained from the inspection checklist. The inspection checklist question regarding sloughing (checklist question #18) only provides information on conditions observed during the inspection. Seepage is addressed by two parts of the inspection checklist: (i) checklist question #21 addresses seepage observed during the inspection, and (ii) a supplement page is provided that requests information on past seepage and subsequent mitigation measures. A "Y" answer indicates sloughing and/or historic or current seepage has occurred at the facility.

<u>Are trees growing on embankment (Y/N)?</u>

Checklist question #9 relates the presence or absence of woody vegetation on slopes of the embankment.

<u>Is there major erosion or slope deterioration (Y/N)?</u>

Checklist question #19 of the inspection checklist relates the presence of major erosion or slope deterioration on the embankment.

**<u>Database Development</u>**

At an initial stage, the type of impoundment was identified based on the criteria in the USEPA inspection checklist. Incised impoundments were excluded from the analyses because they do not have the ability to fail like a diked impoundment. Cross–valley, embankment, side-hill impoundments, or any combination impoundment that included one of these three types, were retained in the analysis. Additionally, embankments were excluded if they were considered landfills or did not receive CCR.

Generally, the review was limited to the report text, tables, and figures in the Report, including the checklist. If data could not be found in the report after a reasonable examination, "unknown" was entered into the database. A "reasonable examination" included reading applicable sections of the text, tables, figures and the inspection checklist in the Report.

A Report was not prepared for the Kingston Dredge Cell Area as it existed in 2008. Therefore, to permit comparison to other facilities, information on physical and operational features for the Kingston Dredge Cell Area was obtained from other existing reports and interviews with knowledgeable personnel. The primary source of data was the 2009 "Root Cause Analysis of TVA Kingston Dredge Pond Failure on December 22, 2008"[1].

The authors did not verify the accuracy of the Reports. However, many of the Reports contain more than one value for the same key characteristic. For example, an impoundment's dike/embankment height may be assigned differing values on site drawings, in the main body of text, and in the inspection checklist. While these differences may represent reporting errors, discrepancies may also be attributed to actual variations in the dike/embankment height or to embankment alternations occurring over time. While such discrepancies were observed intermittently in the Reports, differences between the reported values were generally small.

Responses to the eight key characteristics are compiled in a Microsoft Access® database. From the database, trends and ranges in embankment characteristics are quantified.

Approximately 30% of the facilities were randomly selected for quality control (QC). Database output for 54 facilities (and all associated impoundments) was evaluated against the original Report to verify accuracy. Any errors identified during the QC review were evaluated to determine if disagreements were because of data entry error, differing report interpretation methods, or systemic data handling procedures. No systemic errors were identified in the QC review process.

Graphics were then created in Microsoft Excel®. Histograms relate the frequencies of numeric responses by bins.[Footnote 2] Summaries of characteristics having discrete responses are related in pie charts. Findings are discussed in the Results section.

## RESULTS

The results of the data assessment of all impoundments (greater than 429) described in the 180 Reports are summarized as follows:

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[2] Bin sizes are discrete intervals appearing on the x-axis of a histogram.

1. **Hazard potential classification.**

The hazard potential classifications of embankments described in the Reports are as follows: 45 (10%) high, 198 (46%) significant, 160 (37%) low, and 25 (6%) less than low (Figure 1). One embankment was not rated. Three of the embankments that had previously failed were classified as posing a significant hazard and three were classified as high hazard.

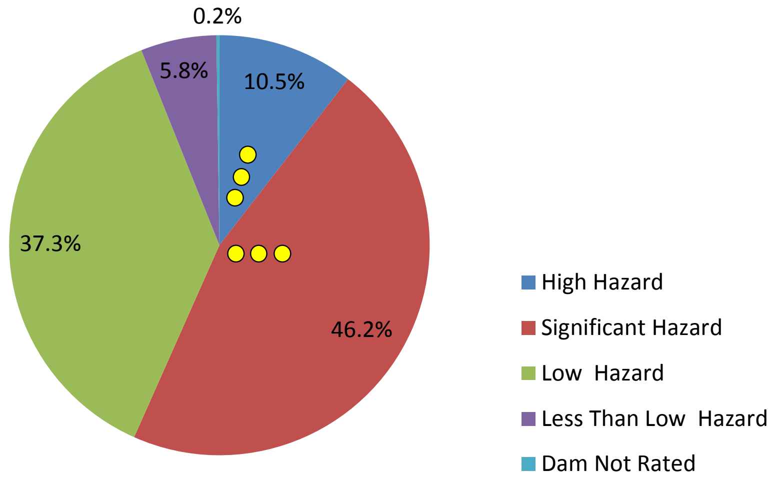


Figure 1. Hazard potential classifications of embankments.
Yellow circles indicate the category of failed embankments.

2. **Embankment Height.**

Histograms for embankment heights for all impoundments are provided in Figure 2. The tallest embankment (400+ feet) is at the FirstEnergy Little Blue Run impoundment. The results indicate the majority of the embankments had a height greater than 2 feet and less than or equal to 25 feet (227 embankments, 53%), and greater than 25 feet and less than or equal to 50 feet (132 embankments, 31%). The heights of the six embankments which have previously failed ranged from 28 feet to 85 feet, with four embankments in the 25 to 50 foot range, one embankment in the 50 to 75 foot range, and one embankment in the 75 to 100 foot range.

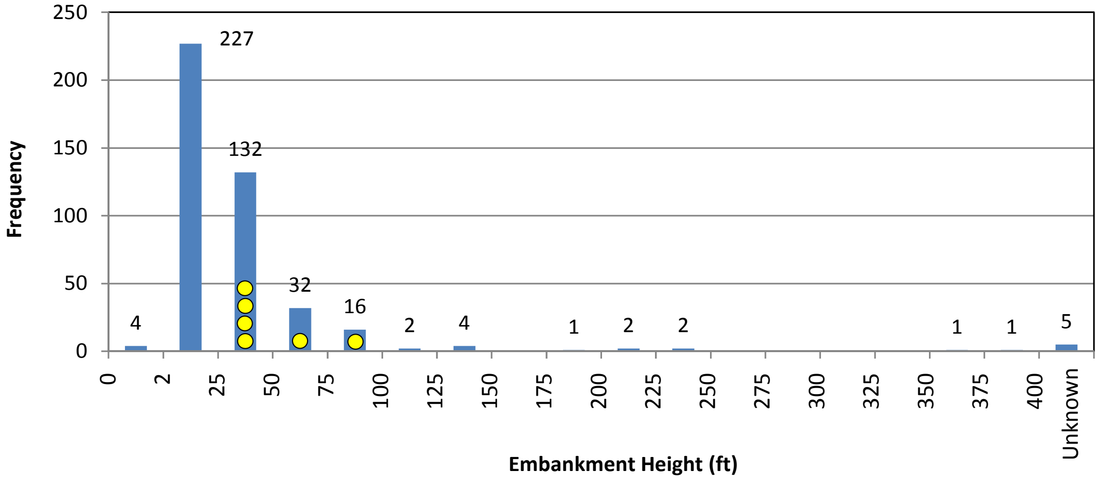


Figure 2. Embankment height. Yellow circles indicate the category of failed embankments. Bins are inclusive of their maximum value (e.g. 227 embankments have heights that are greater than 2 and less than or equal to 25 feet).

## 3. <u>Downstream slope.</u>

Reported downstream slopes of embankments ranged from 0.25H: 1V to 30H: 1V (Figure 3). The downstream slopes of 54 embankments were not described in the Reports. The median slope was 2.5H: 1V, the average slope was 2.67H: 1V, with a standard deviation of 2.3. Of the six embankments that previously failed, three had slopes of 2H: 1V, two had slopes of 3H: 1V, and one embankment had a slope of 4H: 1V.

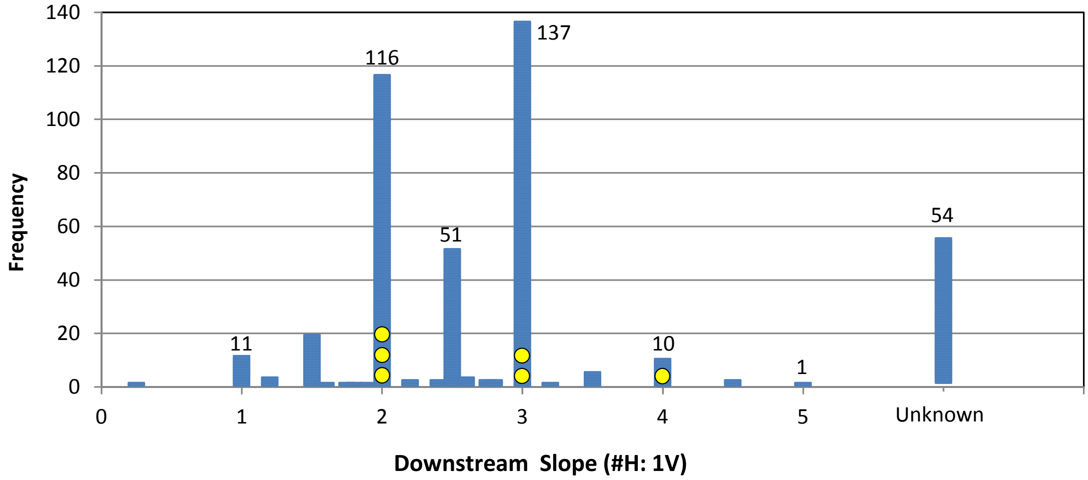


Figure 3. Histogram of downstream slope (#H:1V) of embankments.
Yellow circles indicate the category of failed embankments.
Three embankments with slopes greater than 5H:1V are not shown.

An example of the height of a 145-ft high, fly ash pond, earthen embankment and downstream slope are shown in Figure 4.

Figure 4. An example downstream slope of a fly ash pond earthen embankment.[2]

## 4. **Evidence of failures.**

Only *evidence of failures* that may lead to failure is included; the data exclude the six failed embankments or facilities if a feature other than the embankment failed. Four of the failed facilities occurred before the inspection and are excluded. The results indicate that a minor or significant failure has occurred at 73 (17%) of the reviewed CCR impoundments (Figure 5). The remaining 83% of embankments are reported to have no evidence of failures. One embankment (Primary Ash Storage Basin at the Dan River Steam Station) failed after the inspection. USEPA inspections for the five remaining embankments that failed prior to the USEPA inspections had evidence of failures that was not related to the more significant previous failure.

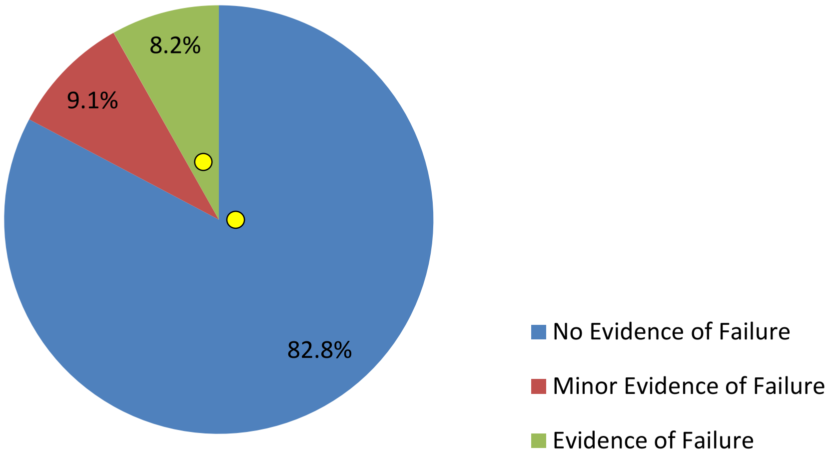


Figure 5. Evidence of failure of embankments.
Yellow circles indicate the category of failed embankments.

**5. Construction materials.**

The construction materials of 62 (14.5%) of the embankments reviewed are either entirely or partially of ash (Figure 6). The remaining 367 embankments reviewed (86.5%) are earth embankments and did not include ash. Three of the six embankments that previously failed contained ash.

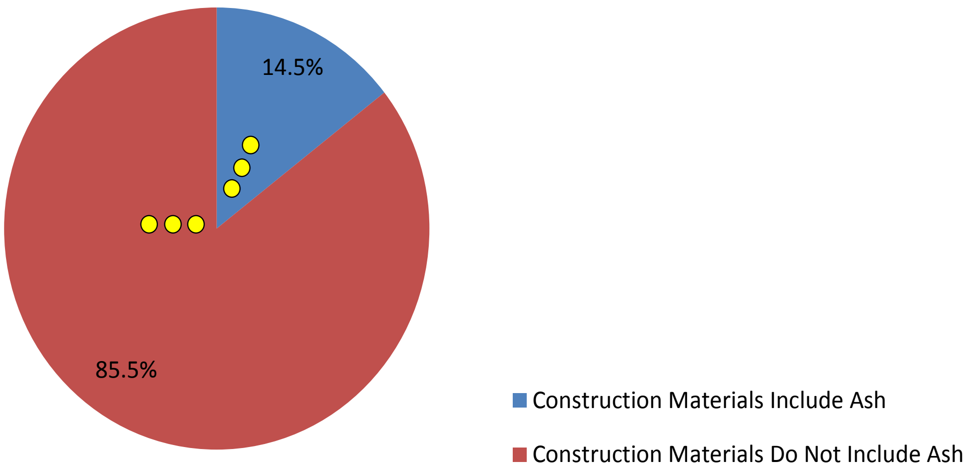


Figure 6. Embankment dike construction materials.
Yellow circles indicate the category of failed embankments.

**6. Evidence of seepage or sloughing.**

Evidence of seepage was present at approximately 40% (171 embankments) of the reviewed impoundments, including five embankments that previously failed (Figure 7). The remaining 60% of embankments (258) had no evidence of seepage or sloughing.

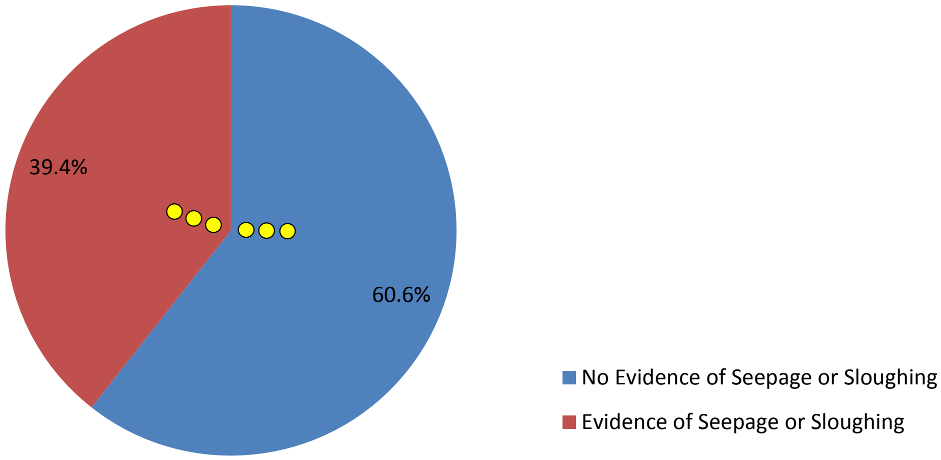


**Figure 7**. Evidence of seepage or sloughing observed on embankments. Yellow circles indicate the category of failed embankments.

An example of evidence of seepage is shown in Figure 8 and a slough is shown on Figure 9.

Figure 8. An example of perennially wet ground and cattails from seepage.[2]

Figure 9. An example of a slough/scarp.[3]

## 7. **Presence of Woody Vegetation**.

Woody vegetation was present on 167 (39%) of the embankments having Reports, including two embankments (Secondary Fly Ash Pond at Baldwin Power Station and the Gypsum Stack Embankment at Widows Creek Fossil Plant) that had previously failed (Figure 10). The remaining 262 embankments reviewed (61%) were reported to not have woody vegetation present on the slopes.

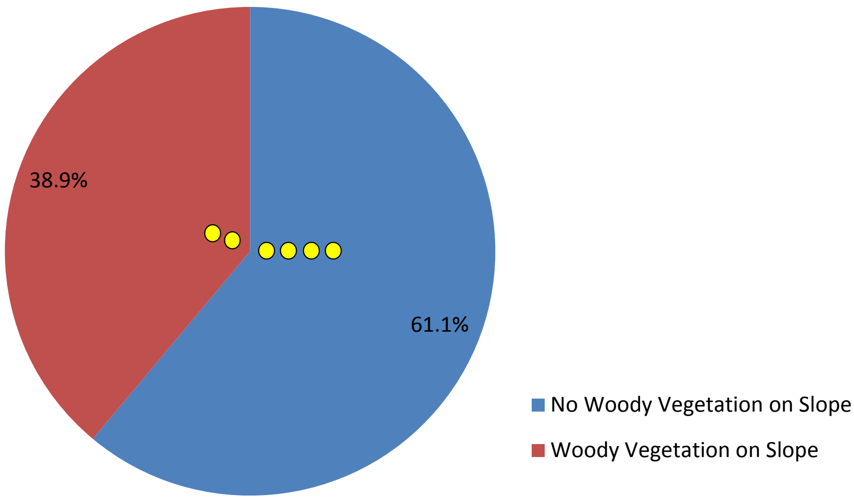


Figure 10. Woody vegetation on embankment slope.
Yellow circles indicate the category of failed embankments.

An example of woody vegetation on embankment slope is shown on Figure 11.

Figure 11. An example of woody vegetation on a downstream slope.[4]

## 8. Major erosion or slope deterioration.

The majority (364, 85%) of the embankments described in the Reports were reported to not have major erosion or slope deterioration (Figure 12). Five of the six embankments that previously failed reported no major erosion or slope deterioration; we have made the assumption that this condition was reflective of the failed facilities at the time of failure. The remaining 65 (15%) of the embankments reviewed reported major erosion, including one of the embankments that had previously failed.

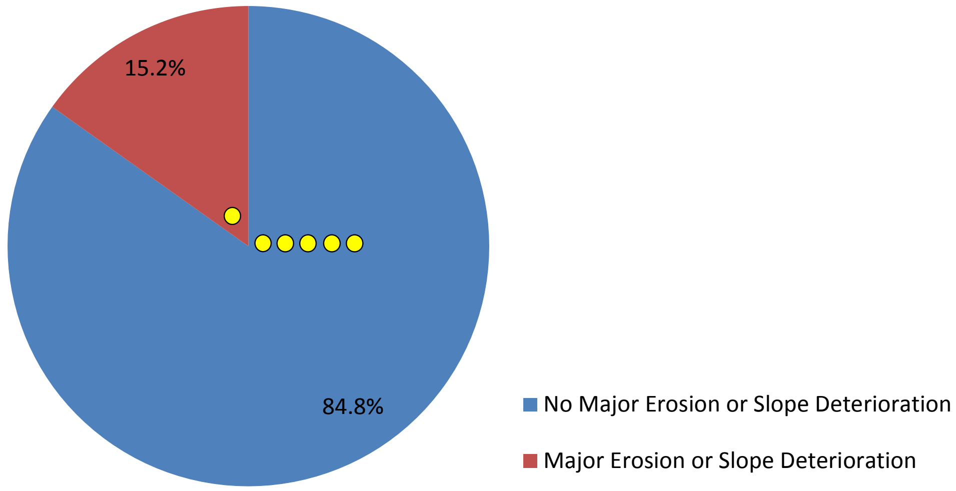


Figure 12. Major erosion or slope deterioration on embankment.
Yellow circles indicate the category of failed embankments.

## PREVIOUS FAILURES

This section presents a summary of documented failures. Failure is described as a loss of containment of CCR stored behind the embankment. The failures are presented chronologically from the oldest to most recent. Of the six failures, only one failure, that was located at the Dan River Facility, occurred after the inspection was conducted.

This section also examines: (i) whether the failure could have been predicted based upon information that was obtained during a visual inspection - for the case where failure occurred after the inspection; and (ii) whether the failure could have been predicted based upon information that would have been obtained if the inspection was conducted before the failure.

A summary of the eight key characteristics for six facilities with previous failures is presented in Table 1.

Table 1. Report Data for Failed Facilities.

| Impoundment Name | Hazard Classification | Embankment Height (ft) | Approximate Downstream Slope (#H:1V) | Evidence of Failure | Embankment Construction Material | Evidence of Seepage or Sloughing | Woody Vegetation on Slope | Major Erosion or Slope Deterioration |
|---|---|---|---|---|---|---|---|---|
| Dan River Steam Station Primary Ash Storage Basin | Significant | 40 | 2 | No | Other | Yes | No | No |
| Baldwin Power Station Secondary Fly Ash Pond | Significant | 55 | 3 | Yes | Other | No | Yes | No |
| Eagle Valley Generating Station Pond D | High | 38 | 3 | Yes | Ash | No | No | Yes |
| Eagle Valley Generating Station Pond E | Significant | 28 | 3 | Yes | Ash | No | No | Yes |
| Martin's Creek Electric Station Ash Basin Number 4 | High | 45 | 2 | Yes | Other | No | No | No |
| Tennessee Valley Authority Kingston Dredge Cell | High | 85 | 4 | Yes | Ash | Yes | No | No |
| Widows Creek Fossil Plant Gypsum Stack | Significant | 35 | 2 | Yes | Other | Yes | Yes | No |

## Baldwin Facility

The Baldwin Ash Pond Facility had a deep-seated embankment failure in 1995. The facility is located in Baldwin, Illinois. An aerial view is provided in Figure 13. The embankment was reported to be constructed using “earth fill” and “impervious fill” that is presumed to be locally obtained loess deposits and low plastic clay, respectively. The embankment was originally constructed to be 35-ft high and later was vertically extended with a 20-ft dam rising. The raised embankment was constructed out of clayey soil over bottom ash and with no offset from the original embankment.[3]

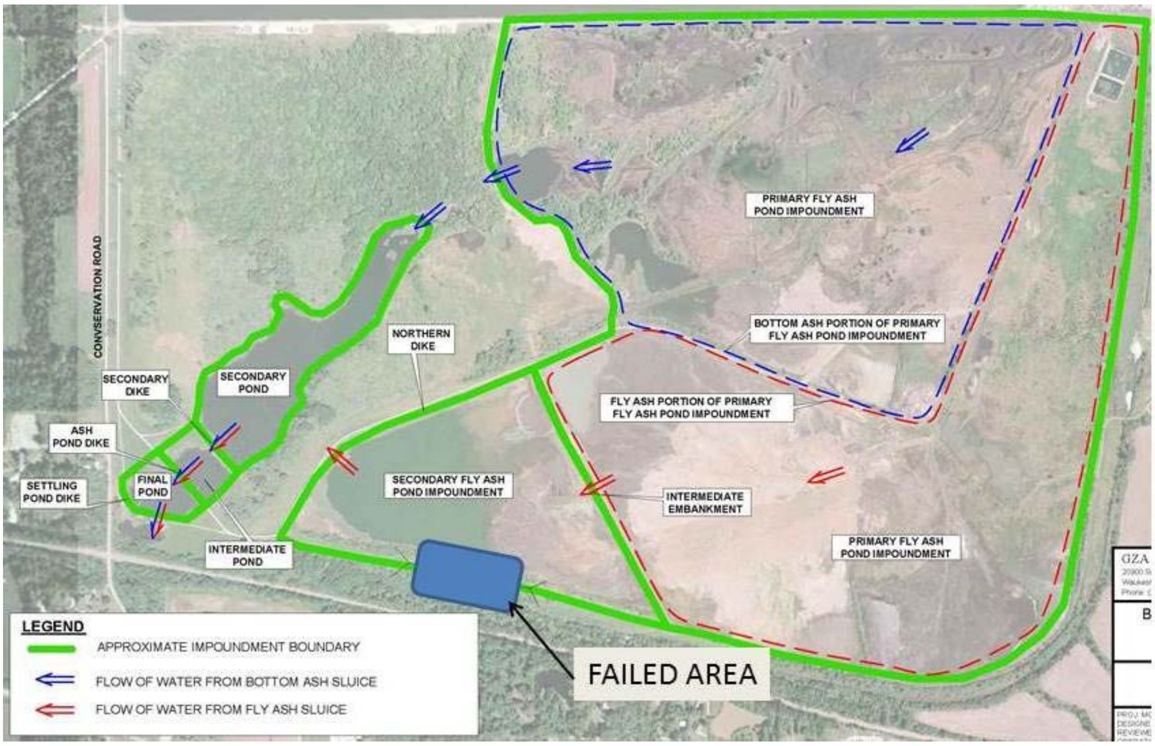


Figure 13. Baldwin Facility Site Plan[3], with highlights by the authors

The downstream side slope of the embankment where the failure occurred was 3H:1V. Failure analysis indicated that the failed section of the embankment had a factor of safety less than the generally excepted value of 1.5. No further information was provided.

Of the key characteristics, “evidence of seepage or sloughing” and “major erosion or slope deterioration”, were identified at the facility in the USEPA inspection. If those features existed before the failure, they would have been an indication of a higher potential for failure.

**Martins Creek Facility**

The Martins Creek Steam Electric Station Facility is located in Martins Creek, Pennsylvania. An aerial view is provided in Figure 14. The facility had four CCR treatment and disposal ponds that were utilized for disposal of CCRs. In 2005, an incident occurred where a discharge water system failed causing a significant release of water and fly ash. The mixture of water and fly ash spread into surrounding fields, into Oughoughton Creek and the Delaware River. The coal fired units have been retired since 2007 and the ponds were decommissioned.

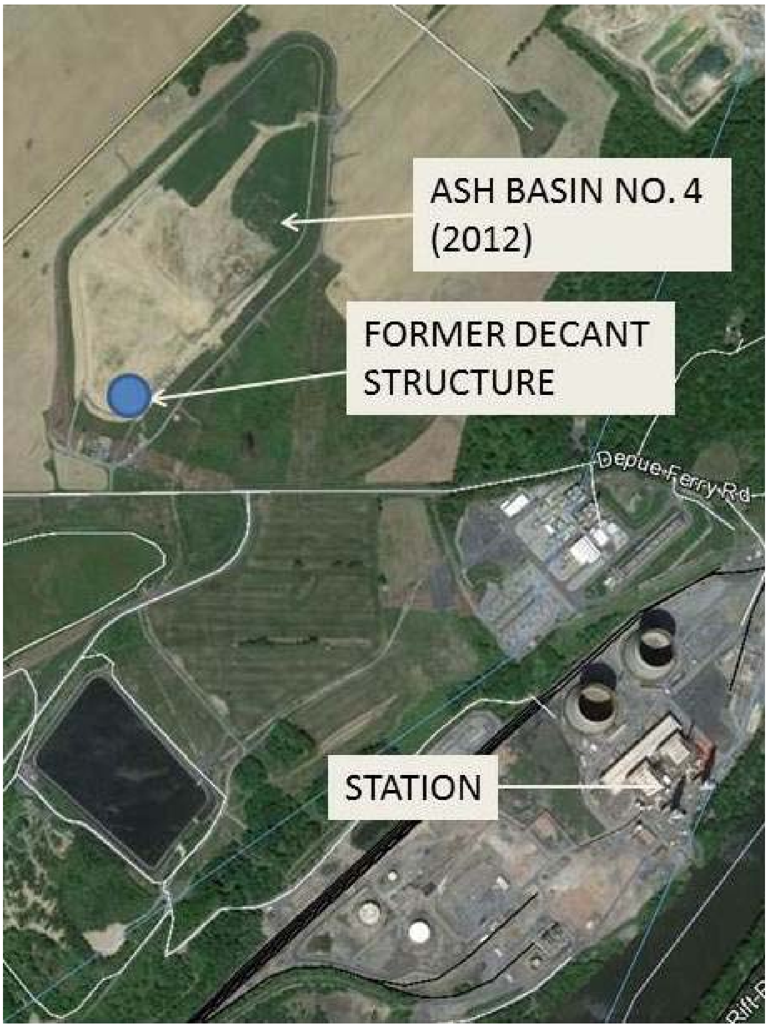


Figure 14. Martins Creek Site Plan.
Source: Google Earth, imagery date 5/19/2012

The cause of the failure was reported to be a failed wooden stop log, which was reported to have had a fabrication defect. The stop log was the second (out of forty) from the bottom and is presumed to normally have been submerged. Once the stop log failed, there was no shutoff valve in the discharge pipe or other secondary barrier to prevent the spill or slow the release. The failure of the stop log caused an uncontrolled release of approximately 100 million gallons of fly ash slurry over three day period[5]. USEPA considered this incident as a proven damage case based on the results of an environmental study conducted after the failure. It is reported the response action cost approximately $37 million.[6]

It appears that the failed stop log could only have been visually inspected using a remote underwater video camera. If it could have been observed, the defect would likely not have been detected through visual observation by remote camera inspection. It appears that none of the typical inspection characteristics would have identified a manufacturing defect and therefore the visual inspections could not have predicted this failure.

**Eagle Valley Facility**

The Eagle Valley Generating Station Facility is located north of Martinsville, Indiana. An aerial view is provided in Figure 15. It has five ponds (Ponds A through E) that receive various slurried CCR products for treatment. These ponds are separated with internal divider embankments.


Figure 15. Eagle Valley Site Plan[7], with highlights by the authors

The embankment was designed and constructed with generally 3H:1V slopes. Embankment failures occurred at the facility in 2007 and 2008. Both failures occurred in the same embankment separating Pond D and Pond E. The Reports indicate that the failed embankment was made of fly ash. The containment embankments were reported to be constructed of “compacted fill & ash” or “earthen/ash”. These two failure events are considered one failure because they occurred at the same location.

In 2007, the embankment between Ponds D and E failed causing Pond D to flow into Pond E causing the northern embankment of Pond E to overtop, releasing 30 million gallons of treated pond water into the discharge canal. A similar failure occurred in 2008 at the same location causing another 30 million gallons of treated pond water to spill into the discharge canal.

The cause of the 2007 failure was reported by BT Squared to be slope instability combined with piping (seepage that carries or erodes soil particles from within the embankment) through the embankment (CDM 2010). The cause of the 2008 failure was reported by BT Squared to have resulted from an overestimation of the shear strength of fly ash by the designer and the redesigned embankment was inadequate to support the loading conditions on the embankment between Pond D and Pond E.[7]

For an embankment failure of this type the steepness of the slope would be generally reflective of the design. For example, steeper slopes would be reflective that the embankment materials and subgrade are stronger than for an embankment with a flatter slope given an analysis yielding the same factor of safety for both slopes. Therefore, in both failure instances, the embankment slope, which is approximately 3H:1V, would not have been a good indicator of potential instability because all of the slopes for Pond D and Pond E were reported to be constructed at slopes of approximately 3H:1V and are constructed of similar materials and only the divider embankment failed.

Further, a visual inspection would not have been predictive of failure if the cause is a design parameter that was not reflective of the strength of the embankment. However, if piping would have been observed during an inspection, it could have been an indicator of potential future instability, or at a minimum, an indication that further analysis would be merited.

**Kingston Facility**

The Kingston Fossil Plant Facility is located in Harriman, Tennessee. An aerial view is provided in Figure 16. It had two main CCR handling areas: (i) Ash Pond C, used for treating and storing fly ash and bottom ash; and (ii) the FGD Landfill, used for storing FGD sludge. In addition to Ash Pond C and the FGD Landfill, the plant had a dredge cell to store fly ash (currently decommissioned due to the failure in 2008). The dredge cell had received CCR in the form of slurry until it reached its capacity in the early 1980s, after which the dredge cell was vertically expanded by constructing elevated cell containment embankments primarily out of ash. The expansion embankment was set back a minimum of 200 ft from the main embankment surrounding the dredge cell. The facility underwent a number of subsequent raisings of the containment embankment using the upstream construction method.

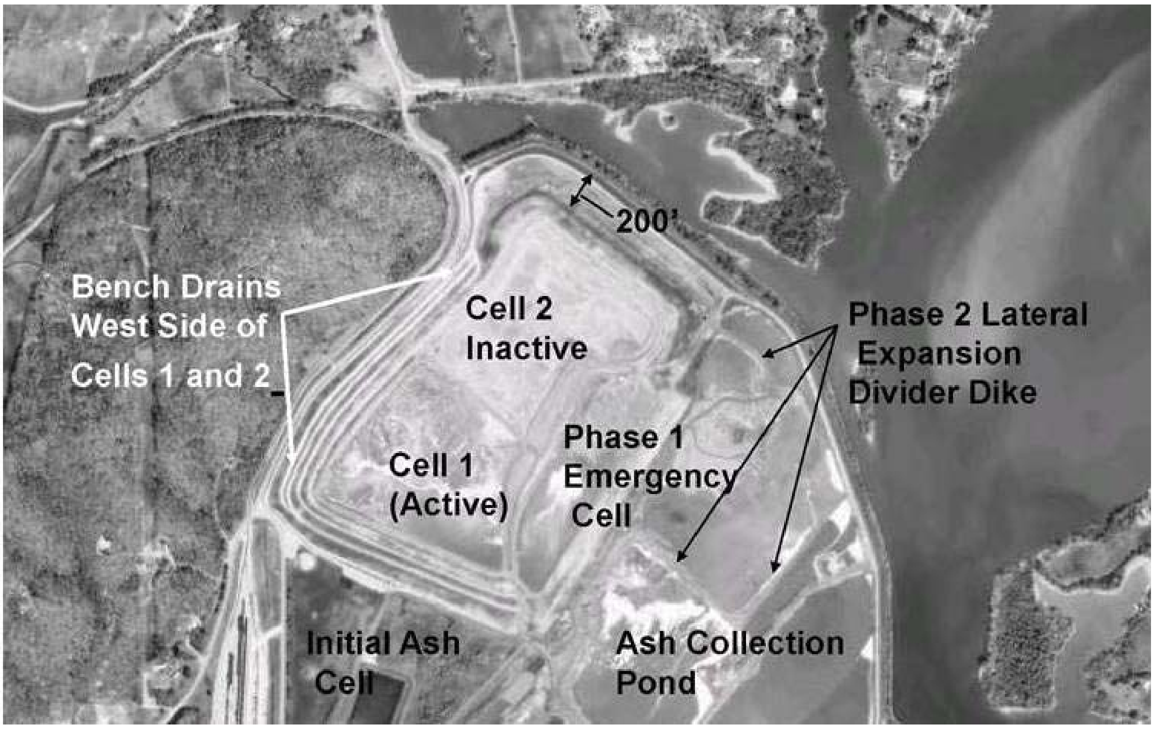


Figure 16. Kingston Dredge Cell Site Plan (2008).[1]

In 2008, the dredge cell had a major failure in the northern portion of the site causing an uncontrolled release of approximately five million cubic yards of ash slurry that flooded more than 300 acres of land, impacted the Emory River and Clinch River, disrupted power, ruptured a gas line, knocked one home off its foundation and damaged others. Fortunately, there were no casualties. The failure caused the largest ash release in the United States.

An aerial view of the facility after the failure is shown on Figure 17.

Figure 17. An aerial view of Kingston Dredge Cell 2 Failure[1]

The release occurred as a result of a series of progressive failures of dredge cell containment embankments that were constructed as part of vertical expansions of the dredge cell. The dredge cell containment embankments failed over a period of hours. It was reported that several factors lead to failure, including: i) the relatively fast rate of vertical expansion; ii) the nature of loose wet ash foundation materials below the containment embankments; iii) fill setback and geometry, and iv) unusually weak slimes layer located under the raised dredge cell containment embankments.[8] The cost of failure is estimated to be approximately $3 billion including the cleanup cost and ecological and socio-economic damages.[6]

The USEPA could not conduct an inspection of the facility as it had previously failed and was not rebuilt. However, the key characteristics from the USEPA inspection checklist were recreated by Geosyntec personnel that had worked at the dredge cell before the failure and from the Root Cause Analysis.[8]

The following key characteristics were identified in the recreated inspection sheet:

- Seepage was identified in areas that were addressed along Swan Pond Road by improvement of drainage (pore pressure relief) from behind the embankment. Because seepage mitigation did not occur on the failed embankment, it is assumed that seepage was not identified in TVA inspections along the failed embankment.

- Sloughing was identified along Swan Pond Road. Because sloughing mitigation did not occur on the failed embankment, it is assumed that sloughing was not identified in TVA inspections along the failed embankment.

- The slopes of the embankment were approximately 4H:1V which is significantly flatter than the majority of the data which indicates 42% are in the range of 2.5H:1 to 3H:1V. For comparison, the Eagle Valley divider dike was sloped at 3H:1V.

- Evidence of failure could be considered to have been identified along Swan Pond Road but that "failure" was not a loss of containment from behind the containment berm. However, the "failure" was relatively small (several dump trucks) from the surface of the embankment that was primarily made out of fly ash. This failure is more accurately considered a "slough".

- The embankment was constructed primarily of fly ash. The data indicate that 14% of the embankments evaluated for this study were made primarily of ash.

The inspection data collected does not appear to have been a good predictor of failure. The slopes were approximately 4H: 1V, flatter than other failed slopes constructed primarily of fly ash (failed embankment at the Eagle Valley facility had approximately 3H:1V slopes). Seepage and more importantly piping and significant erosion were not reported [Footnote 3] on prior periodic TVA inspections in the failed embankment. Further, one of the causes of failure was the slimes layer, which was not comprehended prior to the failure.

**<u>Widows Creek Facility</u>**

Widows Creek Fossil Plant Facility of Tennessee Valley Authority, located in Stevenson, Alabama, has two main CCR collection areas: (i) the Main Ash Complex – used for impounding fly ash and bottom ash; and (ii) the Gypsum Stack – used for storing gypsum. An aerial view is provided in Figure 18. The Gypsum Stack received sluiced gypsum prior to failure. TVA would then mechanically collect the wet gypsum, spread it out within the dredge cell for drying, and when dried, placed the material onto the stack.

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[3] Significant erosion was documented along Swan Pond Road, but that area was repaired and internal drainage was constructed and this portion of the embankment was not the main failed embankment.


Figure 18. Widows Creek Site Plan.[9] (Appended Stantec February 2010 Report of Phase 2 Geotechnical Exploration) with highlights by the authors

There were two incidents that occurred at the facility, one in 2009 and one in 2010, each causing an uncontrolled release of gypsum. In 2009, an abandoned weir from an internal drainage system failed releasing gypsum into the gypsum stack stilling pond and into Widows Creek.[9] Approximately 6.1 million gallons of slurry carrying approximately 5,000 cubic yards of gypsum and some fly ash was released into Widows Creek which flows into the Tennessee River. The cleanup cost for the 2009 incident was reported to be approximately $9.2 million.[6] USEPA did not classify this incident as a damage case, because samples at relevant points of potential exposure did not exceed applicable standards.[9]

In 2010, a newly constructed spillway pipe from a stormwater pond in the Gypsum Stack washed out causing gypsum to slide down the stack and into the stilling pond. It was reported that spill in 2010 was contained in the stilling pond[9] and was not released into nearby Widows Creek and therefore is not a “failure” as defined here.

It appears that none of the typical inspection parameters included in this analysis would have been a precursor to failure. However, checklist question 21 provides related information on seepage, including whether seepage is coming from “Around the outside of the decant pipe”. While it was an “abandoned weir” from an internal drainage system that failed and not a decant pipe, it could be presumed that an experienced inspector would have noted seepage from around the weir if it was on the inspection checklist.

**Dan River Plant**

The Dan River Plant is located in Eden, North Carolina. It has two ash ponds, the Primary Pond and Secondary Pond, both of which were utilized for impounding CCR slurry. An aerial view is provided in Figure 19. These ponds were constructed over 36-in. and 48-in. diameter stormwater pipes that had been installed prior to construction of the ash ponds. It was reported that a minimum of three feet of soil cover was maintained between the top of the stormwater pipes and the bottom of the ponds.[11]

Figure 19. Dan River Site Plan,[11] with highlights by the authors

In February 2014, a portion of the 48-in stormwater pipe under the Primary Pond collapsed[11], causing approximately 30,000 to 39,000 tons of ash to drain into the Dan River. A timeline of events is presented here:

http://portal.ncdenr.org/web/guest/dan-river-spill

Visual inspection of the collapsed pipe performed after the failure revealed that portion of the pipe where the pipe collapsed was corrugated metal pipe. The rest of the pipe was concrete[11].

It appears that it is unlikely that any of the typical inspection characteristics would have identified a precursor to failure of a buried stormwater pipe.

## CONCLUSIONS

The review of the selected data from the USEPA inspection sheets indicated that four of the six facilities did not inspect the features that contributed to failure. Of the other two, one (Eagle Valley) could have identified piping if the divider dike was on the inspection regime, and the other (Baldwin) did not have enough information to draw a conclusion.

Therefore, the inspection data do not appear to be reliable to predict failure based upon the six observed failures (which is a relatively small sample size) out of hundreds of facilities. However, inspections are required by the standards of the industry and are effective methods of maintaining embankments that reduces the potential for failure.

There are other tools available that could be used to assess the potential for an embankment to fail and develop a monitoring program to detect and mitigate signs of potential failure. These tools are the standard of practice for water retention dam safety in the United States. The Federal Energy Regulatory Commission (FERC) utilizes dam safety performance monitoring plan tools for hydropower dams. They can be found at:

http://www.ferc.gov/industries/hydropower/safety/guidelines/dspmp/background/per-plan.asp

In summary, FERC states:

> *"The Engineering Guidelines, Draft Chapter 14 titled, "Dam Safety Performance Monitoring Program" provides recommended procedures and criteria to develop a Performance Monitoring Program based upon "potential failure mode thinking" which assists in reviewing and evaluating the safety and performance of water retaining structures regulated by FERC".*

This approach can be used for any water retention structure, including embankments that retain water and wet CCRs. Essentially, a Potential Failure Mode Analysis (PFMA) is conducted and a Performance Monitoring Plan (PMP) is customized for the facility based on the PFMA.

Per FERC,

> *"The PFMA is conducted jointly by the licensee, Independent Consultant and FERC staff. This process is guided by a facilitator. For the most part the PFMA is a one-time exercise. Due to its "question asking approach" the potential failure mode examination process:*
>
> - *Enhances the dam safety inspection process*
> - *Enhances and focus the visual surveillance and instrumented monitoring program*
> - *Identifies shortcomings or oversights in data, information or analyses necessary to evaluate dam safety and a potential failure mode*
> - *Helps identify the most effective dam safety risk reduction measures.*
>
> *Based upon the results of the PFMA, the Performance Monitoring Program is developed. The PMP defines the appropriate monitoring for the water retaining structures based upon the PFMA."*

The integration of a PFMA with a PMP results in an efficient and effective dam safety program. The following are examples of the author's experience where a PFMA was conducted to identify and mitigate potential failure modes.

1. An abandoned spillway structure that had not been filled with concrete or grout under the embankment that eventually could collapse, similar to the Dan River facility, was identified and subsequently filled with grout to reduce the potential for such failure.
2. Deteriorating stop logs were identified and subsequently repaired, which reduced the potential for uncontrolled discharge, similar to the Martins Creek facility.

Additional potential failure modes (PFMs) were identified, prioritized and addressed such that the potential for failure was reduced. The keys to the success of the PFMA process was the openness of all Owner stakeholders (plant operations, safety, environmental and legal personnel) to identify the PFM, initiate and maintain a performance monitoring program, and prioritize mitigation to address the highest priorities first followed by lower priorities.

## QUALIFICATIONS

This paper presented the raw data from 180 inspection reports completed by many consulting engineering firms and took that data and compared it to six CCR facility failures. This paper did not provide an independent nor exhaustive analysis of all of the failures. Recognizing that most if not all of the six facilities also involve litigation and/or third party damage assessments, the conclusions are not intended to provide any new causes of failure or responsibility for failure, but relied upon statements in the literature that were available.

Therefore, conclusions have been drawn to provide general guidance that there are more thorough methods to assess embankment stability than uniform visual inspections. Those other methods are the PFMA and PMP processes implemented at FERC facilities.

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