Inventory, Inspection and Management Practices of CCR Facility Spillways at TVA Paradise Fossil Plant

Shane Harris¹, Stuart Harris, PE, PMP², Vincent J. Severance, PE³, and Erin Mattmiller, PE³

¹ Tennessee Valley Authority, P.O. Box 1010, Muscle Shoals, AL 35662
² Tennessee Valley Authority, 1101 Market Street, Chattanooga, TN 37401
³ Stantec Consulting Services, Inc., 1409 North Forbes Road, Lexington, KY 40511

KEYWORDS:
Coal ash spillways, spillway inventory, spillway inspection, spillway abandonment.

ABSTRACT
Poorly maintained spillways at coal combustion residuals (CCR) storage facilities can result in spillway failures and uncontrolled coal ash releases to the environment. Therefore, TVA performs a spillway management program for over 50 active and inactive spillway pipes and embankment penetrations at the TVA Paradise Fossil Plant in western Kentucky. The spillway management program consists of maintaining a current inventory list of active and inactive spillways, performing scheduled inspections of existing facility spillways, scoring spillways based on design deficiencies and inspection results, identifying spillways that require repair or removal, and developing construction plans for formal abandonment or removal.

This paper highlights the evaluation and management of coal ash facility spillways at TVA’s Paradise Fossil Plant, presents proper spillway inventory, inspection and abandonment methods, and provides lessons for operators of other coal ash storage facilities.

PROJECT OVERVIEW
The TVA Paradise Fossil Plant (PAF) is located in western Kentucky approximately six miles northeast of Drakesboro in Muhlenberg County as shown in Figure 1. PAF is situated on a 5.4 square mile reservation along the west bank of Green River. The plant has been in operation since the early 1960’s and currently consists of three coal-fired electric generating units producing approximately 1.1 million cubic yards of coal combustion residual (CCR) materials per year. CCR materials at PAF consist primarily of fly ash, bottom ash, and synthetic gypsum CCR which are stored in various ash ponds and dry stack storage facilities. Currently, TVA maintains over 50 active and inactive spillway pipes and embankment penetrations at PAF.
Since 2009, TVA and Stantec have performed a spillway management program at PAF consisting of maintaining a current inventory list of active and inactive spillways, performing scheduled inspections of existing facility spillways, scoring spillways based on design deficiencies and inspection results, identifying spillways that require repair or removal, and developing construction plans for formal abandonment or removal.

HISTORIC SPILLWAY FAILURES

A number of recent spillway failures and uncontrolled coal ash releases to the environment have demonstrated the need for mitigating risk with improved spillway management. In February 2014, the sudden failure of a storm water pipe located under an ash basin at a retired Duke coal plant resulted in a coal ash release into the Dan River.1 In 2009, a sudden failure of an abandoned spillway pipe at the TVA Widows Creek Gypsum Stack facility caused uncontrolled flow from an ash pond into a downstream sediment pond as shown in Figure 2. The spillway failure resulted in a coal ash release into the Tennessee River.
The failure was due to an improperly abandoned spillway pipe with only a concrete plug installed in the spillway inlet. Figure 3 shows the area of the failed spillway inlet.
ADDITIONAL SPILLWAY FAILURE EXAMPLES

In January 2010, a contractor had just installed a pipe to convey sluice water into a new cell at the TVA Widows Creek Gypsum Stack facility. During initial operation of the new cell, seepage and piping along the horizontal section of pipe resulted in a localized failure as shown in Figure 4.

Figure 4 – 2010 Failure Due to Seepage and Piping

At TVA’s Johnsonville Fossil Plant in 1994, joint separation failure of a spillway pipe resulted in surging flow conditions and development of a sinkhole over the top of the spillway pipe. An example of a pipe with joint separations is shown as Figure 5. A 1984 slope failure at TVA’s Shawnee Plant Ash Pond produced wave action across the pond and overturned the top two riser sections of two spillways.
Lastly, spillway failure was imminent at the TVA Widow’s Creek Ash Pond facility when TVA found that all five, 36-foot-tall spillways were leaning in the same direction at the same joint. TVA concluded a dredge operator tried to “push” ash up next to the spillways to stabilize them but actually pushed the structures over causing about a 1.5-inch-wide gap in each vertical riser joint, 10 feet below the water surface.

SPILLWAY COMPONENTS

The spillways at PAF primarily consist of two basic types:

1. Morning glory spillways, and
2. Flash board riser spillways.

Morning glory spillways are permanent structures typically used to transfer water from onsite to offsite to a receiving waterbody such as the Green River; such discharge points are often regulated by the state. The flash board riser spillways are typically used to transfer water from pond to pond and are less permanent. If necessary, the flash board riser spillways can be moved to better facilitate flow of sluice.

Six morning glory spillways are currently in service at PAF, and each of the morning glory spillways handles roughly 8 to 10 MGD on a routine basis. These spillways
discharge process water from the Peabody Ash Pond Stillng Pond facility to Jacobs Creek and the Slag Ponds Stillng Pond facility to the Green River. In addition, there are six abandoned morning glory spillways in the Jacob’s Creek Stillng Pond and the Coal Fines Complex.

Morning glory spillways at PAF Fossil Plant consist of a 48-inch-diameter vertical riser that rests on a 6-foot by 6-foot square base that rises 4 feet in a box style. A horizontal section of 36-inch-diameter pipe extends from the base of the structure and consists of Class IV reinforced concrete pipe. To mitigate blockage of the spillway, a 10-foot-diameter metal skimmer with three-inch angle iron supports rest on top of the concrete riser. None of the PAF spillways have end-wall treatments. The outfalls typically have riprap or some shotcrete channel lining to protect the embankment from erosion. Examples of morning glory spillways are provided as Figures 6 through 8.
The original 48-inch-diameter vertical riser sections were made from bell and spigot pipe. Since the late 1980's and 1990's the vertical sections are often raised by the use of manhole risers. Note the riser steps shown in Figure 9.
Sealing joints on morning glory spillways has historically been problematic at PAF. Joints in the older spillways had oakum packed into their vertical riser sections to provide for a watertight seal. Over time, the oakum would rot and leakage would take place. The newer riser sections are constructed using foam with a hydraulic grout, rubber gaskets or black mastic seals to prevent leakage. Examples of compromised seals are provided in Figures 10 and 11.

Figure 10 – Displaced Riser Joint Seal

Figure 11 – Leaking Spillway Riser Joint
The flash board riser spillways at PAF are mainly used for transfer of water from pond to pond at the Gypsum Stack facility. At PAF, these spillways typically consist of a corrugated metal half pipe structure approximately 48 inches wide that stands 8 feet tall or more. The horizontal pipe is typically an 18-inch or 24-inch-diameter fully coated bituminous corrugated metal pipe, PVC or HDPE pipe. The original flash boards would usually consist of 2-inch x 6-inch southern pine No. 2 boards. A typical flash board riser spillway is shown in Figure 12.

*Figure 12 - Typical Flash Board Riser Spillway*

**SPILLWAY FAILURE MODES**

For the purposes of developing a spillway priority ranking system, TVA and Stantec identified possible failure mechanisms associated with the various spillway configurations at PAF. Identified failure modes and example causes are discussed below.
SEEPAGE AND INTERNAL EROSION

Internal erosion in earth filled dams and dikes can lead to soil piping and eventually failure of the embankment. Internal erosion can advance quickly prior to detection, and remediation of damages can be very expensive.

- **Active Soil Piping** – soil piping is subsurface soil erosion and is most common in cases of improper compaction around pipes and inadequate seepage control. Uncontrolled seepage can erode soil from an embankment or foundation causing the formation of voids. Former voids then collect additional seepage causing the erosion to advance along the pipe and could potentially cause sinkhole formation resulting in embankment failure and loss of pool.

- **Sinkhole Formation** – sinkholes form when voids collapse to the ground or embankment surface. This condition can quickly lead to breach of the embankment or spillway pipe and sudden release of the pool.

HYDRAULIC FAILURE

Hydraulic failure is defined as a loss of pool via overtopping of the embankment. Blockage of the inlet or outlet of a spillway pipe by debris or other obstructions may affect the hydraulic capacity of the pipe and lead to overtopping of the embankment. Material deposition in outlet pipes could also affect the capacity of a spillway.

STRUCTURAL FAILURE

Structural failures of spillway components can result in an uncontrolled release of impounded water. Examples of structural failures are described below.

- **Surging / submerged outlet** – Due to low outlet pipe elevations, periods of high water levels on nearby rivers and lakes can cause submerged outlets and pipe surging, which may lead to joint separations or broken pipes.

- **Joint separation** – TVA’s spillway systems at PAF are constructed with unrestrained pipe systems. Joint separation of unrestrained pipe systems can occur due to differential settlement, pipe surging, or eccentric loading of risers.

- **Riser height** – riser systems consisting of unrestrained pipe and manhole segments are susceptible to tipping. Risers of greater height are more susceptible due to lack of lateral support.

- **Leaning riser** – extensive leaning of a riser could cause joint separation, seepage, and an increased susceptibility to tipping.
- Inadequate cover depth – inadequate cover depth can lead to pipe crushing under traffic or wheel loads.

- Pipe material – structural failure maybe attributed to corrugated metal pipe material due to susceptibility to corrosion.

- Erosion near outlet – erosion near the outlet of a spillway could eventually spread and wash out soil under the outlet pipe. If support soil is washed out from beneath the pipe, it may lead to pipe deflection.

- Eccentric loading at top of riser – eccentric loadings (i.e. access walkways, etc.) may lead to joint separations and tipping of riser structures.

- Stacked riser inlet – stacked risers do not have restrained joints and generally are not laterally supported. This condition poses a risk of joints separating or tipping due to impacts from operation equipment (barges, cranes, etc.), wave action, and eccentric loading among others.

**SPILLWAY MANAGEMENT PROGRAM**

After the 2009 spillway failure at the Widows Creek Gypsum Stack Facility, TVA recognized the need for a program solely dedicated to the management of spillways and other embankment pipe penetrations. TVA and Stantec initiated this work in 2010 with an inventory and prioritization of spillways and pipe penetrations at TVA’s twelve fossil plants located in Kentucky, Tennessee, and Alabama. Using the 2010 inventory, TVA and Stantec developed a Spillway Management Program for TVA’s Paradise Fossil Plant with the following goals.

- Identify, evaluate, and remove inactive spillways and embankment pipe penetrations.

- Identify and evaluate active spillways and embankment pipe penetrations that need to be repaired or replaced.

- Execute work plans for the removal, abandonment, repair, or replacement of the identified pipes as appropriate.

- Evaluate the condition of previously abandoned spillways and embankment pipe penetrations.

The Spillway Management Program is made up of the following components.

- Spillway Inventory

- Inspection Program

- Remedial Measures Program
Figure 13 shows how the Spillway Management Program components interact.

**Figure 13 - Spillway Management Program**

**SPILLWAY INVENTORY**

Stantec compiled a pipe inventory of active and inactive pipe penetrations at twelve TVA fossil plants located in the states of Kentucky, Tennessee, and Alabama. Stantec utilized the following sources to compile spillway inventory information at the PAF Plant:

- Stantec’s Phase 1 Facility Assessment;
- documents provided by TVA (e.g. historical drawings, inspections, etc.);
- plant personnel interviews;
- field observations.

Documents provided by TVA included inspection reports; previous spillway investigations; design and construction drawings; design feasibility and CCR management reports; permit documents; design calculations; aerial imagery; and various other correspondence and documentation. Stantec reviewed historical drawings for pipe locations which were noted and located in the field (if possible). If located and accessible, pipes were visually reviewed in an effort to determine their condition. Stantec reviewed TVA’s inspection reports and previous spillway
investigations to identify actions or recommendations associated with pipe maintenance or abandonment. TVA permit documents were also reviewed to assign outfall numbers to corresponding conduits in the spillway inventory.

Stantec conducted field visits to locate and observe (when possible) the general condition of spillways and other pipe penetrations. Data collection included documentation of active seepage areas, deposition in outlet pipes, submerged pipe outlets and presence of surging, joint separations in pipes (if accessible), leaning risers, pipe and riser material and type, and erosion near pipe inlets or outlets. Global Positioning System (GPS) units were used to estimate the location of pipe inlets and outlets when accessible during pipe inventory observations. Stantec also conducted interviews with plant personnel during site visits to gain additional information and identify concerns and issues related to spillways and pipe penetrations at PAF.

Stantec used the data collected during document review and field visits to create a spillway inventory/database for the PAF. Spillways and pipe penetration locations were added to the inventory using GPS or other coordinates estimated using historical drawings. Each pipe in the inventory was assigned a unique ID as shown in Figure 14. Since the spillway inventory was established, Stantec and TVA have referenced the unique pipe IDs in photo logs and annual inspection reports.

![Figure 14. Naming Convention](image_url)

Additional information (if available) for each pipe penetration was incorporated into the spillway inventory including description; condition; historical drawing numbers; NPDES permit discharge numbers; inlet and outlet invert elevations; riser heights; and documented problems and comments. A map illustrating the spillway inventory for the Gypsum Stack facility at PAF is provided as Figure 15.
PRIORITY RANKING SYSTEM

Stantec assigned each spillway in the inventory a relative ranking based on readily observable features to prioritize spillways with higher concerns and support TVA decision-making processes for the allocation of resources to mitigate risk associated with spillways and pipe penetrations.

Stantec established a scoring system that:

1. identified possible failure mechanisms associated with various spillway configurations;
2. accounted for the likelihood of failure for each failure mechanism with a weighting value; and
3. allowed the user to assign a factor to account for other conditions.

As the likelihood of failure for each failure mechanism increases, so does the weighting value for that mechanism. Failure mechanisms were divided into three primary categories: (1) seepage and internal erosion; (2) hydraulic; and (3) structural. Table 1 below details the weighting system failure categories and subcategories and corresponding weighting values and factors.
The score for each conduit was assigned by multiplying the weight by the weighting factor and summing these values for each potential failure mechanism. For example, a pipe with a stacked riser inlet (weight of 5 x factor of 1 = 5), 3-5 feet of freeboard (weight of 20 x factor of 0.5 = 10), a riser height of less than 10 feet (weight of 20 x factor of 0 = 0), and constant surging (weight of 30 x factor of 1 = 30) would receive a score of 45.

Limitations of the scoring system are related to the lack of available information and the inaccessibility of some pipe penetrations for direct observation. In addition, interdependencies of factors upon one another could lead to “dual weighting” which could result in higher scores. TVA and Stantec have not identified cases of interdependencies within the system; however, the potential for interdependencies should be taken into consideration when analyzing spillway scores.
ANNUAL INSPECTION PROGRAM

TVA performs annual inspections of all CCR disposal facilities to evaluate current conditions, document improvements since the last annual inspection, and provide recommendations for improvements and maintenance. The inspections consist of site walkovers and include visual inspections of spillway weirs, riser inlets, spillway outlet pipes, and storm water pipes. The inspection team records data including access points, size, type, material, riser height, and headwall type for each spillway and pipe penetration as applicable. Observed conditions such as joint separations, observations including the presence of joint separations, misaligned joints, leaning risers, and inlet/outlet blockage are documented for each structure with an inspection form and photographs. The inspection team prepares an annual inspection report to document field observations and provide recommendations such as further inspection, improvements, maintenance, and abandonment of spillway and pipe penetrations. A priority ranking is assigned to each recommendation that prescribes a timeframe for completion of the recommendation.

CCTV CAMERA SURVEYS

In 2014, Stantec completed design for two spillway improvements projects for the Slag Stilling Pond and Peabody Ash Pond at PAF. The proposed improvements included raising the crest of the overflow elevation in the ponds to provide required freeboard for the established design flood. Raising the crest elevation would also increase peak pool elevations resulting in increased head on the risers and discharges through the spillway. Prior to construction of the proposed improvements, TVA performed CCTV camera surveys of the spillway risers and discharge pipes to:

1. evaluate the existing conditions of the structures before changing their operational conditions and
2. obtain data to support recommendations for continued operations under the proposed conditions.

These surveys are typically performed with a video camera mounted on a remotely-operated rover vehicle as shown in Figure 16. The inspection team remotely operates the rover from a truck while viewing live video feed from the video camera. The operator moves the rover through the pipe to inspect its condition and record defects. The inspection team later analyzes the video footage to identify and classify defects using the National Association of Sewer Service Companies (NASSCO) Pipeline Assessment and Certification Program (PACP) coding standards. CCTV camera surveys are documented with an inspection report that includes a diagram which shows the entry and exit points for the camera rover and still images of identified defects.

CCTV surveys of spillways require significant planning to:

1. clean sediment and debris from pipes to provide access for the camera rover;
(2) determine the logistics required to access and inspect the spillways and

(3) identify and mitigate safety hazards associated with preparing for and executing the inspection.

For example, logistics for the inspection of the Slag Stilling Pond spillways included removing the morning glory skimmer, placing riser extensions to temporarily halt flow through the riser during the CCTV inspection, as well as removal of the riser extension and reinstallation of the skimmer. The CCTV subcontractor used a man-lift to inspect the Slag Stilling Pond spillways as shown in Figure 17.
REMEDIAL MEASURES PROGRAM

TVA has completed several remedial measures projects at PAF to mitigate risk associated with spillways and pipe penetrations. Projects completed to date involved spillway pipe repair, replacement as well as abandonment of unnecessary embankment pipe penetrations.

TVA typically initiates remedial measures projects with an analysis of possible alternatives for addressing the risks associated with the subject structure. Work plans consisting of a conceptual construction plan, material quantity estimate, and cost opinion are prepared for the preferred alternative. TVA uses the work plan to support final design and construction of the project.

SPILLWAY PIPE CLEANING

Spillway pipes must be properly cleaned to maintain adequate flow capacity when sediment and debris begin to accumulate within the pipe. TVA uses pipe cleaning contractors to professionally clean spillway pipes prior to performing CCTV surveys or to prepare the pipe for abandonment and grouting. A typical high pressure water probe used to clean spillway pipes at TVA facilities is shown in Figure 18.
SPILLWAY REPAIR

When feasible, TVA has typically repaired defective spillway pipes and riser structures. TVA is currently considering possible slip-liner pipe repair options for several aging RCP spillway pipes which exhibit defects such as minor pipe joint leaks, small pipe fractures, or root intrusions. Slip liner pipe repairs can extend the life of aging spillway components and are typically less expensive than spillway replacement options.

SPILLWAY REPLACEMENT

In 2009, Stantec and TVA replaced the Gypsum Stack West Pond spillway pipe and CMP flash board spillway riser. An old, brittle, PVC profile spillway pipe was replaced with a new, 408 foot long, 18-inch diameter, solid wall HDPE spillway pipe. The continuous joint-fused HDPE pipe provided improved durability and watertight joints. The pipe trench excavation and riser foundation for the new spillway installation is shown in Figure 19.
A new precast flash board spillway riser was also installed to replace the old CMP flashboard riser. The completed riser installation is shown in Figure 20.
In 2010, Stantec and TVA designed and installed a new CMP flash board riser and a 2000 foot long, 18-inch diameter, HDPE spillway pipe for a portion of the Gypsum Stack West Pond modified to facilitate several relocated gypsum/ash sluice lines. The completed riser installation is shown in Figure 21.

![Figure 21 – New Fabricated CMP Flashboard Spillway Riser](image)

**SPILLWAY ABANDONMENT**

Many historic spillway failures have resulted from low cost spillway abandonment/closure procedures such as leaving the spillway to remain open indefinitely or placing a small amount of concrete in the spillway inlet and covering the inlet with fill material. When spillways are no longer needed due to new spillway installations or facility closures, they should be properly abandoned or removed. In many instances, complete spillway pipe removal is not feasible or cost effective because the spillway riser and outlet pipe is deeply buried below constructed facility embankments and/or CCR material sediments. An example of a questionable abandoned morning glory type spillway is shown in Figure 22.
In 2010, TVA and Stantec performed an abandonment project to close a CMP flashboard riser and 18-inch diameter profile PVC spillway pipe at the Gypsum Stack West Pond. The CMP flashboard riser structure and a portion of the spillway pipe was excavated and removed, however approximately 360 feet of the remaining spillway pipe length was buried too deeply within the Gypsum Stack outer slopes to feasibly remove. TVA first hired a pipe cleaning and CCTV camera contractor to pressure clean and survey the full length of the remaining spillway pipe. After TVA and Stantec determined the pipe was structurally sound to remain within the embankment, Stantec designed a pressure grouting program to fully grout the remaining spillway pipe through the embankment.

The spillway grouting plan consisted of a reinforced concrete bulkhead constructed at the downstream pipe outlet equipped with a pressure grout inlet pipe and a vent pipe with valves as shown in Figure 23. Approximate 25 cubic yards of a 4,000 psi, pea-gravel based grout mix was pumped continuously into the downstream bulkhead while carefully monitoring grout pressure at the bulkhead to avoid bursting the PVC spillway pipe. Pressure grouting was continued until clean grout was observed flowing from the upstream end of the spillway pipe as shown in Figure 24.
Figure 23 – Reinforced Concrete Bulkhead for Pressure Grouting Spillway Pipe

Figure 24 – Observed Grout Flowing from Upstream Spillway Pipe Inlet
CONTINGENCY PLANNING

A typical spillway management program should also include contingency planning for spillway emergencies. TVA typically has equipment and stockpiled materials readily available if needed to temporarily stabilize damaged spillways or slope failures. A typical list of equipment and materials that TVA maintains available on site is listed below:

- 50 cubic yards of large diameter channel lining / riprap stone
- 50 cubic yards of 3” diameter crushed stone
- 50 cubic yards of river sand
- 500 feet of geotextile filter fabric
- 500 feet of geogrid reinforcement material
- 8 cubic yard dump truck
- Track mounted hydraulic excavator
- Small dozer

LESSONS LEARNED

The TVA Dam Safety Governance/Stantec team has learned lessons at PAF that can be applied to the spillway management of other, similar projects.

- A facility-wide spillway inventory should be developed and maintained.
- A facility-wide inspection program should be performed on a regular basis.
- Structural, hydrologic and hydraulic spillway evaluations should be performed when a CCR facility design is modified.
- It does not take a major embankment failure to result in a significant ash spill. A small spillway failure can cause a large ash spill.
- Improperly abandoned spillways are high risk for failures.
- All inspections, modifications, and abandonments should be properly documented with construction reports and record drawings.

CLOSURE

In response to recent spillway failures and uncontrolled coal ash releases to the environment, TVA and Stantec have initiated a spillway management program at PAF. The team mitigates risks associated with spillways and pipe penetrations by maintaining
a spillway inventory, conducting regular inspections, and executing remedial measures projects. TVA and Stantec will continue to update and refine the program components to address changing needs as the PAF Plant continues to generate power and comply with new CCR guidelines from the Environmental Protection Agency.

REFERENCES

