Instrumentation and Monitoring Program
TVA Coal Combustion By-Product Storage Facilities

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1. INTRODUCTION/BACKGROUND

Subsequent to the failure of the dredge cell at the Kingston Fossil Plant in December of 2008, the Tennessee Valley Authority (TVA) initiated an Instrumentation and Monitoring Program, along with seepage and stability evaluations, for the coal combustion product (CCP) storage facilities at each of TVA’s eleven coal fired power plants. The ten plants included in the Valley Wide Instrumentation and Monitoring Program include Allen (ALF), Bull Run (BRF), Cumberland (CUF), Colbert (COF), Gallatin (GAF), Johnsonville (JOF), John Sevier (JSF), Paradise (PAF), Shawnee (SHF), and Widows Creek (WCF), while Kingston (KIF) instruments were part of a separate monitoring program due to the on-going Recovery Project from the failure. The CCP storage facilities at these plants consist of ash ponds, scrubber sludge (gypsum) stacks or ponds, wet ash dredge cells and dry ash stacks. In some cases, as described later, the facilities were first developed as ash ponds and later converted to dry stacks constructed over the ash ponds. While several of the facilities have completed their design life; a majority of them are still currently receiving CCPs. Figure 1 below shows the location of the coal combustion plants in TVA’s valley-wide program.
Following the failure of the dredge cell at the Kingston Fossil Plant, Stantec was retained by TVA to perform geotechnical explorations at the eleven fossil plants in 2009 and 2010 to evaluate the facilities for acceptable Factors of Safety against slope stability failure and seepage piping failure. These explorations and engineering analysis were considered Phase 2 of a 4-Phase approach to the facility assessments and CCP management. During these initial and subsequent additional geotechnical explorations performed at some of the facilities, Stantec installed over 600 geotechnical instruments consisting of piezometers and slope inclinometers. The monitoring data was obtained manually from the instruments initially and used in performing the engineering analyses and stability assessments of the facilities.

After the completion of the Phase 2 Reports, Stantec was retained to establish a valley wide Instrumentation and Monitoring Program in 2010 for the recently installed instruments. The initial program scope consisted of continuing the collection of instrumentation data with manual readings, reviewing the instrumentation data after each reading, and performing follow up analysis, when necessary, at all eleven fossil plants. In June 2010, URS began taking manual readings and reviewing the data at the BRF, COF, GAF, JSF and WCF Plants, while Stantec continued taking readings at the ALF, CUF, JOF, PAF and SHF plants (Kingston Fossil Plant instrumentation is monitored outside the valley-wide Instrumentation Monitoring Program). Table 1 below shows each facility included in the Instrumentation Monitoring Program for each plant and the current consultant responsible for instrumentation monitoring and reporting to TVA.
### Table 1 - Instrumentation Monitoring Program Facilities

<table>
<thead>
<tr>
<th>Plant</th>
<th>Facility</th>
<th>Size (acres)</th>
<th>Storage Type</th>
<th>Contractor</th>
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<tr>
<td>Allen</td>
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<td>45</td>
<td>Ash Pond</td>
<td>Stantec</td>
</tr>
<tr>
<td></td>
<td>Dry Fly Ash Stack</td>
<td>46</td>
<td>Dry Stack</td>
<td>Stantec</td>
</tr>
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<td>Bull Run</td>
<td>Bottom Ash Disposal Area 1</td>
<td>40</td>
<td>Dry Stack</td>
<td>URS</td>
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<tr>
<td></td>
<td>Gypsum Disposal Area 2A</td>
<td>35</td>
<td>Gypsum Pond</td>
<td>URS</td>
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<tr>
<td></td>
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<td>41</td>
<td>Ash Pond</td>
<td>URS</td>
</tr>
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<td>50</td>
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</tr>
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<td></td>
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<td>Stantec</td>
</tr>
<tr>
<td></td>
<td>Gypsum Disposal Complex</td>
<td>100</td>
<td>Gypsum Stack</td>
<td>Stantec</td>
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<tr>
<td></td>
<td>Ash Disposal Area 5</td>
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<tr>
<td></td>
<td>Stilling Pond C</td>
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</tr>
<tr>
<td></td>
<td>Stilling Pond D</td>
<td>9</td>
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<td>URS</td>
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<td></td>
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<td>URS</td>
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<td>Stantec</td>
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<tr>
<td></td>
<td>Dry Fly Ash Stack</td>
<td>90</td>
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<td>Stantec</td>
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<tr>
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<td>J-Pond</td>
<td>22</td>
<td>Ash Pond (Closed)</td>
<td>Stantec</td>
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<tr>
<td></td>
<td>Bottom Ash Disposal Area 2</td>
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<td>Peabody Ash Pond</td>
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<td>Ash Pond</td>
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<td></td>
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<td>Stantec</td>
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<td>Shawnee</td>
<td>Ash Ponds 1 and 2</td>
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<td>Ash Ponds</td>
<td>Stantec</td>
</tr>
<tr>
<td></td>
<td>Consolidated Waste Dry Stack</td>
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<td>Stantec</td>
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<td>Ash Pond</td>
<td>URS</td>
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<td></td>
<td>Gypsum Stack</td>
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<td>Gypsum Pond</td>
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<td></td>
<td>Gypsum Stack Stilling Pond</td>
<td>9</td>
<td>Stilling Pond</td>
<td>URS</td>
</tr>
</tbody>
</table>

2. **TYPICAL CCP FACILITIES AND PURPOSE OF INSTRUMENTATION**

The CCP storage facilities at TVA’s fossil plants consist of ash ponds, scrubber sludge (gypsum) stacks or ponds, dredge cells and dry ash stacks. With construction of TVA’s fossil plants having begun as long ago as the late 1940’s, the CCP management units have undergone a continual process of new construction, expansion, rehabilitation, repair, modification, and/or closure (for the older or initial disposal facilities).

The majority of the facilities began as ash ponds when the plants were first operational. An initial starter dike was constructed out of clayey soil and CCP material was wet sluiced to the ponds. As the ponds reached capacity for the initial dike, in most cases the dike was raised to create more storage capacity. The raised dikes were built using the upstream method of construction, typically of clayey or CCP material. This continued as necessary for storage capacity, and the pool level within the pond would increase as well with each dike raising.
In some cases, ash would be dredged from an ash pond and hauled to a dry stack where the ash would be dumped and spread. These stacks were typically converted ash ponds where dry ash was being stacked over previously sluiced ash. If the fossil plants’ CCP disposal systems produced dry CCP material, then it would be trucked to the dry stack and continued to be placed over previously sluiced ash.

Gypsum began being produced when scrubbers were added at the fossil plants. Gypsum stacks/ponds were constructed in the same manner as ash ponds. Operations consisted of constructing an initial starter dike and sluicing gypsum material to the pond. A rim ditch was typically constructed along the interior perimeter of the stack crest and gypsum was excavated from the rim ditch and stacked on the perimeter of the dikes using upstream construction to raise the dikes.

Typical cross sections for the various types of facilities’ configurations are presented below. Figure 2 provides a typical cross-section of an ash pond with initial clay starter dike and upstream raised clay dike impounding sluiced water and ash.

![Figure 2 - Typical Ash Pond Section - Johnsonville Fossil Plant](image)

Figure 3 depicts a typical dry ash stack situated on top of a previous ash pond site. The site originally consisted of an ash pond with hydraulically placed ash impounded by an original starter clay dike and raised clay dike. Following reduction of capacity of the ash pond, and switching to dry placement of ash, the stack now consists of dry placed and compacted ash.
Figure 4 depicts a typical dredge cell. The facility consists of clay starter and raised dikes impounding hydraulically placed dredged fly ash. The upper perimeter dikes consist of placed bottom ash.

Figure 5 depicts a typical gypsum stack or pond situated on top of a previous ash pond site. The site originally consisted of an ash pond with hydraulically placed ash impounded by an original starter clay dike and raised clay dike. Following reduction of capacity of the ash pond, the facility was converted to a gypsum disposal area. These stacks now consist of dry or hydraulically placed gypsum impounded by either clay perimeter dikes or gypsum dikes constructed with the rim-ditching method of upstream construction.
Historical documents were reviewed to determine how each of the CCP facilities was constructed and target the geotechnical exploration sampling and instrumentation to specific critical cross-sections and material profiles. A lack of adequate sub-drainage systems to control seepage was noted during Stantec’s Phase 2 evaluation of the CCP facilities. In many cases, sub-drainage systems were either missing or not performing as designed based on a review of historical documentation and field observations. Because of this, the phreatic level across the dikes or stack embankments was uncontrolled. The high phreatic surfaces were noted as a potential cause for slope instability and seepage concerns. Previous localized slope failures and slope maintenance issues were noted at several facilities during earlier periodic inspections.

As part of the geotechnical explorations piezometers were installed to determine the phreatic surface and it’s fluctuations along each cross-section. This information was then used to calibrate seepage models, perform slope stability evaluations of the dikes and predict fluctuations in the phreatic surface based on routine operational changes of the facilities. Slope inclinometers were also installed at critical locations to monitor deep-seated slope deformations. The instrumentation data was used in conjunction with the engineering analysis to predict current Factors of Safety and monitor the possible variations in Factors of Safety over time.

3. STABILITY AND SEEPAGE ANALYSES AND DETERMINATION OF THRESHOLD VALUES

Seepage and stability engineering analysis were performed for each CCP facility utilizing the Geostudio suite of products. This package includes SLOPE/W module for slope stability analysis and SEEP/W module for seepage analysis. Subsurface conditions were modeled based on the Phase 2 and subsequent additional geotechnical explorations, and the instrumentation monitoring data collected since the instrument installations. Based on TVA’s Programmatic Document, the required minimum Slope Stability Factor of Safety (FS) is 1.5 and the Seepage Gradient FS is 4.0. The Phase 2 analysis was performed for static long-term conditions to compare current conditions against the programmatic requirements for each structure. The results of the analysis were presented to TVA for each structure, and recommendations were made to
implement remediation projects where the Factors of Safety were deficient as compared to the guidelines.

Phase 3 projects were designed and constructed to improve the Factor of Safety to acceptable values for each structure. During Phases 2 and 3 of the projects, the Instrumentation and Monitoring Program continued with a minimum of monthly data collection and status reporting to TVA on the instrumentation readings.

Following the completion of the Phase 2 analysis, threshold and action levels were developed for all piezometers and slope inclinometers monitored as part of this program to satisfy TVA Dam Safety guidelines. The threshold and action levels are used as part of the monthly instrumentation and monitoring program to provide a check of the current Factor of Safety of each structure in accordance with the fluctuations in instrumentation readings. For the analysis, two types of response levels were defined: Threshold and Action levels. A threshold level is defined as the water elevation in a particular piezometer reading that causes the long-term slope stability factor of safety to reach 1.5 during analysis. An action level is intended to signal a review of conditions that may be adverse, but may not necessarily be representative of deficient stability conditions. Examples for action levels include reaching a historical high reading, drastic changes in consecutive readings, a water elevation at the ground surface, a particular area is under repair with an existing factor of safety less than 1.5, or artesian conditions exist.

The static long-term slope stability analysis was utilized as a starting point for the threshold analysis to establish threshold and action levels for each piezometer. The consultants for the Valley Wide Instrumentation Project, Stantec and URS, were responsible for performing this analysis for their respective plant’s instruments. The purpose of the analysis was to evaluate potentially critical phreatic surface elevations encountered during the piezometer monitoring and to assess the potential impacts on seepage and slope stability. A summary of the general analysis approach is described below.

The threshold analysis approach relies upon variations in phreatic surface elevations at the piezometer locations. A sensitivity analysis was also performed to evaluate operational and design changes that may result in higher ash elevations and loading conditions. Additionally, long-term trends in the groundwater elevations in piezometers at the same cross-section were identified and utilized in selecting phreatic surface locations for the sensitivity analyses.

The key steps utilized in the analysis approach are outlined below. However, it should be noted that engineering judgment was utilized by each design team in evaluating the feasibility of these approaches for their facilities and site specific considerations.

1. Select a representative cross-section to model the analysis at a given instrument location.
2. Review previous analysis at the cross-section location for the following:
   a. Cross-section geometry;
   b. Boundary condition;
c. Loading conditions;
d. Pool elevation, river elevation and/or phreatic surface elevation;
e. Soil hydraulic parameters;
f. Soil strength parameters.

3. Update the existing models to incorporate the following:
   a. Revising assumptions and soil parameters based on Engineer's interpretation of the available data;
   b. Updating soil parameters based upon any supplemental investigation data;
   c. Changes in cross-section geometry, boundary and/or loading conditions resulting from construction or operational changes;
   d. Incorporating baseline phreatic surface as described below.

4. Create a baseline phreatic surface:
   a. Review historic piezometric data and geometry to determine appropriate piezometric elevation(s) for establishing baseline;
   b. Establish pool elevation from field measurements at the corresponding time of piezometric data and geometry. If the facility does not contain a static water source (pool), proceed to item 4.e. below;
   c. Incorporate known seepage locations from facility-specific Stantec Seepage Action Plans or other available field data and/or groundwater control measures into the baseline model;
   d. Use an iterative procedure in which seepage properties of the dike materials (hydraulic conductivity, hydraulic conductivity ratio) are varied within pre-established ranges until a reasonable match between the results of the SEEP/W analysis and piezometer, seepage and pool measurements is obtained. Where multiple piezometers exist in a cross-section, the above approach may not result in good agreement with the seepage model and in such cases may need to follow item 4.e. below;
   e. If no static water source (pool) exists at the facility, the baseline phreatic surface may be established using piezometric lines from representative historic measurements. However, engineering judgment will be required when applying this approach to other facilities and interpreting historic measurement data.
   f. Perform slope stability sensitivity analysis:
   g. Incorporate the above baseline phreatic surface into the slope stability model;
   h. Perform a slope stability sensitivity analysis at the selected cross-section location to establish the failure surface geometry and factor of safety;
i. If the cross-section geometry varies with time, rerun the slope stability sensitivity analysis for both the existing, interim and top elevation at the end of the calendar year.

5. Incrementally raise the baseline phreatic surface:
   a. Select a single (reference) piezometer location;
   b. Raise pool elevation and run SEEP/W analysis until baseline phreatic surface at the reference piezometer location is raised 1 foot;
   c. If no static water source (pool) exists, the established baseline piezometric line is raised in a one foot increment at the reference piezometer location;
   d. For multiple piezometers at the same cross-section, establish numerical correlation between the rises in the reference piezometer to the rise in the other piezometers based upon review of available piezometer data.

6. Establish Threshold Value
   a. Incorporate the incrementally raised phreatic surface into SLOPE/W, and utilize the failure surface established from the slope stability sensitivity analysis described above;
   b. Utilize this iterative procedure until resulting FS is 1.5. The elevation of the phreatic surface at the PZ location will be the threshold value;
   c. Note applicable site conditions and/or monitoring data at the threshold value that can be reviewed by field personnel to verify when the condition has been reached (i.e. pool elevation, seepage elevation, changes in piezometer elevation from baseline reading).

4. INSTRUMENTATION TYPES AND MONITORING PROGRAM SUMMARY

The Instrumentation and Monitoring Program utilizes different types of instruments to monitor early indicators of slope movement, settlement and potential failure modes of the CCP containment embankments. These instruments are strategically installed around the impoundment facilities, typically in series, located in cross sections at the crest, mid-slope, and toe, of the embankments. The three different types of instruments being utilized are piezometers (Standpipe, Vibrating Wire), slope inclinometers, and Sondex settlement systems. The total number and types of instruments for each facility is provided in Table 2. A portion of the standpipe piezometers at each facility have been automated, however, manual readings are still being collected on automated piezometers in order to validate automation and calibration records. Automated piezometers are included in the Standpipe Piezometer column in Table 2.
Table 2 – Total Instrumentation

<table>
<thead>
<tr>
<th>Plant</th>
<th>Standpipe Piezometer</th>
<th>Vibrating Wire Piezometer</th>
<th>Slope Inclinometer</th>
<th>Sondex Settlement</th>
<th>Total Instrumentation</th>
</tr>
</thead>
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<td>Allen</td>
<td>17</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>17</td>
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<tr>
<td>Bull Run</td>
<td>53</td>
<td>34</td>
<td>0</td>
<td>0</td>
<td>87</td>
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<tr>
<td>Colbert</td>
<td>63</td>
<td>12</td>
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<td>76</td>
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<td>4</td>
<td>0</td>
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<td>57</td>
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<td>0</td>
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<td>0</td>
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<td><strong>58</strong></td>
<td><strong>17</strong></td>
<td><strong>1</strong></td>
<td><strong>545</strong></td>
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Manual readings on these instruments are collected on a monthly basis (typical), and automated readings are transmitted hourly (in areas where instrumentation has been automated). Once all instrumentation has been automated and calibrated, manual readings are expected to cease.

The most common instruments utilized for early detection of slope instability is piezometers. Every TVA CCP facility has piezometers installed around their containment embankments. Piezometers are relatively easy to install, and do not require special hardware to collect readings. Piezometers measure pore water pressure to evaluate slope stability. Another instrument used for early indication of slope instability is slope inclinometers, which unlike piezometers are not installed at every CCP facility. Inclinometers require special measuring equipment and calibration factors to collect readings. Inclinometers are useful in measuring subsurface slope movement in embankments, and can provide an early indication and depth of the potential failure surface. Additionally, the instrumentation program uses Sondex settlement systems to measure the rate and amount of settlement in active stacking areas. The Sondex settlement systems are a recent addition to the Instrumentation and Monitoring Program, with additional installations planned in the near future. The purpose of these various instruments and details of their functionality are further described below.

**Piezometers**: Piezometers measure the water level depths within the containment embankments and the associated pore pressures. High water levels in the slopes, or exceedance of the slopes threshold level, are indicators that sloughing, lateral movement, or slope failure may occur. Piezometer locations vary from CCP facility to facility, although they are typically installed in series, meaning several piezometers are
Traditional standpipe piezometers can be installed during geotechnical subsurface investigations and do not require any calibrated components. Figure 6 shows a typical installation detail of a traditional non-automated standpipe piezometer, which consist of a PVC filter tip joined to a PVC riser pipe. Water flows from the surrounding soil, through the filter sand and into the slotted screen. Manual depth measurements of piezometers are collected by measuring the distance from the top of the piezometer, down to the water level with a water level indicator.

Vibrating wire piezometers are also used at some CCP facilities and consist of a vibrating wire pressure transducer and signal cable. Vibrating wire piezometers convert water pressure to a frequency signal via a diaphragm, a steel vibrating wire, and electromagnetic plucking and pickup coils. Vibrating wire piezometers are more difficult, and more costly, to install than standpipe piezometers, however offer several advantages. These advantages include increased accuracy, readability, and reduced cost for automation. Additionally, multiple vibrating wire piezometers can be installed at different depths at the same location. This allows for the monitoring of pore pressure at different zones in the borehole. Figure 7 shows a vibrating wire diagram configuration.
Slope Inclinometers: Slope inclinometers measure the lateral movement in the embankment, and establish whether movement is constant or accelerating. Slope inclinometer casings are installed in traditional boreholes and typically grouted in place or backfilled with a stiff material. Once a slope inclinometer is installed, a baseline reading of the initial embankment position is collected. All subsequent readings are compared to the initial reading and the amount and rate of lateral movement occurring within the embankment is determined. Inclinometer casing has groves, which ensure that the measuring probe for collecting readings remains uniform during data collection, as shown in Figure 8. During readings, the probe is drawn upwards from the bottom of the casing to the top, halted in its travel at 2-ft intervals for tilt measurements. The cumulative changes from each reading are plotted over time to create displacement profiles, which are useful for determining the magnitude, depth, direction, and rate of ground movement.

Figure 8 - Slope Inclinometer Casing and Measuring Probe

Sondex Settlement Systems: Sondex settlement systems are used to monitor settlement and heave in the active waste stacking areas of certain CCP facilities. The installation process for the Sondex is similar to that of a Slope Inclinometer, with the
addition of a corrugated sleeve with sensing rings around the inclinometer casing. The Sondex system consists of a probe, signal cable, and a cable reel with a built-in voltmeter, and a number of stainless steel sensing rings, as shown in Figure 9. Once installed, a baseline reading of the sensing ring depths is recorded, then all subsequent readings collected thereafter measure the amount of settlement or heave that has occurred in that location. The measuring probe is drawn through the center of the casing and a buzzer sounds when a ring is detected. A depth measurement is read from the survey tape. Settlement or heave is calculated by comparing the current depth to the initial depth.

5. MONITORING DATA COLLECTION AND REVIEW PROCESS

As discussed above, TVA manages a variety of CCP facilities spanning the states of TN, KY and AL. Due to the variability of site and facility conditions and use of multiple consultants and personnel, a flow chart was developed to facilitate a consistent and effective approach to collecting and responding to the instrumentation data. Figure 10 presents the Flow Diagram for Instrumentation Collection & Response. In addition, details of each step in the flow diagram are provided below. At each step in the flow chart, a yes or no response is required. If a yes response is provided, subsequent standard processes apply; however, if a no response is provided, additional action is required.
1. **Step 1 – Data Collection** – The first step in the process involves the collection of manual and automation readings at all instruments on a monthly basis. During data collection, a calibration is performed to assess the accuracy and physical condition of the recording instrument. Any deficiencies identified during data collected are reported to the Design Team and TVA PM (refer to Figure 11 below).
The depth to water in each piezometer is read using a manual water level indicator and recorded in the field data collection form to the nearest tenth of a foot. For piezometers that have a casing stick-up above grade, the length of stick-up is measured, and compared to the historical value, to verify if any changes in configuration have occurred. In areas where the stick-up changes more than 6 inches, a photograph of the piezometer with a ruler measuring stick-up relative to the ground surface is taken and physical conditions around the piezometer recorded. Observations of field conditions at the piezometer well are noted in the field data collection form using a standardized observation descriptor.

The physical condition of each instrument is observed and any damages or unusual conditions found are recorded on the field data collection form. Routine maintenance issues that can be repaired, such as missing caps on piezometer wells or inclinometer casing, accumulation of soil or water in flush mount casings, or missing bolts for protective instrument covers, are addressed by the data collection personnel.

![Flowchart Diagram](image-url)

**Figure 11 - Step 1 – Data Collection**
2. Step 2 – Field Interpretation – After collecting the manual readings, the next step includes a field comparison of water surface elevations to threshold levels and/or action levels. At instruments where these levels have been met or exceeded, manual data collection shall be repeated to confirm the data. In addition, at slope Inclinometers where 0.2 inches of movement and/or shear planes are developing and at Sondex settlement locations where changes between readings exceed 10% standard deviation, a second reading is obtained to confirm the data (refer to Figure 12 below). Field personnel also perform a field review and photo documentation of the surrounding area, checking for any signs of seepage along the slope, areas showing signs of slope lateral displacement including sloughs or scarps, and any other indicators that support reasoning for threshold/action level exceedance.

In the event that adverse changes or movement occurs, immediate notification is provided from the field. These conditions may include substantial rises in water levels above threshold/action levels, development of shearing planes within inclinometer data or observations of seepage or slope movements.

3. Step 3 – Field Response – All piezometers where the threshold level and/or action level has been met or exceeded are revisited during the same site visit for a second reading and third reading. The second reading is taken immediately to confirm the data, using another instrument, and then a minimum of 60 minutes
later, a third reading is obtained. The responsible manager is notified within 24 to 48 hours of an exceedance event (refer to Figure 13 below).

**Step 3.0 Field Response**

Recollect (2\(^{nd}\) and 3\(^{rd}\) Time) and Field Review; Notify Responsible Manager; Issue Resolved

- Yes
- No

**Issue Resolved**

Review and Evaluate Data

**Step 4.0 Threshold Assessment**

Assess Data; Reanalyze Slope Stability/Seepage; If Evaluation Period Reaches 7 days, global FS<1.5, Notify Dam Safety; Issue Resolved

Figure 13 - Step 3 – Field Response

4. Step 4 – Threshold Assessment – Piezometer readings that meet or exceed the threshold level and/or action level and slope inclinometers that exceed 0.2 inches of movement, in comparison to last month’s readings, and/or detect shear movement are evaluated by the Design Team. The evaluation typically includes reanalysis of slope stability and/or seepage and is performed within 24 to 48 hours of receiving notification of the exceedance event. Following the analysis, a decision is made by the Design Team on proceeding to Step 5, performing increased monitoring, or continuing with scheduled monthly monitoring and reporting. If the monitoring and evaluation period reaches 7 days and the global stability factors of safety are less than 1.5, then the notification is elevated to TVA’s Dam Safety Group for further evaluation (refer to Figure 14 below).
Figure 14 - Step 4 – Threshold Assessment

5. Step 5 – Increased Monitoring – During the increased monitoring phase, manual or automated readings are collected on a more frequent interval and the Design Team reviews the data and assesses the need to follow the Plant Seepage/Emergency Action Plan (SAP) and implement Step 6 (refer to Figure 15 below).
6. Step 6 – Temporary Stability Improvements (TSI) – Following the increased monitoring phase, if readings remain at or above threshold/action levels, the Design Team will assess the need for temporary stability improvements. The timing, methods, and implementation of the TSI is dependent upon site specific conditions and is to be coordinated with the plant and entire project team (refer to Figure 15 above).

7. Steps 7 and 8 – Assessment of TSI and Additional Instrumentation – Following the construction of the TSI, the final steps include evaluation of the adequacy of the temporary improvement for long-term stability and the need for additional instrumentation to facilitate future monitoring of the stabilized area. Upon completion of Steps 7 and 8, the exceedance event and associated stability concern is considered to be successfully remediated.
The results of the analyses, evaluations and associated conclusions from the above processes are presented in a formal monthly instrumentation report. Additional details of this report are presented below.

6. DESCRIPTION OF MONTHLY/QUARTERLY/ANNUAL REPORTING

The primary reporting frequency for summarizing the instrumentation data collected for each CCP facility is once a month. The manual instrumentation data readings are collected within the first two weeks of every month, with the corresponding report outlining the instrumentation data readings compiled and submitted at the end of the corresponding month. Automated readings are collected by TVA, and transmitted to URS and Stantec for analysis, and are incorporated into the monthly report. The monthly reports include a summary of the current month’s readings and any conclusions or observations based on the current readings. The reporting process is also completed on other frequencies, including quarterly and annual reports, in addition to the monthly reports. The quarterly report includes the same information provided in the monthly reports, yet additionally includes the number of instrumentation readings, any significant findings or trends established during that quarter, and the scheduled readings for the next quarter. Quarterly reports are submitted in place of monthly reports, every third month of the year. The annual report summarizes the readings collected, piezometric trends established, and site evaluations recorded during the previous year, and definition of the scope and schedule of work for the program for next year. The annual report is submitted at the end of each fiscal year.

The monthly piezometer readings are compared to the threshold/action levels to determine if corrective actions or emergency response procedures are necessary. The monthly report outlines the piezometric water levels in tabular and graphical form, as shown in Figure 16. Tabular piezometer data presents the current month, and previous two month’s water level readings, and the graphical data shows water elevations relative to the threshold / action level throughout the entire monitoring history. When a piezometer reading exceeds its threshold/action level, the stability of the slope where the piezometer is located is evaluated as discussed above. The results of the stability analysis and applicable conclusions and recommendations are included within the monthly reports.
Slope inclinometer data is plotted graphically, presenting comparative slope displacements from the baseline measurement to the present date, as show in Figure 17. Since special measurement devices are required to collect readings on inclinometers, only graphical representation of the slope’s movement is presented in the monthly reports. The reports also include any site observations made by the field personnel. In the event that slope movement exceeds 0.20 inches from the previous month’s reading, the location and extent of the movement is reviewed for current stability by plotting the information on pertinent cross sections. The results of the review and applicable conclusions and recommendations are included within the monthly reports.
Sondex Settlement data is collected manually using special measuring equipment that records the depth of each sensing ring installed. The monthly data is presented in tabular and graphical format, outlining the amount of settlement or heave occurring at that location. A settlement profile of a Sondex settlement system at an active dry stack is shown in Figure 18. During installation of the Sondex settlement system, boring logs are created providing detailed subsurface conditions throughout the installed depth. Therefore, when settlement occurs, the corresponding subsurface layer (soil or CCPs) can be compared to the sensing ring depth for further analysis. Settlement is also compared to the rate and amount of active stacking occurring in that area.
7. PROPOSED AND ONGOING AUTOMATION

Obtaining monthly, manual instrumentation readings on over 600 instruments at 10 fossil plants spread across the Tennessee Valley is not cost effective and often times does not represent a worst case scenario. There are significant costs associated with “boots on the ground” man power, even on a once a month basis as staff are required to travel hundreds of miles and spend 1 to 2 weeks collecting all of the data. Furthermore, the data collected during the monthly interval rarely corresponds to worst case scenarios the earth embankments and CCP stacks might be exposed to, like severe weather, as measurements are usually conducted during quiescent conditions. In order to acquire the most meaningful data, while simultaneously controlling the associated costs with instrumentation monitoring TVA initiated an ambitious program to automate the data acquisition process. To date, most active CCP storage facilities have undergone the first phase of the automation process and have had selected instruments automated. At this time TVA’s Generation and Construction Organization has the ability to download, remotely monitor, and analyze the instrumentation data and is working with consultants, Stantec and URS, who are still taking manual monthly readings at this time. TVA is working with its software provider, Geocomp, and consultants URS and Stantec to ensure that the data obtained by both the automated system and the manual readings are consistent.

The construction side of the program has continued to evolve in parallel with the evolution of the automated data acquisition system with the focus on keeping it flexible enough to meet new demands as the system continues through its transitional phases. Due to the extensive construction occurring through the Tennessee Valley at its facilities, TVA was inspired by the idea of achieving the maximum amount of flexibility at structures that are or will soon be undergoing large scale construction projects. In order to install automation in areas with a high volume of heavy equipment traffic, the TVA team looked to create a way of automating the instrument in which the hardware could be removed and the instrumentation protective features be flush mounted to allow for manual readings during construction and then return the automation hardware at the completion of the construction project.
The original design shown in Figure 19 included a permanent installation which utilized sonotubes filled with concrete as the base for the bollards, remote stations, and risers.

![Figure 19 – Original Instrumentation Automation Design](image)

The current design shown in Figure 20 utilizes lifting lugs so that the entire pad with bollards, riser, and remote station can be moved if need be for any reason. This design is not only cost effective, but has significantly reduced damages to existing instrumentation and the need for repair and/or replacement.
8. THE FUTURE OF THE INSTRUMENTATION PROGRAM

Moving forward, all of the instrumentation data and associated information will be stored in electronic formats and will be geo-referenced in a Web-accessible Microsoft SQL Database Management System. The instrumentation data will then be utilized to feed geotechnical computational models that are used to predict potential failure modes. In the future TVA engineers and/or Partners/Consultants will have the ability to remotely monitor instrumentation data for all automated facilities using Web browsers and Hand-held device application(s). The program will continue to put its main focus on event driven monitoring and other changes of a significant nature such as rainfall, earthquakes, and river or pond water level elevation changes. Sudden and/or anticipated changes will trigger more frequent reading intervals of instruments as well as a staged alarm system response. This will include future instrumentation that is planned and includes strong ground motions detectors such as accelerometers and seismometers for site seismic/dynamic measurements, and those for monitoring Quality Control (QC)/Quality Assurance (QA) performance of CCP Stacking Operations such as Intelligent Compaction detectors, GPS controlled CCP Hauling/Compaction Equipment movement trackers, and other types of sensors based on site specific needs determined during the initial Potential Failure Mode Analysis (PFMA) that will be conducted as part of Phase II of the Instrumentation Automation Program.