- Cracks in the masonry walls were observed within a radius of about 20 ft of Column MG-15. These cracks included stair-stepping cracks on the east, south, and west walls of the break room; stair-stepping cracks on the north and west walls of the restrooms; a horizontal crack on the east wall of Technical Support Center Room 127; and stair-stepping cracks on both walls of the Technical Support Center Corridor 126 east of the entrance to Room 127. Additional detail is provided in the discussion of KDI #3 (see Section 4.0).
- GPR performed on the floor slab near Column MG-15 identified possible voids below the floor slab. Additional detail is provided in the discussion of KDI #3 (see Section 4.0).
- Holes drilled through the floor slab near Column MG-15 identified a void below the floor slab up to about 0.667 ft thick. Additional detail is provided in the discussion of KDI #3 (see Section 4.0).
- A solution containing a florescent dye was poured through the expansion joint gap adjacent to Column MG-15, and the Turbine Building sump pit was observed for 24 hours for evidence of the dye. No dye was observed in the Turbine Building sump pit during the observation time. It was later found that the dye was able to penetrate no further than approximately 3 feet into the relatively impermeable compacted lean clay fill which is present below the floor slab at this location.
- Thin-walled Shelby tubes samples were collected at two test boring locations near Column MG-15 between the bottom of the floor slab and about 4 ft below the bottom of the floor slab. Material was logged as silty clay and clayey silt fill with dry densities ranging from about 97 to 106 pcf and water contents ranging from about 17 to 25 percent. Typical Standard Proctor values for this material would have maximum dry densities ranging from about 102 to 107 pcf and optimum water contents ranging from 17 to 19 percent. Additional detail is provided in the discussion of KDI #3 (see Section 4.0).
- The geotechnical report prepared for the original portion of the Maintenance Shop, "Report of Subsoil Investigation for Proposed Maintenance Shop Addition to the OPPD Fort Calhoun Station," dated July 14, 1977, identified dry densities and water contents in the existing fill that are outside the typical values for structural fill consisting of similar soil. Borings B-1 and B-4 both show silty clay to clayey silt fill with dry densities ranging from about 92 to 95 pcf and water contents ranging from about 20 to 24 percent. Typical Standard Proctor values for this material would have maximum dry densities ranging from about 102 to 107 pcf and optimum water contents ranging from 17 to 19 percent. The geotechnical report did not recommend removal of the low density existing fill below the structure.
- As early as 1993, excessive flow into a sump in the Turbine Building basement was observed. Subsequently, this flow was attributed to unfiltered groundwater entering breaks in drainage pipes under the Turbine Building basement floor slab. The Turbine Building is located south of and adjacent to the Maintenance Shop.
- In 1997 a void, estimated to be approximately 10 x 8 x 1 ft, was documented below the basement floor slab in the Turbine Building. For further information see Section 5.8. A more detailed discussion of this KDI is presented in Section 4.1.

6.4.3 Assessment Methods and Procedures

6.4.3.1 Assessment Procedures Accomplished

Assessments of the Maintenance Shop included the following:

- A visual inspection of perimeter rooms on the lowest level, upper level offices, and the exterior walls along the north and east sides to look for signs of structure distress

- A visual inspection of the walls of the Technical Support Center adjacent to the Maintenance Shop to look for signs of structure distress
- An assessment of survey data collected to date to determine if deformation trends are occurring
- A review of previously documented condition reports, building plans, and geotechnical reports to look for conditions that could be affected by the 2011 flood
- Observation of the Turbine Building sump pit for 24 hours for evidence of a solution containing a florescent dye that was poured through the expansion joint gap adjacent to Column MG-15.
- GPR in the corridor near Column MG-15 to look for anomalies below the floor slab
- Drilling through the floor slab in the corridor near Column MG-15 and visual inspection below the floor slab with a borescope to visually observe whether voids are present below
- SCP tests to a depth of about 5 ft in each of the drill holes near Column MG-15 to determine the stiffness and consistency of the subgrade soils
- DCP tests to a depth of about 25 ft in some of the drill holes near Column MG-15 to determine the stiffness and consistency of the subgrade soils
- Geotechnical test borings adjacent to Column MG-15
- Results of KDI #1 forensic investigation (see Section 4.1)
- Results of KDI #3 forensic investigation (see Sections 4.3 and 8.3)

6.4.3.2 Assessment Procedures Not Completed

No additional assessment procedures were identified for the Maintenance Shop.

6.4.4 Analysis

Identified PFMs were initially reviewed as discussed in Section 3.0. The review considered the preliminary information available from OPPD data files and from initial walk-down observations. Nineteen PFMs associated with eight different Triggering Mechanisms were determined to be "non-credible" for all Priority 2 Structures, as discussed in Section 3.6. The remaining PFMs were carried forward as "credible." After the design review for each structure, the structure observations, and the results of available geotechnical, geophysical, and survey data were analyzed, a number of CPFMs were ruled out as discussed in Section 6.4.4.1. The CPFMs carried forward for detailed assessment are discussed in Section 6.4.4.2.

6.4.4.1 Potential Failure Modes Ruled Out Prior to the Completion of the Detailed Assessment

The ruled-out CPFMs reside in the Not Significant/High Confidence category and for clarity will not be shown in the Potential for Failure/Confidence matrix.

Triggering Mechanism 2 – Surface Erosion
CPFM 2a – Undermining shallow foundation/slab/surfaces

Reasons for ruling out:

- The structure was protected from floodwater by an Aqua Dam for the majority of the 2011 flood; however, the Aqua Dam failed for a short period of time because it was damaged, which allowed floodwater to enter the area inside the perimeter of the Aqua Dam.

- Surface erosion was not identified near the structure at the time of the site observations.

Triggering Mechanism 4 – Hydrostatic Lateral Loading (water loading on structures)
CPFM 4a – Overturning
CPFM 4b – Sliding
CPFM 4c – Wall failure in flexure
CPFM 4d – Wall failure in shear
CPFM 4e – Excess deflection

Reason for ruling out:

- Distress to the structure that can be attributed to this Triggering Mechanism and associated CPFMs was not identified at the time of the site observations.

Triggering Mechanism 5 – Hydrodynamic Loading
CPFM 5a – Overturning
CPFM 5b – Sliding
CPFM 5c – Wall failure in flexure
CPFM 5d – Wall failure in shear
CPFM 5e – Damage by debris
CPFM 5f – Excess deflection

Reasons for ruling out:

- Sufficient high floodwater velocities were not identified near the structure.
- The structure was protected from floodwater by an Aqua Dam for the majority of the 2011 flood; however, the Aqua Dam failed for a short period of time because it was damaged, which allowed floodwater to enter the area inside the perimeter of the Aqua Dam.
- Distress to the structure that can be attributed to this Triggering Mechanism and associated CPFMs was not identified at the time of the site observations.

Triggering Mechanism 6 – Buoyancy, Uplift Forces on Structures
CPFM 6b – Cracked slab, loss of structural support
CPFM 6c – Displaced structure/broken connections

Reasons for ruling out:

- The building floor slab is at el. 1007.5 ft, which is above the peak flood elevation of approximately 1006.9 ft.
- The elevator pit floor is at el. 1003 ft, which would have been susceptible to buoyancy and uplift forces. The elevator pit is a rigid structure supporting mezzanine columns and should be able to resist buoyancy and uplift forces. Visual observation of the elevator pit did not identify distress that can be attributed to this Triggering Mechanism and associated CPFMs.

Triggering Mechanism 7 – Soil Collapse (first time wetting)

CPFM 7a – Cracked slab, differential settlement of shallow foundation, loss of structural support

CPFM 7b – Displaced structure/broken connections

CPFM 7c – General site settlement

Reason for ruling out:

- Review of previous geotechnical borings, current field observations, and current field and laboratory testing did not identify low quality fill or conditions that would result in subgrade or column settlement of the magnitude observed. Additional detail is provided in the discussion of KDI #3 (see Section 4.3 and 8.3).

Triggering Mechanism 9 – Swelling of Expansive Soils

CPFM 9a – Cracked slab, differential heave of shallow foundation, loss of structural support

CPFM 9b – Displaced structure/broken connections

Reasons for ruling out:

- Expansive soils were not identified in the geotechnical report.
- Distress to the structure that can be attributed to this Triggering Mechanism and associated CPFMs was not identified at the time of the site observations.

Triggering Mechanism 11 – Loss of Soil Strength due to Static Liquefaction or Upward Seepage

CPFM 11a – Cracked slab, differential settlement of shallow foundation, loss of structural support

CPFM 11b – Displaced structure/broken connections

CPFM 11c – Additional lateral force on below-grade walls

Reason for ruling out:

- Liquefaction was not observed at the site in the vicinity of the Maintenance Shop and surrounding structures.

6.4.4.2 Detailed Assessment of Credible Potential Failure Modes

The following CPFMs are the only CPFMs carried forward for detailed assessment for the Maintenance Shop as a result of the 2011 flood. This detailed assessment is provided below.

Triggering Mechanism 3 – Subsurface Erosion/Piping

CPFM 3a – Undermining and settlement of shallow foundation/slab/surfaces (due to pumping)

The Maintenance Shop has observable settlement of a column (MG-15) in the corridor running east to west. The column was noted in CR 2010-4755 when the settlement was first observed. On June 30, 2011, Column MG-15 dropped down abruptly, as referenced in OPPD CR 2011-5895. Further investigations have determined voids to exist below the slab in the vicinity of the

settling column. These voids may be attributed to CPFM 3a. Further information on this investigation and findings are given under KDI #3 in Section 4.3.

The Turbine Building, which is located south of and adjacent to the Maintenance Shop, has a void below the foundation slab that was first documented in 1997. This void was confirmed via a borescope through holes drilled in the foundation slab and camera recordings of broken drain piping under the floor slab. According to OPPD personnel, groundwater has been flowing at varying rates through these broken pipes into the sump pit from 1993 to the present day. The rate of flow into the sump is directly related to the hydraulic head of the groundwater. As the floodwater increased in elevation across the site, observed flow rates increased. The flow of groundwater into this drain piping system through the breaks in the pipes are addressed under KDI #1, in Section 4.1. This drain pipe system was designed as a closed system; therefore, the pipes are not surrounded by appropriate filter systems to preclude the transportation of soils from the surrounding area under the slab. It is logical to assume that because the groundwater moves below the foundation and into the broken pipes, some movement of the soil has occurred. These voids may to continue under the Maintenance Shop, and could be large enough to cause the overlying soils to collapse. The structures supported by this soil would become unsupported and possibly experience settlement.

The following table describes observed distress indicators and other data that would increase or decrease the potential for degradation associated with this CPFM for the Maintenance Shop.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
A documented void exists under the foundation slab of the Turbine Building with a known hydraulic connection between groundwater elevation and unfiltered groundwater flows into the sump pit.	
Column MG-15 in the Service Building has settled approximately 2 in.	
The floor slab near Column MG-15 has a void below it up to about 0.667 ft deep.	
The masonry walls within a radius of about 20 ft from Column MG-15 have signs of distress.	
Data Gaps: • None	

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

Voids below the foundation slab in the Maintenance Shop and the Turbine Building are known to exist with a possible connection between them. Because the 2011 flood caused increased groundwater flow through the broken drain pipes, and abrupt settlement of the Maintenance Shop column occurred during this increased flow period, the potential that the flood caused

further and more rapid degradation due to this Triggering Mechanism and associated CPFM 3a is high.

Implication

The occurrence of this CPFM could cause settlement of the shallow foundations or slab on grade and has the potential to cause cracking of the walls, cracking of the slabs, or distress to the architectural coverings. If degradation occurred it would be slower to develop and would allow time to respond with corrective action which is what has been observed to date. Minor amounts of settlement would be considered a serviceability problem, not a strength or safety issue. Therefore, this implication of the potential degradation for this CPFM is low.

Confidence

Further data collected under KDIs #1 and #3 discussed in Section 4 have increased the confidence to high for this CPFM (see Section 8.3).

Summary

For CPFM 3a, as discussed above, the combined consideration of the potential for degradation and the implications of that degradation to a structure of this type puts it in the "significant" category. The extensive additional forensic investigations for KDI #1 and KDI #3 have resulted in a high confidence in the above assessment, and more data or continued monitoring and inspections are not necessary to draw a conclusion.

6.4.5 Results

The CPFM evaluated for the Maintenance Shop is presented in the following matrix, which shows the rating for the estimated significance and the level of confidence in the evaluation. CPFM 3a for the Maintenance Shop is associated with KDIs #1 and #3. Sections 4.1, 4.3, and 8.3 present the results of additional forensic investigations that were conducted to ascertain whether the CPFM could be ruled out. The results of the additional forensic investigations show that if the recommendations for physical modifications in KDI #1 and KDI #3 are implemented that this CPFM will be ruled out. Therefore, the CPFM will be moved to the quadrant of the matrix representing "No Further Action Recommended Related to the 2011 Flood."

	Low Confidence (Insufficient Data)	High Confidence (Sufficient Data)
Potential for Failure **Significant**	CPFM 3a	
Potential for Failure **Not Significant**		

6.4.6 Conclusions

In the assessment of the FCS Structures, the first step was to develop a list of all Triggering Mechanisms and PFMs that could have occurred due to the prolonged inundation of the FCS site during the 2011 Missouri River flood and could have negatively impacted these structures. The next step was to use data from various investigations, including systematic observation of the structures over time, either to eliminate the Triggering Mechanisms and PFMs from the list or to recommend further investigation and/or physical modifications to remove them from the list for any particular structure. Because all CPFMs for the Maintenance Shop other than CPFM 3a, 7a, 7b, and 7c have been ruled out, and because CPFM 3a, 7a, 7b, and 7c will be ruled out when the physical modifications recommended for KDIs #1 and #3 in Sections 4.1, 4.3, and 8.3 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Maintenance Shop. HDR has concluded that the geotechnical and structural impacts of the 2011 Missouri River flood will be mitigated by the implementation of the physical modifications recommended in this Assessment Report. Therefore, after the implementation of the recommended physical modifications, the potential for failure of this structure due to the flood will not be significant.