5.13 Circulating Water System

5.13.1 Summary of Circulating Water System

Baseline information for the Circulating Water System is provided in Section 2.0, Site History, Description, and Baseline Condition

The Circulating Water System is composed of two cast-in-place concrete tunnel components that provide water from the Intake Structure to the Turbine Building and discharge from the Turbine Building to the river. The tunnel structures intersect and stack at the southwest corner of the intake structure and remain stacked under the Service Building. The tunnels rotate to side-by-side where they extend under the Turbine Building. The discharge tunnel extends along the west wall of the Intake Structure then turns 60° east to the outlet located at the riverbank between the Intake Structure and the Condensate Storage Tank. The bottom of the tunnel is generally at el. 972.5. The top of the tunnel is at el. 997 ft where the tunnels are stacked and el. 986 ft where the tunnels are side-by-side. The system is founded on 12-in.-diameter Class B steel pipe piles that are driven to bedrock and concrete filled. Some Class B piles are designated as tension piles and include reinforcing dowels to provide positive tension connection to the foundation mat.

The Intake Structure, Service Building, and Turbine Building are supported on deep foundations with bottom floor elevations of 966 ft, 1007.5 ft, and 990 ft, respectively.

The raw water discharge pipe and the Turbine Building sump pump pipe discharge into the Circulating Water Discharge Tunnel.

5.13.2 Inputs/References Supporting the Analysis

Table 5.13-1 lists references provided by OPPD used to support HDR's analysis.

Table 5.13-1 - References for Circulating Water System

Document Title	OPPD Document Number (if applicable)	Date	Page Number(s)
Piling Plan Turbine Room & Service Building	11405-S-274, Rev. 11 (#16506)	1/17/1975	
Piling Plan Intake Structure	11405-S-275, Rev. 6 (#16507)	1/20/1975	
Circulating Water Tunnels Plans	11405-S-299, Rev. 7 (#16522)	1/22/1975	
Circulating Water Tunnels Section & Details	11405-S-300, Rev. 6 (#16523)	1/22/1975	
Intake Structure & Tunnel Foundation Plan & Details	11405-S-311, Rev. 2 (#16531)	1/23/1975	
Intake Structure & Tunnel Sections & Details	11405-S-317, Rev. 8 (#16537)	1/9/1975	
Intake Structure & Tunnel Miscellaneous Details	11405-S-320 Rev. 5 (#16540)	1/29/1975	
Incident Report Summary	CR 2011-5369	6/5/2011	All

Table 5.13-1 - References for Circulating Water System			
Document Title	**OPPD Document Number (if applicable)**	**Date**	**Page Number(s)**
Incident Report Summary	CR 2011-5254	6/1/2011	All
Incident Report Summary	CR 2011-5321	6/3/2011	All
Incident Report Summary	CR 2011-5323	6/3/2011	All
Incident Report Summary	CR 2011-5377	6/5/2011	All
Incident Report Summary	CR 2011-5384	6/6/2011	All
Incident Report Summary	CR 2011-5473	6/10/2011	All
Incident Report Summary	CR 2011-5737	6/22/2011	All
Incident Report Summary	CR 2011-5805	6/26/2011	All
Incident Report Summary	CR 2011-5932	7/1/2011	All
Turbine Building 6" and 10" Floor Drain Pipe Breaks	(Summary of CR2009-1365)	Unknown	All
Design Basis Document – Geotechnical	PLDBD-CS-54	Unknown	All
Summary Report of Broken Floor Drain Pipes		3/24/2009	All

Detailed site observations—field reports, field notes, and inspection checklists—for the Circulating Water System are provided in Attachment 8.

Observed performance and pertinent background data are as follows:

- No utilities are known to cross under the Circulating Water System.
- The Trenwa, Main Underground Cable Bank (between MH-31 and MH-5), Fire Loop, Raw Water Piping, and a group of 7 pipes encased in concrete are known to cross over the top of the Circulating Water Tunnels.
- Concrete pavement in the corridor that extends between the Service Building and the Intake Structure exhibits conditions that indicate distress, including cracking, slab settlement, and undermining. Pavement slab settling was observed northwest of the Intake Structure and east of the abandoned acid tank. A hollow-sounding pavement area was noticed east of the Service Building truck dock. Pavement cracking was evident throughout the entire area, although most of the pavement cracking could be pre-existing conditions due to the age and use of the facility.
- [redacted]
- The Aqua Dain that surrounded much of the PA bisected the Circulating Water Tunnel.
- The Class B piles consist of pipe with 12.75-in. outside diameter and 0.25-in. wall thickness, which meets ASTM A252 Grade 2 (F_y = 35 ksi). The piles were driven closed-ended to refusal on bedrock and filled with 4000 psi concrete (see PLDBD-CS-54).
- Below is a summary report of broken floor drain pipes with reference to CR2009-1365:
  - CR2009-1365 was created on March 24, 2009.
  - There are two drain lines that run parallel to each other; the 6-in. floor drain and the 10-in. waterbox drain. A vendor was brought in to visually inspect the drain lines because undocumented water was observed draining into the sump pit from both lines. They found a break in the 10-in. drain at the branch tee from the VD-193 drain valve. They could not inspect

the 6-in. floor drain because the line does not have a cleanout connection in this area and accessibility through floor drains is restricted by the drain trap at each location.
- Review of system files shows that a break in the waterbox drain line has been known since at least 1993. In 1997, a repair was attempted by core drilling holes in the vicinity the break and pressure grouting to seal the pipe. Per the "Water Systems Report Card for Report Period April 1 Through June 30, 1997" (memo PED/EOS SYE 97-123):

> Repair of the Turbine Building Basement Drain line header was attempted during this period. The repair procedure consisted of core drilling holes in the vicinity of the leak and pressure grouting to seal the leak. Approximately 10 holes were drilled and it was estimated that a void of approximately 10 by 8 by 1 ft existed under the concrete slab. The void was filled with cement grout but the leak could not be stopped. Boroscope inspection of the pipe exterior performed through the core drills showed considerable pipe damage, in more than one location. The extent of the damage and concern over collapsing the line were determining factors in terminating the pressure grouting operation. FC ECN 97-213 was originated to request that a new drain header be installed.

- The river bank is armored and has historically protected and stabilized the existing river bank.
- USACE reduced Missouri River Mainstem System releases to 40,000 cfs on October 2, 2011. River levels corresponding to the 40,000 cfs release rate stabilized at FCS on October 4, 2011, at about el. 995 ft.

5.13.3 Assessment Methods and Procedures

5.13.3.1 Assessment Procedures Accomplished

Assessments were made by walking the corridor between the Service Building and the structures located at the riverbank and observing surface features of the system and the paved surface overlying the Circulating Water Tunnel. The structure is located below the corridor paving, limiting visual observation to surface pavement movement, settlement, and distress. The surface assessment included using a fiberglass T-probe to hand probe the ground surface in adjacent areas to determine relative soil strength. Soil probing was limited to areas beyond the surface paving and paving joints that would accommodate the probe. The assessment focused on identifying conditions indicative of potential flood-related impacts or damage to the structure as follows:

- Ground surface conditions overlying and immediately adjacent to the structure
- Soft ground surface areas (native soil, engineered fill, and/or limestone gravel pavement) as determined by probing (where possible)
- Damage to at-grade or above-grade system features and equipment
- Variance from normal installation conditions including settled, tilted, or heaved pavements
- Operation of the system and appurtenant equipment (i.e., is the system operational?)

Additional investigations were performed to further characterize the subsurface at the facility, including areas where conditions indicative of potential flood-related impacts or damage was observed. These included the following non-invasive geophysical and geotechnical investigations:

- GPR along the pavement between the Intake Structure and the Service Building. (Test reports were not available at the time of Revision 0.)
- Seismic surveys (seismic refraction and refraction micro-tremor) in the PA. (Test reports were not available at the time of Revision 0.)
- Geotechnical test borings in the PA. Note that OPPD required vacuum excavation for the first 10 ft of proposed test holes to avoid utility conflicts. Therefore, test reports will not show soil conditions in the upper 10 ft of test boring logs. (Test reports were not available at the time of Revision 0.)

5.13.3.2 Assessment Procedures Not Completed

Assessments of the Circulating Water System that were not completed include the following:

- Video inspection of tunnels to determine the current condition. (Video inspections are not currently planned to be performed).
- Visual inspection of the tunnel outfall structure at the river was not possible due to the current river elevation. (Visual inspection of the outfall is not currently planned because the river level is not expected to drop below the Discharge Tunnel floor).

5.13.4 Analysis

Identified PFMs were initially reviewed as discussed in Section 3.0. The initial review considered the preliminary information available from OPPD data files and from initial walk-down observations. Eleven PFMs associated with five different Triggering Mechanisms were determined to be "non-credible" for all Priority 1 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 preliminary results of available geotechnical, geophysical, and survey data were analyzed, a number of CPFMs were ruled out as discussed in Section 5.13.4.1. The CPFMs carried forward for detailed assessment are discussed in Section 5.13.4.2.

5.13.4.1 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 2b – Loss of lateral support for pile foundation

Reasons for ruling out:

- Bathymetric survey did not identify scour at the discharge tunnel.
- Surface erosion was not observed in the area of the tunnels during the field assessments.

Triggering Mechanism 3 – Subsurface Erosion/Piping

CPFM 3e – Loss of lateral support for pile foundation (due to river drawdown)
CPFM 3f – Undermined buried utilities (due to river drawdown)

Reason for ruling out:

- The tunnels are a sufficient depth below the ground surface to be outside the zone of influence of these CPFMs.

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

Reason for ruling out:

- The portion of this system that is subjected to hydrodynamic loads is the Discharge Tunnel. The Discharge Tunnel is located on the south side (downriver) of the Intake Structure. The riverbank is protected by revetment above and upstream of the Discharge Tunnel.

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
CPFM 7d – Piles buckling from down drag

Reason for ruling out:

- The Circulating Water System is located adjacent to the Missouri River. The soil surrounding the structure, including the subgrade, has been in the past or is normally in a saturated condition.

Triggering Mechanism 10 – Machine/Vibration-Induced Liquefaction

CPFM 10b – Displaced structure/broken connections
CPFM 10c – Additional lateral force on below-grade walls
CPFM 10d – Pile/pile group instability

Reason for ruling out:

- This phenomenon was not observed at the site.

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

CPFM 11b – Displaced structure/broken connections
CPFM 11c – Additional lateral force on below-grade walls
CPFM 11d – Pile/pile group instability

Reason for ruling out:

- This phenomenon was not observed at the site.

Triggering Mechanism 12 – Rapid Drawdown

CPFM 12a – River bank slope failure and undermining surrounding structures
CPFM 12b – Lateral spreading

Reasons for ruling out:

- Slope failure was not observed at the site.
- River stage level has dropped and stabilized at a level corresponding to the nominal normal river level at 40,000 cfs as of October 4, 2011.

Triggering Mechanism 13 – Submergence

CPFM 13b – Corrosion of structural elements

Reasons for ruling out:

- The soil surrounding the structure, including the subgrade, is normally in a saturated condition.
- Conditions have not changed due to flood conditions.

Triggering Mechanism 14 – Frost Effects

CPFM 14a – Heaving, crushing, or displacement

Reasons for ruling out:

- The Circulating Water System is founded below frost level.
- Conditions have not changed due to flood conditions.

5.13.4.2 Detailed Assessment of Credible Potential Failure Modes

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

Triggering Mechanism 3 – Subsurface Erosion/Piping

CPFM 3b – Loss of lateral support for pile foundation (due to pumping)

The Turbine Building has a documented history of a void below the foundation dating back to 1997. The flow of groundwater into the Turbine Building sump through breaks in the drainage pipes is one of the KDIs discussed in Section 4.

The Triggering Mechanism and CPFM could then occur as follows: the seepage condition will remain until the breaks in the drainage pipes are repaired, which means the potential for further erosion continues unarrested. Erosion could extend out, creating voids under the Circulating Water Tunnel.

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 Circulating Water System.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
Previously documented void under the foundation in the Turbine Building.	The bottom of the tunnels is more than 5 ft below the broken pipe locations.
Documented breaks in the drain piping below the foundation in the Turbine Building.	
Documented continual groundwater flow from the broken drain piping into the sump in the Turbine Building.	
The soil around the piling was not compacted to the same requirements as the material under the Class I structures (vibroflotation effort).	
Pavement distress was observed between the Intake Structure and the Service Building.	
Data Gaps: • The size and location of voids below the Turbine Building foundation and whether they extend below the tunnels	

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

Indicators for this CPFM have been observed in the Turbine Building. A void below the mat foundation in the Turbine Building is known to exist, and groundwater is constantly flowing into the sump from the five drain lines. Because the 2011 flood caused increased groundwater flow through the broken drain pipes, the potential that the 2011 flood caused further and more rapid degradation due to this CPFM is high. However, it is unlikely that these voids extend downward and below the Circulating Water Tunnel.

Implication

The occurrence of this CPFM on a large scale could negatively impact the capacity of the piling supporting the Circulating Water System. This is not expected to occur to the extent that would negatively impact the integrity or intended function of the Circulating Water Tunnels. Therefore, the implication of the potential degradation to the Circulating Water Tunnels for this CPFM is low.

Confidence

The data at hand are not sufficient to rule out this CPFM or to conclude that physical modification to ensure that the pilings that support this building have lost capacity because of this CPFM. Therefore, the confidence in the above assessment is low, which means more data are needed to draw a conclusion.

Summary

For CPFM 3b, as discussed above, the potential for degradation is low because it is unlikely the voids extend downward and below the Circulating Water Tunnel. The combined consideration of the potential for degradation and the implications of that degradation to a structure of this type puts it in the "not significant" category. The data currently collected are not sufficient to rule out this CPFM. Therefore, the confidence in the above assessment is low, which means more data or continued monitoring and inspections might be necessary to draw a conclusion.

5.13.5 Results and Conclusions

The CPFMs evaluated for the Circulating Water System are presented in the following matrix, which shows the rating for the estimated significance and the level of confidence in the evaluation.

	Low Confidence (Insufficient Data)	High Confidence (Sufficient Data)
Potential for Failure **Significant**		
Potential for Failure **Not Significant**	CPFM3b	

5.13.6 Recommended Actions

The following actions are recommended for the Circulating Water System:

Review the geotechnical and geophysical data and assess the impact on the Circulating Water System. Further forensic investigations and physical modifications are recommended to address CPFM 3b associated with the Turbine Building basement drain piping system (KDI #1). These recommendations are described in detail in Section 4.1.3.

5.13.7 Updates Since Revision 0

Revision 0 of this Assessment Report was submitted to OPPD on October 14, 2011. Revision 0 presented the results of preliminary assessments for each Priority 1 Structure. These assessments were incomplete in Revision 0 because the forensic investigation and/or monitoring for most of the Priority 1 Structures was not completed by the submittal date. This revision of this Assessment Report includes the results of additional forensic investigation and monitoring to date for this structure as described below.

5.13.7.1 Additional Data Available

The following additional data were available for the Circulating Water System for Revisions 1 and 2 of this Assessment Report:

- Results of KDI #1 forensic investigation (see Section 4.1)
- Results of KDI #2 forensic investigation (see Section 4.2)
- Additional groundwater monitoring well and river stage level data from OPPD.
- Field observations of the river bank (see Section 5.25).
- Results of FWD investigation by AET (see Attachment 6B).
- Results of geophysical investigation by Geotechnology (see Attachment 6C).
- Results of geotechnical investigation by Thiele Geotech (see Attachment 6A).
- Data obtained from inclinometers by Thiele Geotech (see Attachment 6A).
- Results of continued survey by LRA (see Attachment 6E).

5.13.7.2 Additional Analysis

The following analyses and review of test data were completed in addition to analysis performed related to KDI #1 and KDI #2:

- Groundwater monitoring well and river stage level data from OPPD.

  Data shows that the river and groundwater have returned to nominal normal levels.

- Field observations of river bank

  No significance distress from the 2011 Flood was observed.

- Results of FWD investigation by AET.

FWD and associated GPR testing performed in the Paved Access Area identified anomalies such as soft clay and broken pavement. Additional ground truthing of the investigation results were performed as part of the KDI #2 additional investigations.

- Results of geophysical investigation report by Geotechnology.

  Seismic Refraction and Seismic ReMi tests performed around the outside perimeter of the power block as part of KDI #2 identified deep anomalies that could be gravel, soft clay, loose sand, or possibly voids.

- Results of geotechnical investigation by Thiele Geotech.

  Six test borings were drilled, with continuous sampling of the soil encountered, to ground truth the Geotechnology seismic investigation results as part of the KDI #2 forensic investigation. Test bore holes were located to penetrate the deep anomalies identified in the seismic investigation. The test boring data did not show any piping voids or very soft/very loose conditions that might be indicative of subsurface erosion/piping or related material loss or movement.

  All of the SPT and CPT test results conducted for this Assessment Report were compared to similar data from numerous other geotechnical investigations that have been conducted on the FCS site in previous years. This comparison did not identify substantial changes to the soil strength and stiffness over that time period. SPT and CPT test results were not performed in the top 10 ft to protect existing utilities.

  Data from inclinometers to date, compared to the original baseline measurements, have not exceeded the accuracy range of the inclinometers. Therefore, deformation at the monitored locations since the installation of the instrumentation has not occurred.

- Results of continued survey by LRA.

  Survey data to date compared to the original baseline surveys have not exceeded the accuracy range of the surveying equipment. Therefore, deformation at the monitored locations, since the survey baseline was shot, has not occurred.

Triggering Mechanism 3 – Subsurface Erosion/Piping
CPFM 3b – Loss of lateral support for pile foundation (due to pumping)

CPFM 3b for the Circulating Water System is associated with KDI #1 and KDI #2. Sections 4.1, 4.2, and 8.3 present the results of additional forensic investigation that was conducted to ascertain whether this CPFM could be ruled out. The results of the additional forensic investigations show that if the recommendations for physical modifications in KDI #1 are implemented that this CPFM is ruled out. Therefore, this CPFM is moved to the quadrant of the matrix representing "No Further Action Recommended Related to the 2011 Flood."

5.13.7.3 Revised Results

The CPFMs evaluated for the Circulating Water System are presented in the following matrix, which shows the rating for the estimated significance and the level of confidence in the evaluation.

	Low Confidence (Insufficient Data)	High Confidence (Sufficient Data)
Potential for Failure **Significant**		
Potential for Failure **Not Significant**		CPFM3b

5.13.7.4 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 Circulating Water System other than CPFM 3b had been ruled out prior to Revision 1, and because CPFM 3b will be ruled out when the physical modifications recommended for KDI #1 in Section 4.1 and 8.3 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Circulating Water System. 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.