Section 5.12

Underground Cable Trench

Omaha Public Power District

5.12 Underground Cable Trench

5.12.1 Summary of Underground Cable Trench

Baseline information for the Underground Cable Trench (Trenwa, Inc.) is provided in Section 2.0, Site History, Description, and Baseline Condition.

The Trenwa is the trench system that contains the security system cabling for FCS. The Trenwa is a precast concrete cable trench that follows the PA perimeter. The Trenwa varies between 5 and 7 ft wide and is between approximately 1.8 and 3.2 ft deep, depending on location. Drain holes are interspersed along the Trenwa alignment. The Trenwa is covered with precast lids. At traffic crossings, specialized lids are in place to allow vehicular traffic to cross the Trenwa. The Trenwa section is modified for these locations, including a thicker base and unistrut inserts at both legs. Trenwa bedding at typical road crossings was specified to be compacted subgrade and backfill with a minimum 95 percent of maximum dry density per ASTM D1557.

Trenwa bedding is compacted subgrade soil. Per the drawing notes, engineered bedding was not specified except at certain locations. The design plan General Notes state the following: "Soil compaction under the trench brackets should be equal to the undisturbed average soil. Soil compaction must equal 4000# per square ft or 28# per square inch." Pedestrian crossings and drain pipe crossings included a minimum bedding of 3 in. of crushed rock underlain with geotextile fabric. Drawings 88-185-1 and 9364-C-0012, files 47643 and 46463, respectively, include notes and details for Trenwa bedding and subgrade.

The Trenwa system is located inside the facility perimeter fence and follows the fence alignment around the site. The Trenwa is constructed as long, straight alignments along most sides of the facility except at the southeast corner of the site where it jogs around the Security Building and the Condensate Storage Tank. It connects to the north and south sides of the Intake Structure. The Trenwa section ends approximately 200 ft north of the Intake Structure. Underground cabling continues beyond the Trenwa to equipment connected to the cabling system. The original northern section of the Trenwa was aligned where the north face of the New Warehouse is located. The Trenwa system ends at a point that corresponds to the north face the New Warehouse, but security system cabling with handhole access points has been extended around the ISFSI facility, the New Warehouse, and the security perimeter at the northeast corner of the site. See drawings listed in Table 5.12-1 for location and details.

5.12.2 Inputs/References Supporting the Analysis

Table 5.12-1 lists references provided by OPPD and other documents used to support HDR's analysis.

Table 5.12-1 - References for Underground Cable Trench

Document Title	OPPD Document Number (if applicable)	Date	Page Number(s)
Cable Trench Layout	88-185-1 (#47643)	6/30/1988	
Cable Trench Layout	88-185-2 (#47644)	6/30/1988	
Cable Trench Layout	88-185-3, Rev.1 (#47645)	7/1/1988	
Cable Trench Details	88-185-4 (#47646)	7/1/1988	
Cable Trench Layout	89-67-1 (#49669)	3/17/1989	

Table 5.12-1 - References for Underground Cable Trench

Document Title	OPPD Document Number (if applicable)	Date	Page Number(s)
Cable Trench Layout	89-67-2 (#49670)	3/17/1989	
Cable Trench Details	89-67-5 (#49717)	3/17/1989	
Cable Trench Layout	89-132-1 (#49750)	5/10/1989	
Cable Trench Layout	89-132-2 (#49751)	5/10/1989	
Cable Trench Layout	89-132-3 (#49752)	5/10/1989	
Cable Trench Details	89-132-4 (#49753)	5/10/1989	
Cable Trench Details	89-132-5 (#49754)	5/10/1989	
Precast Concrete Cable Trench Layout	9364-C-0106, Sht. 1, Rev. 2 (#47449)	Unknown	
Security System Duct Bank Sections and Cable Trench Details	9364-C-00012, Sht. 1, Rev. 0 (#46463)	4/6/1988	
Independent Spent Fuel Storage Installation ISFSI Cable Trench and Raceway	59058-EE-6A, Rev. 1 (#60753)	Unknown	
Independent Spent Fuel Storage Installation ISFSI Cable Trench Section & Details	59058-EE-6B (#60754)	Unknown	
Cable Trench Layout	04-8491 (#60819)	11/9/2004	
Naval Facilities Engineering Command, Design Manual 7.01, Soil Mechanics		9/1986	All

Detailed site observations—field reports, field notes, and inspection checklists—for the Underground Cable Trench are provided in Attachment 8.

Observed performance and pertinent background data are as follows:

- The Trenwa covers appeared straight and level along the north, west, and south sides, which were accessible during site inspections.
- Some differential settlement was noted where the Trenwa section varied due to connectivity to structures, changes in alignment, and at vehicle crossing points. Because the Trenwa base is set above standard frost depth for this area, some minor differences in the top elevation of the system are to be expected.
- The riverbank section of the Trenwa and the section at the northeast corner of the site were not inspected due to heavy deposits of silt in some areas and inundation by floodwaters at the northeast corner of the site when field inspections were being made.
- Soils along the Trenwa alignment were normally stable and firm. Isolated locations of soft soil were encountered. Most soft soil locations were observed where the soil showed signs of being saturated or moist and in their lowest strength condition. It is anticipated that the soils will dry and re-stabilize in the future.

5.12.3 Assessment Methods and Procedures

5.12.3.1 Assessment Procedures Accomplished

Assessments were made by walking the Trenwa alignment and observing surface features of the system (manholes), the precast concrete cover, and the ground surface adjacent to the Trenwa cover. The surface assessment included using a 4-ft-long, 0.5-in.-diameter, steel-tipped fiberglass T-handle soil probe to hand probe the ground surface to judge the relative soil strength. The assessment focused on identifying conditions indicative of potential flood-related impacts or damage to the utility, as follows:

- Ground surface conditions immediately adjacent to the utility including scour, subsidence or settlement, lateral spreading, piping, and heave
- Soft ground surface areas (native soil, engineered fill, and limestone gravel surfacing), as determined by probing
- Water accumulations and flows in subsurface system components (manholes and concrete cable encasement pipes)
- Damage to at-grade or above-grade system features and equipment
- Variance from normal installation conditions including settled, tilted, or heaved system features and equipment
- Operation of the system and appurtenant equipment (i.e., is the system operational and operating as intended?)

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 invasive geotechnical investigations:

- GPR. (Test reports were not available at the time of Revision 0.)

5.12.3.2 Assessment Procedures Not Completed

Assessments of the Trenwa that were not completed include the following:

- The interior of the Trenwa was not observed except for visual observations that were possible through small openings between joints in the Trenwa cover. It is not expected that interior observations will increase the confidence in the conclusion because it is anticipated that only sediment deposits in the Trenwa would be observed.
- No excavation to inspect underground systems and conditions was performed because it was not deemed necessary for this structure.
- Inclinometer readings along the river that will provide an indication of slope movement.

5.12.4 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. 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 results of available geotechnical, geophysical, and survey data were analyzed, a number of CPFMs were ruled out as discussed in Section 5.12.4.1. The CPFMs carried forward for detailed assessment are discussed in Section 5.12.4.2.

5.12.4.1 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 Trenwa system survey was not completed due to inundation of the facility at the time of inspection. Although this PFM is not considered credible based on field observations completed, it has the potential to occur in flooded areas that have not been observed. However, due to silt deposited between the PA fencing and the existence of riverbank armoring, this PFM was judged to be unlikely for the unobserved areas also.
- Some localized and limited surface erosion was noted at the site, including adjacent to the sidewalls of the Trenwa. According to the drawings, the Trenwa bottom is at least 1.8 ft below the ground surface. Undermining of the Trenwa base was not considered credible because it is well below the depths of surface erosion observed in the field. The site perimeter fence includes a 4-ft-tall New Jersey Barrier as part of the bottom reinforced section. The New Jersey Barrier is mounted to a concrete footing. The barrier is continuous around the site, preventing direct flow onto and across the site and Trenwa. Blockage of direct flows onto the site reduces the likelihood that surface erosion will affect the Trenwa.

Triggering Mechanism 2 – Surface Erosion
CPFM 2c – Undermined buried utilities

Reasons for ruling out:

- The Trenwa system observation was not completed due to inundation of the facility at the time of inspection. Although this PFM is not considered credible based on present field observations, it has the potential to occur in flooded areas that are unobserved. Little or no surface erosion was observed along the Trenwa, and silt deposits that were observed across almost the entire Trenwa area indicate flow velocity rates that were too low to initiate scour-induced failure. No flows through the northeast site were observed at the time of field observations, and fencing and other structures observed from a distance appeared to be intact and unaffected by the flood. This PFM was judged to be unlikely for the unobserved areas.
- The Trenwa is designed for some displacement and flexibility, and cabling inside the Trenwa is a flexible system. The system will tolerate some movement without loss of functionality or damage to enclosed utilities.
- According to the drawings, the Trenwa bottom is at least 1.8 ft below the ground surface. Undermining of the Trenwa base was not considered credible because it is below the depths of surface erosion observed in the field.

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:

- Soil supporting and surrounding a majority of the Trenwa system has been previously wetted. The peak flood elevation prior to 2011 was 1003.3 ft, which occurred in 1993.

Triggering Mechanism 10 – Machine/Vibration-Induced Liquefaction

CPFM 10a – Cracked slab, differential settlement of shallow foundation, loss of structural support
CPFM 10b – Displaced structure/broken connections
CPFM 10c – Additional lateral force on below-grade walls

Reasons for ruling out:

- Machine vibrations from the facility (turbine and various pumps) have historically occurred, and no indications of these CPFMs are evident.
- Pumps used on site during the 2011 flood were judged to be of insufficient size to cause ground or structure vibrations to initiate soil liquefaction.
- No structure movements indicative of soil liquefaction and resultant settlement were observed; no structure cracking, settlements, or lateral movements were observed.

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

Reasons for ruling out:

- This has not been observed on site.
- The sandboil/piping feature observed in the missile room was determined to be too shallow to be significant.

Triggering Mechanism 12 – Rapid Drawdown

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

Reasons for ruling out:

- The structures did not have evident signs of distress identified during the field assessments.
- Slope failure was not observed at the site.
- River stage level has receded and stabilized as of October 4, 2011.

- As of October 11, 2011, groundwater elevations had already had one week to stabilize to at least a partial degree.
- The river bank is armored and has historically protected and stabilized the existing river bank.

Triggering Mechanism 13 – Submergence
CPFM 13a – Corrosion of underground utilities

Reasons for ruling out:

- Groundwater elevations controlled by Missouri River water elevations and percolation of storm precipitation, including winter snowmelt, would be expected to contact underground improvements including constructed steel and concrete facility elements. As such, steel and concrete site improvements are assumed to be designed to withstand the corrosive environment of groundwater and wetted soil.
- Conditions have not been changed due to the 2011 flood.

5.12.4.2 Detailed Assessment of Credible Potential Failure Modes

The following CPFMs are the only CPFMs carried forward for detailed assessment for the Trenwa 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)
CPFM 3c – Undermined buried utilities (due to pumping)

The Triggering Mechanism and CPFM could occur as follows: multiple potentially connected seepage paths existed in the soil backfill at the site, including soil backfill in utility trenches, granular trench bedding, and pre-existing defects/voids under pavement. The paths are exposed at some locations to the river floodwaters (i.e., open areas outside the Aqua Dam perimeter or the hole in the pavement north of the Security Building). This network of seepage paths is connected to pumping sources on the site: the Trenwa beside the Security Building and inside the HESCO barrier, and the numerous pumps inside the perimeter of the Aqua Dam and the HESCO barrier. The pumps were operated for an extended period, maintaining a head differential on the seepage path networks. Gradient was sufficient to begin erosion of surrounding soil. Seepage is unfiltered and erosion continues unarrested. Erosion extends out, intercepting the network of utility trenches, including the Trenwa. Voids are created under and along the utility trench walls, utilities, structures, and pavements. The potential damage includes settlement of the Trenwa. Significant settlement might cause a loss of electrical connectivity.

Below are field observations and data that support the likelihood of these CPFMs:

- Trenwa trenches beside the Security Building were pumped for the duration of flooding to remove water coming in from outside Trenwa locations. This created a head differential.
- Site drainage pumps inside the perimeter of the Aqua Dam and HESCO barriers pumped from numerous sources around the perimeter of the facility. The Aqua Dam was located in proximity to the Trenwa along the west, south, and east sides of the PA. The HESCO barriers that were used to protect the Security Building crossed the Trenwa.

- A hole in the pavement with a void area beneath the concrete slab was observed just north of the Security Building and east-southeast of MH-5. The hole and void area could be the result of piping and subsurface erosion. The hole and void area are located in proximity to the Trenwa.
- Based on a conversation with the OPPD operations employee testing FP-3E on September 13, 2011, fire hydrant FP-3C, located northeast of the Security Building, was tested on September 13, 2011, and failed. According to the OPPD operations employee, when opening the valve to test the hydrant, the base cracked and leaked, and the valve had to be closed. The access cabinet was tagged-out for repair at that time. The fire hydrant that failed is located in proximity to the Trenwa.
- Concrete areas in the Paved Access Area and pedestrian areas between the river and Service Building north of where the ductbank crosses the Paved Access Area have exhibited distress including cracking, slab settlement, and undermining (as evidenced by hollow-sounding pavement areas).
- An area of apparent pavement settlement, located in the Paved Access Area west-northwest of the Intake Structure overhead door, is located near the northern raw water alignment.

Below are field observations and data that indicate this CPFM is unlikely:

- The observed hole in the pavement, north of the Security Building, could have been developed by outflow from the surface pumps and is not associated with these CPFMs. Temporary surface pumps were pumping water back into the river with hoses placed over the Aqua Dam. One of the discharge points was near the observed hole based on visual site observations. Concentrated discharge flow could have eroded pavement and created the observed hole.
- Most areas along the alignment of the Trenwa were not subjected to pumping. The only exception to this is the Trenwa installation at the Security Building.

The following are data gaps (data yet required to assess these CPFMs):

- The extent of the subsurface erosion is not known at this time.
- GPR data (awaiting).

The following table describes observed distress indicators and other data that would increase or decrease the potential for degradation associated with these CPFMs for the Trenwa.

Adverse (Degradation/Direct Floodwater Impact More Likely)	**Favorable (Degradation/Direct Floodwater Impact Less Likely)**
A pavement hole and void area north of the Security Building and an approximately 1.8-ft void west of the Security Building.	The observed hole north of the Security Building could have been developed by outflow from the surface pumps and might not be associated with this CPFM. Temporary surface pumps were pumping water over the Aqua Dam. One of the pump discharge points was near the observed hole. Concentrated discharge flow could have created the observed hole.
Failed fire protection cabinet FP-3C north of the Security Building	
Data Gaps: • Geophysical investigation data to address observed concerns • Existence, size, and location of voids	

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

Indicators for these CPFMs have been observed. The pavement void area and fire cabinet test failure north of the Security Building are in the proximity of the Trenwa. It is possible that subsurface erosion extends below the Trenwa northeast of the Security Building. Therefore, the potential for degradation due to these CPFMs is judged to be high.

Implication

The occurrence of these CPFMs could cause the collapse of the Trenwa. However, the Trenwa is flexible and will tolerate movement without loss of functionality or detrimental effects on the exposed utilities. Therefore, the implication of the potential degradation for these CPFMs is low.

Confidence

There are multiple elements to these CPFMs: the inflow of water into MH-5 during the 2011 flood, the hole in the pavement north of the Security Building, and the settled pavement section in the Paved Access Area between the Service Building and the Intake Structure. However, even though the confidence is high that there are some voids under the corridor pavement, the extent of these voids is not known.

Available data are not sufficient to rule out these CPFMs or lead to a conclusion that subsurface erosion has undermined the Trenwa. Therefore, the confidence in the assessment is low, which means more data are necessary to draw a conclusion.

Summary

For CPFMs 3a and 3c, as discussed above, the potential for degradation is high because the pavement void area and fire cabinet test failure north of the Security Building are in the proximity of the Trenwa. This degradation could have caused enough erosion to impact the integrity or intended function of the structure. 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 these CPFMs. 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.

Triggering Mechanism 3 – Subsurface Erosion/Piping

CPFM 3d – Undermining and settlement of shallow foundation/slab (due to river drawdown)
CPFM 3f – Undermined buried utilities (due to river drawdown)

These CPFMs are similar to and in addition to CPFM 3a and 3c, but instead of pumping, the gradient is created by rapidly receding river level.

The Triggering Mechanism and CPFM could then occur as follows: river level drops faster than pore water pressure in the soil foundation can dissipate. A gradient is created that moves soil into existing defects and enlarges voids under or along the Trenwa walls or utility lines. Depending on the extent of the voids created, impacts can include the following: trench subsidence, unsupported Trenwa sections, Trenwa failures, unsupported pipe sections, pipe deflections, pipe failure, and possible impacts on adjacent improvements or utilities.

Field observations and data that support the likelihood of these CPFMs are as follows:

- Subsurface erosion is known to exist beneath buildings and slabs on site. However, it is unknown whether these erosion and piping features have extended beneath the Trenwa.
- Areas of soft soils were observed in localized areas adjacent to the Trenwa sidewalls.
- The east segment of the Trenwa structure is relatively close to the river and is therefore susceptible to subsurface piping associated with drawdown of the river.

Field observations and data or site conditions that indicate these CPFMs are unlikely are as follows:

- The Trenwa has been subjected to flooding events in the past, and evidence of erosion and piping or impacts have not been recorded.
- The east segment of the Trenwa is near the river. However, the majority of the Trenwa is well away from the river. Increased distance from the riverbank reduces the likelihood of subsurface erosion/piping related to the river drawdown.

The following are data gaps (data yet required to assess these CPFM):

- Geophysical investigation data to address adjacent pavement areas
- Inclinometer data to address observed concerns
- Record of water level measurements in existing piezometers/monitoring wells

The following table describes observed distress indicators and other data that would increase or decrease the potential for degradation associated with these CPFMs for the Trenwa.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
Floodwaters at a high level existing for an extended period of time that could allow surrounding soils to become saturated.	USACE suspended the river drawdown between August 27 and September 18, 2011. This gap in the scheduled reduction of dam release rates was provided to allow groundwater elevations to equalize with river flow elevations.
	Riverbank is armored and protects against creation of a weakened flow path. Indications of these CPFMs have not been exhibited or reported for previous floods.
Data Gaps: • Field observations after river drawdown • Geophysical investigation data to address adjacent pavement slabs • Inclinometer data to address observed concerns	

Conclusion

Significant

Potential for Degradation/Direct Floodwater Impact

None of the indicators for the CPFMs has been observed at the Trenwa. However, voids due to rapid drawdown might not have been evident at the time of the field assessments. Additionally, the extent of voids created by rapid drawdown could be insignificant. The potential that degradation due to this CPFM has occurred is low.

Implication

The occurrence of these CPFMs could cause the collapse of the Trenwa. However, the Trenwa is flexible and will tolerate movement without loss of functionality or detrimental effects on the exposed utilities. Therefore, the implication of the potential degradation for these CPFMs is low.

Confidence

The data at hand are not sufficient to rule out these CPFMs or to lead to a conclusion that subsurface erosion would undermine the Trenwa. Therefore, the confidence in the assessment is low, which means more data are necessary to draw a conclusion.

Summary

For CPFMs 3d and 3f, as discussed above, the potential for degradation is low. This degradation would have to occur on a large scale to impact the integrity or intended function of the Trenwa. 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 these CPFMs. Therefore, the confidence in the above assessment is "low," which means more data or continued monitoring and inspections might be necessary to draw a final conclusion.

Triggering Mechanism 14 – Frost Effects
CPFM 14a – Heaving, crushing, or displacement

Heave associated with frost penetration below the Trenwa could occur.

The Triggering Mechanism and CPFM could occur as follows: the trigger for frost penetration to occur is no different than in previous years. However, higher subsurface water level and increased moisture content of near-surface soils could increase the magnitude of frost movement over the upcoming winter season.

Field observations and data that support the likelihood of this CPFM are as follows:

- Wet soil conditions were observed near the Trenwa structure, especially near the northeast corner of the site.

Field observations and data or site conditions that indicate this CPFM is unlikely are as follows:

- Conditions required to trigger this CPFM have typically occurred every year since construction.
- The majority of the Trenwa, except the east segment, is well away from the river and potential subsurface water associated with the river.

The following are data gaps (data yet required to assess this CPFM):

- Geophysical investigation data to address observed concerns
- No Condition Reports are available to review to address whether or not instances of frost heave have created problems in the past. However, any reports of past frost heave are not needed for increasing the confidence in the conclusion since conditions that trigger the CPFM typically happen on a yearly basis.

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 Trenwa.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
Wet soil conditions currently exist.	The Trenwa is designed for shallow installation and frost impacts.
Data Gaps: • Geophysical investigation data to address observed concerns	

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

None of the indicators for this CPFM has been observed along the structure. However, below-freezing temperatures have not occurred since the 2011 flood. The potential that degradation due to this CPFM will occur is low.

Implication

The occurrence of this CPFM below the Trenwa would likely not affect the performance of the Trenwa because it is normally subjected to frost conditions. Therefore, the implication of the potential degradation for the CPFMs is low.

Confidence

The potential impact on the structure from this CPFM is not known due to unknown supporting/surrounding soil saturation levels. River and groundwater levels at this time are such that this CPFM might occur.

The data at hand are not sufficient to rule out this CPFM or to lead to a conclusion that frost effects would negatively affect the Trenwa. Therefore, the confidence in the assessment is low, which means more data are necessary to draw a conclusion.

Summary

For CPFM 14a, as discussed above, the potential for degradation is low. 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 these CPFMs. Therefore, the confidence in the above assessment is "low," which means more data or continued monitoring and inspections might be necessary to draw a final conclusion.

5.12.5 Results and Conclusions

The CPFMs evaluated for the Trenwa 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**	CPFM 3a CPFM 3c CPFM 3d CPFM 3f CPFM 14a	

5.12.6 Recommended Actions

Further forensic investigations and physical modifications are recommended to address CPFMs 3a, 3c, 3d, and 3f for the Trenwa. CPFMs 3a and 3c are associated with the distress in and near the Paved Access Area between the Service Building and the Intake Structure (Key Distress Indicator #2). These recommendations are described in detail in Section 4.2.5.

Also, monitoring of groundwater well data and a review of the geophysical data, when available, should be done. The results of this monitoring will be used increase the confidence in the assessment results. At the time of Revision 0, groundwater levels had not yet stabilized to nominal normal levels. Therefore, it is possible that new distress indicators could still develop. If new distress indicators are observed before December 31, 2011, appropriate HDR personnel should be notified immediately to determine whether an immediate inspection or assessment should be conducted. Observation of new distress indicators might result in a modification of the recommendations for this structure.

5.12.7 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.

5.12.7.1 Additional Data Available

The following additional data were available for the Underground Cable Trench for Revisions 1 and 2 of this Assessment Report:

- 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 geophysical investigation by Geotechnology, Inc. (see Attachment 6).
- Results of geotechnical investigation by Thiele Geotech, Inc. (see Attachment 6).
- Data obtained from inclinometers by Thiele Geotech, Inc. (see Attachment 6).
- Results of continued survey by Lamp Rynearson and Associates (see Attachment 6).
- Field assessment of the Trenwa in areas that were inaccessible prior to Revision 0 of the report and a visual inspection of interior sections of the Trenwa where the system had been opened.

5.12.7.2 Additional Analysis

Five CPFMs were identified in Revision 0. Since Revision 0, additional data have become available which has clarified the significance and confidence for these CPFMs. The following presents the previously identified CPFMs and the new interpretation of their significance and confidence based upon the new data.

- 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 geophysical investigation report by Geotechnology, Inc.

  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, Inc.

  Six test borings were drilled, with continuous sampling of the soil encountered, to ground truth the Geotechnology, Inc. 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 feet 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 Lamp Rynearson and Associates.

  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.

Additional visual inspections were completed since Revision 0 of this Assessment Report to assess possible changes due to reduced river levels. The areas not visited prior to Revision 0 were visited and the documented condition of the Trenwa was found similar to the areas that were previously inspected. Interior inspections of the Trenwa were completed where the top had been removed. The interior areas inspected had soil deposits in the bottom of the trench. Extensive areas of the Trenwa were not asked to be opened. It was not expected that interior observations would increase the confidence in the conclusion because it was anticipated that only additional sediment deposition would be observed.

Triggering Mechanism 3 – Subsurface Erosion/Piping

CPFM 3d – Undermining and settlement of shallow foundation/slab (due to river drawdown)

CPFM 3f – Undermined buried utilities (due to river drawdown)

The groundwater elevation measured in the monitoring wells closely followed the river level as the floodwater receded. The data indicate that groundwater elevation was about 2 ft above the river level near the beginning of October 2011 and receded to match the river level by about October 14, 2011. Therefore the differential head created by the river drawdown was insufficient to facilitate subsurface erosion.

Triggering Mechanism 14 – Frost Effects

CPFM 14a – Heaving, crushing, or displacement

The foundation for the Trenwa is not below frost depth and is therefore subjected to frost effects during prolonged periods of cold weather. Areas of the Trenwa that were not inspected due to inundation for Revision 0 of the report have now been visited. Though there were a few soft spots, soils in the areas visited were generally firm. In addition, the groundwater elevation measured in the monitoring wells closely followed the river level as the floodwater receded. The data indicate that groundwater elevation was about 2 ft above the river level near the beginning of October 2011 and receded to the river level by about October 14, 2011. Since current groundwater levels are not different than normal seasonal levels and prolonged cold weather has not yet occurred, the effects of frost heave on the Trenwa are no longer applicable.

5.12.7.3 Revised Results

The CPFMs evaluated for the Underground Cable Trench are presented in the following matrix, which shows the rating for the estimated significance and the level of confidence in the evaluation. CPFMs 3d, 3f, and 14a for the Underground Cable Trench are not associated with Key Distress Indicators. Inspections of the Trenwa not visited prior to Revision 0 and visual inspections of the inside of the Trenwa have been completed. Updated groundwater and river level data were reviewed. The results of the additional forensic investigation show that these CPFMs are ruled out. Therefore, these CPFMs are moved to the quadrant of the matrix representing "No Further Action Recommended Related to the 2011 Flood." CPFMs 3a and 3c for the Underground Cable Trench are associated with Key Distress Indicator #2. Section 4.2 presents the results of additional forensic investigation that was conducted to ascertain whether these CPFMs could be ruled out. The results of the additional forensic investigation show that these CPFMs are ruled out. Therefore, these CPFMs are 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**		
Potential for Failure **Not Significant**		CPFM 3a CPFM 3c CPFM 3d CPFM 3f CPFM 14a

5.12.7.4 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 Underground Cable Trench other than CPFMs 3a, 3c, 3d, 3f, and 14a had been ruled out prior to Revision 1, because CPFMs 3d, 3f, and 14a have been ruled out as a result of the Revision 1 findings, and because CPFMs 3a and 3c have been ruled out using the results of the KDI #2 investigation presented in Section 4.2, no Triggering Mechanisms and their associated PFMs remain credible for the Underground Cable Trench. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Underground Cable Trench because the potential for failure of this structure due to the flood is not significant.

Section 5.10

Turbine Building South Switchyard

5.10 Turbine Building South Switchyard

5.10.1 Summary of Turbine Building South Switchyard

Baseline information for the Turbine Building South Switchyard is provided in Section 2.0, Site History, Description, and Baseline Condition.

5.10.2 Inputs/References Supporting the Analysis

Table 5.10-1 lists references provided by OPPD and other documents used to support HDR's analysis.

Table 5.10-1 - References for Turbine Building South Switchyard

Document Title	OPPD Document Number (if applicable)	Date	Page Number(s)
Foundation Plan – Transformer Yard	11405-S-411, Rev. 12 (#16582)	Unknown	
Foundation Details – Transformer T1	11405-S-412 (#16583)	Unknown	
Foundation Details – Transformer T1A-1,2,3&4	11405-S-413 (#16584)	Unknown	
Foundation Details – 161kV Transmission Tower And Retaining Walls	11405-S-414 Rev. 1 (#16585)	Unknown	
Naval Facilities Engineering Command, Design Manual 7.01, Soil Mechanics		9/1986	All

Detailed site observations—field reports, field notes, and inspection checklists—for the Turbine Building South Switchyard are provided in Attachment 8.

Observed performance and pertinent background data are as follows:

- The foundation for Transformer T1 is a 1.5-ft-thick pile cap supported on ten 10BP42 steel piles (see 11405-S-412). Top-of-concrete elevation for this foundation is 1005.5 ft.
- The foundation for Transformers T1A-1 and T1-A2 is a 1.5-ft-thick pile cap supported on four 10BP42 steel piles (see 11405-S-413). Top-of-concrete elevation for this foundation is 1005.5 ft.
- The foundation for Transformers T1A-3 and T1-A4 is a 1.5-ft-thick pile cap supported on four 10BP42 steel piles (see 11405-S-413). Top-of-concrete elevation for this foundation is 1005.5 ft.
- The foundation for Transformer T1C-3B is an approximately 0.7-ft-thick pile cap supported on four 8-in.-diameter auger cast piles with tip elevation of 997 ft (see 11405-S-412). Top-of-concrete elevation for this foundation is approximately 1004.8 ft. The piles are reinforced with a single #7 bar centered in the pile, with the bar having a straight development into the slab.
- The foundation for the small switchgear located on the southwest corner of the west cable trench is an approximately 0.7-ft-thick slab-on-grade foundation.
- The Dead End/161 Structure is a two-column frame, approximately 27 ft in height, with interconnecting cross beams. There are separate foundations for each octagonal column. The piers are 5 ft by 5 ft by 3 ft in height. Top-of-pier elevation is 1004.5 ft. Top-of-concrete elevation for the pile cap is 1001.5 ft. Each cap is 4 ft thick, 7 ft by 20 ft in plan dimensions, supported by six 12-in.-diameter auger cast piles with tip elevation of 940 ft (see 11405-S-414). The piles are

reinforced with a single #11 bar centered in the pile, with the bar having a straight development into the slab.

- The driving criteria, tip elevation, and capacities of the 10BP42 piles are unknown. However, the tops of the piles are capped with a plate and anchor rods for a positive shear and uplift connection (see 11405-S-412).
- The capacities of the 8-in.- and 12-in.-diameter auger cast piles are unknown.
- A continuous cable trench is adjacent to each transformer (see 11405-S-411). This conduit trench is a cast-in-place concrete trench with intermittent drain holes in the walls. The trench also has a vertical drain pipe penetrating the west end of the trench with the perforated pipe noted as heading west "to storm sewer manhole." The trench backfill below the slab and around the walls is free-draining granular material (see 11405-S-412).
- An approximately 0.7-ft-thick concrete block separation wall is located between Transformer T1 and T1-A2. This wall is constructed on a continuous, cast-in-place concrete grade beam spanning to isolated footings. The wall is laterally braced via anchor straps to 8WF31 piles (see 11405-S-414).
- The structures were originally contained within a cast-in-place retaining wall that projected approximately 6 in. above the surrounding grade. On approximately June 10, 2011, OPPD built an additional approximately 0.7-ft-thick cast-in-place concrete wall in insulated concrete forms (ICF) on top of the existing wall. This additional wall was approximately 3.3 ft tall, which placed the top of concrete at about 1008.3 ft.
- Condition report summaries were not available for these structures.
- The structures were protected from floodwater for the majority of the 2011 flood by an Aqua Dam; however, the Aqua Dam failed for a short period of time due to being damaged, allowing floodwater to enter the area inside the Aqua Dam perimeter.
- These structures were located within the Aqua Dam perimeter and were also protected by the cast-in-place wall in insulated wall forms.
- The areas surrounding the transformers were filled with small riprap. Small depressions were dug out in the riprap, creating a low spot where portable pumps were placed to remove water infiltration around the foundations.
- In general, there were no signs of soil movement around these structures with the exception of a soft spot on the southwest corner of the west cable trench. This soft spot resulted in differential settlement of the switch pad located adjacent to the trench.
- Portable pumps were removing groundwater from the cable trenches, and there appeared to be a layer of sediment on the cable tray, the conduit, and on the bottom of the trench.
- Assessment of survey elevations to date shows no movement of the structure.

5.10.3 Assessment Methods and Procedures

5.10.3.1 Assessment Procedures Accomplished

Assessments of the Turbine Building South Switchyard included the following:

- Visual inspection of the exterior of the structures where accessible. Observations were made from outside the ICF concrete wall due to "Danger – High Voltage" warning tape and signs.
- Assessment of collected survey data to date for indications of trends in the movement of the structure.
- Review of previously referenced documents listed in Table 5.10-1.

- Identification of relative surface soil densities (native soil, engineered fill, and limestone gravel pavement) as determined by hand probing.
- Observations and documentation of water accumulations and flows in subsurface system components (manholes and concrete trenches).

Additional investigations were performed. These included the following non-invasive geophysical and invasive geotechnical investigations:

- Seismic surveys (seismic refraction and refraction micro-tremor). (Test reports were not available at the time of Revision 0.)
- Geotechnical investigations including test borings with field tests (SPT and CPT) and laboratory tests. Note that OPPD required vacuum excavation for the first 10 ft of proposed test holes to avoid utility conflicts. Therefore, test reports will not address soil conditions in the upper 10 ft of site and locations where shallow utilities exist. (Test reports were not available at the time of Revision 0.)
- Inclinometers had not been installed at the time of Revision 0 and therefore no data were available. Inclinometer data is not required to reach a confident conclusion but is used to supplement the other data used to reach the conclusion.

5.10.3.2 Assessment Procedures Not Completed

Assessments of the Turbine Building South Switchyard that were not completed include the following:

- The interior of the cable trench was not observed except for visual observations that were possible from outside the wall because they were in an area labeled “Danger – High Voltage.”
- No excavation to inspect underground systems and conditions was performed because the underground systems are located beneath the equipment in the switchyard.
- No probing or soil investigations were done within the ICF wall at the time of Revision 0 because the area was labeled “Danger – High Voltage.”

5.10.4 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. 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 the 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 5.10.4.1. The CPFMs carried forward for detailed assessment are discussed in Section 5.10.4.2.

5.10.4.1 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
CPFM 2b – Loss of lateral support for pile foundation
CPFM 2c – Undermined buried utilities

Reasons for ruling out:

- The Turbine Building South Switchyard is located a sufficient distance away from the riverbank and was within the Aqua Dam perimeter, and was therefore not subjected to surface erosion.
- Surface erosion was not identified in or around the Turbine Building South Switchyard during the field assessments.

Triggering Mechanism 3 – Subsurface Erosion/Piping

CPFM 3d – Undermining and settlement of shallow foundation/slab (due to river drawdown)

Reason for ruling out:

- The Turbine Building South Switchyard is located a sufficient distance away from the riverbank and was therefore not subjected to subsurface erosion due to river drawdown.

Triggering Mechanism 3 – Subsurface Erosion/Piping

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

Reason for ruling out:

- The Turbine Building South Switchyard is located a sufficient distance away from the riverbank and was therefore not subjected to subsurface erosion due to river drawdown.

Triggering Mechanism 3 – Subsurface Erosion/Piping

CPFM 3f – Undermined buried utilities (due to river drawdown)

Reason for ruling out:

- The Turbine Building South Switchyard is located a sufficient distance away from the riverbank and was therefore not subjected to subsurface erosion due to river drawdown.

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:

- The structure was protected from floodwater by an Aqua Dam except during a short period of time when the Aqua Dam failed due to being damaged, which allowed floodwater to enter the area inside the Aqua Dam perimeter.

- Visual observation did not identify distress to the structure that can be attributed to these CPFMs.

Triggering Mechanism 6 – Buoyancy, Uplift Forces on Structures
CPFM 6a – Fail tension piles

Reason for ruling out:

- The equipment foundations within the Turbine Building South Switchyard that have either steel or concrete piles have pile caps near the ground surface and were not subjected to net buoyancy uplift forces.

Triggering Mechanism 6 – Buoyancy, Uplift Forces on Structures
CPFM 6b – Cracked slab, loss of structural support

Reasons for ruling out:

- The equipment foundations within the Turbine Building South Switchyard that have either steel or concrete piles have pile caps near the ground surface and were not subjected to net buoyancy uplift forces.
- The cable trench was designed with drain holes within the trench walls and a foundation drain system complete with free-draining backfill on the walls and below the slab. Therefore, the trench was not subjected to buoyancy forces.

Triggering Mechanism 6 – Buoyancy, Uplift Forces on Structures
CPFM 6c – Displaced structure/broken connections

Reasons for ruling out:

- The equipment foundations within the Turbine Building South Switchyard that have either steel or concrete piles have pile caps near the ground surface and were not subject to net buoyancy uplift forces.
- The cable trench was designed with drain holes within the trench walls and a foundation drain system complete with free-draining backfill on the walls and below the slab. Therefore, the trench was not subjected to buoyancy forces.

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 peak flood elevation prior to 2011 was 1003.3 ft, which occurred in 1993. The peak flood elevation in 2011 was approximately 1006.9 ft. Elevations in the South Turbine Switchyard are such that the area would not be subjected to first time wetting.

Triggering Mechanism 10 – Machine/Vibration-Induced Liquefaction

CPFM 10a – Cracked slab, differential settlement of shallow foundation, loss of structural support

Reasons for ruling out:

- There is no permanent equipment within the Turbine Building South Switchyard that has the capacity to produce significant dynamic forces due to vibration.
- Temporary pumping equipment located on the ground within the Aqua Dam perimeter was small and therefore deemed to have inconsequential effect.
- Liquefaction was not observed near the Turbine Building South Switchyard.

Triggering Mechanism 10 – Machine/Vibration-Induced Liquefaction

CPFM 10b – Displaced structure/broken connections

Reasons for ruling out:

- There is no permanent equipment within the Turbine Building South Switchyard that has the capacity to produce significant dynamic forces due to vibration.
- Temporary pumping equipment located on the ground within the Aqua Dam perimeter was small and therefore deemed to have inconsequential effect.
- No broken structural connections or structural displacement were observed.
- Liquefaction was not observed near the Turbine Building South Switchyard.

Triggering Mechanism 10 – Machine/Vibration-Induced Liquefaction

CPFM 10d – Pile/pile group instability

Reasons for ruling out:

- There is no permanent equipment within the Turbine Building South Switchyard that has the capacity to produce significant dynamic forces due to vibration.
- Temporary pumping equipment located on the ground within the Aqua Dam perimeter was small and therefore deemed to have inconsequential effect.
- Liquefaction was not observed near the Turbine Building South Switchyard.

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

Reason for ruling out:

- Visual observations and survey measurements indicate no structure movement. Therefore, differential settlement and loss of structural support did not occur at the observed structures.

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

CPFM 11b – Displaced structure/broken connections

Reasons for ruling out:

- Visual observations and survey measurements indicate no structure movement. Therefore, degradation that can be attributed to this CPFM did not occur near the Turbine Building South Switchyard.
- No instances of broken connections were observed.

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

CPFM 11d – Pile/pile group instability

Reason for ruling out:

- Visual observations and survey measurements indicate no structure movement. Therefore, degradation that can be attributed to this CPFM did not occur near the Turbine Building South Switchyard.

Triggering Mechanism 12 – Rapid Drawdown

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

Reason for ruling out:

- The Turbine Building South Switchyard is a sufficient distance away from the riverbank and was therefore not subjected to riverbank slope failure or lateral spreading because of rapid drawdown.

Triggering Mechanism 13 – Submergence

CPFM 13a – Corrosion of underground utilities
CPFM 13b – Corrosion of structural elements

Reason for ruling out:

- The Turbine Building South Switchyard has not been subjected to corrosive circumstances that would be considered beyond the normal conditions. The structure was protected from floodwater by an Aqua Dam except during a short period of time when the Aqua Dam failed due to being damaged, which allowed floodwater to enter the area inside the Aqua Dam perimeter.

Triggering Mechanism 14 – Frost Effects

CPFM 14a – Heaving, crushing, or displacement

Reasons for ruling out:

- The equipment foundations within the Turbine Building South Switchyard have either steel or concrete piles with pile caps near the ground surface. The piles have an anchor plate with anchor rods developed into the pile cap, indicating a positive tension connection. In addition, the frost uplift on the pile caps will not be different than the condition prior to the flood.

- The cable trench was designed with drain holes within the trench walls and a foundation drain system complete with free-draining backfill on the walls and below the slab. Therefore, the trench is not subjected to frost effects.

5.10.4.2 Detailed Assessment of Credible Potential Failure Modes

The following CPFMs are the only CPFMs carried forward for detailed assessment for the Turbine Building South Switchyard 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 nearby Turbine Building has a documented history of a void below the foundation slab and groundwater drainage to broken floor and condensate drains. The floodwater elevations associated with the 2011 flood have increased the hydraulic head feeding water to the broken pipes in the floor drain system. The sump in the Turbine Building and Manhole MH-5 were continually pumped, maintaining the hydraulic gradient between saturated soils and broken pipes in the system.

The Triggering Mechanism and CPFM could then occur as follows: the hydraulic gradient begins erosion or increases erosion of surrounding soils. Seepage is unfiltered and erosion continues unarrested. Erosion extends out beneath the Turbine Building or from Manhole MH-5 and extends toward the Turbine Building South Switchyard. Voids form under utilities and structures in the Turbine Building South Switchyard or adjacent to the Turbine Building South Switchyard. Settlement of non-pile-supported structures and utilities occurs and causes distress or failure of improvements, utilities, or systems.

Field observations indicated that the switch foundation slab located on the southwest corner of the west cable trench is currently settling on the east side adjacent to the conduit trench, resulting in tilting of the equipment.

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 Turbine Building South Switchyard.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
Documented void under the foundation slab of the adjacent Turbine Building.	There have been no observed signs of structural distress in the CMU screen wall.
Differential settlement has occurred on the switch foundation located on the southwest corner of the west cable trench.	Sinkholes and other piping features were not observed during site inspections in the Turbine Building Switchyard or adjacent areas, except for the settlement noted near the switch foundation, and the sand boil/piping feature observed in the missile room of the Auxiliary Building.
Pavement failures were observed east of the Turbine Building.	

Data Gaps:

- Survey data to track trends in vertical movement of the CMU screen wall and cable trench.
- Visual inspection of the cable trench was not possible because the trench is located in an area that was not accessible due to safety tape. Where the trench was accessible, temporary pumps were drawing water from the bottom of the trench, and the inside was covered with sediment.
- Existence, size, and location of voids.
- Seismic refraction data are not yet available.

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

Many indicators for the CPFM have been observed. Pumping to remove water from the Turbine Building sump and from Manhole MH-5 carried through a system of broken pipes and granular trench backfill. This provides the system for this CPFM. Known voids exist under the adjacent Turbine Building. Settlement issues have been observed in the Paved Access Area between the Service Building and the Intake Structure. Settlement of the switch foundation slab near the southwest corner of the west cable trench has already occurred due to this CPFM. Therefore, the potential that degradation due to this CPFM is occurring due to the 2011 flood is high.

Implication

Settlement of the switch foundation slab near the southwest corner of the west cable trench has already occurred due to this CPFM. The CMU wall is supported on shallow foundations. This CPFM could affect the shallow foundation systems. The CMU wall could show signs of distress, and wall failure could damage adjacent facilities or equipment. Therefore, the implication of the potential degradation for this CPFM is high due to the nature of the adjacent structure.

Confidence

Observations have shown that settlement has occurred on the switch foundation slab. Subsurface erosion is believed to have occurred under the adjacent Turbine Building foundation and at some nearby areas of pavement.

Therefore, the confidence in the above assessment is high, indicating that repairs and more data are necessary.

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. There is high confidence that there has been significant degradation to the soil surrounding the Turbine Building South Switchyard. Repairs and further monitoring are needed.

Triggering Mechanism 3 – Subsurface Erosion/Piping

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

The nearby Turbine Building has a documented history of a void below the foundation slab and groundwater drainage to broken floor and condensate drains. The floodwater elevations associated with the 2011 flood have increased the hydraulic head feeding water to the broken pipes in the floor drain system. The sump in the Turbine Building and Manhole MH-5 were continually pumped, maintaining the hydraulic gradient between saturated soils and broken pipes in the system.

The Triggering Mechanism and CPFM could then occur as follows: the hydraulic gradient begins erosion or increases erosion of surrounding soils. Seepage is unfiltered and erosion continues unarrested. Erosion extends out beneath the Turbine Building or Manhole MH-5 and extends toward the Turbine Building South Switchyard. Voids form under utilities and structures in the Turbine Building South Switchyard or adjacent to the Turbine Building South Switchyard. Settlement of non-pile-supported structures and utilities occurs and causes distress or failure of improvements, utilities, or systems.

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 Turbine Building South Switchyard.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
Documented void under the foundation slab of the adjacent Turbine Building.	Review of survey data indicates that there have been no observed signs of movement of the pile foundations.
Data Gaps: • Existence, size, and location of voids. • Seismic refraction data are not yet available.	

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

Many indicators for the CPFM have been observed. Pumping to remove water from the Turbine Building sump and from Manhole MH-5 carried through a system of broken pipes and granular trench backfill. This provides the system for this CPFM. Known voids exist under the adjacent Turbine Building. Settlement issues have been observed in the Paved Access Area between the Service Building and the Intake Structure. Therefore, the potential that degradation due to this CPFM is occurring due to the 2011 flood is high.

Implication

Loss of lateral support for the pile supported foundations has the potential to cause structural instability of the foundations for the transformers. Therefore, the implication of the potential degradation for this CPFM is high.

Confidence

Subsurface erosion is believed to have occurred under the adjacent Turbine Building foundation and at some nearby areas of pavement. However, there are insufficient data on the existence, size and location of voids to determine whether this CPFM has or will occur at this location.

Therefore, the confidence in the above assessment is low, which means more data are necessary to draw a conclusion.

Summary

For CPFM 3b, as discussed above, the combined consideration of the potential for degradation and the implications of that degradation to the structure puts it in the "significant" category. There is low confidence that there has been significant degradation to the soil surrounding the Turbine Building South Switchyard due to the lack of test data available at this time. More data or continued monitoring and inspections are needed.

Triggering Mechanism 3 – Subsurface Erosion/Piping
CPFM 3c – Undermined buried utilities (due to pumping)

The nearby Turbine Building has a documented history of a void below the foundation slab with a potential for increased erosion with greater external water head (see Section 5.8).

The Triggering Mechanism and CPFM could then occur as follows: there is a potential for the previously documented void to erode larger voids under the Turbine Building and out to the surrounding structures. Buried utilities within the Turbine Building South Switchyard include cable trenches, ductbanks, underdrains, and storm drain pipes. Three fire protection pipes are routed beneath the Turbine Building South Switchyard, just west of Transformer T1. The Aqua Dam was placed over the fire lines near where they are routed into the Turbine Building. This provides a possible flow path directed toward the Turbine Building. Connectivity is possible to flow paths feeding the broken floor and condensate drain pipes in the basement.

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 Turbine Building South Switchyard.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
Documented void under the foundation slab of the adjacent Turbine Building.	There have been no observed signs of structural distress in the CMU screen wall.
Differential settlement has occurred on the switch foundation located on the southwest corner of the west cable trench.	
Data Gaps: • Visual inspection of the cable trench was not possible because the trench is located in an area that was not accessible due to safety tape. Where the trench was accessible, temporary pumps were drawing water from the bottom of the trench, and the inside was covered with sediment. • Existence, size, and location of voids. • Seismic refraction data are not yet available.	

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

Many indicators for the CPFM have been observed. Pumping to remove water from the Turbine Building sump and from Manhole MH-5 carried through a system of broken pipes and granular trench backfill. This provides the system for this CPFM. Known voids exist under the adjacent Turbine Building. Settlement issues have been observed in the Paved Access Area between the Service Building and the Intake Structure. Therefore, the potential that degradation due to this CPFM is occurring due to the 2011 flood is high.

Implication

A large number of utilities are buried under the Turbine Building South Switchyard, which is adjacent to documented indicators in the Turbine Building. The occurrence of this CPFM could negatively impact integrity or intended function of a number of buried utilities near the Turbine Building South Switchyard. Therefore, the implication of the potential degradation for this CPFM is high.

Confidence

Subsurface erosion is known to have occurred under the adjacent Turbine Building foundation. With the increased head pressure due to the 2011 flood, the amount of water moving through the system has potentially increased, which in turn increases the likelihood of instigating subsurface erosion in the Turbine Building South Switchyard adjacent to the Turbine Building. However, there are insufficient data on the existence, size and location of possible voids to determine whether this CPFM has or will occur.

Therefore, the confidence in the above assessment is low, which means more data are necessary to draw a conclusion.

Summary

For CPFM 3c, 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. There is low confidence that there has been significant degradation to the soil surrounding the Turbine Building South Switchyard due to the lack of test data available at this time. More data or continued monitoring and inspections are needed.

5.10.5 Results and Conclusions

The CPFMs evaluated for the Turbine Building South Switchyard are presented in the following matrix, which shows the rating for the significance and the level of confidence in the evaluation.

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

5.10.6 Recommended Actions

The following actions are recommended for the Turbine Building South Switchyard.

The settlement of the switch foundation slab located on the southwest corner of the west cable trench should be corrected as soon as possible.

The CMU wall should be observed by OPPD on a regular basis for signs of distress such as cracking or tipping.

Given the Low Confidence rating for CPFMs 3b and 3c, continued monitoring is recommended to include a continuation of the elevation surveys of the previously identified targets on this structure and surrounding site. The purpose is to monitor for signs of structure distress and movement or changes in soil conditions around the structure. The results of this monitoring will be used to increase the confidence in the assessment results. Elevation surveys should be performed weekly for 4 weeks and biweekly until December 31, 2011. At the time of Revision 0, groundwater levels had not yet stabilized to nominal normal levels. Therefore, it is possible that new distress indicators could still develop. If new distress indicators are observed before December 31, 2011, appropriate HDR personnel should be notified immediately to determine whether an immediate inspection or assessment should be conducted. Observation of new distress indicators might result in a modification of the recommendations for this structure.

Further forensic investigations and physical modifications are recommended to address CPFMs 3a, 3b, and 3c for the Turbine Building South Switchyard. CPFM 3a, 3b, and 3c are associated with unfiltered flow of groundwater into the Turbine Building basement drain piping system (Key Distress Indicator #1). These recommendations are described in detail in Section 4.1.3. CPFM 3a is associated with the distress in and near the Paved Access Area between the Intake Structure and the Service Building (Key Distress Indicator #2). These recommendations are described in detail in Section 4.2.5.

5.10.7 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.

5.10.7.1 Additional Data Available

The following additional data were available for the Turbine Building South Switchyard 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)
- Assessment teams from HDR on site for continued monitoring of the Key Distress Indicators have visually inspected the cable trenches and CMU wall where visible outside the area marked "Danger – High Voltage" and the settlement of the switch foundation slab near the southwest corner of the west cable trench.
- Additional groundwater monitoring well and river stage level data from OPPD.
- Results of falling weight deflectometer investigation by American Engineering Testing, Inc. (see Attachment 6).
- Results of geophysical investigation by Geotechnology, Inc. (see Attachment 6).
- Results of continued survey by Lamp Rynearson and Associates (see Attachment 6).

5.10.7.2 Additional Analysis

The following analysis of additional data was conducted for the Turbine Building South Switchyard:

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

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

- Results of falling weight deflectometer investigation by American Engineering Testing, Inc.

  Falling Weight Deflectometer 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 by Geotechnology, Inc.

  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, Inc.

  Six test borings were drilled with continuous sampling of the soil encountered, to ground truth the Geotechnology, Inc. 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 feet to protect existing utilities.

- Results of continued survey by Lamp Rynearson and Associates.

  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.

Follow-up inspections since Revision 0 of the report have noted that the standing water and sediment has been removed from the cable trenches around the switchyard.. The bottom of the cable trench was able to be viewed beyond the area labeled "Danger – High Voltage" but no additional information regarding the trenches was obtained from this observation. The observation also noted no visible distress or cracking of the CMU wall.

Triggering Mechanism 3 – Subsurface Erosion/Piping

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

CPFM 3a for the Turbine Building South Switchyard as it relates to the settlement of the switch foundation slab near the southwest corner of the west cable trench is not associated with Key Distress Indicators. Additional inspection since Revision 0 indicates that the switch foundation slab was not remediated as recommended. The results of the additional forensic investigation show that this CPFM is not ruled out; therefore, the recommendation from Revision 0 has not changed. Therefore, assuming that OPPD implements the recommended physical modification and assuming that no further concerns are identified for CPFM 3a as it relates to Key Distress Indicator #1 and #2 (see Sections 4.1 and 4.2) or through the monitoring program for the Turbine Building South Switchyard (discussed in Section 5.10.6 and continuing until December 31, 2011), this CPFM is moved to the quadrant of the matrix representing "No Further Action Recommended Related to the 2011 Flood."

Triggering Mechanism 3 – Subsurface Erosion/Piping

CPFM 3b - Loss of lateral support for pile foundation (due to pumping)
CPFM 3c - Undermined buried utilities (due to pumping)

CPFMs 3b and 3c for the Turbine Building South Switchyard are associated with Key Distress Indicator #1. Section 4.1 presents the results of additional forensic investigation that was conducted to ascertain whether these CPFMs 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, assuming that no further concerns are identified through the monitoring program for the Turbine Building South Switchyard (discussed in Section 5.10.6 and continuing until December 31, 2011), these CPFMs are moved to the quadrant of the matrix representing "No Further Action Recommended Related to the 2011 Flood."

5.10.7.1 Revised Results

The CPFMs evaluated for the Turbine Building South Switchyard are presented in the following matrix, which shows the rating for the significance and the level of confidence in the evaluation. Note that the placement of CPFM 3a in the "No Further Action Recommended Related to the 2011 Flood" is dependant on the remediation of the switch foundation slab located near the southwest corner of the west cable trench.

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

5.10.7.2 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 Turbine Building South Switchyard other than CPFMs 3a, 3b, and 3c had been ruled out prior to Revision 1, because CPFM 3a will be ruled out upon completion of the remediation to the switch foundation slab described above, and because CPFMs 3b and 3c will be ruled out when the physical modifications recommended for KDI #1 in Section 4.1, no Triggering Mechanisms and their associated PFMs will remain credible for the Turbine Building South Switchyard. 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.

Section 5.11

Condensate Storage Tank

Omaha Public Power District

5.11 Condensate Storage Tank

5.11.1 Summary of Condensate Storage Tank

Baseline information for the Condensate Storage Tank is provided in Section 2.0, Site History, Description, and Baseline Condition.

The 150,000-gallon welded steel plate Condensate Storage Tank is located at the riverbank east of the power block and south of the Intake Structure. The tank shell is about 30 ft tall and 30 ft in diameter.

The tank foundation is a 2-ft-minimum-thickness concrete mat supported on 13 10BP42 steel piles driven to bedrock at approximate el. 934 ft. The top-of-concrete elevation is 1005.5 ft. This concrete slab is approximately 41 ft in diameter, resulting in a walkway around the tank. This slab is cast within a steel sheet pile system that is driven into the riverbank to approximately el. 944.8 ft, which is approximately 10 ft above bedrock.

5.11.2 Inputs/References Supporting the Analysis

Table 5.11-1 lists references provided by OPPD and other documents used to support HDR's analysis.

Table 5.11-1 - References for Condensate Storage Tank

Document Title	OPPD Document Number (if applicable)	Date	Page Number(s)
30ft Dia By 30ft High Vertical Field Erected Tank	80087, Rev 1 (#002391)	Unknown	
Tank Foundations	11405-S-418, Rev. 11 (#16588)	Unknown	
Foundation Details – Transformer T1	11405-S-412 (#16583)	Unknown	
Naval Facilities Engineering Command, Design Manual 7.01, Soil Mechanics		9/1986	All

Detailed site observations—field reports, field notes, and inspection checklists—for the Condensate Storage Tank are provided in Attachment 8.

Observed performance and pertinent background data are as follows:

- The Condensate Storage Tank is a welded steel storage tank designed to the American Water Works Association (AWWA) D100-65 (see 002391).
- The tank is a flat-bottom storage tank without anchor bolts.
- Construction of the foundation is a cylindrical sheet pile wall driven through the riverbank. The inside of the sheet pile wall was backfilled to the bottom of the slab elevation. Steel piles were then driven within the contained sheet piles and capped with a structural cast-in-place slab (see tank foundation drawing 11405-S-418).
- The adjacent bank is such that the eastern half of the sheet pile wall is exposed to the river from the bottom-of-concrete slab el. 1003.5 ft to bank grade of approximately 994.4 ft, with the normal river water elevation of 992 ft (see tank foundation drawing 11405-S-418).

- The exposed side of the sheet pile wall was painted with rust-inhibiting paint and constructed with five 3-in.-diameter weep holes at approximately 7 ft on center. These weeps are located at approximate el. 997.5 ft.
- The steel piles are 10BP42 driven to bedrock and capped with a welded steel plate and anchor rods providing positive shear and tension connection to the base slab. This pile size and anchor details are the same as those shown for the transformer foundations in the Turbine Building South Switchyard.
- The driving criteria, tip elevation, and capacities of the 10BP42 piles are unknown. However, the top of the piles are capped with a plate and anchor rods for a positive shear and tension connection (see 11405-S-412).
- The Condensate Storage Tank was outside the Aqua Dam perimeter and was therefore unprotected from the hydrostatic flood load and hydrodynamic forces from the river flow.
- In accordance with tank levels provided by OPPD, the Condensate Storage Tank was maintained at a minimum of 72 percent full for the duration of the flood event.
- At the time of inspection, the river level had dropped below the surrounding grade. Observations were made around the western half of the Condensate Storage Tank. Access was not available through the security gate onto the walkway on the river side. Observations of the sheet pile wall and the surrounding riverbank were not feasible due to the river level.
- There was a thick layer of river sediment along the concrete foundation and surrounding grade.
- The Trenwa was covered with river sediment with indications that sediment had seeped into the trench via gaps in the removable covers.
- Small localized areas of erosion and scour were observed at the security fence on the north and south sides of the Condensate Storage Tank. No erosion or scour was observed at the tank structure.
- The tank shell, nozzle necks, and flanges below the flood elevation showed signs of surface corrosion through holidays in the coating system. No pitting or significant loss of plate thickness was observed. The bottom plates could not be adequately seen because of the deposit of river sediment.
- The tank shell appears to bulge outward with a point of inflection at about the painted horizontal stripe and another point of inflection just below the rim angle. The magnitude of this deviation from the cylindrical shape cannot be determined from visual observations, and therefore, it is not known if it meets normal AWWA D100 tolerances for tank construction. It is unknown whether this shell deformation is a result of the initial construction or whether it was directly or indirectly caused by the 2011 flood.
- Because of the river level at the time of the field assessment, it was not possible to get a good view of the east (river) side of the east (river) side of the tank. Observations from just north of the Security Building indicate that the out-of-tolerance shape might be limited to all sides of the Condensate Storage Tank except the east side.
- Survey data points were set on the north, south, and west quadrants of the tank. Assessment of current survey data for these points indicates no vertical movement.

5.11.3 Assessment Methods and Procedures

5.11.3.1 Assessment Procedures Accomplished

Assessments of the Condensate Storage Tank included the following:

- Visual inspection of the exterior of the structure, where accessible..
- An assessment of collected survey data to date for indications of trends in the movement of the structure.
- A review of previously referenced documents listed in Table 5.11-1.
- A relative surface soil density test via probing was attempted. However, because of the crushed rock surface below the sediment, it was not possible to push the probe rod into the subgrade.

Additional investigations were performed. These included the following non-invasive geophysical and invasive geotechnical investigations:

- Seismic surveys (seismic refraction and refraction micro-tremor) in the protected area. (Test reports were not available at the time of Revision 0.)
- GPR in the protected area. (Test reports were not available at the time of Revision 0.)
- Geotechnical test borings in the protected area. 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.)

5.11.3.2 Assessment Procedures Not Completed

Assessments of the Condensate Storage Tank that were not completed include the following:

- Inspection of the river side of the Condensate Storage Tank was not accomplished due to current river levels. Once the river level drops, the remainder of the structure will need to be inspected.
- Inspection of the riverbank on the north and south sides of the Condensate Storage Tank was not accomplished due to current river levels. Once the river level drops, the remainder of the structure will need to be inspected.
- Inspection of the tank and foundation interface was not accomplished due to the large amount of river sediment deposited adjacent to the tank. Once the sediment is removed, the foundation interface will be inspected.
- Inclinometer readings along the river that will provide an indication of slope movement. Inclinometers have not been installed; therefore, readings were not available at the time of Revision 0.

5.11.4 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. 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 results of available geotechnical, geophysical, and survey data were analyzed, a number of

CPFMs were ruled out as discussed in Section 5.11.4.1. The CPFMs carried forward for detailed assessment are discussed in Section 5.11.4.2.

5.11.4.1 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 2c – Undermined buried utilities

<u>Reasons for ruling out:</u>

- Observed surface erosion in the Condensate Storage Tank area was limited to a few localized areas along the security fence south of the structure. In addition, only localized and limited surface erosion was observed on the ground surface across the facility.

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

<u>Reason for ruling out:</u>

- The nearby Turbine Building has a documented history of a void below the foundation slab with a potential for increased erosion with greater external water head. For further information see Section 5.8. A more detailed discussion of this Key Distress Indicator is presented in Section 4.1. There is a potential for this previously documented condition to erode larger voids under the Turbine Building and out into the surrounding structures. However, the piles for the Condensate Storage Tank are protected by a sheet pile wall to within approximately 10 ft above bedrock and are therefore not subjected to loss of pile support due to pumping.

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

<u>Reasons for ruling out:</u>

- At the 2011 peak flood elevation of approximately 1006.9 ft, the Condensate Storage Tank shell had a maximum of 1.5 ft of external water head on the tank shell.
- Overturning and sliding stability conditions are not credible because the external water force is balanced around the circumference of the tank.
- There were no field observations or indications of tank shell deformations due to flexure or shear.
- OPPD records indicate that the Condensate Storage Tank was maintained at a minimum of 72 percent full during the 2011 flood.

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:

- At the 2011 peak flood elevation of approximately 1006.9 ft, the Condensate Storage Tank shell had a maximum of 1.5 ft of external water head on the tank shell.
- OPPD records indicate that the tank was maintained at a minimum of 72 percent full during the 2011 flood.
- Overturning and sliding stability conditions are not credible because there was a sufficient internal liquid head resisting structure movement that was much larger than the external hydrodynamic load.
- There were no field observations or indications of tank shell deformations due to flexure or shear.
- There were no field observations of debris around the tank shell, and there was no observed damage to the tank shell and nozzles due to flexure or shear.

Triggering Mechanism 6 – Buoyancy, Uplift Forces on Structures

CPFM 6a – Fail tension piles
CPFM 6b – Cracked slab/loss of structural support
CPFM 6c – Displaced structure/broken connections

Reasons for ruling out:

- At the 2011 peak flood elevation of approximately 1006.9 ft, the Condensate Storage Tank shell had a maximum of 1.5 ft of external water head on the tank shell.
- OPPD records indicate that the Condensate Storage Tank was maintained at a minimum of 72 percent full during the flood event.
- Because of the internal water head, there was no condition where the piling was subjected to net uplift.
- There were no field observations that would indicate uplift on the tank structure.
- There were no field observations of broken structural connections.

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

<u>Reasons for ruling out:</u>

- The peak flood elevation prior to 2011 was 1003.3 ft, which occurred in 1993. The ground surface outside the tank is about el. 1005 ft. Therefore, the soils had been previously saturated.
- The Condensate Storage Tank structure has a pile-supported foundation, and therefore, loss of structural support for shallow foundations is not credible.
- No broken structural connections or structural displacement was observed.
- No site settlement around the Condensate Storage Tank was observed.

Triggering Mechanism 10 – Machine/Vibration-Induced Liquefaction

CPFM 10a – Cracked slab, differential settlement of shallow foundation, loss of structural support

<u>Reasons for ruling out:</u>

- No permanent equipment in the Condensate Storage Tank has the capacity to produce significant dynamic forces due to vibration.
- Liquefaction was not observed.

Triggering Mechanism 10 – Machine/Vibration-Induced Liquefaction

CPFM 10b – Displaced structure/broken connections

<u>Reasons for ruling out:</u>

- No permanent equipment in the Condensate Storage Tank area has the capacity to produce significant dynamic forces due to vibration.
- No broken structural connections or structural displacement was observed.
- Liquefaction was not observed.

Triggering Mechanism 10 – Machine/Vibration-Induced Liquefaction

CPFM 10d – Pile/pile group instability

<u>Reasons for ruling out:</u>

- No permanent equipment within the Condensate Storage Tank area has the capacity to produce significant dynamic forces due to vibration.
- Liquefaction was not observed.

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
CPFM 11d – Pile/pile group instability

Reasons for ruling out:

- Liquefaction was not observed at the Condensate Storage Tank.
- Visual observations and survey measurements indicate no structure movement. Therefore, differential settlement and loss of support (CPFM 11a) did not occur at the surveyed structures.
- No broken structural connections or structural displacement were observed.

Triggering Mechanism 12 – Rapid Drawdown

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

Reasons for ruling out:

- The structures did not have evident signs of distress identified during the field assessments.
- Slope failure was not observed at the site.
- River stage level has receded and stabilized as of October 4, 2011.
- As of October 11, 2011, groundwater elevations had already had one week to stabilize.
- The river bank is armored and has historically protected and stabilized the existing river bank.

Triggering Mechanism 13 – Submergence

CPFM 13a – Corrosion of underground utilities
CPFM 13b – Corrosion of structural elements

Reason for ruling out:

- The Condensate Storage Tank and the surrounding utilities have not been subjected to corrosive circumstances that would be considered beyond the normal conditions.

Triggering Mechanism 14 – Frost Effects

CPFM 14a – Heaving, crushing, or displacement

Reason for ruling out:

- The Condensate Storage Tank is on a deep pile foundation system that is not frost susceptible.

5.11.4.2 Detailed Assessment of Credible Potential Failure Modes

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

Triggering Mechanism 2 – Surface Erosion
CPFM 2b – Loss of lateral support for pile foundation

Observable signs of surface erosion were limited to very small localized areas at the security fence. No large-scale surface erosion was observed around the Condensate Storage Tank or the tank foundation. However, at the time of the inspection, the site was covered with a thick layer of river sediment; therefore, an adequate assessment could not be completed to determine whether areas had experienced erosion. Hand probing of the surrounding soil at the top of the riverbank was not possible due to the presence of a layer of crushed rock at the surface.

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 Condensate Storage Tank.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
	Observed surface erosion in the Condensate Storage Tank area was limited to a few localized areas along the security fence south of the structure. In addition, only localized and limited surface erosion was observed on the ground surface across the facility.
	The area on the top of the riverbank is covered with revetment to prevent erosion.
Data Gaps: • Observations of the east (river) side of the Condensate Storage Tank foundation including the sheet pile will be performed once the river has receded. • Observation of the ground surface around the tank will be performed once the deposited sediment is removed.	

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

The Condensate Storage Tank foundation is protected by a sheet pile skirt wall extending from the bottom of the tank to about 10 feet above the bedrock. The skirt wall would protect the tank pile foundations from surface erosion. The surface erosion around the skirt wall was not deep enough to affect skirt wall. Therefore, the potential for degradation is low.

Implication

The occurrence of this CPFM would negatively impact the capacity of the piling supporting the Condensate Storage Tank. This could lead to excessive foundation movement and negatively impact the integrity or intended function of the Condensate Storage Tank. Therefore, the implication of the potential degradation for this CPFM is high.

Confidence

Indicators for this CPFM have not been observed; however, inspection of the east side of the tank and the ground surface around the tank was not possible. Survey data to date have indicated no trends in structure movement. The available data are not sufficient to rule out this CPFM or lead to a conclusion that surface erosion has occurred under the Condensate Storage Tank. Therefore, the confidence in the above assessment is low, which means more data are necessary to draw a conclusion.

Summary

For CPFM 2b, 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 "not significant" category. The data currently collected are not sufficient to rule out this CPFM due to the 2011 flood. 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.

Triggering Mechanism 3 – Subsurface Erosion/Piping

CPFM 3c – Undermined buried utilities (due to pumping)

Buried utilities in the area of the Condensate Storage Tank include a 10-in. Force Water (FW) from the Condensate Storage Tank, the Trenwa, the Raw Water Piping, and the ductbank west of the Raw Water Piping with various utilities.

The Triggering Mechanism and CPFM could occur as follows: utility lines can act as possible seepage paths. These seepage paths could connect to several pumping sources such as the Turbine Building (see Key Distress Indicator #1 in Section 4.1), Manhole MH-5, and a number of pumps that were used within the Aqua Dam perimeter. The pumps were operated for an extended period (the pump in the Turbine Building sump will continue to operate until the breaks in the drain pipes are sealed), maintaining a head differential on the seepage path networks. Some gradients created by the head differential may have been sufficient to begin erosion of surrounding soil. If seepage is unfiltered and erosion continues unarrested, erosion will extends out intercepting the network of utility trenches, including the 10-in. FW from the Condensate Storage Tank. The potential damage includes settlement of pipe or thrust blocks. Settlement could overstress a pipe that is corroded, could cause a pipe to break, or could cause the displacement of a thrust block, which in turn could cause failure of a pipe operating under pressure.

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 Condensate Storage Tank.

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 flows into the building sump. A more detailed discussion of this Key Distress	There have been no observed indications of site settlement in the area directly surrounding the Condensate Storage Tank.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
Indicator is presented in Section 4.1.	
MH-5 on the dry side of the Aqua Dam was pumped continually.	
Pumping within the Aqua Dam perimeter.	

Data Gaps:

- Observation of the ground surface around the tank will be performed once the deposited sediment is removed.
- Additional data will be acquired from GPR, seismic survey, and geotechnical test borings in the Paved Access Area.

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

The CPFM has not been observed at the structure. However, voids created due to groundwater pumping at MH-5 might not have been evident at the time of the field assessments. Additionally, the extent of voids due to pumping of groundwater in the Turbine Building sump has not been determined. Indicators for this CPFM have been observed within the paved area between the Service Building and the Condensate Storage Tank. Observations indicate the potential that degradation has occurred due to this CPFM is high. The potential for further degradation will remain until the leaking drain pipes in the Turbine Building are sealed.

Implication

The occurrence of this CPFM on a large scale could cause pipe settlement, thrust block movement, and negatively impact the functionality of the Condensate Water Tank FW. The implication of the potential degradation for this CPFM is judged to be low.

Confidence

Indicators for this CPFM have not been observed; however, inspection of the east side of the tank and the ground surface around the tank was not possible and geotechnical and geophysical information from the Paved Access Area was not complete. Survey data to date have indicated no trends in structure movement. The available data are not sufficient to rule out this CPFM, or lead to a conclusion that subsurface erosion will negatively impact the Condensate Storage Tank FW. Therefore, the confidence in the above assessment is low, which means more data are necessary to draw a conclusion.

Summary

For CPFM 3c, 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 "not significant" category. There is Low Confidence that there has been significant degradation to soil beneath the Condensate Storage Tank FW due to the 2011 flood.

Triggering Mechanism 3 – Subsurface Erosion/Piping

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

The sheet pile wall enclosing the pile foundation has weep holes on the east face to allow water to drain from the inside of the wall back to the river when the river elevation is below el. 997 ft 6 in. As the river level drops, there will be a hydrostatic head pushing water out of the weep holes, which has the potential to erode the soils surrounding the piles from within the wall, if not properly filtered at the weep holes.

The Triggering Mechanism and CPFM could then occur as follows: river water elevation rises to a level that saturates the soil surrounding the piles within the sheet pile wall. As the river level drops below the weep holes, there is a differential head that drains the sheet pile wall. As the water drains, there is a potential for the soil to erode, creating voids around the piling system. If the erosion were to continue, the voids could get large enough to create a loss of lateral support for the piling.

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 Condensate Storage Tank.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
Open weep holes in the sheet pile wall have the potential to allow free movement of soil.	Survey data collected to date indicate no movement of the structure.
	The intent of the weep holes is to drain the sheet pile walls and if designed and constructed properly they should not degrade the soil fill within the sheet pile wall.
Data Gaps: • Observations of the east (river) side of the Condensate Storage Tank foundation including the sheet pile will be performed once the river has receded. • Observation of the ground surface around the tank will be performed once the deposited sediment is removed. • Observations of the weep holes is not considered necessary based on the current collected data.	

Conclusion

<u>Significance</u>

Potential for Degradation/Direct Floodwater Impact

The structure has undergone wetting cycles previously. It is reasonable to assume that the foundation system and weep hole drainage system were designed to account for flooding over the top of the weep holes. Therefore, the potential that the 2011 flood caused further degradation for this CPFM is low.

Implication

The occurrence of this CPFM is not expected to negatively impact the capacity of the piling supporting the Condensate Storage Tank, since the distance from the weep holes to the bottom of the tank floor is about 5 feet. A 5 feet void at the top of the piles is not expected to cause the piles to buckle. Therefore, the implication of the potential degradation for this CPFM is low.

<u>Confidence</u>

Indicators for this CPFM have not been observed; however, inspection of the east side of the tank, the ground surface around the tank, and sheet pile wall weep holes was not possible. Survey data to date have indicated no trends in structure movement. The available data are not sufficient to rule out this CPFM or lead to a conclusion that subsurface erosion has occurred under the Condensate Storage Tank support slab. Therefore, the confidence in the above assessment is low, which means more data are necessary to draw a conclusion.

<u>Summary</u>

For CPFM 3e, 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 "not significant" category. The data currently collected are not sufficient to rule out this CPFM due to the 2011 flood. 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.

Triggering Mechanism 3 – Subsurface Erosion/Piping

CPFM 3f – Undermined buried utilities (due to river drawdown)

This CPFM is similar to CPFM 3c described above, but the gradient is created by rapidly receding river level instead of pumping.

The Triggering Mechanism and CPFM could then occur as follows: if the river level drops faster than pore water pressure in the foundation soil can dissipate, a gradient could be created that erodes the soil. Depending on the extent of the voids created, impacts could include the following: trench subsidence, unsupported pipe sections, pipe deflections, pipe failure, and possible impacts on adjacent improvements or utilities.

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 Condensate Storage Tank.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
Condensate Storage Tank and utilities are located on the riverbank.	No signs of distress have been observed.
	The river stage level has receded and stabilized at a level corresponding to the nominal normal river level at 40,000 cfs as of October 4, 2011.

Data Gaps:

- Observations of the east (river) side of the Condensate Storage Tank foundation including the sheet pile will be performed once the river has receded.
- Observation of the ground surface around the tank will be performed once the deposited sediment is removed.
- Additional data will be acquired from GPR, seismic survey, and geotechnical test borings in the Paved Access Area.

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

The potential degradation from this CPFM may not have occurred yet, since groundwater levels have likely not receded to a nominal normal level.

None of the indicators for the CPFM has been observed at the structures. However, voids due to rapid drawdown might not have been evident at the time of the field assessments. Additionally, the extent of voids created by rapid drawdown could be small. The potential that degradation has occurred due to this CPFM is low.

Implication

The occurrence of this CPFM could negatively impact the operation of the structure. This could lead to pipe or thrust block settlement and could negatively impact the integrity or intended functionality of the Condensate Storage Tank piping system. The implication of the potential degradation for this CPFM is considered high.

Confidence

Indicators for this CPFM have not been observed; however, inspection of the east side of the tank and the ground surface around the tank was not possible and geotechnical and geophysical information from the Paved Access Area was not complete. Survey data to date have indicated no trends in structure movement. The available data are not sufficient to rule out this CPFM or lead to a conclusion that subsurface erosion will negatively impact the Condensate Storage Tank piping system. Therefore, the confidence in the above assessment is low, which means more data are necessary to draw a conclusion.

Summary

For CPFM 3f, 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 "not significant" category. There is Low Confidence that there will be significant degradation to soil beneath the Condensate Storage Tank piping system due to the 2011 flood.

5.11.5 Results and Conclusions

The CPFMs evaluated for the Condensate Storage Tank 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**	CPFM 2b CPFM 3c CPFM 3e CPFM 3f	

5.11.6 Recommended Actions

The following actions are recommended for the Condensate Storage Tank:

- In-depth tank survey including a shell distortion map with results and recommendations.
- Visual inspection of the east side of the tank and the ground surface around the tank
- Further forensic investigations and physical modifications are recommended to address CPFM 3a (Key Distress Indicator #1). These recommendations are described in detail in Section 4.1.3.

While inspection of the weep holes in the sheet pile wall would be beneficial, it is not deemed necessary at this time.

Continued monitoring is recommended to include a continuation of the elevation surveys of the previously identified targets on this structure and surrounding site. In addition, a review of the ongoing geophysical investigations and monitoring of inclinometer readings is recommended. The purpose is to monitor for signs of structure distress and movement or changes in soil conditions around the structure. The results of this monitoring will be used to increase the confidence in the assessment results. Elevation surveys should be performed weekly for 4 weeks and biweekly until December 31, 2011. At the time of Revision 0, groundwater levels had not yet stabilized to nominal normal levels. Therefore, it is possible that new distress indicators could still develop. If new distress indicators are observed before December 31, 2011, appropriate HDR personnel should be notified immediately to determine if an immediate inspection or assessment should be conducted. Observation of new distress indicators might result in a modification of the recommendations for this structure.

5.11.7 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.

5.11.7.1 Additional Data Available

The following additional data were available for the Condensate Storage Tank 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 falling weight deflectometer investigation by American Engineering Testing, Inc. (see Attachment 6).
- Results of geophysical investigation by Geotechnology, Inc. (see Attachment 6).
- Results of geotechnical investigation by Thiele Geotech, Inc. (see Attachment 6).
- Data obtained from inclinometers by Thiele Geotech, Inc. (see Attachment 6).
- Results of continued survey by Lamp Rynearson and Associates (see Attachment 6).
- Field assessments of the tank and foundation interface.

Note: OPPD requested information from HDR on firms that specialize in in-depth tank surveys to assist them in a follow-up investigation for possible shell distortion of the tank. HDR has provided this information to OPPD.

5.11.7.2 Additional Analysis

The following analysis of additional data was conducted for the Condensate Storage Tank:

- 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 falling weight deflectometer investigation by American Engineering Testing, Inc.

  Falling Weight Deflectometer 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 by Geotechnology, Inc.

  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, Inc.

  Six test borings were drilled, with continuous sampling of the soil encountered, to ground truth the Geotechnology, Inc. 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 feet 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 Lamp Rynearson and Associates.

  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 2 – Surface Erosion

CPFM 2b – Loss of lateral support for pile foundation

Field observations of the Condensate Storage Tank, after OPPD removed the deposited sediment, identified that the surrounding grades were predominately surfaced in gravel. Observations of the grades did not determine that surface erosion had occurred. Observations of the sheet pile skirt wall identified the visible portions of the wall to be in good condition.

Significance

Potential for Degradation/Direct Floodwater Impact

The Condensate Storage Tank foundation is protected by a sheet pile skirt wall extending from the bottom of the tank to about 10 feet above the bedrock. The skirt wall protected the foundations from surface erosion. Therefore, the potential that the 2011 flood caused further degradation for this CPFM is low.

Implication

The occurrence of this CPFM would negatively impact the capacity of the piling supporting the Condensate Storage Tank. This could lead to excessive foundation movement and negatively impact the integrity or intended function of the Condensate Storage Tank. Therefore, the implication of the potential degradation for this CPFM is high.

Confidence

The extent of surface erosion and its potential impact on the tank was not known at the time of Revision 0 due to the river sediment that had been deposited around the tank restricting access and visibility. Subsequent field inspections and a review of surveyed data indicate no structure movement. Since the structure has been monitored and no signs of movement have been detected, the confidence in the assessment of degradation for this CPFM has increased. If further structure monitoring reveals no further issues the confidence of the assessment for this CPFM becomes high.

Summary

For CPFM 2b, as discussed above, the potential for degradation is low because the tank foundations are protected by a sheet pile skirt wall. It is unlikely this degradation would have occurred to cause impact on the integrity or intended function of the structure. 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 collected since Revision 0 are sufficient to rule out this CPFM assuming the previously recommended monitoring schedule is continued. Therefore, the confidence in the above assessment is high, which means no additional data and inspections are necessary to draw a conclusion.

Triggering Mechanism 3 – Subsurface Erosion/Piping

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

Field observations of the Condensate Storage Tank after OPPD removed the deposited sediment did not identify distress to the tank foundation. Observations of the sheet pile skirt wall identified the visible portions of the wall to be in good condition.

Significance

Potential for Degradation/Direct Floodwater Impact

The structure has undergone wetting cycles previously. It is reasonable to assume that the foundation system and weep hole drainage system were designed to account for flooding over the top of the weep holes. Therefore, the potential that the 2011 flood caused further degradation for this CPFM is low.

Implication

The occurrence of this CPFM would negatively impact the capacity of the piling supporting the Condensate Storage Tank. This could lead to excessive foundation movement and negatively impact the integrity or intended function of the Condensate Storage Tank. Therefore, the implication of the potential degradation for this CPFM is high.

Confidence

The extent of subsurface erosion and its potential impact on the tank was not known at the time of Revision 0 due to the river sediment that had been deposited around the tank restricting access and visibility and not having inspected the weep holes. The groundwater elevation measured in the monitoring wells closely followed the river level as the floodwater receded and the differential head created by the river drawdown was insufficient to facilitate subsurface erosion. Subsequent field inspections and a review of surveyed data indicate no structure movement; and an observation of the weep holes was not deemed necessary. Since the structure has been monitored and no signs of movement have been detected, the confidence in the assessment of degradation for this CPFM has increased. If further structure monitoring reveals no further issues, the confidence of the assessment for this CPFM becomes high.

Summary

For CPFM 3e, as discussed above, the potential for degradation is low because it is reasonable to assume that the foundation system and weep hole drainage system were designed to account for flooding over the top of the weep holes. It is unlikely this degradation would have occurred to cause impact to the integrity or intended function of the structure. 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 collected since Revision 0 are sufficient to rule out this CPFM assuming the previously recommended monitoring schedule is continued. Therefore, the confidence in the above assessment is high, which means no additional data and inspections are necessary to draw a conclusion.

Triggering Mechanism 3 – Subsurface Erosion/Piping
CPFM 3f – Undermined buried utilities (due to river drawdown)

Significance

Potential for Degradation/Direct Floodwater Impact

The groundwater elevation measured in the monitoring wells closely followed the river level as the floodwater receded. The data indicate that groundwater elevation was about 2 ft above the river level near the beginning of October 2011 and receded to the river level by about October 14, 2011. Therefore the differential head created by the river drawdown was insufficient to facilitate subsurface erosion. The potential that degradation has occurred due to this CPFM is low.

Implication

The occurrence of this CPFM could negatively impact the operation of the structure. This could lead to pipe or thrust block settlement and could negatively impact the integrity or intended functionality of the Condensate Storage Tank piping system. The implication of the potential degradation for this CPFM is considered high.

Confidence

The extent of subsurface erosion and its potential impact on the piping system was not known at the time of Revision 0 due to the river sediment that had been deposited around the tank restricting access and visibility. Subsequent field inspections and a review of surveyed data indicate no structure movement. Since the structure has been monitored and no signs of movement have been detected, the confidence in the assessment of degradation for this CPFM has increased. If further structure monitoring reveals no further issues, the confidence of the assessment for this CPFM becomes high.

Summary

For CPFM 3f, as discussed above, the potential for degradation is low because the differential head created by the river drawdown was insufficient to facilitate subsurface erosion. It is unlikely this degradation would have occurred to cause impact on the integrity or intended function of the structure. 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 collected since Revision 0 are sufficient to rule out this CPFM assuming the previously recommended monitoring schedule is continued. Therefore, the confidence in the above assessment is high, which means no additional data and inspections are necessary to draw a conclusion.

5.11.7.1 Revised Results

The CPFMs evaluated for the Condensate Storage Tank are presented in the following matrix, which shows the rating for the significance and the level of confidence in the evaluation. CPFMs 2b, 3e, and 3f for the Condensate Storage Tank are not associated with Key Distress Indicators. The results of the additional forensic investigation show that these CPFMs are ruled out. Therefore, assuming that no further concerns are identified through the monitoring program for the Condensate Storage Tank (discussed in Section 5.11.6 and continuing until December 31, 2011), these CPFMs are moved to the quadrant of the matrix representing "No Further Action Recommended Related to the 2011 Flood." CPFM 3c for the Condensate Storage Tank is associated with Key Distress Indicators #1 and #2. Sections 4.1 and 4.2 present the results of additional forensic investigation that was 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 are implemented that this CPFM is ruled out. Therefore, assuming that no further concerns are identified through the monitoring program for the Condensate Storage Tank (discussed in Section 5.11.6 and continuing until December 31, 2011), and the physical modifications recommended for KDI #1 are implemented, the CPFM is 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**		
Potential for Failure **Not Significant**		CPFM 2b CPFM 3c CPFM 3e CPFM 3f

5.11.7.2 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 Condensate Storage Tank other than CPFMs 2b, 3c, 3e, and 3f had been ruled out prior to Revision 1, because CPFMs 2b, 3e, and 3f have been ruled out as a result of the Revision 1 findings, and because CPFM 3c will be ruled out when the physical modifications recommended for KDI #1 in Section 4.1 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Condensate Storage Tank. 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.

Section 5.13

Circulating Water System

Omaha Public Power District

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	16506	1/17/1975	11405-S-274
Piling Plan Intake Structure	16507	1/20/1975	11405-S-275
Circulating Water Tunnels Plans	16522	1/22/1975	11405-S-299
Circulating Water Tunnels Section & Details	16523	1/22/1975	11405-S-300
Intake Structure & Tunnel Foundation Plan & Details	16531	1/23/1975	11405-S-311
Intake Structure & Tunnel Sections & Details	16537	1/9/1975	11405-S-317
Intake Structure & Tunnel Miscellaneous Details	16540	1/29/1975	11405-S-320
Incident Report Summary	CR 2011-5369	6/5/2011	All
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

Table 5.13-1 - References for Circulating Water System			
Document Title	**OPPD Document Number (if applicable)**	**Date**	**Page Number(s)**
Incident Report Summary	CR 2011-5737	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
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.
- King Tut blocks (20 to 25 thousand pounds each) located adjacent to the PA fence at the north end of the corridor, east of the Maintenance Building, were loaded onto trucks and removed from this area on September 14, 2011. The assessment team observed and photographed this operation. No pavement displacement or deflection was observed during the lifting or removal of these blocks.
- The Aqua Dam surrounding the facility 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 for quite some time. 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 4-ft-long, 0.5-in.-diameter, steel-tipped fiberglass T-handle soil 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 protected area. (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. (TV 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 receded 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 Key Distress Indicators 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 (Key Distress Indicator #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 falling weight deflectometer investigation by American Engineering Testing, Inc. (see Attachment 6).
- Results of geophysical investigation by Geotechnology, Inc. (see Attachment 6).
- Results of geotechnical investigation by Thiele Geotech, Inc. (see Attachment 6).
- Data obtained from inclinometers by Thiele Geotech, Inc. (see Attachment 6).
- Results of continued survey by Lamp Rynearson and Associates (see Attachment 6).

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 falling weight deflectometer investigation by American Engineering Testing, Inc.

  Falling Weight Deflectometer 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, Inc.

  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, Inc.

  Six test borings were drilled, with continuous sampling of the soil encountered, to ground truth the Geotechnology, Inc. 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 feet 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 Lamp Rynearson and Associates.

  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 Key Distress Indicator #1 and Key Distress Indicator #2. Sections 4.1 and 4.2 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, assuming that no further concerns are identified through the monitoring program for the Circulating Water System (discussed in Section 5.13.6 and continuing until December 31, 2011), this CPFM is moved to the quadrant of the matrix representing "No Further Action Recommended Related to the 2011 Flood."

5.13.7.1 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

5.13.7.2 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 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.

Section 5.14

Demineralized Water Tank, Pump House, and RO Unit

Omaha Public Power District

5.14 Demineralized Water Tank, Pump House, and RO Unit

5.14.1 Summary of Demineralized Water Tank, Pump House, and RO Unit

Baseline information for the Demineralized Water Tank, Pump House, and RO Unit is provided in Section 2.0, Site History, Description, and Baseline Condition.

The Demineralized Water Tank is a 33-ft-inside-diameter storage tank that extends approximately 31 ft above grade. The tank is fabricated of stainless steel to meet the requirements of the API Standard 650. The tank is supported around its perimeter on a continuous cast-in-place concrete ring wall that is about 1.2 ft wide by 2 ft tall. The interior of the tank bears on a layer of sand on top of a geotextile filter fabric, which in turn is on top of a free-draining crushed limestone aggregate. The crushed limestone aggregate is drained by three 1.5-in.-diameter foundation drains spaced equally around the concrete ring wall.

The Pump House is a small pre-engineered metal building supported on a 6-in. slab.

The entire tank footprint, including the concrete ring wall and the interior crushed rock along with the Pump House slab, is supported on a rammed aggregate piers soil improvement system.

The RO Unit resides in the northern section of the Old Warehouse. The Old Warehouse is a pre-engineered metal building supported on a cast-in-place slab and perimeter stem wall on continuous footings that extend below frost depth.

5.14.2 Inputs/References Supporting the Analysis

Table 5.14-1 lists references provided by OPPD and other documents used to support HDR's analysis.

Table 5.14-1 - References for Demineralized Water Tank, Pump House, and RO Unit

Document Title	OPPD Document Number (if applicable)	Date	Page Number(s)
Site Plan		8/28/2009	1 of 2
Details		8/28/2009	2 of 2
Geopier® Foundation System P09-PMN-00097		4/20/2010	GEO-1 & GEO-2
Naval Facilities Engineering Command, Design Manual 7.01, Soil Mechanics		9/1986	All

Detailed site observations—field reports, field notes, and inspection checklists—for the Demineralized Water Tank, Pump House, and RO Unit are provided in Attachment 8.

Observed performance and pertinent background data are as follows:

- The soils below the Demineralized Water Tank and Pump House were improved by installation of fifty 30-in.-diameter-by-18-ft-minimum-depth rammed aggregate piers (see Geo-1 and Geo-2).
- A total of 41 rammed aggregate piers were installed below the tank footprint, and 9 were installed under the Pump House slab.

- The tank foundation system, including crushed rock interior, is shown on the site plan and detail sheets by LRA in table 5.14-1.
- Structural drawings for the Old Warehouse are not available, so descriptions of the foundations are assumed based on normal standard practice for foundation construction for a pre-engineered metal building.
- The Aqua Dam surrounding the Demineralized Water Tank and Pump House failed for an unknown amount of time, allowing floodwater to enter the area inside the Aqua Dam perimeter. Based on observed water marks on the Demineralized Water Tank and Pump House, water levels reached approximately 2.5 ft above grade.
- The interiors of the Pump House and Old Warehouse showed signs of upward seepage at slab-on-grade joints. Other HDR employees observed upward seepage from joints in the slab during previous inspections.
- Site soils were saturated at the times of inspection.
- Small channels of water flow were observed as water dissipated from the vicinity of the tank and Pump House.
- Neither the Demineralized Water Tank nor the Pump House has a foundation that extends below frost depth.
- Foundation drains for the tank were found to be clogged with sediment at the time of inspection.
- Areas of relatively soft soils were observed by using a soil probe in the general vicinity of the tank and Pump House, but these areas are out of the zone of influence for the foundation systems.
- Probed areas around the Pump House are soft in the upper 6 in. in general. One spot near the southwest corner of the Pump House foundation did have softer soils; the probe could be pushed in to a depth of 2 ft.
- In an area between the Demineralized Water Tank and Pump House approximately 10 ft from the east side of the structures, the probe could be pushed in to the full depth of the probe. The soils were not uniform; some layers were soft and others stiffer. At this distance the soft soils are out of the zone of influence for the foundation systems.
- A void estimated to be 4 ft in diameter and 1.5 to 2 ft deep was observed below a transformer pad at the northeast corner of the Old Warehouse. This area was pumped with a small pump for the duration of the 2011 flood.
- The area directly east of the Old Warehouse between the rock road and the building was dug out and used as a water collection trough. These areas had multiple small portable pumps removing water from the trench.

5.14.3 Assessment Methods and Procedures

5.14.3.1 Assessment Procedures Accomplished

Assessments of the Demineralized Water Tank, Pump House, and RO Unit included the following:

- Visual inspection of the interior and exterior of the north side of the Old Warehouse at the water treatment facility and also the exterior of the tank and Pump House
- An assessment of collected survey data to date for indications of trends in the movement of the structures
- Probe of surrounding grades to determine stiffness and consistency of soils
- A review of previously referenced documents listed in Table 5.14-1

Additional investigations were performed. These included the following non-invasive geophysical and invasive geotechnical investigations:

- Geotechnical test borings in the protected area. 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.)

5.14.3.2 Assessment Procedures Not Completed

Assessments of the Demineralized Water Tank, Pump House, and RO Unit that were not completed include the following:

- Review of as-built construction drawings for the Old Warehouse, including the water treatment area, was not completed because at the time of Revision 0, the drawings were not available.

5.14.4 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. 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 detailed 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 5.14.4.1. The CPFMs carried forward for detailed assessment are discussed in Section 5.14.4.2.

5.14.4.1 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
CPFM 2c – Undermined buried utilities

Reason for ruling out:

- The site was observed after floodwaters had begun to recede from the area. No signs of surface erosion were seen that could contribute to undermining of the foundations or slabs for these structures.

Triggering Mechanism 4 – Hydrostatic Lateral Loading (water loading on structures)

CPFM 4c – Wall failure in flexure
CPFM 4d – Wall failure in shear
CPFM 4e – Excess deflection

Reasons for ruling out:

- In accordance with conversations with OPPD personnel, the Demineralized Water Tank was kept full during the 2011 flood, resulting in no net differential wall pressures.
- The Pump House was inundated at the time of the Aqua Dam failure, resulting in no net differential wall pressures.
- Water surrounded the Pump House and Demineralized Water Tank on all sides, creating equal hydrostatic pressure.
- The water treatment area of the Old Warehouse was isolated from floodwaters by an Aqua Dam.

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:

- Overland flow velocity at this location was very low, creating very minimal forces due to hydrodynamic loading. Observed scouring in this location was isolated to areas where the flow area was reduced and the velocity increased (i.e., the King Tut blocks). In general, the area had sediment deposits that would indicate low flow velocity.
- Floodwaters have since begun to recede from the site, and no signs of distress that could be attributed to hydrodynamic loading have been observed.

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:

- In accordance with conversations with OPPD personnel, the Demineralized Water Tank was kept full during the 2011 flood, resulting in no net buoyancy effects.
- The Pump House was inundated at the time of the Aqua Dam failure, resulting in no net differential wall pressures.
- Although a net uplift force from floodwaters might have occurred on the Old Warehouse floor slabs, cracking or loss of structural support of the slabs was not observed at the time of the inspection.

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:

- Soil collapse due to first time wetting occurs immediately once soils are wetted. Degradation related to this CPFM would have been apparent at the time of inspection.

Triggering Mechanism 10 – Machine/Vibration-Induced Liquefaction

CPFM 10a – Cracked slab, differential settlement of shallow foundation, loss of structural support
CPFM 10b – Displaced structure/broken connections

Reasons for ruling out:

- Vibrations from equipment in the Pump House and Old Warehouse are very small and create minimal localized vibrations that could not cause liquefaction.
- No signs of liquefaction were observed during the inspection.

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

Reason for ruling out:

- Visual observations and survey measurements show no structure movement. Therefore, degradation that can be attributed to this CPFM did not occur.

Triggering Mechanism 12 – Rapid Drawdown

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

Reason for ruling out:

- The structures are located outside of the PA and are a sufficient distance away from the riverbank to be outside the zone of influence of a bank slope failure.

Triggering Mechanism 13 – Submergence

CPFM 13b – Corrosion of structural elements

Reasons for ruling out:

- The Demineralized Water Tank and connected piping are stainless steel and have not been subjected to corrosive circumstances that would be considered beyond the normal conditions.

- The Pump House was inundated at the time of the Aqua Dam failure. However, this inundation duration was short, and no abnormal corrosion on the building was observed.
- The water treatment area of the Old Warehouse was isolated from floodwater by the Aqua Dam.

5.14.4.2 Detailed Assessment of Credible Potential Failure Modes

The following CPFMs are the only CPFMs carried forward for detailed assessment for the Demineralized Water Tank, Pump House, and RO Unit 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)

Subsurface erosion was observed at the northeast corner of the Old Warehouse where localized pumping of floodwaters occurred. The approximately 4-ft-diameter-by-1.5-ft-deep void has caused some undermining of the transformer foundation to the point of exposing some buried conduit. Observations made by HDR in June and July showed water coming up through the joints in the floor slab.

No pumping occurred in the vicinity of the Demineralized Water Tank or Pump House; therefore, these structures would not be subjected to this CPFM.

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 Demineralized Water Tank, Pump House, and RO Unit.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
Possible subsurface erosion due to pumping was observed under a transformer pad on the exterior northeast corner of the Old Warehouse building and warehouse floor.	Erosion observed did not appear to extend deep enough to reach the foundations of the Old Warehouse.
Soils in the vicinity were found to be of varying densities, which could include loose soils that are more susceptible to erosion due to pumping.	Soils where pumping occurred seemed to be a gravel/structural fill with relatively high density, which is less susceptible to erosion.
Observations in June and July indicated water infiltration through the RO Unit building slab joints.	
Data Gaps: • The presence of subsurface erosion under the RO Unit in the Old Warehouse slab due to pumping is not known to exist. • Geotechnical borings and CPT soundings in the vicinity of the structures to determine current soil conditions and capacities have not been conducted.	

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

Indicators for the CPFM have been observed, although they seem to be isolated to one area below a transformer pad on the northeast corner outside of the Old Warehouse and in the center of the Warehouse floor. The void below the transformer pad is known to exist, and the extent of the void can easily be observed. The void does not appear to extend below the building foundation. Because there are observed signs of flow under the floor and a known void adjacent to the Old Warehouse building, it is possible that this void extends under the building and possibly undermines the foundation, although observations do not indicate this to be the case. The potential is low that this CPFM will occur under the building in the area housing the RO Unit.

Implication

The occurrence of this CPFM could negatively impact the capacity of the Old Warehouse building foundation. This could lead to gradual foundation movement but should not negatively impact the integrity or intended function of the building before remedial action can be implemented. Therefore, the implication of the potential degradation for this CPFM is low.

Confidence

The extent of subsurface erosion and its potential impact on the Old Warehouse building is not known due to the lack of data gathered on subsurface conditions. Because there is not enough information on the subsurface conditions at this time, and the pumping occurred directly adjacent to the building that could have caused subsurface erosion under the building, the confidence for this PFM is low.

Summary

For CPFM 3a, as discussed above, the potential for degradation is low because the extent of erosion occurring is visible and does not extend below the building foundation. The combined consideration of the potential for degradation and the implications of that degradation to a structure of this type puts 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 continued monitoring is necessary to draw a conclusion.

Triggering Mechanism 14 – Frost Effects

CPFM 14a – Heaving, crushing, or displacement

The foundations for the Demineralized Water Tank and Pump House are not below frost depths and are therefore subjected to frost effects.

The Triggering Mechanism and CPFM could then occur as follows: soils may be saturated when the ground freezes, which would increase the potential for excessive frost heave. Drains below the tank appear to be clogged, not allowing water under the tank to drain before it freezes, which would not be the design intent of the tank.

The Old Warehouse is on footings that extend below frost and is not susceptible to this CPFM.

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 Demineralized Water Tank, Pump House, and RO Unit.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
Soils were saturated at the time of inspection.	The Demineralized Water Tank and Pump House have been previously subjected to freeze-thaw cycles.
Due to the time of year, groundwater could freeze at any time.	
Tank foundation drains were plugged.	
Data Gaps: • Geotechnical borings and CPT soundings in the vicinity of the structures to determine current soil conditions and capacities have not been conducted.	

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

The potential for this CPFM exists on the Demineralized Water Tank and Pump House due to the foundation systems used for these structures and the clogged drains below the tank. Due to the saturated soils and the time of year, it is possible the ground will freeze before the water levels in the soil have a chance to reduce to normal levels, causing excessive soil expansion. Due to the type of foundation system used, the tank and pump house have been subjected to freeze-thaw cycles in the past although potentially not to this extent and not with the drains below the tank clogged. The potential is low that this CPFM will affect the Demineralized Water Tank and Pump House since the increase in effect due to the clogged drains and high groundwater levels is expected to have minimal effect.

Implication

The occurrence of this CPFM could potentially cause some movement in the Tank and Pump House foundation systems; however, because the foundations have always been subjected to freeze-thaw cycles, the additional movement under current conditions is not expected to cause an excessive increase in movement. Therefore, the implication of the potential degradation for this CPFM is low.

Confidence

At this time, it is not known whether the ground will freeze before soil water levels are able to lower to a normal condition. In addition, the foundation drains were completely plugged with sediment, which does not allow the crushed rock bedding to drain and could cause adverse effects on the bottom of the tank if the ground were to freeze in this condition. Therefore, the data at hand are not sufficient to rule out this CPFM. As a result, the confidence in the assessment is low, which means more data are necessary to draw a conclusion.

Summary

For CPFM 14a, as discussed above, the potential for degradation is low because the effects due to frost heave are expected to cause minimal effects on the structures. The combined consideration of the potential for degradation and the implications of that degradation to the structures 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 continued monitoring is necessary to draw a conclusion.

5.14.5 Results and Conclusions

The CPFMs evaluated for the Demineralized Water Tank, Pump House, and RO Unit 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**	CPFM 3a CPFM 14a	

5.14.6 Recommended Actions

Continued monitoring is recommended to include a continuation of the elevation surveys of the previously identified targets on this structures and surrounding site. The purpose is to monitor for signs of structure distress and movement or changes in soil conditions around the structures. The results of this monitoring will be used to increase the confidence in the assessment results. Elevation surveys should be performed weekly for 4 weeks and biweekly until December 31, 2011. At the time of Revision 0, groundwater levels had not yet stabilized to nominal normal levels. Therefore, it is possible that new distress indicators could still develop. If new distress indicators are observed before December 31, 2011, appropriate HDR personnel should be notified immediately to determine whether an immediate inspection or assessment should be conducted. Observation of new distress indicators might result in a modification of the recommendations for these structures.

5.14.7 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.

5.14.7.1 Additional Data Available

The following additional data were available for the Demineralized Water Tank, Pump House, and RO Unit for Revisions 1 and 2 of this Assessment Report:

- Additional groundwater monitoring well and river stage level data from OPPD.
- Results of geophysical investigation by Geotechnology, Inc. (see Attachment 6).
- Results of geotechnical investigation by Thiele Geotech, Inc. (see Attachment 6).
- Results of continued survey by Lamp Rynearson and Associates (see Attachment 6).
- Review of as-built construction drawings for the Old Warehouse, including the water treatment area, was not completed because at the time of Revision 1, the drawings were not available.

5.14.7.2 Additional Analysis

The following analysis of additional data was conducted for the Demineralized Water Tank, Pump House, and RO Unit:

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

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

- Results of geophysical investigation by Geotechnology, Inc.

  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, Inc.

  Six test borings were drilled, with continuous sampling of the soil encountered, to ground truth the Geotechnology, Inc. 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 feet to protect existing utilities.

- Results of continued survey by Lamp Rynearson and Associates.

  Survey data to date compared to the original baseline surveys have exceeded the accuracy range of the surveying equipment. However, the deviations are small and are not of a concern for structures of this type.

Several CPFMs were identified in Revision 0. Since Revision 0 additional data have become available which has clarified the significance and confidence for these CPFMs. The following presents each of the previously identified CPFMs and the new interpretation of their significance and confidence based upon the new data.

Triggering Mechanism 3 – Subsurface Erosion/Piping

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

Subsurface erosion was observed at the northeast corner of the Old Warehouse where localized pumping of floodwaters occurred. The approximately 4-ft-diameter-by-1.5-ft-deep void has caused some undermining of the transformer foundation to the point of exposing some buried conduit. Observations made by HDR in June and July showed water coming up through the joints in the floor slab.

No pumping occurred in the vicinity of the Demineralized Water Tank or Pump House; therefore, these structures would not be subjected to this CPFM.

<u>Significance</u>

Potential for Degradation/Direct Floodwater Impact

Indicators for the CPFM have been observed, although they seem to be isolated to one area below a transformer pad on the northeast corner outside of the Old Warehouse. The void below the transformer pad is known to exist, and the extent of the void can easily be observed. The void does not appear to extend below the building foundation. Because there is a known void adjacent to the Old Warehouse building, it is possible that this void extends under the building and possibly undermines the foundation, although observations do not indicate this to be the case. The potential is low that this CPFM will occur under the building in the area housing the RO Unit.

Implication

The occurrence of this CPFM could negatively impact the capacity of the Old Warehouse building foundation. This could lead to gradual foundation movement but should not negatively impact the integrity or intended function of the building before remedial action can be implemented. Therefore, the implication of the potential degradation for this CPFM is low.

Confidence

The extent of subsurface erosion and its potential impact on the building was not known due to the lack of data gathered on subsurface conditions. Subsequent field inspections and a review of surveyed data indicate no significant structure movement. Since the structure has been monitored and no signs of movement have been detected, the confidence for this CPFM is high.

Summary

For CPFM 3a, as discussed above, the potential for degradation is low because signs of distress were not observed. It is unlikely this degradation would have caused enough erosion to impact the integrity or intended function of the structure. The combined consideration of the potential for degradation and the implications of that degradation to a structure of this type put it in the "not significant" category. The data collected since Revision 0 are sufficient to rule out this CPFM assuming the previously recommended monitoring schedule is continued. Therefore, the confidence in the above assessment is high, which means no additional data and inspections are necessary to draw a conclusion. The data previously thought to be required to rule out this CPFM, which includes a geotechnical investigation and a review of as-built drawings, are no longer required.

Triggering Mechanism 14 – Frost Effects

CPFM 14a – Heaving, crushing, or displacement

The foundations for the Demineralized Water Tank and Pump House are not below frost depths and are therefore subjected to frost effects. Soils were thought to have a potential of being saturated when the ground froze, creating a potential for excessive frost heave. Drains below the tank appeared to be clogged at the time of the initial inspection, not allowing water under the tank to drain, which would not meet the design intent for the tank. The Old Warehouse is on footings that extend below frost and is not susceptible to this CPFM.

Significance

Potential for Degradation/Direct Floodwater Impact

The groundwater elevation measured in the monitoring wells closely followed the river level as the floodwater receded. The data indicate that groundwater elevation was about 2 ft above the river level near the beginning of October 2011 and receded to the river level by about October 14, 2011. Therefore, saturated soil conditions beyond normal are no longer an issue and the potential for degradation for this CPFM is low.

Implication

The occurrence of this CPFM could cause some movement in the tank and Pump House foundation systems; however, because the foundations have always been subjected to freeze-thaw cycles, the additional movement under current conditions is not expected to cause an excessive increase in movement. Therefore, the implication of the potential degradation for this CPFM is low.

Confidence

At this time, it is known that the ground will not freeze before soil water levels are able to lower to a normal condition because water levels have been determined to be at normal conditions at the time of Revision 1 and the ground has not frozen. Therefore, the data at hand are sufficient to rule out this CPFM. As a result, the confidence in the assessment is high, which means no other data are necessary to draw a conclusion.

Summary

For CPFM 14a, as discussed above, the potential for degradation is low because the effects due to frost heave are not applicable due to lowered groundwater levels. The combined consideration of the potential for degradation and the implications of that degradation to the structures of this type put it in the "not significant" category. The data currently collected are sufficient to rule out this CPFM. Therefore, the confidence in the above assessment is high, which means no additional data and inspections are necessary to draw a conclusion. The data previously thought to be required to rule out this CPFM, which includes the geotechnical information, are no longer required.

5.14.7.1 Revised Results and Recommendations

The CPFMs evaluated for the Demineralized Water Tank, Pump House, and RO Unit are presented in the following matrix, which shows the rating for the estimated significance and the level of confidence in the evaluation. CPFMs 3a and 14a for the Demineralized Water Tank, Pump House, and RO Unit are not associated with Key Distress Indicators. Results of survey data, ground well monitoring data, and field inspections do not indicate signs of significant structure movement or other adverse effects that could be attributed to these CPFMs. Therefore, assuming that no further concerns are identified through the monitoring program for the Demineralized Water Tank, Pump House, and RO Unit (discussed in Section 5.14.6 and continuing until December 31, 2011), these CPFMs 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**		
Potential for Failure **Not Significant**		CPFM 3a CPFM 14a

5.14.7.2 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 Demineralized Water Tank, Pump House, and RO Unit other than CPFMs 3a and 14a had been ruled out prior to Revision 1, and because CPFMs 3a and 14a have been ruled out as a result of the Revision 1 findings, no Triggering Mechanisms and their associated PFMs will remain credible for the Demineralized Water Tank, Pump House, and RO Unit. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Demineralized Water Tank, Pump House, and RO Unit because the potential for failure of this structure due to the flood is not significant.

Section 5.15

Raw Water Piping

Omaha Public Power District

5.15 Raw Water Piping

5.15.1 Summary of Raw Water Piping

Baseline information for the Raw Water Piping is provided in Section 2.0, Site History, Description, and Baseline Condition.

The Raw Water Piping is a once-through cooling water system that removes heat from the component cooling water system. The Raw Water Piping also provides direct cooling water through the component cooling water piping to selected safety-related components in the event that the component cooling water system is unavailable.

The Raw Water Piping serves as a conduit for discharging water to the river from various sources.

The system is composed of four motor-driven pumps, two strainers and motor sets, valves, piping, instrumentation, and controls.

Two 20-in. raw water pipes are routed between the Intake Structure and the southeast corner of the Auxiliary Building. Alignments of the given pipes are shown on the drawings noted in Table 5.15-1.

Raw water pipes are carbon steel pipe (Attachment 18, OPPD SDBD-AC-RW-101).

The first raw water line is routed out the north side of the Intake Structure to a point where it clears the the Discharge Tunnel and other Intake Structure utility lines before it bends 90° and runs about 88.8 ft toward the Service Building. It then makes another 90° bend and is routed to the south, parallel to the Service Building. The alignment in front of the Service Building is routed to avoid Fuel Oil Tank 10 and the Underground Cable Bank. After crossing the Underground Cable Bank north of MH-5, the raw water line is routed west between the Turbine Building and the Turbine Building South Switchyard. After clearing the limits of the Turbine Building, it is routed to the south side of the Auxiliary Building at the southeast corner.

The second 20-in. raw water line exits the south side of the Intake Structure adjacent to and east of other connecting utilities. The raw water line and adjacent utilities are concrete-encased together and routed to the south. Once the utilities clear the Discharge Tunnel (see 11405-M-312 and 314), they make a 45° bend to the southwest and follow a path that passes the southeast corner of MH-5. Once beyond the limits of MH-5, the encased utility lines are routed to the west, and the raw water line continues along an alignment to the southwest. When the raw water line reaches a point south of the Turbine Building South Switchyard, it makes a 45° bend and is routed to the west, parallel to the south face of the Service Building and outside of the limits of Turbine Building South Switchyard. At a point 18.5 ft west of the location of where the first raw water line enters the Auxiliary Building, it makes a 90° bend to the north and extends to the Auxiliary Building and penetrates into the building at el. 996 ft.

5.15.2 Inputs/References Supporting the Analysis

Table 5.15-1 lists references provided by OPPD and other documents used to support HDR's analysis.

Table 5.15-1 - References for Raw Water Piping

Document Title	OPPD Document Number (if applicable)	Date	Drawing No./ Page Number(s)
Yard Piping Sheet 1	10752	Unknown	11405-M-312
Yard Piping	10753	Unknown	11405-M-313
Yard Piping Sheet 3	10754	8/8/1973	11405-M-314
Yard Piping	10755	Unknown	11405-M-315
Design Basis Document	SDBD-AC-RW-101	2011-10-06	
Naval Facilities Engineering Command, Design Manual 7.01, Soil Mechanics		9/1986	All

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

Observed performance and pertinent background data are as follows:

- Groundwater was observed flowing into the basement sump of the Turbine Building from floor and condensate drain pipes not designed to intercept groundwater. This condition has a recorded history dating back to 1997. The Turbine Building is west of the corridor and utilities between the Intake Structure and the Service Building.
- Settlement of a column in the Maintenance Building, north of the Turbine Building, has been documented. The Turbine Building and the Maintenance Building are west of the corridor and associated utility alignments within the corridor.
- The Aqua Dam surrounding the facility crossed the alignment of the Raw Water Piping.
- The Aqua Dam failed for a short period of time due to being damaged, allowing floodwater to enter the area inside the Aqua Dam perimeter. Surfaces above the Raw Water Piping were inundated with water when the facility Aqua Dam failed.
- Areas outside the perimeter of the replacement Aqua Dam were inundated for an extended period.
- Concrete areas in the corridor (paved drive and pedestrian areas between the river and the Service Building) have exhibited distress including cracking, slab settlement, and undermining. However, most of the pavement cracking and the other conditions could be pre-existing conditions due the age and use of the facility.
- There is a hole in the pavement and void area beneath the concrete slab north of the Security Building and east-southeast of MH-5. The hole and void area are outside the perimeter of the Aqua Dam that surrounded the facility. The pavement failure occurred at the intersection point of pavement jointing. The hole in the pavement is irregular-shaped and is more than 1 ft wide both in the north–south and east–west directions. The void area beneath the hole was approximated as a 4-ft-diameter-by-0.8-ft-deep void as measured by a tape measure through the hole. The void could be attributed to subsurface erosion.

- The hole in the pavement is near the observed discharge point of a pump operated prior to the removal of the Aqua Dam. The void could be attributed to scour created by the discharge of the pipe operating for an extended period in one place.
- Fire Protection Cabinet FP-3C north of the Security Building and east-southeast of MH-5 is located in proximity to the pavement failure and void area. The fire hydrant was tested September 13, 2011 (reportedly), and failed. According to OPPD operations personnel testing FP-3E during site inspections, the base of FP-3C cracked when the valve was opened. The fire hydrant was shut down, and the access cabinet was tagged out. The cause of failure was unknown at the time field observations were made.
- 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.
- The fire hydrant located in FP-3E was being tested on September 13, 2011, during site investigations. No operational problems were observed during the time on site.
- OPPD operations personnel testing the fire hydrant at FP-3E on September 13, 2011, were questioned about other fire hydrant tests. The OPPD employee questioned noted that no problems were observed for the fire hydrant at FP-3D during testing. The information on the problem at FP-3C, noted previously, was gathered at this time.

5.15.3 Assessment Methods and Procedures

5.15.3.1 Assessment Procedures Accomplished

Assessments were made by walking the Raw Water Piping system alignment and observing the ground surface overlying the underground piping system. The surface assessment included using a 4-ft-long, 0.5-in.-diameter, steel-tipped fiberglass T-handle soil probe to hand probe the ground surface along the utility alignments and adjacent areas to determine relative soil strength. The assessment focused on identifying conditions indicative of potential flood-related impacts on or damage to the utility as follows:

- Ground surface conditions overlying and immediately adjacent to the utility and its backfilled trench including scour, subsidence or settlement, lateral spreading, piping, and heave
- Soft ground surface areas (native soil, engineered fill, and/or limestone gravel pavement) as determined by probing
- Water accumulations and flows in subsurface system components (manholes and concrete cable encasement pipes)
- Damage to at-grade or above-grade system features and equipment
- Variance from normal installation conditions including settled, tilted, or heaved system features and equipment
- 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 were observed. These included the following non-invasive geophysical and invasive geotechnical investigations.

- GPR. (Test reports were not available at the time of Revision 0.)
- Seismic surveys (seismic refraction and refraction micro-tremor). (Test reports were not available at the time of Revision 0.)
- Geotechnical investigations including test borings with field tests (SPT and CPT) and laboratory tests. 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.)

5.15.3.2 Assessment Procedures Not Completed

Assessments of the Raw Water Piping that were not completed include the following:

- No excavation to inspect underground systems and conditions was performed.
- No video inspection of the system was completed.
- Inclinometer readings along the river that will provide an indication of slope movement.

5.15.4 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 results of available geotechnical, geophysical, and available survey data were analyzed, a number of CPFMs were ruled out as discussed in Section 5.15.4.1. The CPFMs carried forward for detailed assessment are discussed in Section 5.15.4.2.

5.15.4.1 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
CPFM 2c – Undermined buried utilities

Reason for ruling out:

- No surface erosion was observed along the surface overlying the raw water alignment. In addition, only localized and limited surface erosion was observed on the ground surface across the facility. The raw water system is constructed below frost depth, and sufficiently below potential scour depths indicated by erosion features observed in other areas.

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

Reasons for ruling out:

- Soil supporting and surrounding the raw water lines has been previously wetted. The peak flood elevation prior to 2011 was 1003.3 ft, which occurred in 1993. Ground elevations above the raw water alignments are in the range of 1003 to 1004 ft. The raw water lines were installed as part of the original plant construction in the early 1970s. With the exception of possible trench backfill above repair areas, the trench backfill above the raw water lines has been saturated or wetted over the course of almost 40 years.
- The climate of the region includes times of snow accumulation during the winter and seasonal wet periods (springtime rain events), which can be significant and extended over a period of days. Site soils are subjected to saturation during snowmelt periods and during extended rainstorm events. Most trenches with loose backfill exhibit signs of subsidence within 1 or 2 years. After an almost 40-year period, trench backfill over the raw water lines has been wetted and saturated numerous times.

Triggering Mechanism 10 – Machine/Vibration-Induced Liquefaction

CPFM 10a – Cracked slab, differential settlement of shallow foundation, loss of structural support

CPFM 10b – Displaced structure/broken connections

Reasons for ruling out:

- Machine vibrations from the facility (turbines in the Turbine Building, pumps in the Intake Structure, or other pieces of equipment) have historically occurred, and no indications of these CPFMs are evident.
- Pumps used on site during the 2011 flood did not cause ground or structure vibrations sufficient to initiate soil liquefaction. Visible indications of liquefaction were not observed around the areas where the pumps were operating, and no occurrences of liquefaction were reported to HDR.
- No structure movements indicative of soil liquefaction and resultant settlement were observed. No structure cracking or lateral movements were observed.

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

Reasons for ruling out:

- The structures did not have evident signs of distress identified during the field assessments.
- Liquefaction 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:

- The structures did not have evident signs of distress identified during the field assessments.
- Slope failure was not observed at the site.
- River stage level had receded and stabilized as of October 4, 2011.
- As of October 11, 2011, groundwater elevations had had one week to stabilize to at least a partial degree.
- The river bank is armored and has historically protected and stabilized the existing river bank.

Triggering Mechanism 13 – Submergence
CPFM 13a – Corrosion of underground utilities
CPFM 13b – Corrosion of structural elements

Reasons for ruling out:

- There are no flood-induced changes to the nature of the buried raw water pipe system.
- The raw water piping system is below the design flood elevation for the facility. Groundwater elevations controlled by Missouri River water elevations, percolation of storm precipitation, and winter snowmelt would be expected to contact the piping system and appurtenant improvements. Such buried elements are normally designed and installed to withstand the environment of groundwater and wetted soil.
- Structural elements associated with the raw water pipe system are assumed to include the construction of thrust blocks at pipe bends in the system. Thrust blocks are normally installed in conjunction with water piping where groundwater and wetted soil is expected. Degradation of the thrust blocks is not expected.
- The raw water system is installed in an area of structural backfill, and corrosion due to corrosive soil conditions is not expected.

Triggering Mechanism 14 – Frost Effects
CPFM 14a – Heaving, crushing, or displacement

Reasons for ruling out:

- The Raw Water Piping is installed below the depth of frost penetration.
- Conditions have not changed due to flood conditions.

5.15.4.2 Detailed Assessment of Credible Potential Failure Modes

The following CPFMs are the only CPFMs carried forward for detailed assessment for the Raw Water Piping system 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)

CPFM 3c – Undermined buried utilities (due to pumping)

This Triggering Mechanism and CPFM could occur as follows: multiple potentially connected seepage paths existed in the soil backfill at the site, including soil backfill in utility trenches, granular trench bedding, building floor drains with open/broken joints, and pre-existing defects/voids under pavement. The paths are exposed at some locations to the river floodwaters (e.g., a hole in the ground north of the Security Building). This network of seepage paths is connected to several pumping sources: the sump pit in the Turbine Building, Manhole MH-5, and a series of surface pumps along the interior perimeter of the Aqua Dam. The pumps were operated for an extended period, maintaining a head differential on the seepage path networks. Gradient was sufficient to begin erosion of surrounding soil. Seepage is unfiltered and erosion continues unarrested. Erosion extends out, intercepting the network of utility trenches, including the Raw Water Piping System. Voids are created under the pavement and along the utility trench walls or pipes. The potential damage includes settlement of pipe or thrust blocks. Settlement can overstress a pipe that is corroded, can cause a pipe to break, or can cause the displacement of a thrust block, which, in turn, could cause failure of a pipe operating under pressure.

Below are field observations and data that support the likelihood of this CPFM:

- The raw water alignments crossed the Aqua Dam installation.
- MH-5, located within the Aqua Dam perimeter, was pumped for the duration of flooding. This created a head differential. Raw water lines are routed in close proximity to MH-5 and also underground cable banks connected to MH-5.
- The flow of water into MH-5 was observed on multiple field visits. Sources of the water could not be determined.
- The area inside the perimeter of the Aqua Dam was pumped dry, which created a conditional hydrostatic head between the inside and outside of the Aqua Dam perimeter. The area within the perimeter of the Aqua Dam was pumped from several locations, creating points toward which underground piping and subsurface flows would tend to flow.
- Void areas and potential piping location were observed beneath the concrete slab just north of the Security Building (east-southeast of MH-5) and directly west of the Security Building.
- Based on a conversation with the OPPD operations employee testing FP-3E on September 13, 2011, fire hydrant FP-3C, located northeast of the Security Building, was tested that day and failed. According to the OPPD operations employee, when opening the valve to test the hydrant, the base cracked and leaked, and the valve had to be closed. The access cabinet was tagged out for repair at that time.
- Fire hydrant FP-3D has also been marked with an impairment tag according to October 7, 2011, field observations. The tag states that there was extensive leakage when the isolation valve was opened.
- Concrete areas in the corridor (paved drive and pedestrian areas between the east fence line and the Service Building) have exhibited pavement distress including cracking, slab settlement, and undermining (as evidenced by hollow-sounding pavement areas).
- The Turbine Building sump pit was pumped continually during the 2011 flood. The five pipes connected to this sump pit are floor drain and condensate system flush drain pipes.

Since this is a floor drain system, no infiltration of ground water should occur in the system. The infiltration of groundwater into the system indicates an open flow path of some sort. A record of this drainage issue dates back to 1997.

- An area of apparent pavement settlement, located in the driveway corridor west-northwest of the Intake Structure overhead door, is near the northern raw water alignment.

Below are field observations and data that indicate these CPFMs are unlikely:

- Sediment accumulations and small fish were observed at the bottom of manhole MH-5 at the time MH-5 was being emptied (on September 14, 2011) and might not be associated with this CPFM. The manhole was uncovered when the Aqua Dam failed and the area was flooded. Sediment and fish could have entered the manhole with floodwaters as a result of the Aqua Dam failure. Thus, MH-5 might not be an operational termination point of subsoil piping.
- Alternatively, the observed hole in the pavement north of the Security Building could have been developed by outflow from the surface pumps and is not associated with this CPFM. Temporary surface pumps were pumping water back into the river with hoses placed over the Aqua Dam. One of the discharge points was near the observed hole (see photos). Concentrated discharge flow might have eroded pavement and created the observed hole.

The following table describes observed distress indicators and other data that would increase or decrease the potential for degradation associated with these CPFMs for the Raw Water system.

Adverse (Degradation/Direct Floodwater Impact More Likely)	**Favorable (Degradation/Direct Floodwater Impact Less Likely)**
Electrical MH-5 was pumped continually during the flood event and created a point source for underground water to flow toward.	
Pavement distress was noted at multiple locations in the corridor between the Intake Structure and the Service Building. The fire line is located in the same narrow corridor.	
Electrical MH-5 was pumped continually during the flood. Fire protection lines cross the electrical duct banks that connect to the manhole.	
The Turbine Building sump pit has a history of groundwater inflows. Flood conditions increased the hydraulic head of water flowing to the sump.	
Fire Hydrants FP-3C and FP-3D have both failed during testing of the fire protection system subsequent to the subsidence of floodwaters from the site. The fire hydrants noted are located to the north and south of the Intake Structure.	

Data Gaps:

- The extent of the subsurface erosion is not well known at this time.
- Geophysical investigation reports to evaluate data related to the raw water system.
- Seismic Survey (refraction/tomography and refraction microtremor).

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

The field observations indicate that the trigger to these CPFMs might have initiated in close proximity to the Raw Water lines. Multiple indications of subsurface distress are located along the corridor between the Service Building and the Intake Structure. Pavement slab settlement, undermining (as evidenced by a hollow-sounding pavement area), and a hole in the pavement with visible undermining were observed in the field. Floodwater inundation and impacts are likely causes for the distress and failures observed in the field.

Fire hydrants to the north and south of the Intake Structure have failed during testing performed subsequent to the subsidence of floodwaters from the site. The raw water supply lines connect to the north and south sides of the Intake Structure and are located in proximity to the two fire hydrants.

The raw water line also runs in close proximity to the Service Building and into the Auxiliary Building. Subsurface erosion due to the Turbine Building sump could impact the system. Refer to the discussion of Key Distress Indicator #1 in Section 4.1 for additional information.

With indications of distress throughout the area, the potential for degradation exists.

Implication

The occurrence of these CPFMs on a large scale could cause void areas that would induce pipe settlement, loss of pipe restraint or failure of the pipe system. Therefore, the implication of the potential degradation for these CPFMs is high.

Confidence

There are multiple elements to these CPFMs, including the inflow of water into MH-5 during the 2011 flood, the hole in the pavement north of the Security Building, and the settled pavement section in the corridor, fire hydrant failures, and groundwater drainage to the Turbine Building sump. However, even though the confidence is high that there are multiple distress indicators, the extent and possible impact of these CPFMs on the raw water system is not fully understood.

The data at hand are not sufficient to rule out these CPFMs or to lead to a conclusion that subsurface erosion has undermined the Raw Water Piping system. Additional geophysical data are needed to help determine the possible occurrence of these CPFMs and whether they could impact the Raw Water Piping system.

Therefore, the confidence in the above assessment is low, which means more data are necessary to draw a conclusion.

Summary

For CPFMs 3a and 3c, as discussed above, the potential for degradation is high because distress indicators exist in close proximity to the system. This degradation in the region could have caused erosion that impacts the integrity or intended function of the structure. The combined consideration of the potential for degradation and the implications of that degradation to the system puts it in the "significant" category. The data currently collected are not sufficient to rule out these CPFMs. 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.

Triggering Mechanism 3 – Subsurface Erosion/Piping

CPFM 3d – Undermining and settlement of shallow foundation/slab (due to river drawdown)

CPFM 3f – Undermined buried utilities (due to river drawdown)

These CPFMs are similar to CPFMs 3b and 3c, but instead of pumping, the gradient is created by rapidly receding river level.

The Triggering Mechanism and CPFM could then occur as follows: river level drops faster than pore water pressure in the soil can dissipate. A gradient is created that moves soil into existing defects and enlarges voids under or along the utility trench walls or utility pipes. Dependent on the extent of the voids created, impacts might include the following: trench subsidence, unsupported pipe sections, pipe deflections, pipe failure, and even possible impacts on adjacent improvements or utilities.

Below are field observations and data that support the likelihood of these CPFMs:

- The Raw Water Piping is located close to the Missouri River Bank.

Below are field observations and data or site conditions that indicate these CPFMs are unlikely:

- The Raw Water Piping system is offset from the River Bank. This offset from the river bank reduces the likelihood that rapid drawdown and related bank failure will impact the system.
- Soils in the area of the Raw Water Piping system and to the east are backfill materials that were placed and compacted during construction of site improvements and therefore would be expected to be less susceptible to rapid drawdown impacts. (Structural fill materials are expected to be homogenous and of a structural nature. Compacted in place, they should form a homogenous soil mass with no expected weak planes or layers conducive to form drainage paths through the soil.)
- Indications of this type of CPFM were not observed during the most recent site inspection on October 4 and October 7, 2011.
- The River Bank is armored and protected.

The following table describes observed distress indicators and other data that would increase or decrease the potential for degradation associated with these CPFMs for the Raw Water Piping system.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
Floodwaters were at a high level for an extended period, which allowed surrounding soils to become saturated.	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.
	River bank is armored and has been protected in previous floods.
Data Gaps: • Observations of the riverbank following drawdown to normal river elevations • Geophysical investigation data to address observed concerns	

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

The potential for degradation exists since river levels are still adequate for these CPFMs to occur. However, 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. Groundwater levels have thus started to stabilize between the termination of drawdown and the time of Revision 0. The potential for development of subsurface erosion due to river drawdown decreases with time due to stabilization between groundwater elevations and river elevations. The potential for degradation will decrease with time.

Implication

The occurrence of these CPFMs would likely only affect the utility installations near the river. Most of the Raw Water Piping system is located away from the zone of influence of these CPFMs with the exception of the supply lines that connect to the Intake Structure. Thus, the two most important supply components of the system are at the point of greatest risk from these CPFMs.

As groundwater elevations and river elevations stabilize, the potential head differential between them will decrease, and the possibility of subsurface erosion will also decrease. In addition, the stabilized river embankment reduces the likelihood of these CPFMs.

The implication of the CPFMs affecting the Raw Water Piping system is considered low.

Confidence

The data at hand are not sufficient to rule out these CPFMs or to lead to a conclusion that subsurface erosion has undermined the Raw Water Piping system. Therefore, the confidence in the above assessment is low, which means more data are necessary to draw a conclusion.

Summary

For CPFMs 3d and 3f, as discussed above, the potential for degradation is considered low. The combined consideration of the potential for degradation and the implications of that degradation to the structure puts it in the "not significant" category. The data currently collected are not sufficient to rule out these CPFMs. Therefore, the confidence in the above assessment is low, which means more data or continued monitoring and inspections are necessary to make a final assessment.

5.15.5 Results and Conclusions

The CPFMs evaluated for the Raw Water Piping 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**	CPFM 3a CPFM 3c	
Potential for Failure **Not Significant**	CPFM 3d CPFM 3f	

5.15.6 Recommended Actions

The following actions are recommended for the Raw Water Piping:

- Further forensic investigations and physical modifications are recommended to address CPFMs 3a, 3c, 3d, and 3f for the Raw Water Piping. CPFMs 3a and 3c are associated with unfiltered flow of groundwater into the Turbine Building basement drain piping system (Key Distress Indicator #1). These recommendations are described in detail in Section 4.1.3. CPFMs 3a, 3c, 3d, and 3f are associated with the distress in and near the Paved Access Area between the Service Building and the Intake Structure (Key Distress Indicator #2). These recommendations are described in detail in Section 4.2.5.
- Monitoring of groundwater well data and a review of the geophysical data when available should be done. The results of these reviews will be used to increase the confidence in the assessment results. At the time of Revision 0, groundwater levels had not yet stabilized to nominal normal levels. Therefore, it is possible that new distress indicators could still develop. If new distress indicators are observed before December 31, 2011, appropriate HDR personnel should be notified immediately to determine whether an immediate inspection or assessment should be conducted.

Observation of new distress indicators might result in a modification of the recommendations for this structure.

- Continued monitoring is recommended to include a continuation of the elevation surveys of the previously identified targets on this utility and surrounding site. The purpose is to monitor for signs of structure distress and movement or changes in soil conditions around the structure. The results of this monitoring will be used to increase the confidence in the assessment results. Elevation surveys should be performed weekly for 4 weeks and biweekly until December 31, 2011. At the time of the writing of this version of the Report, groundwater levels had not yet stabilized to nominal normal levels. Therefore, it is possible that new distress indicators could still develop. If new distress indicators are observed before December 31, 2011, appropriate HDR personnel should be notified immediately to determine whether an immediate inspection or assessment should be conducted. Observation of new distress indicators might result in a modification of the recommendations for this structure.
- Review geophysical and geotechnical reports to evaluate the data as they pertain to the Raw Water System.
- Make additional river bank inspections to evaluate whether signs of CPFMs 3a, 3c, 3d, or 3f exist.
- Install inclinometers to monitor the river bank.
- Perform a detailed analysis of the pavement subgrade and trench alignments if the pavement in the corridor between the Intake Structure and the Service Building is replaced.

5.15.7 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.

5.15.7.1 Additional Data Available

The following additional data were available for the Raw Water Piping 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 falling weight deflectometer investigation by American Engineering Testing, Inc. (see Attachment 6).
- Results of geophysical investigation by Geotechnology, Inc. (see Attachment 6).
- Results of geotechnical investigation by Thiele Geotech, Inc. (see Attachment 6).
- Data obtained from inclinometers by Thiele Geotech, Inc. (see Attachment 6).
- Results of continued survey by Lamp Rynearson and Associates (see Attachment 6).

5.15.7.2 Additional Analysis

The following analysis of additional data was conducted for the Raw Water Piping System:

- 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 falling weight deflectometer investigation by American Engineering Testing, Inc.

  Falling Weight Deflectometer 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 by Geotechnology, Inc.

  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, Inc.

  Six test borings were drilled, with continuous sampling of the soil encountered, to ground truth the Geotechnology, Inc. 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 feet 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 Lamp Rynearson and Associates.

  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.

Updates to assessment procedures not completed are outlined in Section 5.15.3.2. Excavation to inspect underground systems is included with the KDI#2 investigation. Video inspection of the system was not completed and is not planned due to the expected low value of data produced with respect to addressing these CPFMs.

Triggering Mechanism 3 – Subsurface Erosion/Piping

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

CPFM 3c – Undermined buried utilities (due to pumping)

CPFMs 3a and 3c for the Raw Water Piping System are associated with Key Distress Indicator #1. Section 4.1 presents the results of additional forensic investigation that was conducted to ascertain whether these CPFMs could be ruled out. The results of the additional forensic investigation show that, assuming the implementation of the physical modifications recommended for KDI #1, these CPFMs are ruled out. Therefore, assuming that no further concerns are identified through the monitoring program for the Raw Water Piping System (discussed in Section 5.15.6 and continuing until December 31, 2011), these CPFMs are moved to the quadrant of the matrix representing "No Further Action Recommended Related to the 2011 Flood."

Triggering Mechanism 3 – Subsurface Erosion/Piping

CPFM 3d – Undermining and settlement of shallow foundation/slab (due to river drawdown)

CPFM 3f – Undermined buried utilities (due to river drawdown)

CPFMs 3d and 3f for the Raw Water Piping System are associated with Key Distress Indicator #2. Section 4.2 presents the results of additional forensic investigation that was conducted to ascertain whether these CPFMs could be ruled out. The results of the additional forensic investigation show that these CPFMs are ruled out. Therefore, assuming that no further concerns are identified through the monitoring program for the Raw Water Piping System (discussed in Section 5.15.6 and continuing until December 31, 2011), these CPFMs are moved to the quadrant of the matrix representing "No Further Action Recommended Related to the 2011 Flood."

5.15.7.1 Revised Results and Recommendations

The CPFMs evaluated for the Raw Water Piping 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 5.15.8 **Significant**		
Potential for Failure **Not Significant**		CPFM 3a CPFM 3c CPFM 3d CPFM 3f

5.15.8.1 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 Raw Water Piping System other than CPFMs 3a, 3c, 3d, and 3f had been ruled out prior to Revision 1, because CPFMs 3d and 3f were ruled out using the results of the KDI #2 investigation presented in Section 4.2, and because CPFMs 3a and 3c will be ruled out when the physical modifications recommended for KDI # 1 in Section 4.1 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Raw Water Piping 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.

Section 5.16

Fire Protection System Piping

5.16 Fire Protection System Piping

5.16.1 Summary of Fire Protection System Piping

Baseline information for the Fire Protection System Piping is provided in Section 2.0, Site History, Description, and Baseline Condition.

The Fire Protection System Piping has two vertical turbine-type fire pumps, each rated for 2000 gpm at 125 pounds per square inch gauge (psig). One fire pump is driven by an electric motor and the other fire pump is driven by a diesel engine. Both pumps deliver screened and strained Missouri River water to the underground water distribution system, which, in turn, supplies the automatic water fire suppression systems, the interior hose stations, and the fire hydrants in the yard.

During normal operation, the system is pressurized to 125 to 135 psig and held at that pressure by a small pressure maintenance pump (jockey pump). The primary purpose of this pump is to prevent frequent operation of the main fire pumps. The pressure maintenance pump is automatically started and stopped based on system pressure. The water distribution system consists of underground piping that delivers water to the following:

- Yard hose and hydrant houses
- Wet pipe sprinkler systems
- Dry pipe sprinkler systems
- Preaction sprinkler systems
- Deluge/water spray systems

The underground yard fire main system is provided with post indicator-type sectionalizing valves and underground sectionalizing valves with roadway boxes (curb valves) to facilitate the isolation of portions of the system for maintenance or repair without interrupting the supply to the remaining system. Each water suppression system is provided with an outside screw and yoke (OS&Y) gate valve where the system connects to the internal main loop. Each 6-in. lateral connecting the hydrant to the yard main loop has a valve installed to allow isolation of individual hydrants for maintenance purposes. Hydrants are placed at approximately 300-ft intervals around the yard main loop and approximately 50 ft from buildings. Freezing of the fire water distribution system is prevented by burying the piping below the frost line and by routing indoor piping through heated areas. The underground yard fire main loop is constructed of 12-in. and 10-in. transite (asbestos cement) pipe and cast (ductile iron) pipe with cement lining.

5.16.2 Inputs/References Supporting the Analysis

Table 5.16-1 lists references provided by OPPD and other documents used to support HDR's analysis.

Table 5.16-1 - References for Fire Protection System Piping

Document Title	OPPD Document Number (if applicable)	Date	Drawing Number/ Page Number(s)
Underground Piping Extension	44740	8/23/1990	FC-UG-1A
Underground Fire Loop	41428	Unknown	E-4182
Fire Protection	SDBD-FP-115	3/9/2011	All

Table 5.16-1 - References for Fire Protection System Piping			
Document Title	**OPPD Document Number (if applicable)**	**Date**	**Drawing Number/ Page Number(s)**
Naval Facilities Engineering Command, Design Manual 7.01, Soil Mechanics		9/1986	All

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

Observed performance and pertinent background data are as follows:

- The fire protection loop and lateral system crosses multiple other utility lines around the facility.
- Groundwater was observed flowing into the basement sump of the Turbine Building from floor and condensate drain pipes not designed to intercept groundwater. This condition has a recorded history dating back to 1997. The Turbine Building is west of the corridor, and utilities are located between the Intake Structure and the Service Building.
- Settlement of a column in the Maintenance Building, north of the Turbine Building, has been documented. The Turbine Building and the Maintenance Building are west of the corridor and associated utility alignments within the corridor.
- The Aqua Dam surrounding the facility crossed the alignment of the fire protection piping at multiple locations, including the following:
  - Fire supply lines from the Intake Structure feeding the yard main loop system.
  - The fire supply line feeding FP-3D.
  - The fire supply lateral feeding the fire hydrant northeast of the New Warehouse.
  - The building fire supply line to the New Warehouse.
  - The fire supply line that is routed along the west side of the New Warehouse and to FP-3I and FP-3J.
  - The main fire loop where the fire supply line extends to the west toward the Welding Fab Shop.
  - After turning to the south along the west side of the facility, the Aqua Dam crosses the main yard loop line northwest of the Rad Waste Building.
  - Along the west side of the facility, it appears that the Aqua Dam was located over the top of a longitudinal alignment of a supply line that was routed to FP-3K.
  - The Old Warehouse fire supply line.
  - The yard main loop where the west leg extends to the south toward the site perimeter/security fence.
  - The yard main loop crossed the location of the Aqua Dam where the line runs north of the Security Building.
- The Aqua Dam failed for a short period of time due to being damaged, allowing floodwater to enter the area inside the Aqua Dam perimeter. All surfaces above the fire protection piping were inundated when the facility Aqua Dam failed.
- Areas outside the perimeter of the replacement Aqua Dam were inundated for an extended period.
- Concrete areas in the corridor (paved drive and pedestrian areas between the river and Service Building) have exhibited distress including cracking, slab settlement, and undermining. Some of these conditions are reported to be new, although pavement spalling and cracking is likely to have existed prior to the flooding.
- A hole in the pavement and void area beneath the concrete slab is north of the Security Building and east-southeast of MH-5. The hole and void area are outside the perimeter of the Aqua Dam that surrounded the facility. The pavement failure occurred at the intersection point of pavement

jointing. The hole in the pavement is irregular-shaped and is more than 1 ft wide both in the north–south and east–west directions. The void area beneath the hole was approximated as a 4-ft-diameter-by-10-in.-deep void as measured by a tape measure through the hole. The void might be attributable to subsurface erosion.

- The hole in the pavement is near the observed discharge point of a pump operated prior to the removal of the Aqua Dam. The void might be attributable to scour created by the discharge of the pipe operating for an extended period in one place.
- The fire hydrant located in FP-3E was tested on September 13, 2011, during site investigations. No operational problems were observed during the time on site.
- Fire Protection Cabinet FP-3C north of the Security Building and east-southeast of MH-5 is located in proximity to the pavement failure and void area. The fire hydrant was tested on September 13, 2011 (reportedly), and failed. According to OPPD operations personnel testing FP-3E during site inspections, the base of FP-3C cracked when the valve was opened. The fire hydrant was shut down, and the access cabinet was tagged out. The cause of failure was unknown at the time field observations were made.
- OPPD operations personnel testing the fire hydrant at FP-3E on September 13, 2011, were questioned about other fire hydrant tests. The OPPD employee questioned noted that no problems were observed for the fire hydrant at FP-3D during testing. The information on the problem at FP-3C, noted previously, was gathered at this time.
- Fire hydrant FP-3D has also been marked with an impairment tag according to October 7, 2011, field observations. The tag states that there was extensive leakage when the isolation valve was opened.
- 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.

5.16.3 Assessment Methods and Procedures

5.16.3.1 Assessment Procedures Accomplished

Assessments were made by walking the fire protection system alignment and observing surface features of the system, post indicator valves, fire cabinets, and the ground surface overlying the underground pipe. The surface assessment included using a 4-ft-long, 0.5-in.-diameter, steel-tipped fiberglass T-handle soil probe to hand probe the ground surface along the utility alignments and adjacent areas to determine relative soil strength. The assessment focused on identifying conditions indicative of potential flood-related impacts or damage to the utility as follows:

- Ground surface conditions overlying and immediately adjacent to the utility and its backfilled trench, including scour, subsidence or settlement, lateral spreading, piping, and heave
- Soft ground surface areas (native soil, engineered fill, or limestone gravel pavement) as determined by probing
- Water accumulations and flows in subsurface system components (manholes and concrete cable encasement pipes)
- Damage to at-grade or above-grade system features and equipment
- Variance from normal installation conditions including settled, tilted, or heaved system features and equipment
- 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 were observed. These included the following non-invasive geophysical and geotechnical investigations.

- GPR. (Test reports were not available at the time of Revision 0.)
- Seismic surveys (seismic refraction and refraction micro-tremor). (Test reports were not available at the time of Revision 0.)
- Geotechnical investigations including test borings with field tests (SPT and CPT) and laboratory tests. Note that OPPD required vacuum excavation for the first 10 ft of proposed test holes to avoid utility conflicts. Test reports will thus not address soil conditions in the upper 10 ft of site and locations where shallow utilities exist. (Test reports were not available at the time of Revision 0.)
- Paved areas were evaluated with GPR and dynamic deflection methods (i.e., drop weight deflectometer). (Test reports were not available at the time of Revision 0.)

5.16.3.2 Assessment Procedures Not Completed

Assessments of the Fire Protection System Piping that were not completed include the following:

- Assessment of subgrade conditions in the corridor will be evaluated at the time of pavement replacement in the Paved Access Area between the Security Building and the Intake Structure. Work in the area is scheduled to begin November 3, 2011.

5.16.4 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. 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 results of available geotechnical, geophysical, and available survey data were analyzed, a number of CPFMs were ruled out as discussed in Section 5.16.4.1. The CPFMs carried forward for detailed assessment are discussed in Section 5.16.4.2.

5.16.4.1 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
CPFM 2c – Undermined buried utilities

Reasons for ruling out:

- Minor surface erosion was observed south of the Auxiliary Building adjacent to and extending through the inside perimeter fence. This observed surface erosion is attributed to multiple pump discharge lines that were pumped over the Aqua Dam. Discharge lines were tied to the fence, which held them continually in place over one general area. The location of the scour is in close proximity to where the yard fire loop is routed. The scour is approximately 0.5 ft deep and did not appear to affect anything beyond the immediate points of pump discharge.

- In addition, only localized and limited surface erosion was observed on the ground surface across the entire facility. This PFM was discredited due to the depth that fire protection piping is installed compared to the minor scouring that was observed on the site.

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

Reasons for ruling out:

- Soil supporting and surrounding the Fire Protection System has been previously wetted. The peak flood elevation prior to 2011 was 1003.3 ft which occurred in 1993.
- However, isolated cases of soil collapse could be applicable if recent water line replacements have been made. OPPD Condition Reports (CRs) would be required to check for isolated cases that might exist.

Triggering Mechanism 10 – Machine/Vibration-Induced Liquefaction

CPFM 10a – Cracked slab, differential settlement of shallow foundation, loss of structural support
CPFM 10b – Displaced structure/broken connections

Reasons for ruling out:

- Machine vibrations from the facility (turbine and various pumps) have historically occurred, and no indications of these PFMs are evident.
- Pumps used on site during the 2011 flood were too small to cause ground or structure vibrations sufficient to initiate soil liquefaction. Visible indications of liquefaction were not observed around the areas where the pumps were operating, and no occurrences of liquefaction were reported to HDR.
- No structure movements indicative of soil liquefaction and resultant settlement were observed; no structure cracking or lateral movements were observed.

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

Reasons for ruling out:

- The structures did not have evident signs of distress identified during the field assessments.
- Liquefaction was not observed at the site.

Triggering Mechanism 13 – Submergence
CPFM 13a – Corrosion of underground utilities

Reason for ruling out:

- Underground utilities and structures are located below the design flood elevation for the facility. Groundwater elevations controlled by Missouri River water elevations, percolation of storm precipitation, and winter snow melt would be expected to contact underground improvements including constructed steel and concrete facility elements. As such, steel and concrete site improvements are assumed to be designed to withstand the corrosive environment of groundwater and wetted soil.

Triggering Mechanism 13 – Submergence
CPFM 13b – Corrosion of structural elements

Reason for ruling out:

- The only structural elements of the system are possible concrete thrust blocks installed at pipe bends and pipe connection points. The 2011 flood has not changed the conditions that normally affect buried concrete thrust blocks.

Triggering Mechanism 14 – Frost Effects
CPFM 14a – Heaving, crushing, or displacement

Reasons for ruling out:

- The fire protection piping is installed below the depth of frost penetration. The system components that are above ground are designed to accommodate freeze/thaw cycles.
- Conditions have not been changed due to 2011 flood conditions.

5.16.4.2 Detailed Assessment of Credible Potential Failure Modes

The following CPFMs are the only CPFMs carried forward for detailed assessment for the Fire Protection System Piping 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)
CPFM 3c – Undermined buried utilities (due to pumping)

The Triggering Mechanism and CPFM could occur as follows: multiple potentially connected seepage paths existed in the soil backfill at the site, including soil backfill in utility trenches, granular trench bedding, building floor drains with open/broken joints, and pre-existing defects/voids under pavement. The paths are exposed at some locations to the river floodwaters (e.g., a hole in the ground north of the Security building). This network of seepage paths is connected to three pumping sources: the sump pit in the Turbine Building, Manhole MH-5, and a series of surface pumps along the interior of the Aqua Dam perimeter. The pumps were operated for an extended period, maintaining a head differential on the seepage path networks. Gradient was sufficient to begin erosion of surrounding soil. Seepage is unfiltered, and erosion continues unarrested. Erosion extends out, intercepting the network of utility trenches, including the Fire Protection System. Voids are created under the pavement and along the utility trench walls. The potential damage includes settlement of pipe(s) causing joints to open, overstressing the pipe, causing the pipe to break, or undermining thrust blocks.

Below are field observations and data that support the likelihood of these CPFMs:

- The fire protection loop crosses multiple other utility lines and covers the entire perimeter of the facility. Interconnectivity between crossing pipe trenches creates possible piping routes for subsurface water flow.
- MH-5 was pumped for the duration of flooding to remove water entering into the manhole. Known water sources included ducts from MH-31 and ducts running to the Auxiliary Building. This created a head differential.
- The flow of water into MH-5 was observed on multiple field visits. Water was documented to be entering through two conduits on the south wall of the manhole. It was not conclusively demonstrated that this was the only route of water entry.
- Sediment deposits (and fish) were observed in the bottom of the MH-5 when it was emptied on September 14, 2011. The sediment could be an indication of piping and subsurface erosion.
- The area inside the perimeter of the Aqua Dam was pumped dry, which created a hydrostatic head condition between the area inside and the area outside the Aqua Dam. The area inside the perimeter of the Aqua Dam was pumped from several locations, creating points toward which underground piping and subsurface flows would tend to flow.
- Void areas and potential piping location were observed beneath the concrete slab just north of the Security Building (east-southeast of MH-5) and directly west of the Security Building.
- Based on a conversation with the OPPD operations employee testing FP-3E on September 13, 2011, fire hydrant FP-3C, located northeast of the Security Building, was tested that day, and failed. According to the OPPD operations employee, when opening the valve to test the hydrant, the base cracked and leaked, and the valve had to be closed. The access cabinet was tagged out for repair at that time.
- Fire hydrant FP-3D has also been marked with an impairment tag according to October 7, 2011, field observations. The tag states that there was extensive leakage when the isolation valve was opened.
- Pavement distress was observed along the paved access area between the Intake Structure and the Service Building. The area north of where the fire protection piping crosses the corridor includes observed slab settlement and undermining (as evidenced by hollow-sounding pavement areas).
- The Turbine Building sump pit was pumped continually during the 2011 flood. The five pipes connected to this sump pit are floor drain and condensate system flush drain pipes. Since this is a floor drain system, no infiltration of groundwater should occur in the system. The infiltration of groundwater into the system indicates an open flow path of some sort.

Below are field observations and data that indicate these CPFMs are unlikely:

- Sediment and fish were observed in the bottom of MH-5 when it was emptied on September 14, 2011. Sediment accumulations and small fish at the bottom of MH-5 might not be associated with these CPFMs. The manhole was uncovered when the Aqua Dam failed and the area was inundated. Sediment and fish could have been transported into the manhole with floodwaters.

- The observed hole in the pavement, north of the Security Building, could have been developed by outflow from the surface pumps and might not be associated with these CPFMs. Temporary surface pumps were pumping water back into the river with hoses placed over the Aqua Dam
- One of the discharge points was near the observed hole (See site photos). Concentrated discharge flow could have eroded pavement and created the observed hole.
- Fire hydrants that are part of the yard loop system have been tested since floodwaters have receded from the facility. The system is pressurized and operational. Isolated cases of failure can be assessed as CRs are produced and repairs are made.
- Observed subsurface damage indicators or known instances of damage in the corridor are not located immediately adjacent to the Fire Protection System Piping.

Yard fire loop alignments were walked and soils were probed over the pipe alignments and to either side of the pipe alignments. Soils on site were generally firm and stable. Site soils that were visibly wet or moist were the only areas where soil probing showed some degree of penetration. Only a couple of locations along the fire main loop on the north, west, and south sides of the facility were observed to be wet or moist. 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 Fire Protection System Piping.

Adverse (Degradation/Direct Floodwater Impact More likely)	**Favorable (Degradation/Direct Floodwater Impact Less Likely)**
FP-3C failed during system testing.	FP-3E was tested on September 13, 2011 and operated without incident.
FP-3D was marked with an impairment tag that stated the isolation valve leaked extensively when opened.	Except for the fire hydrants marked with impairment tags, the system is operational
The Turbine Building sump pit has a history of groundwater inflows. Flood conditions increased the hydraulic head of water flowing to the sump.	
Pavement distress was noted at multiple locations in the corridor between the Inlet Structure and the Service Building. The fire line is located in the same narrow corridor.	
Electrical MH-5 was pumped continually during the flood. Fire protection lines cross the electrical duct banks that connect to the manhole.	

Data Gaps:

- Ground Penetrating Radar data are not available at the time of this draft report to assist in determining possible void areas at the facility.
- The extent of the subsurface erosion is not well-known at this time.
- Seismic Survey (refraction/tomography and refraction microtremor).
- OPPD CRs related to fire main repairs required as part of ongoing yard system testing.

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

Field observations indicate that this CPFM might have initiated in close proximity to the Fire Protection yard piping system. Multiple indications of subsurface distress are located along the paved access area between the Service Building and the Intake Structure. Pavement slab settlement, undermining (as evidenced by a hollow-sounding pavement area), and a hole in the pavement with visible undermining was observed in the field. Floodwater inundation and impacts are likely causes for the distress and failures observed in the field.

In addition, fire hydrant FP-3C failed during testing on September 13, 2011. The base of the fire hydrant cracked when opening the valve for testing. Fire hydrant FP-3D has also been marked with an impairment tag according to October 7, 2011 field observations. The tag states that there was extensive leakage when the isolation valve was opened. These conditions likely indicate a degraded condition due to floodwater inundation. The fire hydrant failures indicate some form of impairment on lines that are on both the north and south sides of the Intake Structure. This places known failures on the same sides as both supply lines from the Intake Structure.

Implication

The occurrence of this CPFM could impact sections of the fire protection yard piping system and adjacent utilities or structures. The fire protection pipe system loops the entire facility and it is located in close proximity to many other utilities and structures. Since the fire protection system is highly pressurized, failure of the system could, in turn, impact adjacent structures or utilities significantly if a pipe breaks and pressurized water erodes soils around the point of failure.

The Fire Protection System is a looped system and includes isolation valves at lateral pipe connection tees and on the main loop on each side of the lateral connection. Thus, the system is designed to be shut down in sections for repair purposes with continued supply to fire supply lines on both sides of potential line breaks. An operative fire protection system is required at all times on the site. The Fire Protection System has been tested since floodwaters have receded and it is an operative system, but has a minimum of two known impairments that have shut down lateral fire hydrant lines. Therefore, the implication of the potential degradation for these CPFMs is high.

Confidence

The fire protection system is an extensive system that circles the entire FCS facility. Therefore problems could exist in some areas of the site that are not indicative of problems systemwide. Indications of possible degradation exist within the paved access area between the Intake Structure and the Service Building. The lateral and vertical extent of subsurface erosion on the site is not known and ground penetrating radar report data have not yet been received to address this issue in detail. Therefore, confidence with the assessment is low.

Summary

For CPFMs 3a and 3c, as discussed above, the potential for degradation is high because distress indicators exist in close proximity to the system and two connected fire hydrants have failed during testing since floodwaters have subsided. This degradation in the region could have caused enough erosion to impact the integrity or intended function of the structure. The combined consideration of the potential for degradation and the implications of that degradation to the system put it in the "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 could be necessary to draw a conclusion.

Triggering Mechanism 3 – Subsurface Erosion/Piping

CPFM 3d – Undermining and settlement of shallow foundation/slab (due to river drawdown)

CPFM 3f – Undermined buried utilities (due to river drawdown)

These CPFMs is similar to CPFMs 3a and 3c but instead of pumping, the gradient is created by rapidly receding river level.

The Triggering Mechanism and CPFMs could then occur as follows: river level drops faster than pore water pressure in the soil/foundation can dissipate. A gradient is created that moves water and soil into existing defects and enlarges voids near or adjacent to the fire protection system and through the soil toward the river via piping features or networks. Dependent on the extent of the voids created, impacts might include the following effects: trench subsidence, unsupported pipe sections, pipe deflections, pipe failure, and possible impacts on adjacent improvements or utilities.

Field observations and data that support the likelihood of these CPFMs:

- Field observation data have not been gathered along the river bank and nearest utility installations on a scheduled or regular basis to inspect for developing conditions or distress indicators.

Field observations and data or site conditions that indicate these CPFMs are unlikely:

- 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 the FCS on October 4, 2011.
- Indications of this type of CPFM were not observed during the most recent site inspections on October 4, 7, and October 27 2011.

The Fire Protection System Piping is offset from the river bank which reduces the likelihood that rapid drawdown and related subsurface piping to the river bank will impact the Fire Protection System Piping.

Soils in the area of the Fire Protection System Piping and to the east are backfill materials that were placed and compacted during construction of site improvements and, therefore, would be expected to be less susceptible to rapid drawdown impacts.

The following table describes observed distress indicators and other data that would increase or decrease the potential for degradation associated with these CPFMs for the Fire Protection System Piping.

Adverse (Degradation/Direct Floodwater Impact More likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
Floodwaters inundated the site for an extended period of time and totally saturated site soils.	The existing river bank is protect and armored. No history of river bank failure has been noted at the site due to past flood events.
	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 the FCS on October 4, 2011.
Data Gaps: • Inspection of the riverbank following drawdown to normal river elevations. • Geophysical investigation data to address any observed concerns.	

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

Indications that subsurface erosion might exist within the corridor between the Intake Structure and the Service Building is apparent from pavement distress indicators and fire service line failures nearest the river. The nearest installations of the fire protection system to the river bank are the connection points to the north and south sides of the Intake Structure. The fire protection system is fed from fire pumps in the Intake Structure. Subsurface erosion along the face of the intake building or between utility trenches or lines and the nearest point of the river bank has the possibility of impacting the utilities that connect to the Intake Structure.

The failure of fire hydrant FP-3C and FP-3D indicate that potential problems already exist in the system. Complications instigated by CPFMs 3d and 3f could compound problems that already exist.

The river bank is armored and has historically protected and stabilized the existing river bank. The potential for degradation is reduced due to these improvements.

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 the FCS on October 4, 2011. Groundwater levels have thus started to stabilize between the termination of drawdown reduction and the time of this report. The potential for development of subsurface erosion due to river drawdown decreases with the time due to stabilization between groundwater elevations and river elevations.

Implication

The occurrence of these CPFMs would likely only affect the utility installations nearest the river. Most of the fire protection system is located well away from the zone of influence from these CPFMs with the exception of the supply lines that connect to the Intake Structure. Thus, the two most important supply components of the system are located at the point of greatest potential for degradation from these CPFMs.

As groundwater elevations and river elevations stabilize, the head potential between the two conditions will decrease and the possibility of subsurface erosion will also decrease correspondingly. In addition, the stabilized river embankment reduces the likelihood of these CPFMs.

The implication of the CPFMs affecting the fire protection system is considered low.

Confidence

Data are not available to make a determination on subsurface erosion due to river drawdown. Time between the termination of the steady reduction of dam release rates and the most current time without indications of subsurface erosion does not in fact decrease the likelihood that damage is not present. Thus, confidence with the assessment is low.

Summary

For CPFMs 3d and 3f, as discussed above, the potential for degradation is considered low because the potential for highly elevated groundwater elevations versus river elevations is unlikely due to stabilized river levels, structural soil backfill on the site, and the protected nature of the existing bank. The combined consideration of the potential for degradation and the implications of that degradation to the structure 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 could be necessary to make a final assessment.

Triggering Mechanism 12 – Rapid Drawdown

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

The Triggering Mechanism and CPFMs could occur as follows: the river level drops faster than pore water pressure in the soil can dissipate. The saturated soil is elevated above the dropping river level. The sloped bank of the river provides no lateral pressure support for the saturated soil. At some point there is insufficient support on the river side to support the saturated soils. At that point, the soils experience slope movements or even failure. Generally, slope failures associated with rapid drawdown are relatively localized and shallow in nature; however, deeper failures can occur.

The river stage level has receded and stabilized at a level corresponding to the nominal normal river level at 40,000 cfs as of October 4, 2011. At the time of the writing of this version of the Report the groundwater levels had not yet stabilized to nominal normal levels. Therefore, it is possible that new distress indicators could still develop. Field observation of the river bank area has not been performed since the river level has dropped.

The following table describes observed distress indicators and other data that would increase or decrease the potential for degradation associated with these CPFMs for the Fire Protection System Piping.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
The Main Fire Protection System Piping is in close proximity to the river.	No distress was observed at the time of site inspections.
Elevated saturated soils and elevated flood levels provided a water source.	

Data Gaps:
- Observations of the riverbank following drawdown to nominal normal river elevations.
- Geophysical investigation data to address any observed concerns.
- Inclinometer readings which that will monitor for possible slope movements.

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

The river stage level has receded and stabilized at a level corresponding to the nominal normal river level at 40,000 cfs as of October 4, 2011. Rapid drawdown has been controlled and continued river drawdown is not expected to occur at a rate that would initiate these CPFMs. Since it is believed that a potential for degradation of the structure exists but is not likely, these CPFMs are considered low.

Implication

The occurrence of these CPFMs on a large scale could negatively impact the integrity of the system. No distress has been observed during our inspections. Therefore, the implication of the potential degradation for these CPFMs is low.

Confidence

Although no distress has been observed to date, the river bank has not been inspected for signs of degradation and slope failure. Therefore, the confidence for these CPFMs is low.

Summary

For CPFMs 12a and 12b, 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 "not significant" category. The river bank has not been inspected for signs of degradation and slope failure. Therefore we cannot rule out these CPFMs and the confidence is low, which means continued monitoring and inspections could be necessary to draw a conclusion.

5.16.5 Results and Conclusions

The CPFMs evaluated for the Fire Protection System Piping 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**	CPFM 3a CPFM 3c	
Potential for Failure **Not Significant**	CPFM 3d CPFM 3f CPFM 12a CPFM 12b	

5.16.6 Recommended Actions

The following actions are recommended for the Fire Protection System:

Further forensic investigations and physical modifications are recommended to address CPFMs 3a, 3c, 3d, and 3f for the Fire Protection System. CPFMs 3a and 3c are associated with unfiltered flow of groundwater into the Turbine Building basement drain piping system (Key Distress Indicator #1). These recommendations are described in detail in Section 4.1. CPFMs 3a, 3c, 3d, and 3f are associated with the distress in and near the Paved Access Area between the Service Building and the Intake Structure (Key Distress Indicator #2). These recommendations are described in detail in Section 4.2.

A review of the geophysical and geotechnical reports as they pertain to the Fire Protection System should be done when available.

OPPD should initiate a procedure to monitor for problems during cable pulling operations. Problems associated with cable pulling operations to and from MH-5 might be indicative of problems that could affect the Fire Protection System.

A detailed analysis of the pavement subgrade and trench alignments should be performed if the pavement in the paved access area between the Intake Structure, around gate one, and the Service Building is replaced.

The results of proceeding recommendations will be used to increase the confidence in the assessment results.

At the time of the writing of this version of the Report, groundwater levels had not yet stabilized to nominal normal levels. Therefore, it is possible that new distress indicators could still develop. If new distress indicators are observed before December 31, 2011, appropriate HDR personnel should be notified immediately to determine whether an immediate inspection or assessment should be conducted. Observation of new distress indicators might result in a modification of the recommendations for this structure.

5.16.7 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.

5.16.7.1 Additional Data Available

The following additional data were available for the Fire Protection System Piping 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 falling weight deflectometer investigation by American Engineering Testing, Inc. (see Attachment 6).
- Results of geophysical investigation by Geotechnology, Inc. (see Attachment 6).
- Results of geotechnical investigation by Thiele Geotech, Inc. (see Attachment 6).
- Data obtained from inclinometers by Thiele Geotech, Inc. (see Attachment 6).
- Results of continued survey by Lamp Rynearson and Associates (see Attachment 6).

5.16.7.2 Additional Analysis

The following analysis of additional data was conducted for the Fire Protection System Piping:

- 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.

/50

- Results of falling weight deflectometer investigation by American Engineering Testing, Inc.

  Falling Weight Deflectometer 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 by Geotechnology, Inc.

  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 Inc.

  Six test borings were drilled, with continuous sampling of the soil encountered, to ground truth the Geotechnology, Inc. 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 feet 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 Lamp Rynearson and Associates.

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

CPFM 3c – Undermined buried utilities (due to pumping)

<u>Significance</u>

Potential for Degradation/Direct Floodwater Impact

Except for Turbine Building sump, conditions which could cause subsurface erosion no longer exist due to present site and flood conditions. Site pumping sources have been removed and high groundwater conditions no longer exist. The potential for this CPFM to occur presently only exists in conjunction with KDI#1. Recommended actions in conjunction with KDI#2 address a majority of the areas in question as part of the "Paved Access Area." Therefore, with known issues being addressed and further investigated by OPPD, the potential degradation due to this CPFM is low.

Implication

The occurrence of this CPFM could impact sections of the fire protection yard piping system and adjacent utilities or structures. The fire protection pipe system loops the entire facility and it is located in close proximity to many other utilities and structures. Since the fire protection system is highly pressurized, failure of the system could in turn, impact adjacent structures or utilities significantly if a pipe breaks and pressurized water erodes soils around the point of failure.

The Fire Protection System is a looped system and includes isolation valves at lateral pipe connection tees and on the main loop on each side of the lateral connection. Thus, the system is designed to be shut down in sections for repair purposes with continued supply to fire supply lines on both sides of potential line breaks. An operative fire protection system is required at all times on the site. The Fire Protection System has been tested since floodwaters have receded and it is an operative system, but has a minimum of two known impairments that have shut down lateral fire hydrant lines. Therefore, the implication of the potential degradation for these CPFMs is high.

Confidence

With investigations and repairs associated with KDI#1 and #2 handling known issues, and contingencies for expanding investigations and repairs as needed and directed by geotechnical inspectors, confidence in addressing issues associated with this CPFM is high.

Summary

Forensic test results received since the issuance of the Rev 0 report have narrowed and defined probable areas impacted by this CPFM. Recommended actions associated with the results of the forensic reports and site inspections will address known problem areas and allow the direction of the expansion of proposed investigations and repairs as necessary to address the conditions created by this CPFM. The combined consideration of the potential for degradation and the implications to that structure or system puts it in the "not-significant" category.

Triggering Mechanism 3 – Subsurface Erosion/Piping

CPFM 3d – Undermining and settlement of shallow foundation/slab (due to river drawdown)

CPFM 3f – Undermined buried utilities (due to river drawdown)

Significance

Potential for Degradation/Direct Floodwater Impact

Based on groundwater monitoring data taken in conjunction with river drawdown and on a continuing weekly basis, groundwater levels have been dropping at a rate that follows the river drawdown rate. Thus, the differential head necessary to create subsurface erosion due to river drawdown is no longer present. The area most conducive to create this CPFM is nearest the river. River bank inspections made since the issuance of the Rev 0 report show no indications of this CPFM. The "Paved Access Area" between the Intake Structure and the Service Building is the developed area nearest the river bank and includes most of the utility services that are critical to the operation of the facility. Recommended actions in association with KDI#2 will repair and address issues that are identified in the area. This will include instances of subsoil erosion that could have been induced by river drawdown. The potential for degradation for this CPFM to occur is considered low.

Implication

The occurrence of these CPFMs would likely only affect the utility installations nearest the river. Most of the fire protection system is located well away from the zone of influence from these CPFMs with the exception of the supply lines that connect to the Intake Structure. Thus, the two most important supply components of the system are located at the point of greatest potential for degradation from these CPFMs.

As groundwater elevations and river elevations stabilize, the head potential between the two conditions will decrease and the possibility of subsurface erosion will also decrease correspondingly. In addition, the stabilized river embankment reduces the likelihood of these CPFMs.

The implication of the CPFMs affecting the fire protection system is considered low.

<u>Confidence</u>

With groundwater data indicating that high head conditions no longer exist and the instigation of recommendations associated with KDI#2, confidence in the assessment associated with this CPFM is high.

<u>Summary</u>

Based on these discussion items, the combined consideration of the potential for degradation and the implications to that structure or system puts it in the "not-significant category" in the assessment matrix.

Triggering Mechanism 12 – Rapid Drawdown

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

<u>Significance</u>

Potential for Degradation/Direct Floodwater Impact

The river stage level has been stabilized at a level corresponding to the nominal "normal" river level at 40,000 cfs since October 4, 2011. Rapid drawdown was controlled by the release rate schedule set by the USACE and continued river drawdown is not expected to occur at a rate that would initiate this CPFM. Groundwater monitoring well measurements have been taken since floodwaters have receded from the site. Groundwater readings based on the weekly records show the groundwater levels dropped at a rate that closely followed the river level drop rate. With groundwater levels dropping in conjunction with river levels there is little chance of highly elevated groundwater levels in comparison to river levels. The river bank is armored and has historically protected and stabilized the existing river bank. In addition, no indications of this type of failure were noted on the most recent riverbank inspection completed as of October 27, 2011. Due to updated data and observations, the potential for degradation due to this CPFM is considered low.

Implication

The occurrence of this CPFM on a large scale could negatively impact the integrity of the system. No distress has been observed during our inspections. Therefore the implication of the potential degradation for this CPFM is low.

Confidence

Based on recent data and observations, this CPFM was not created or initiated by the flood conditions associated with the Missouri River flood of 2011 and confidence in the assessment associated with this CPFM is high.

Summary

Based on these discussion items, the combined consideration of the potential for degradation and the implications to that structure or system puts it in the "not-significant category" in the assessment matrix.

5.16.7.1 Results and Recommendations

The CPFMs evaluated for the Fire Protection System Piping are presented in the following matrix which shows the rating for the estimated significance and the level of confidence in the evaluation.

CPFMs 12a and 12b for the Fire Protection System Piping are not associated with Key Distress Indicators. The results of the additional forensic investigation show that these CPFMs are ruled out. Therefore, assuming that no further concerns are identified through the monitoring program for the Fire Protection System Piping (discussed in Section 5.16.6 and continuing until December 31, 2011), these CPFMs are moved to the quadrant of the matrix representing "No Further Action Recommended Related to the 2011 Flood."

CPFMs 3a and 3c for the fire protection system are associated with Key Distress Indicator #1. Section 4.1 presents the results of additional forensic investigation that was conducted to ascertain whether these CPFMs could be ruled out. The results of the additional forensic investigation show that, assuming the recommendations for physical modifications for KDI #1 are implemented, these CPFMs are ruled out. Therefore, assuming that no further concerns are identified through the monitoring program for the fire protection system (discussed in Section 5.16.6 and continuing until December 31, 2011), these CPFMs are moved to the quadrant of the matrix representing "No Further Action Recommended Related to the 2011 Flood."

CPFMs 3a, 3c, 3d and 3f for the fire protection system are associated with Key Distress Indicator #2. Section 4.2 presents the results of additional forensic investigation that was conducted to ascertain whether these CPFMs could be ruled out. The results of the additional forensic investigation show that these CPFMs are ruled out. Therefore, assuming that no further concerns are identified through the monitoring program for the fire protection system (discussed in Section 5.16.6 and continuing until December 31, 2011), these CPFMs are 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**		
Potential for Failure **Not Significant**		CPFM 3a CPFM 3c CPFM 3d CPFM 3f CPFM 12a CPFM 12b

5.16.7.2 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 Fire Protection System Piping other than CPFMs 3a, 3c, 3d, 3f, 12a, and 12b had been ruled out prior to Revision 1, because CPFMs 12a and 12b have been ruled out as a result of the Revision 1 findings, because CPFMs 3d and 3f were ruled out using the results of the KDI #2 investigation presented in Section 4.2, and because CPFMs 3a and 3c will be ruled out when the physical modifications recommended for KDI # 1 in Section 4.1 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Fire Protection System Piping. 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.

Section 5.17

Waste Disposal Piping

5.17 Waste Disposal Piping

5.17.1 Summary of Waste Disposal Piping

Baseline information for the Waste Disposal Piping is provided in Section 2.0, Site History, Description, and Baseline Condition.

Waste Disposal Piping is a 2-in.-diameter stainless steel pipeline encased in concrete with several other pipe systems. The encased utility bank is routed from the south side of the Turbine Building to the south end of the Intake Structure. The utility bank begins adjacent to Transformer T1 and is routed south of the Underground Cable Bank and MH-5. From the southeast corner of MH-5, the encased utility bank (including the Waste Disposal Piping) is routed to the northeast to a point south of the discharge tunnel. At that point, it turns to the north, crosses the Discharge Tunnel and terminates at the south side of the Intake Structure. The concrete-encased utility bank crosses fire protection lines, sanitary sewer lines, storm drain lines, demineralized water lines, and the Underground Cable Trench (Trenwa) as it is routed across the site.

The Waste Disposal system is used to collect, store, monitor, process, and control the release of radioactive waste. The Waste Disposal Piping is used to release this waste once it has been processed to within acceptable levels.

5.17.2 Inputs/References Supporting the Analysis

Table 5.17-1 lists references provided by OPPD and other documents used to support HDR's analysis.

Table 5.17-1 – References for Waste Disposal Piping

Plan Title/Document Title	OPPD Document Number (if applicable)	Date	Drawing No/ Page Number(s)
Yard Piping Sheet 1	11405-M-312 (#10752)	Unknown	
Yard Piping	11405-M-313 (#10753)	Unknown	
Yard Piping Sheet 3	11405-M-314 (#10754)	8/3/1973	
Waste Disposal System Rev. 28	SDBD-WD-144	7/28/11	All
Naval Facilities Engineering Command, Design Manual 7.01, Soil Mechanics		9/1986	All

Detailed site observations—field reports, field notes, and inspection checklists—for the Waste Disposal Piping are provided in Attachment 8.

Observed performance and pertinent background data are as follows:

- Groundwater was observed flowing into the basement sump of the Turbine Building from floor and condensate drain pipes not designed to intercept groundwater. This condition has a recorded history dating back to 1997. The Turbine Building is west of the corridor and utilities, between the Intake Structure and the Service Building.
- Settlement of a column in the Maintenance Building, north of the Turbine Building, has been documented. The Turbine Building and the Maintenance Building are west of the corridor and associated utility alignments within the corridor.
- The Aqua Dam surrounding the facility crossed the alignment of the Waste Disposal Piping.
- The Aqua Dam failed for a short period of time due to being damaged, allowing floodwater to enter the area inside the Aqua Dam perimeter. Surfaces above the Waste Disposal Piping were inundated when the facility Aqua Dam failed.
- Areas outside the perimeter of the facility Aqua Dam were inundated with water for an extended period of time.
- Concrete areas in the corridor (paved drive and pedestrian areas between the river and Service Building) have exhibited distress, including cracking, slab settlement, and undermining. However, most of the pavement cracking or other conditions could be pre-existing conditions due the age and use of the facility.
- A hole in the pavement and void area beneath the concrete slab is north of the Security Building and east-southeast of MH-5. The hole and void area are located outside the perimeter of the Aqua Dam that surrounded the facility. The pavement failure occurred at the intersection point of pavement jointing. The hole in the pavement is irregular in shape and is more than 1 ft wide both in the north–south and east–west directions. The void area beneath the hole was approximately 4 ft wide by 0.8 ft deep; it was measured by a tape measure through the hole. The void can be attributed to subsurface erosion.
- The hole in the pavement is located near the observed discharge point of a pump operated prior to the removal of the facility Aqua Dam. The void can be attributed to scour created by the discharge of the pipe operating for an extended period in one place.
- Fire Protection Cabinet FP-3C north of the Security Building and east-southeast of MH-5 is located in proximity to the pavement failure and void area. It was reported that the fire hydrant was tested September 13, 2011, and failed. According to OPPD operations personnel testing FP-3E during site inspections, the base of FP-3C cracked when the valve was opened. The fire hydrant was shut down, and the access cabinet was tagged out. The cause of failure was unknown at the time field observations were made.
- 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.
- The fire hydrant located in FP-3E was tested on September 13, 2011, during site investigations. No operational problems were observed during the time on site.
- OPPD operations personnel testing the fire hydrant at FP-3E on September 13, 2011, were questioned about other fire hydrant tests. An OPPD employee who was questioned noted that no problems were observed for the fire hydrant at FP-3D during testing. The information on the problem at FP-3C, noted previously, was gathered at this time.

5.17.3 Assessment Methods and Procedures

5.17.3.1 Assessment Procedures Accomplished

Assessments were made by walking the Waste Disposal Piping alignment and observing the ground surface overlying the underground pipe system. The surface assessment included using a 4-ft-long, 0.5-in.-diameter, steel-tipped fiberglass T-handle soil probe to hand probe the ground surface along the utility alignments and adjacent areas to determine relative soil strength. The assessment focused on identifying conditions indicative of potential flood-related impacts or damage to the utility as follows:

- Ground surface conditions overlying and immediately adjacent to the utility and its backfilled trench including scour, subsidence or settlement, lateral spreading, piping, and heave.
- Soft ground surface areas (native soil, engineered fill, or limestone gravel pavement) as determined by probing.
- Water accumulations and flows in subsurface system components (manholes and concrete cable encasement pipes).
- Damage to at-grade or above-grade system features and equipment.
- Variance from normal installation conditions including settled, tilted, or heaved system features and equipment.
- 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 damages were observed. These were composed of the following non-invasive geophysical and invasive geotechnical investigations:

- GPR. (Test reports were not available at the time of Revision 0.)
- Seismic surveys (seismic refraction and refraction micro-tremor). (Test reports were not available at the time of Revision 0.)
- Geotechnical investigations including borings in the vicinity of the utility to determine current soil conditions and capacities. Note that OPPD required vacuum excavation for the first 10 ft of proposed test holes to avoid utility conflicts. Test reports will thus not show soil conditions in the upper 10 ft of test boring logs. (Test reports were not available at the time of Revision 0.)
- Paved areas were evaluated with GPR and dynamic deflection methods (i.e., drop weight deflectometer). (Test reports were not available at the time of Revision 0.)
- Inclinometer readings along the river that provide an indication of slope movement.

5.17.3.2 Assessment Procedures Not Completed

Assessments of the Waste Disposal Piping that were not completed include the following:

- The interior of underground cable bank manholes and connecting concrete-encased cable pipes in the Protected Area were not inspected except for visual observations that were possible from above and behind temporary safety railings. Manholes are a confined space as defined by OSHA regulations. In accordance with these regulations and OPPD FCS safety procedures, manhole entry is a permit-required confined space entry and can only be performed by appropriately trained OPPD personnel. The underground cable bank and the Waste Disposal Piping system follow a similar route, and surface indicators for the cable bank can also be indicators for the disposal piping.

- No excavation to inspect underground systems and conditions was performed.
- No video inspection of the system was completed.

5.17.4 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 results of available geotechnical, geophysical, and survey data were analyzed, a number of CPFMs were ruled out as discussed in Section 5.17.4.1. The CPFMs carried forward for detailed assessment are discussed in Section 5.17.4.2.

5.17.4.1 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
CPFM 2c – Undermined buried utilities

Reason for ruling out:

- No surface erosion was observed along the surface overlying the Waste Disposal Piping alignment. In addition, only localized and limited surface erosion was observed on the ground surface across the facility. The Waste Disposal Piping system is constructed sufficiently below potential scour depths indicated by erosion features observed in other areas.

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:

- Soil supporting and surrounding the Waste Disposal Piping system has been previously wetted. The peak flood elevation prior to 2011 was 1003.3 ft, which occurred in 1993.

Triggering Mechanism 10 – Machine/Vibration-Induced Liquefaction

CPFM 10a – Cracked slab, differential settlement of shallow foundation, loss of structural support

CPFM 10b – Displaced structure/broken connections

Reasons for ruling out:

- Machine vibrations from the facility (turbine and various pumps) have historically occurred and no indications of these CPFMs were evident.
- Pumps used on site during the flood event were insufficient to cause ground or structure vibrations sufficient to initiate soil liquefaction. Visible indications of liquefaction were not observed around the areas where the pumps were operating and no occurrences of liquefaction were reported to HDR.
- No structure movements indicative of soil liquefaction and resultant settlement were observed; no structure cracking or lateral movements were observed.

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

Reasons for ruling out:

- Liquefaction was not observed along the corridor or across the site.
- Visual observations and survey measurements indicate no structure movement. Therefore, differential settlement, structure displacement, or loss of support (CPFMs 11a and 11b) did not occur at the surveyed structures.

Triggering Mechanism 12 – Rapid Drawdown

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

CPFM 12b – Lateral spreading

Reasons for ruling out:

- The structures did not have evident signs of distress identified during the field assessments.
- Slope failure was not observed at the site.
- River stage level has receded and stabilized as of October 4, 2011.
- As of date of this draft report, October 11, 2011, groundwater elevations have already had one week to stabilize to at least a partial degree.
- The river bank is armored and has historically protected and stabilized the existing river bank.

Triggering Mechanism 13 – Submergence

CPFM 13a – Corrosion of underground utilities

Reasons for ruling out:

- There are no flood-induced changes to the nature of the buried Waste Disposal Piping system.

- The Waste Disposal Piping system is located below the design flood elevation for the facility. Groundwater elevations controlled by Missouri River water elevations, percolation of storm precipitation, and winter snow melt would be expected to contact underground improvements, including constructed steel and concrete facility elements. As such, steel and concrete site improvements are assumed to be designed to withstand the corrosive environment of groundwater and wetted soil.
- The Waste Disposal Piping system is stainless-steel pipe that is encased in concrete and installed in an area of structural backfill. Therefore, corrosion due to flood-induced site changes is not expected.

Triggering Mechanism 14 – Frost Effects
CPFM 14a – Heaving, crushing, or displacement

Reasons for ruling out:

- The Waste Disposal Piping system is installed below the depth of frost penetration.
- Conditions have not changed due to flood conditions.

5.17.4.2 Detailed Assessment of Credible Potential Failure Modes

The following CPFMs are the only CPFMs carried forward for detailed assessment for the Waste Disposal Piping system 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)
CPFM 3c – Undermined buried utilities (due to pumping)

The Triggering Mechanism and CPFMs could occur as follows: multiple potentially connected seepage paths existed in the soil backfill at the site, including soil backfill in utility trenches, granular trench bedding, building floor drains with open/broken joints, and pre-existing defects/voids under pavement. The paths are exposed at some locations to the river floodwaters (e.g., a hole in the ground north of the Security Building). This network of seepage paths is connected to several pumping sources: the sump pit in the Turbine Building, Manhole MH-5, and a series of surface pumps located along the interior of the Aqua Dam perimeter. The pumps were operated for an extended period of time, maintaining a head differential on the seepage path networks. Gradient was sufficient to begin erosion of surrounding soil. Seepage is unfiltered and erosion continues unimpeded. Erosion extends out, intercepting the network of utility trenches including the Underground Cable Bank. Voids are created under the pavement and along the utility trench walls. The potential damage includes settlement of the Underground Cable Bank and manholes causing a loss of electrical connectivity.

Below are field observations and data that support the likelihood of these CPFMs:

- MH-5 was pumped for the duration of flooding to remove water entering into the manhole. Known water sources included ducts from MH-31 and ducts running to the Auxiliary Building. This created a head differential.
- The flow of water into MH-5 was observed on multiple field visits. Sources of the water could not be determined.

- Sediment deposits (and fish) were observed in the bottom of the MH-5 when it was emptied on September 14, 2011. The sediment could be an indication of piping and subsurface erosion.
- The area inside the Aqua Dam perimeter was pumped dry and created a hydrostatic head condition between the area inside and the area outside of the Aqua Dam perimeter. The inside the Aqua Dam perimeter was pumped from several locations creating points where underground piping and subsurface flows would tend to flow.
- A void area and potential piping location were observed beneath the concrete slab just north of the Security Building and east-southeast of MH-5.
- Based on a conversation with an OPPD operations employee testing FP-3E on September 13, 2011, fire hydrant FP-3C, located northeast of the Security Building was tested on September 13, 2011, and failed. According to the OPPD operations employee, when opening the valve to test the hydrant, the base cracked and leaked and the valve had to be closed. The access cabinet was tagged out for repair at that time.
- Pavement distress was observed along the driveway corridor between the Intake Structure and the Service Building. The area north of where the duct bank crosses the corridor includes observed slab settlement and undermining (as evidenced by hollow-sounding pavement areas).
- The Turbine Building sump pit was pumped continually during the flood event. The five pipes connected to this sump pit are floor drain and condensate system flush drain pipes. Since this is a floor drain system, no infiltration of groundwater should occur in the system. The infiltration of groundwater into the system indicates some type of open flow path.

Below are field observations and data that indicate these CPFMs are unlikely:

- Sediment and fish were observed in the bottom of MH-5 when it was emptied on September 14, 2011. Sediment accumulations and small fish at the bottom of MH-5 might not be associated with these CPFMs. The manhole was uncovered when the Aqua Dam failed and the area was inundated with water. Sediment and fish could have been transported into the manhole with floodwaters.
- The observed hole in the pavement, north of the Security Building, could have been developed by outflow from the surface pumps and might not be associated with these CPFMs. Temporary surface pumps were pumping water back into the river with hoses placed over the Aqua Dam. One of the discharge points was near the observed hole (reference figure/photo or field report). Concentrated discharge flow could have eroded pavement and created the observed hole.

Data Gaps (data still required to assess these CPFMs):

- The extent of the subsurface erosion is not known at this time.
- GPR data. (Test reports were not available at the time of Revision 0.)
- Seismic Survey - refraction/tomography and refraction microtremor. (Test reports were not available at the time of Revision 0.)

The following table describes observed distress indicators and other data that would increase or decrease the potential for degradation associated with these CPFMs for the Waste Disposal Piping system.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
A hole in the pavement with a void space beneath was observed north of the Security Building and east of MH-5. This location was outside the Aqua Dam perimeter and could be a sinkhole that developed due to subsurface erosion.	Alternatively, the observed hole could have been developed by outflow from the surface pumps and not be associated with this CPFM. Temporary surface pumps were pumping water back over the Aqua Dam. One of the pump discharge points was near the observed hole. Concentrated discharge flow could have created the observed hole.
Data Gaps: • Geophysical investigation data to address observed concerns. • Geotechnical investigation data to address observed concerns. • Existence, size, and location of voids	

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

Indicators for these CPFMs have been observed in close proximity to the Waste Disposal Piping in multiple locations during field inspections. Due to multiple indications of subsurface failures in the vicinity, the potential for degradation to the system is considered high.

Implication

The occurrence of these CPFMs on a large scale could cause void areas that would induce pipe settlement and loss of pipe restraint. This could lead to excessive movement and negatively impact the integrity or intended function of the Waste Disposal Piping system. Therefore, the implication of the potential degradation for these CPFMs is high.

Confidence

There are multiple elements to these CPFMs. The inflow of water into MH-5 during the flood event, the hole in the pavement north of the Security Building, and the settled pavement section in the corridor. However, even though the confidence is high that there are some voids under the corridor pavement; the extent of these voids is not known.

The data at hand are not sufficient to rule out these CPFMs, or lead to a conclusion that subsurface erosion has undermined the Waste Disposal Piping system. Therefore, the confidence in the above assessment is low, which means more data are necessary to draw a conclusion.

Summary

For CPFMs 3a and 3c, as discussed above, the potential for degradation is high because indicators for these CPFMs have been observed. This degradation could have caused erosion that impacts the integrity or intended function of the structure. 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. That data currently collected are not sufficient to rule out these CPFMs. Therefore, the confidence in the above assessment is low, which means more data or continued monitoring and inspections are necessary to draw a conclusion.

Triggering Mechanism 3 – Subsurface Erosion/Piping

CPFM 3d – Undermining and settlement of shallow foundation/slab (due to river drawdown)
CPFM 3f – Undermined buried utilities (due to river drawdown)

These CPFMs are similar to CPFMs 3a and 3c, but instead of pumping, the gradient is created by rapidly receding river level.

The Triggering Mechanism and CPFMs could then occur as follows: river level drops faster than pore water pressure in the soil can dissipate. A gradient is created that moves water and soil into existing defects. The flow enlarges voids along the utility trench as it moves through the soil toward the river via piping features or networks. Other consequences include damage to adjacent structures, including fire protection piping, underground cable bank, raw water piping, and the Underground Cable Trench.

Field observations and data that support the likelihood of these CPFMs:

- Conditions required to trigger these CPFMs had not occurred at the time of Revision 0. Therefore, field observations and data that support the likelihood of these CPFMs could not be made.
- The river was still beyond its banks at the time of field inspections. Future river drawdown conditions could initiate this CPFM.

Field observations and data or site conditions that indicate these CPFMs are unlikely:

- River stage level has receded and stabilized at a level corresponding to the nominal normal river level at 40,000 cfs as of October 4, 2011. Field observations that indicate that these CPFMs are unlikely have not been made.
- The Waste Disposal Piping is offset from the river bank. This offset from the river bank reduces the likelihood that rapid drawdown and related subsurface piping to the river bank will impact the Waste Disposal Piping System.
- Soils in the area of the Waste Disposal Piping System and to the east are backfill materials that were placed and compacted during construction of site improvements and therefore would be expected to be less susceptible to rapid drawdown impacts.
- Void spaces created by subsurface erosion would have to be significant to create conditions to cause the waste disposal system to fail.

Data Gaps (data has yet to be acquired to assess these CPFMs):

- Observations of the riverbank following drawdown to normal river elevations.
- Geophysical investigation data to address observed concerns.
- Geotechnical investigation data to address observed concerns.

The following table describes observed distress indicators and other data that would increase or decrease the potential for degradation associated with these CPFMs for the Waste Disposal Piping system.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
Flood waters were at a high level for an extended period of time which allowed surrounding soils to become saturated.	USACE suspended the river drawdown between August 27, 2011 and September 18, 2011. This gap period in the scheduled reduction of dam release rates was provided to allow groundwater elevations to equalize with river flow elevations.
	The river bank is armored and protects against the creation of a weakened flow path. Indications of these CPFMs have not been exhibited or reported due to previous floods.

Data Gaps:
- Observations of the riverbank following drawdown to normal river elevations.
- Geophysical investigation data to address observed concerns.
- Geotechnical investigation data to address observed concerns.
- Inclinometer readings to provide an indication of slope movement.

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

The potential for degradation exists since groundwater levels have not yet reached a nominal normal level. Since it is believed that a potential for degradation will affect the structure, these CPFMs are considered high.

Implication

The occurrence of these CPFMs could negatively impact the operation of the structure. This could lead to pipe settlement and negatively impact the integrity or intended functionality of the Waste Disposal Piping system. Therefore, the implication of the potential degradation for these CPFMs is high.

Confidence

The potential impact on the structure from these CPFMs is not known due to unknown future river drawdown rates. Groundwater levels are such that these CPFMs could still occur.

The data at hand are not sufficient to rule out these CPFMs, or lead to a conclusion that subsurface erosion has undermined the Waste Disposal Piping system. Therefore, the confidence in the above assessment is low, which means more data are necessary to draw a conclusion.

Summary

For CPFMs 3d and 3f, as discussed above, the potential for degradation is high because groundwater levels have not yet reached nominal normal levels. This degradation could cause erosion that impacts the integrity or intended function of the structure. 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 data currently collected are not sufficient to rule out these CPFMs. Therefore, the confidence in the above assessment is low, which means more data or continued monitoring and inspections is be necessary to draw a conclusion.

5.17.5 Results and Conclusions

The CPFMs evaluated for the Waste Disposal Piping 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**	CPFM 3a CPFM 3c CPFM 3d CPFM 3f	
Potential for Failure **Not Significant**		

5.17.6 Recommended Actions

The following actions are recommended for the Waste Disposal Piping:

- Review geophysical and geotechnical reports to evaluate the data as they pertain to the Waste Disposal Piping.
- Inspect the interior of MH-5. Inspect walls, floor, cover, joints, and duct bank penetrations. Obtain a photographic record of conditions.
- Perform a detailed analysis of the pavement subgrade and trench alignments, if the pavement in the corridor between the Intake Structure and the Service Building is replaced.

5.17.7 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.

5.17.7.1 Additional Data Available

The following additional data were available for the Waste Disposal Piping 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 falling weight deflectometer investigation by American Engineering Testing, Inc. (see Attachment 6).
- Results of geophysical investigation by Geotechnology, Inc. (see Attachment 6).
- Results of geotechnical investigation by Thiele Geotech, Inc. (see Attachment 6).
- Data obtained from inclinometers by Thiele Geotech, Inc. (see Attachment 6).
- Results of continued survey by Lamp Rynearson and Associates (see Attachment 6).

5.17.7.2 Additional Analysis

The following analysis of additional data was conducted for the Waste Disposal Piping:

- 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 falling weight deflectometer investigation by American Engineering Testing, Inc.

  Falling Weight Deflectometer 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, Inc.

  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, Inc.

  Six test borings were drilled, with continuous sampling of the soil encountered, to ground truth the Geotechnology, Inc. 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 feet 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 Lamp Rynearson and Associates.

  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.

Updates to assessment procedures not completed are outlined in Section 5.17.3.2. Excavation to inspect underground systems is included with the KDI #2 investigation. Video inspection of the system was not completed and is not planned due to the anticipated low value of data produced. Likewise, interior inspections of the manholes were not completed and are no longer deemed necessary.

Triggering Mechanism 3 – Subsurface Erosion/Piping

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

CPFM 3c – Undermined buried utilities (due to pumping)

CPFMs 3a and 3c for the Waste Disposal Piping System are associated with Key Distress Indicator #1. Section 4.1 presents the results of additional forensic investigation that was conducted to ascertain whether these CPFMs could be ruled out. The results of the additional forensic investigation show that assuming the recommendations for physical modifications for KDI #1 are implemented, these CPFMs are ruled out. Therefore, assuming that no further concerns are identified through the monitoring program for the Waste Disposal Piping System (discussed in Section 5.17.6 and continuing until December 31, 2011), these CPFMs are moved to the quadrant of the matrix representing "No Further Action Recommended Related to the 2011 Flood." The observation recommended in Section 5.17.6 regarding the interior inspection of MH-5 is no longer needed because CPFMs 3a and 3c will be ruled out when the physical modifications recommended for KDI # 1 in Section 4.0 are implemented.

Triggering Mechanism 3 – Subsurface Erosion/Piping

CPFM 3d – Undermining and settlement of shallow foundation/slab (due to river drawdown)

CPFM 3f – Undermined buried utilities (due to river drawdown)

CPFMs 3d and 3f for the Waste Disposal Piping System are associated with Key Distress Indicator #2. Section 4.2 presents the results of additional forensic investigation that was conducted to ascertain whether these CPFMs could be ruled out. The results of the additional forensic investigation show that these CPFMs are ruled out. Therefore, assuming that no further concerns are identified through the monitoring program for the Waste Disposal Piping System (discussed in Section 5.17.6 and continuing until December 31, 2011), these CPFMs are moved to the quadrant of the matrix representing "No Further Action Recommended Related to the 2011 Flood."

5.17.7.1 Revised Results

The CPFMs evaluated for the Waste Disposal Piping 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**		CPFM 3a CPFM 3c CPFM 3d CPFM 3f

5.17.7.2 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 Waste Disposal Piping other than CPFMs 3a, 3c, 3d, and 3f had been ruled out prior to Revision 1, because CPFMs 3d and 3f were ruled out using the results of the KDI #2 investigation presented in Section 4.2, and because CPFMs 3a and 3c will be ruled out when the physical modifications recommended for

KDI # 1 in Section 4.1 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Waste Disposal Piping. 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.

Section 5.18

Fuel Oil Storage Tanks and Piping

Omaha Public Power District

5.18 Fuel Oil Storage Tanks and Piping

5.18.1 Summary of Fuel Oil Storage Tanks and Piping

Baseline information for the Fuel Oil Storage Tanks and Piping is provided in Section 2.0, Site History, Description, and Baseline Condition.

The Fuel Oil Storage Tanks and Piping consist of three fuel tanks and associated supply piping located inside the protected area. The purpose of these tanks is to provide fuel oil storage for emergency diesel generators and diesel water pumps. Fuel tank FO-1 is an 18,000-gallon steel underground tank founded on a pile-supported concrete slab located south of the Auxiliary Building. Fuel tank FO-10 is an 18,000-gallon steel underground tank founded on a pile-supported concrete slab located outside the east wall of the Service Building. Tanks FO-1 and FO-10 supply fuel for the diesel-powered generators. Fuel tank FO-27 is a 500-gallon, concrete, aboveground tank located outside the west wall of the Intake Structure. Fuel tank FO-27 is supported by a concrete slab that is part of the pile-supported Intake Structure This tank supplies fuel for the diesel-powered water pump inside the Intake Structure.

5.18.2 Inputs/References Supporting the Analysis

Table 5.18-1 lists references provided by OPPD and other documents used to support HDR's analysis.

Table 5.18-1 - References for Fuel Oil Storage Tanks and Piping			
Document Title	**OPPD Document Number (if applicable)**	**Date**	**Page Number(s)**
Yard Piping Sheet 1	11405-M-312 (#10752)	Unknown	
Yard Piping Sheet 2	11405-M-313 (#10753)	Unknown	
Yard Piping Sheet 3	11405-M-314 (#10754)	8/3/1973	
Tank Foundations	11405-S-418 (#16588)	Unknown	
Foundation Details Transformer T1	11405-S-412 (#16583)	1/29/1973	
Emergency Diesel Generators, Rev 27 DBD	SDBD-DG-112	1/19/2011	All
Intake Structure, Rev 10 DBD	SDBD-STRUCT-503	6/22/2010	All
Naval Facilities Engineering Command Design Manual 7.01, Soil Mechanics		9/1986	All

Detailed site observations—field reports, field notes, and inspection checklists—for the Fuel Oil Storage Tanks and Piping are provided in Attachment 8.

Observations and pertinent background data are as follows:

- Utility lines run in close proximity to tanks FO-1 and FO-10.
- Tank FO-1 is surrounded by a perimeter security fence and could only be inspected from outside the fence.
- A sand boil/piping feature was observed (originally reported in CR 2011-7265) near the southwest corner of the Missile Shield Room. This room is on the outside of the south wall of the Auxiliary Building and has an unfinished, pea-gravel floor surface. Tank FO-1 is south of this Missile Shield Room and fuel oil piping enters this room below floor elevation very near the observed boil/piping

feature. The Main Underground Cable Bank (MH-1 to the Auxiliary Building portion) runs through the subsurface, in proximity to the location of the boil/piping feature.

- A hollow-sounding pavement area was noticed east of the Service Building truck dock; this area is in proximity to underground fuel tank FO-10.
- Groundwater was observed flowing into the basement sump of the Turbine Building from floor and condensate drain pipes not designed to intercept groundwater. This condition has a recorded history dating back to 1997. The Turbine Building is west of the corridor and utilities are located between the Intake Structure and the Service Building.
- Settlement of a column in the Maintenance Building, north of the Turbine Building, has been documented.
- Water inflow into MH-5 occurred during the flood event and was observed during site visits and photographed.
- The Aqua Dam surrounding the facility crossed the alignments of the fire protection/raw water piping, the underground utility bank, the underground cable bank, and the circulation water tunnels.
- The Aqua Dam failed for a short period of time due to being damaged, allowing floodwater to enter the area inside the Aqua Dam perimeter. Surfaces above the site utilities were inundated when the facility Aqua Dam failed.
- Areas outside the facility Aqua Dam were inundated for an extended period of time.
- Concrete areas in the corridor (paved drive and pedestrian areas between the river and Service Building) have exhibited distress including cracking, slab settlement, and undermining. However, most of the pavement cracking or the other conditions could be pre-existing conditions due the age and use of the facility.
- There is a hole in the pavement and void area beneath the concrete slab north of the Security Building and east-southeast of MH-5. The hole and void area are outside the perimeter of the Aqua Dam that surrounded the facility. The pavement failure occurred at the intersection point of pavement jointing. The hole in the pavement is irregular in shape and is more than 1 ft wide both in the north-south and east-west directions. The void area beneath the hole is approximately 4 ft wide by 0.8 ft deep; it was measured by a tape measure through the hole.
- The hole in the pavement is near the observed discharge point of a pump operated prior to the removal of the Aqua Dam. The void can be attributed to scour created by the discharge of the pipe operating for an extended period of time in one place.
- Fire Protection Cabinet FP-3C north of the Security Building and east-southeast of MH-5 is located in proximity to the pavement failure and void area. It was reported that the fire hydrant was tested September 13, 2011 and failed. According to OPPD operations personnel testing FP-3E during site inspections, the base of FP-3C cracked when opening the valve. The fire hydrant was shut down and the access cabinet was tagged out. The cause of failure was unknown at the time field observations were made.
- Pavement slab settling was observed northwest of the Intake Structure and east of the abandoned acid tank.
- The fire hydrant located in FP-3E was being tested on September 13, 2011, during site investigations. No operational problems were observed during the time on site.
- OPPD operation personnel testing the fire hydrant at FP-3E on September 13, 2011, were questioned about other fire hydrant tests. The OPPD employee questioned noted that no problems were observed for the fire hydrant at FP-3D during testing. The information on the problem at FP-3C, noted previously, was gathered at this time.

- The enclosure for fuel tank FO-27, outside the Intake Structure, is designed to withstand an external hydrostatic load due to flooding of the Missouri River to el. 1014.5 ft (see SDBD-STRUC-503).
- The concrete support slabs for fuel tanks FO-1 and FO-10 are 15 ft wide by 25 ft long by 3 ft thick and are founded on four 10BP42 steel-bearing piles. The top of the support slab for tank FO-1 is at el. 989 ft and the top of the support slab for tank FO-10 is at el. 990 ft.
- The driving criteria, tip elevation, and capacities of the 10BP42 piles are unknown. However, the top of the piles are capped with a plate and anchor rods for a positive shear and uplift connection (see 11405-S-412).
- The piles are anchored to the support slab through a welded pile cap plate and 1-in. diameter bent rods that protrude into the slab.
- The tank is attached to the slab by two hold-down straps anchored to the support slab with 1.5-in.-diameter bent rods.
- 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 the FCS on October 4, 2011, at about el. 995 ft.

5.18.3 Assessment Methods and Procedures

5.18.3.1 Assessment Procedures Accomplished

Assessments were made by observing surface features of the system (access points and vent/fill pipes) and the ground surface overlying the underground fuel storage tanks. The surface assessment included using a 4-ft-long, 0.5-in.-diameter, steel-tipped fiberglass t-handle soil probe to hand probe the ground surface along the utility alignments and adjacent areas to determine relative soil strength. The assessment focused on identifying conditions indicative of potential flood-related impacts or damage to the utility as follows:

- Ground surface conditions overlying and immediately adjacent to the utility and backfill.
- Soft ground surface areas as determined by probing.
- Water accumulations and flows in subsurface system components (manholes and concrete cable encasement pipes).
- Damage to at-grade or above-grade system features and equipment.
- Variance from normal installation conditions, including settled, tilted, or heaved system features and equipment.

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

- GPR. (Test reports were not available at the time of Revision 0.)
- Seismic surveys (seismic refraction and refraction micro-tremor). (Test reports were not available at the time of Revision 0.)
- Geotechnical investigations including borings in the vicinity of the utility to determine current soil conditions and capacities. Note that OPPD required vacuum excavation for the first 10 ft of proposed test holes to avoid utility conflicts. Test reports will thus not show

soil conditions in the upper 10 ft of test boring logs. (Test reports were not available at the time of Revision 0.)

- Paved areas were evaluated with GPR and dynamic deflection methods (i.e., drop weight deflectometer). (Test reports were not available at the time of Revision 0.)

5.18.3.2 Assessment Procedures Not Completed

Assessments of the Fuel Oil Storage Tanks and Piping that were not completed include the following:

- No excavation to inspect underground systems and conditions was performed.

5.18.4 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. Eleven PFMs associated with five different Triggering Mechanisms were determined to be "non-credible" for 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 results of available geotechnical, geophysical, and survey data were analyzed, a number of CPFMs were ruled out as discussed in Section 5.18.4.1. The CPFMs carried forward for detailed assessment are discussed in Section 5.18.4.2.

5.18.4.1 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
CPFM 2c – Undermined buried utilities

Reason for ruling out:

- No surface erosion was observed along the surface overlying the Fuel Oil Storage Tanks and Piping. In addition, only localized and limited surface erosion was observed on the ground surface across the facility. Therefore surface erosion-induced failure is discounted as a failure mode applicable to this system.

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

Reasons for ruling out:

- Underground storage tanks and buried piping are designed to be below the groundwater surface.
- The tanks were nearly full during the 2011 flood.

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:

- Fuel storage tanks FO-1 and FO-10 are located below ground and are not susceptible to hydrodynamic loading. Fill and vent pipes for these tanks were exposed to moving water following the failure of the Aqua Dam and until it was replaced. The Intake Structure fuel storage and pipelines (FO-27) are above ground. Fuel storage components susceptible to this loading show no observable signs of movement or distress.

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:

- Underground storage tanks and buried piping are designed to be below the groundwater surface.
- The tanks were nearly full during the 2011 flood.

Triggering Mechanism 7 – Soil Collapse (first time wetting)

CPFM 7b – Displaced structure/broken connections
CPFM 7c – General site settlement
CPFM 7d – Piles buckling from down drag

Reasons for ruling out:

- Soil supporting and surrounding the Fuel Oil Storage Tanks and Piping has been previously wetted. The peak flood elevation prior to 2011 was 1003.3 ft, which occurred in 1993.
- No indication of soil settlement was observed during site inspections pertaining to these fuel storage tanks.

Triggering Mechanism 10 – Machine/Vibration-Induced Liquefaction

CPFM 10b – Displaced structure/broken connections
CPFM 10d – Pile/pile group instability

Reasons for ruling out:

- Machine vibrations from the facility (turbine and various pumps) have historically occurred and no indications of these CPFMs are evident.
- Pumps used on site during the flood event were judged of insufficient size to cause ground or structure vibrations to initiate soil liquefaction.
- Visible indications of liquefaction were not observed around the areas where the pumps were operating and no occurrences of liquefaction were reported to HDR.

- No structure movements indicative of soil liquefaction and resultant settlement were observed; no structure cracking or lateral movements were observed.

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 has not been observed on site.

Triggering Mechanism 12 – Rapid Drawdown

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

Reasons for ruling out:

- The structures did not have evident signs of distress identified during the field assessments.
- Slope failure was not observed at the site.
- River stage level has receded and stabilized at a level corresponding to the nominal normal river level at 40,000 cfs as of October 4, 2011.
- The river bank is armored and has historically protected and stabilized the existing river bank.

Triggering Mechanism 13 – Submergence

CPFM 13a – Corrosion of underground utilities
CPFM 13b – Corrosion of structural elements

Reasons for ruling out:

- Underground fuel tanks and piping are resistant to corrosion by design, through the use of protective coating and corrosion allowance in design. There are no flood-induced changes to the corrosive nature of the environment.
- The aboveground storage tank, FO-27, is a ConVault fuel oil storage tank. This tank is a concrete-encased steel storage tank. The exterior surfaces of the concrete encasement is painted or sealed. Piping components for this tank are located at the top of the tank and not exposed to floodwater.

Triggering Mechanism 14 – Frost Effects
CPFM 14a – Heaving, crushing, or displacement

Reasons for ruling out:

- Fuel oil storage tanks FO-1 and FO-10 are pile-supported with the pile caps located well below frost depth, thus not subject to frost heave.
- Fuel storage tank FO-27 is supported by the Intake Structure, which is pile-supported and not susceptible to frost effects. Piping for this tank is flexible and able to accommodate some movement.
- Conditions have not been changed due to the flood.

5.18.4.2 Detailed Assessment of Credible Potential Failure Modes

The following CPFMs are the only CPFMs carried forward for detailed assessment for the Fuel Oil Storage Tanks and Piping as a result of the 2011 flood. These CPFMs are only applicable to tanks FO-1 and FO-10 and associated piping because Tank FO-27 is supported on the Intake Structure. The detailed assessment is provided below.

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

Subsurface structures in the general vicinity of the fuel oil tanks and piping that were pumped during the flood due to groundwater infiltration included Manhole MH-5 and the Turbine Building sump pit.

This Triggering Mechanism and CPFM could occur as follows: multiple potentially connected seepage paths existed in the soil backfill at the site, including soil backfill in utility trenches, granular trench bedding, building floor drains with open/broken joints, and pre-existing defects/voids under pavement. The potential damage includes settlement of pipe. Settlement can overstress a pipe that is corroded and can cause a pipe or its connections to break, which could cause failure of the piping system.

Following are field observations and data that support the likelihood of these CPFMs:

- The Turbine Building sump pit was pumped continually during the flood event. The five pipes connected to this sump pit are floor drain and condensate system flush drain pipes. Since this is a floor drain system, no infiltration of groundwater should occur in the system. The infiltration of groundwater into the system indicates an open flow path.
- MH-5 was pumped for the duration of flooding to remove water entering into the manhole. Known water sources included ducts from MH-31 and ducts running to the Auxiliary Building. Pumping created a head differential.
- The flow of water into MH-5 was observed on multiple field visits. Sediment deposits (and fish) were observed in the bottom the MH-5 when it was emptied on September 14, 2011. The sediment could be an indication of piping and subsurface erosion.
- A void area was observed beneath the concrete slab just north of the Security Building and east-southeast of MH-5.
- Based on a conversation with the OPPD operations employee testing fire hydrant FP-3E on September 13, 2011, fire hydrant FP-3C, located northeast of the Security Building, was

tested on September 13, 2011, and failed, According to the OPPD operations employee, when opening the valve to test the hydrant, the base cracked and leaked and the valve had to be closed. The access cabinet was tagged out for repair at that time.

- Pavement distress was observed along the driveway corridor between the Intake Structure and the Service Building. Distress indicators include observed slab settlement and undermining (as evidenced by hollow-sounding pavement area).

Following are field observations and data that indicate these CPFMs are unlikely:

- No indications of soil subsidence or piping were observed in areas above the fuel tanks and piping system for tanks FO-1 and FO-10.
- Site soils above and around tank FO-10 and around the perimeter of tank FO-1 were firm and stable. Soil probing indicated no soft spots at the surface.
- Sediment and fish were observed in the bottom of MH-5 when it was emptied on September 14, 2011. Sediment accumulations and small fish at the bottom of MH-5 might not be associated with this failure mode. The manhole was uncovered when the Aqua Dam failed and the area was inundated with water. Sediment and fish could have been transported into the manhole with floodwaters.
- The observed hole in the pavement, north of the Security Building, could have been developed by outflow from the surface pumps and might not be associated with these failure modes. Temporary surface pumps were pumping water back into the river with hoses placed over the Aqua Dam. One of the discharge points was near the observed hole (verify and reference a figure or a field report). Concentrated discharge flow might have eroded pavement and created the observed hole.
- Observed subsurface damage indicators or known instances of damage in the corridor are not located immediately adjacent to the fuel storage components.

Data Gaps (data still required to assess these CPFMs):

- GPR data and reports have not been delivered for assessment of subsurface conditions.
- Seismic Survey (refraction/tomography and refraction microtremor).

The following table summarizes observed distress indicators and other data that would increase or decrease the potential for degradation associated with these CPFMs for the Fuel Oil Storage Tanks and Piping system.

Adverse (Degradation/Direct Floodwater Impact More Likely)	**Favorable (Degradation/Direct Floodwater Impact Less Likely)**
Water was pumped continually pumped from the Turbine Building sump pit and MH-5	Soils were firm and stable surrounding tanks FO-1 and FO-10.
Slab settlement was noted northwest of tank FO-27.	No soil subsidence was noted above or adjacent to tanks FO-1 and FO-10.
Data Gaps: • Geophysical investigation data to address observed concerns. • Geotechnical investigation data to address observed concerns. • Existence, size, and location of voids	

Conclusion

Significant

Potential for Degradation/Direct Floodwater Impact

None of the indicators for these CPFMs have been observed at the structures. However, voids due to pumping of MH-5 might not have been evident at the time of the field assessments. Additionally, the extent of voids due pumping of groundwater in the Turbine Building sump has not been determined. Field observations indicate the potential that degradation has occurred due to these CPFMs is low.

Implication

Depending on the location and extent of the subsurface erosion, these CPFMs could manifest as pipe movement or tilted foundations negatively impacting the integrity or intended function of the Fuel Oil Storage Tanks and Piping. Therefore, the implications of the potential degradation for these CPFMs are high.

Confidence

The data at hand are not sufficient to rule out these CPFMs, or lead to a conclusion that the Fuel Oil Storage Tanks and Piping are or could become undermined because of these CPFMs. Therefore, the confidence in the above assessment is low, which means more data are necessary to draw a conclusion.

Summary

For CPFMs 3b and 3c, as discussed above, the combined consideration of the potential for degradation and the implications of that degradation to a structure of this type put it in the "not significant" category. The data currently collected are not sufficient to rule out these CPFMs. Therefore, the confidence in the above assessment is "low," which means more data or continued monitoring and inspections are necessary to draw a conclusion.

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)

The Triggering Mechanism and CPFM could then occur as follows: the drop in elevation of the river is expected to occur at a higher rate than the drop in elevation of the groundwater. This will result in an increased groundwater gradient. This increase could allow for subsurface erosion to occur.

Following are field observations and data that support the likelihood of these CPFMs:

- Flood waters were at a high level for an extended period of time and saturated soils under and adjacent to facility site improvements.
- The observed void area beneath the concrete slab north of the Security Building and the pavement distress observed along the driveway corridor between the Intake Structure and the Service Building, support the likelihood that subsurface piping features/networks from within the site to the river exist.

Following are field observations and data or site conditions that indicate these CPFMs are unlikely:

- Tank FO-1 is located south of the Auxiliary Building, well away from the river bank. Tank FO-10 is offset from the river bank, outside the east wall of the Service Building. The offset from the river bank reduces the likelihood that rapid drawdown and related subsurface piping to the river bank will impact these components. Void spaces created by subsurface erosion would have to be significant to create conditions to cause the Fuel Oil Storage Tank system to fail.

Data Gaps (data still required to assess these CPFMs):

- Gauge report data for the fuel oil tanks (i.e., records of fuel oil volumes in the tanks and observations by OPPD employees taken as part of other regulatory requirements).

The following table describes observed distress indicators and other data that would increase or decrease the potential for degradation associated with these CPFMs for the Fuel Oil Storage Tanks and Piping system.

Adverse (Degradation/Direct Floodwater Impact More Likely)	**Favorable (Degradation/Direct Floodwater Impact Less Likely)**
Flood waters were at a high level for an extended period of time and saturated soils under and adjacent to facility site improvements.	USACE suspended the river drawdown between August 27, 2011 and September 18, 2011. This gap period in the scheduled reduction of dam release rates was provided to allow groundwater elevations to equalize with river flow elevations.
	Riverbank is armored; bank has been protected in previous floods.
Data Gaps: • Observations of the riverbank following drawdown to normal river elevations. • Geophysical investigation data to address observed concerns. • Geotechnical investigation data to address observed concerns.	

Conclusion

<u>Significance</u>

Potential for Degradation/Direct Floodwater Impact

None of the indicators for theses CPFMs have been observed at the structures. However, voids due to rapid drawdown might not have been evident at the time of the field assessments.

Additionally, the extent of voids created by rapid drawdown could be insignificant. The potential that degradation due to these CPFMs has occurred is low.

Implication

Depending on the location and extent of the subsurface erosion, these CPFMs could manifest as pipe movement or tilted foundations which could negatively impact the integrity or intended function of the Fuel Oil Storage Tanks and Piping. Therefore, the implications of the potential degradation for these CPFMs are high.

Confidence

The data at hand are not sufficient to rule out these CPFMs or lead to a conclusion that the Fuel Oil Storage Tanks and Piping are or could become undermined because of these CPFMs. Therefore, the confidence in the above assessment is low, which means more data are necessary to draw a conclusion.

Summary

For CPFMs 3e and 3f, as discussed above, the combined consideration of the potential for degradation and the implications of that degradation to a structure of this type put it in the "not significant" category. The data currently collected are not sufficient to rule out these CPFMs. Therefore, the confidence in the above assessment is "low," which means more data or continued monitoring and inspections are necessary to draw a conclusion.

5.18.5 Results and Conclusions

The CPFMs evaluated for the Fuel Oil Storage Tanks and Piping 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**	CPFM 3b CPFM 3c CPFM 3e CPFM 3f	

5.18.6 Recommended Actions

The following actions are recommended for the Fuel Oil Storage Tanks and Piping: Review the geotechnical and geophysical data and assess the impact on the Fuel Oil Storage Tanks and Piping. Further forensic investigations and physical modifications are recommended to address CPFMs 3b, 3e, and 3f. These CPFMs are associated the Turbine Building basement drain piping system (Key Distress Indicator #1), the Pavement failure and sinkhole in and near the access area southwest of the condensate storage tank (Key Distress Indicator #2), and Column settlement in the Maintenance Shop building (Key Distress Indicator #3). These recommendations are described in detail in Sections 4.1, 4.2 and 4.3.

CPFM 3c for fuel tank FO-1 will be addressed under separate investigation due to the following:

1. The observed sand-boil/piping feature in the Auxiliary Building missile shield room is not associated with or addressed in the KDI investigations.
2. The distance from fuel tank FO-1 to the access corridor, reduces the likelihood that results from the KDI investigations could be used to rule out CPFM 3c for fuel tank FO-1.

Also, inventory control and leak detection results should continue to be monitored and compared to the results of inventory control and leak detection prior to the 2011 flood.

At the time of Revision 0, groundwater levels had not yet stabilized to nominal normal levels. Therefore, it is possible that new distress indicators could still develop. If new distress indicators are observed before December 31, 2011, appropriate HDR personnel should be notified immediately to determine whether an immediate inspection or assessment should be conducted. Observation of new distress indicators might result in a modification of the recommendations for this structure.

5.18.7 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.

5.18.7.1 Additional Data Available

The following additional data were available for the Fuel Oil Storage Tanks and Piping 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)
- Results of KDI #3 forensic investigation (see Section 4.3)
- Additional groundwater monitoring well and river stage level data from OPPD.
- Field observations of the river bank (see Section 5.25).
- Results of falling weight deflectometer investigation by American Engineering Testing, Inc. (see Attachment 6).
- Results of geophysical investigation by Geotechnology, Inc. (see Attachment 6).
- Results of geotechnical investigation by Thiele Geotech, Inc. (see Attachment 6).
- Data obtained from inclinometers by Thiele Geotech, Inc. (see Attachment 6).
- Results of continued survey by Lamp Rynearson and Associates (see Attachment 6).

5.18.7.2 Additional Analysis

Several CPFMs were identified in Revision 0. Additional analysis related to CPFMs 3b, 3e, and 3f is discussed in Section 4.1 for KDI #1, Section 4.2 for KDI #2, and Section 4.3 for KDI #3. In addition to analysis associated with the KDIs, analysis of the additional data listed above has clarified the significance and confidence for these CPFMs. The following analysis of additional data was conducted for the Fuel Oil Storage Tanks and Piping:

- 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 falling weight deflectometer investigation by American Engineering Testing, Inc.

  Falling Weight Deflectometer 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, Inc.

  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 Inc.

  Six test borings were drilled, with continuous sampling of the soil encountered, to ground truth the Geotechnology, Inc. 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 feet 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 Lamp Rynearson and Associates.

  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.

Updates to assessment procedures not completed are outlined in Section 5.18.3.2.

The following presents the previously identified CPFM 3c for fuel tank FO-1 which is not associated with a KDI and the new interpretation of the significance and confidence based on the new data.

Triggering Mechanism 3 – Subsurface Erosion/Piping
CPFM 3c – Undermined buried utilities (due to pumping)

A sand boil/piping feature was observed in the Auxiliary Building, missile shield room. This feature is an indication of subsurface erosion near fuel tank FO-1, more specifically, the fuel tank piping into the Auxiliary Building.

Significance

Potential for Degradation/Direct Floodwater Impact

Indication of this CPFM has been observed. This appears to be isolated to an area inside the missile shield room. From feature documentation and plant construction plans, the observed feature coincides with the fuel tank piping route into the Auxiliary Building. The potential is high that this CPFM has occurred with respect to the fuel tank piping system.

Implication

The occurrence of this CPFM could negatively impact the functionality of the fuel tank FO-1 piping system. Subsurface erosion occurring over a large area could lead to pipe settlement, or broken pipes or connections, negatively impacting the integrity or intended function of the fuel piping system. Except for the boil/piping feature, no other trench subsidence or soft soil was observed inside or outside the missile shield room. Therefore, the implication of the potential degradation for this CPFM is considered low.

Confidence

The extent of subsurface erosion and the potential impact on the structures was not known due to the lack of data gathered on subsurface conditions. Subsequent field inspections and a review of surveyed data indicate no structure movement on site. The structures have been monitored and no signs of movement have been detected. The magnitude of this CPFM could be inadequate to initiate movement and associated damage of the surrounding structure and piping system. Therefore, the confidence for this potential failure mode is high.

Summary

The combined consideration of the potential for degradation and the implications of that degradation to a structure of this type put it in the "significant" category. The confidence in the above assessment is "high," which means physical modification is necessary.

5.18.7.1 Revised Results and Recommendations

The CPFMs evaluated for the Fuel Oil Storage Tanks and Piping are presented in the following matrix, which shows the rating for the estimated significance and the level of confidence in the evaluation. CPFM 3c for the Fuel Oil Storage Tanks and Piping (tank FO-1) is not associated with the Key Distress Indicators. The recommendations for physical modifications to remediate impacts associated with this CPFM are as follows: excavate the sand boil/piping feature in the missile shield room to determine the extent of potential undermining; then backfill the pipe trench as necessary with compacted granular material. Following the implementation of this recommended physical modification, and assuming that no further concerns are identified through the monitoring program for the Fuel Oil Storage Tanks and Piping (discussed in Section 5.18.6 and continuing until December 31, 2011), this CPFM is moved to the quadrant of the matrix representing "No Further Action Recommended Related to the 2011 Flood." CPFMs 3b, 3e, and 3f for the Fuel Oil Storage Tanks and Piping are associated with Key Distress Indicator KDI #1, KDI #2, and KDI #3. Section 4.1, Section 4.2, and Section 4.3 present the results of additional forensic investigation that was conducted to ascertain whether these CPFMs 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 these CPFMs are ruled out. Therefore, assuming that no further concerns are identified through the monitoring program for the Fuel Oil Storage Tanks and Piping (discussed in Section 5.18.6 and continuing until December 31, 2011), these CPFMs are 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		
Potential for Failure Not Significant		CPFM 3b CPFM 3c CPFM 3e CPFM 3f

5.18.7.2 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 Fuel Oil Storage Tanks and Piping other than CPFMs 3b, 3c, 3e, and 3f have been ruled out prior to Revision 1, because CPFM 3c has been ruled out assuming the implementation of the recommended physical modifications presented in the paragraph above, and because CPFMs 3b, 3e, and 3f will be ruled out when the physical modifications recommended for KDIs #1and #3 in Sections 4.1 and 4.3 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Fuel Oil Storage Tanks and Piping. 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.

Section 5.19

Main Underground Cable Bank, Auxiliary Building to Intake Structure

Omaha Public Power District

5.19 Main Underground Cable Bank, Auxiliary Building to Intake Structure

5.19.1 Summary of Main Underground Cable Bank, Auxiliary Building to Intake Structure

Baseline information for the Main Underground Cable Bank from the Auxiliary Building to the Intake Structure is provided in Section 2.0, Site History, Description, and Baseline Condition.

The portion of the Main Underground Cable Bank system covered under this section extends from the Auxiliary Building to MH-31, which is adjacent to the southwest corner of the Intake Structure. There are two duct banks that begin at the south face of the Auxiliary Building. The two ducts turn 90° and combine into one 7-ft-wide, 3-ft, 2.5-in.-deep, concrete-encased duct bank. The duct bank runs east to MH-5 in a corridor between the outside face of the Turbine Building and the South Switchyard. At MH-5 the ducts are split into two separate duct banks before penetrating the manhole. The ducts then turn 90° to the north and run parallel to the east face of the Service Building. Southeast of the location of Fuel Oil Tank 10, the duct bank turns to the northeast and angles toward the Intake Structure. Adjacent to the southwest corner of the Intake Structure, the duct bank makes a final bend to the east and terminates at MH-31. The duct bank configuration transitions between MH-5 and MH-31. The size of the duct bank entering MH-31 is 4 ft 9 in wide by 4 ft 1.5 in. deep per referenced plan data. The conduits from MH-31 feed into the west side of the Intake Structure. From field observations, MH-31 is partially filled with insulation installed on the north and south walls of the structure and which reduces the open space of the manhole to a very narrow, center channel area.

5.19.2 Inputs/References Supporting the Analysis

Table 5.19-1 lists references provided by OPPD and other documents used to support HDR's analysis.

Table 5.19-1 - References for Main Underground Cable Bank, Auxiliary Building to Intake Structure

Document Title	OPPD Document Number (if applicable)	Date	Drawing No./ Page Number(s)
Underground Duct System	60184	12/13/2002	CE-79-3
Site Plan Underground Ducts – Manholes – Outdoor Lighting – Fence Grounding	12582	Unknown	11405-E-319
Underground Ducts & Manholes Sections & Details SH.1	12583	Unknown	
Underground Ducts & Manholes Sections & Details SH.2	12584	Unknown	11405-E-321
Underground Ducts & Manholes Sections & Details	12585	Unknown	11405-E-322 SH.3
Electrical Underground Duct Bank – Site Plan	16581	Unknown	11405-S-410
Foundation Plan Transformer Yard		Unknown	11405-S-411
Naval Facilities Engineering Command, Design Manual 7.01, Soil Mechanics		9/1986	All

Detailed site observations—field reports, field notes, and inspection checklists—for the Main Underground Cable Bank from the Auxiliary Building to the Intake Structure are provided in Attachment 8.

Observed performance and pertinent background data are as follows:

- OPPD assistance is required for inspection of the electrical duct bank manholes and appurtenant system components. Access and egress into the manholes will be required by OPPD personnel to assist in the evaluation of the system.
- Water levels in the system require that manholes and appurtenant ducts be pumped dry before the interior of manholes can be inspected.
- MH-5 was opened by OPPD employees and then emptied by Thiele Geotechnical employees using a "Jet-Vac" on Wednesday, September 14, 2011. The water level prior to beginning of vacuuming activities measured 8.8 ft from the rim of the manhole. Due to the size of the vacuum storage tank, multiple trips were made to empty the manhole.
- After MH-5 was emptied, observations were made to determine if inflow of water could be observed. No drainage into the manhole was observed during the initial 15 minutes after the manhole was emptied. Approximately 1 hour and 10 minutes later, no additional water accumulation was observed when rechecking the manhole.
- The Aqua Dam surrounding the facility crossed the Underground Cable Bank.
- The Aqua Dam failed for a short period of time due to being damaged, allowing floodwater to enter the area inside the Aqua Dam perimeter. All surfaces above the Underground Cable Bank were inundated when the facility Aqua Dam failed.
- Equipment outside the perimeter of the replacement Aqua Dam was inundated for an extended period of time. A hole in the pavement and void area beneath the concrete slab is north of the Security Building and east-southeast of MH-5. The hole and void area are outside the perimeter of the Aqua Dam that surrounded the facility. The pavement failure occurred at the intersection point of pavement jointing. The hole in the pavement is irregular-shaped and is more than 1 ft wide both in the north-south and east-west directions. The area beneath the hole was approximated as a 4-ft-diameter-by-10-in-deep void as measured by a tape measure through the hole.
- The hole in the pavement is near the observed discharge point of a pump operated prior to the removal of the Aqua Dam. The void might be attributed to scour created by the discharge of the pump operating for an extended period of time in one place or to subsurface erosion.
- Fire Protection Cabinet FP-3C north of the Security Building and east-southeast of MH-5 is located in proximity to the pavement failure and void area discussed above. The fire hydrant was tested on September 13, 2011 (reportedly) and failed. According to OPPD operations personnel testing FP-3E during site inspections, the base of FP-3C cracked when opening the valve. The fire hydrant was shut down and the access cabinet was tagged out.
- Concrete 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. And pavement cracking was evident throughout the entire area, although most of the pavement cracking could be pre-existing conditions due the age and use of the facility.
- Flow into the basement sump of the Turbine Building from the building floor drain system is occurring and has a recorded history dating back to 1997.
- Settlement of a column in the Maintenance Building, north of the Turbine Building, has been documented. The Turbine Building and the Maintenance Building are west of the corridor and associated utility alignments within the corridor.
- The fire hydrant located in FP-3E was being tested on September 13, 2011, during site investigations. No operational problems were observed during the time on site.

- OPPD operation personnel, testing the fire hydrant at FP-3E, were questioned about other fire hydrant tests. The OPPD employee questioned noted that no problems were observed for the fire hydrant at FP-3D during testing. The information on the problem at FP-3C, noted previously, was gathered at this time.

5.19.3 Assessment Methods and Procedures

5.19.3.1 Assessment Procedures Accomplished

Assessments were made by walking the cable bank alignment and observing surface features of the system (manholes) and the ground surface overlying the underground cable bank. The surface assessment included using a 4-ft-long, 0.5-in.-diameter, steel-tipped fiberglass T-handle soil probe to hand probe the ground surface along the utility alignments and adjacent areas to determine relative soil strength. The assessment focused on identifying conditions indicative of potential flood-related impacts or damage to the utility as follows:

- Ground surface conditions overlying and immediately adjacent to the utility and its backfilled trench including scour, subsidence or settlement, lateral spreading, piping, and heave.
- Soft ground surface areas (native soil, engineered fill, or limestone gravel pavement) as determined by probing.
- Water accumulations and flows in subsurface system components (manholes and concrete cable encasement pipes).
- Damage to at-grade or above-grade system features and equipment.
- Variance from normal installation conditions including settled, tilted, or heaved system features and equipment.
- 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 were observed. These included the following non-invasive geophysical and geotechnical investigations.

- GPR. (Test reports were not available at the time of Revision 0.)
- Seismic surveys (seismic refraction and refraction micro-tremor). (Test reports were not available at the time of Revision 0.)
- Geotechnical investigations including test borings with field tests (SPT and CPT) and laboratory tests. Note that OPPD required vacuum excavation for the first 10 ft of proposed test holes to avoid utility conflicts. Test reports will, therefore, not address soil conditions in the upper 10 ft of site and locations where shallow utilities exist. (Test reports were not available at the time of Revision 0.)

5.19.3.2 Assessment Procedures Not Completed

Assessments of the Underground Cable Bank, Auxiliary Building to Intake Structure, that were not completed include the following:

- The interior of underground cable bank manholes and connecting concrete-encased cable pipes in the Protected Area were not inspected except for visual observations that were possible from above and behind temporary safety railings. Manholes are a confined space as defined by OSHA regulations. In accordance with these regulations and OPPD FCS safety procedures, manhole entry is a permit-required confined space entry and can only be performed by appropriately trained OPPD personnel.

- No excavation to inspect underground systems and conditions was performed.
- No camera inspection of the system was completed.

5.19.4 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. 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 results of available geotechnical, geophysical, and survey data were analyzed, a number of CPFMs were ruled out as discussed in Section 5.19.4.1. The CPFMs carried forward for detailed assessment are discussed in Section 5.19.4.2.

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

All of 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

CPFM 2c – Undermined buried utilities

<u>Reason for ruling out:</u>

- No surface erosion was observed along the ground surface overlying the alignment of the Main Underground Cable Bank. In addition, only localized and limited surface erosion was observed on the ground surface across the facility. The Main Underground Cable Bank system is constructed at depths ranging from about 5 to 11 ft below existing ground surface and sufficiently below potential scour depths indicated by erosion features observed in other areas.

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

<u>Reason for ruling out:</u>

- Soil supporting and surrounding the Main Underground Cable Bank system has been previously wetted. The peak flood elevation prior to 2011 was 1003.3 ft, which occurred in 1993.

Triggering Mechanism 10 – Machine/Vibration-Induced Liquefaction

CPFM 10a – Cracked slab, differential settlement of shallow foundation, loss of structural support
CPFM 10b – Displaced structure/broken connections
CPFM 10c – Additional lateral force on below-grade walls

Reasons for ruling out:

- Machine vibrations from the facility (turbine and various pumps) have historically occurred and no indications of these CPFMs are evident.
- Pumps used on site during the flood event were insufficient to cause ground or structure vibrations sufficient to initiate soil liquefaction. Visible indications of liquefaction were not observed around the areas where the pumps were operating and no occurrences of liquefaction were reported to HDR.
- No structure movements indicative of soil liquefaction and resultant settlement were observed; no structure cracking, or lateral movements, were observed.

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

Reasons for ruling out:

- The structures showed no signs of distress at the time of field assessments.
- Liquefaction was not observed at the site.

Triggering Mechanism 13 – Submergence

CPFM 13a – Corrosion of underground utilities

Reason for ruling out:

- Underground utilities and structures are located below the design flood elevation for the facility. Groundwater elevations controlled by Missouri River water elevations, percolation of storm precipitation, and winter snow melt would be expected to contact underground improvements including constructed steel and concrete facility elements. As such, steel and concrete site improvements are designed to withstand the corrosive environment of groundwater and wetted soil.

Triggering Mechanism 14 – Frost Effects

CPFM 14a – Heaving, crushing, or displacement

Reasons for ruling out:

- Utility not adversely affected due to frost heave as long as joints remain tight.
- Manholes are founded below frost level and should not heave.
- Conditions have not been changed due to flood conditions.

5.19.4.2 Detailed Assessment of Credible Potential Failure Modes

The following CPFMs are the only CPFMs carried forward for detailed assessment for the Underground Cable Bank Inside the PA 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)

CPFM 3c – Undermined buried utilities (due to pumping)

The Triggering Mechanism and CPFMs could occur as follows: multiple potentially connected seepage paths existed in the soil backfill at the site, including soil backfill in utility trenches, granular trench bedding, building floor drains with open/broken joints, and pre-existing defects/voids under pavement. The paths are exposed at some locations to the river floodwaters (e.g., a hole in the ground north of the Security building). This network of seepage paths is connected to several pumping sources: the sump pit in the Turbine Building, Manhole MH-5, and a series of surface pumps along the interior of the Aqua Dam perimeter. The pumps were operated for an extended period of time, maintaining a head differential on the seepage path networks. Gradient was sufficient to begin erosion of surrounding soil. Seepage is unfiltered and erosion continues unarrested. Erosion extends out, intercepting the network of utility trenches, including the Underground Cable Bank. Voids are created under the pavement and along the utility trench walls. The potential damage includes settlement of cable bank and manholes causing a loss of electrical connectivity.

Following are field observations and data that support the likelihood of these CPFMs:

- MH-5 was pumped for the duration of flooding to remove water entering into the manhole. Known water sources included ducts from MH-31 and ducts running to the Auxiliary Building. This created a head differential.
- The flow of water into MH-5 was observed on multiple field visits. Sources of the water were not documented.
- Sediment deposits (and fish) were observed in the bottom the MH-5 when it was emptied on September 14, 2011. The sediment could be an indication of piping and subsurface erosion.
- The area inside the Aqua Dam perimeter was pumped dry and created a hydrostatic head condition between the area inside and the area outside of the Aqua Dam. The area inside the Aqua Dam perimeter was pumped from several locations creating points toward which underground piping and subsurface flows would tend to flow.
- A void area and potential piping location was observed beneath the concrete slab just north of the Security Building and east-southeast of MH-5.
- Based on a conversation with the OPPD operations employee testing FP-3E on September 13, 2011, fire hydrant FP-3C, located northeast of the Security Building, was tested that day and failed. According to the OPPD operations employee, when opening the valve to test the hydrant, the base cracked and leaked and the valve had to be closed. The access cabinet was tagged out for repair at that time.
- Pavement distress was observed along the driveway corridor between the Intake Structure and the Service Building. The area north of where the duct bank crosses the corridor includes observed slab settlement and undermining (as evidenced by hollow-sounding pavement areas).

- The Turbine Building sump pit was pumped continually during the flood event. The five pipes connected to this sump pit are floor drain and condensate system flush drain pipes. Since this is a floor drain system, no infiltration of groundwater should occur in the system. The infiltration of groundwater into the system indicates an open flow path of some sort.

Below are field observations and data that indicate these CPFMs are unlikely:

- Sediment and fish were observed in the bottom of MH-5 when it was emptied on September 14, 2011. Sediment accumulations and small fish at the bottom of MH-5 might not be associated with these CPFMs. The manhole was uncovered when the Aqua Dam failed and the area was inundated. Sediment and fish could have been transported into the manhole with floodwaters.
- The observed hole in the pavement, north of the Security Building, could have been developed by outflow from the surface pumps and might not be associated with these CPFMs. Temporary surface pumps were pumping water back into the river with hoses placed over the Aqua Dam. One of the discharge points was near the observed hole. Concentrated discharge flow might have eroded pavement and created the observed hole.
- Subsurface erosion paths are limited between the Intake Structure and the Service Building. The top of the Circulation Tunnel extends to el. 1002.5 ft. Pavement grades in the area are in the range of ±1004 ft. Thus, for a large section of the corridor between the Intake Structure and Service Building, the only possible subsurface flow path is directly beneath the pavement slab.
- Any void spaces created by subsurface erosion will have to be significant to create conditions to cause the duct bank to fail.
- Observed subsurface damage indicators or known instances of damage in the corridor are not located immediately adjacent to the Main Underground Duct Bank.

Data Gaps (data still required to assess these CPFMs):

- GPR Data (Task completed, awaiting reports). The occurrence and extent of subsurface erosion is not known at this time.
- Seismic Survey - refraction/tomography and refraction microtremo.

The following table describes observed distress indicators and factors that would increase the risk associated with these CPFMs and factors that would make these CPFMs less likely.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
A hole in the pavement with a void space underneath was observed north of the Security Building and east of MH-5. This location was outside the Aqua Dam perimeter and might be a void developed due to subsurface erosion.	Alternatively, the observed hole could have been developed by outflow from the surface pumps and might not be associated with these CPFMs. Temporary surface pumps were pumping water back over the Aqua Dam. One of the pump discharge points was near the observed hole (see photo). Concentrated discharge flow could have created the observed hole.
MH-5 was pumped continually during the time the site was flooded.	

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
Monitoring well data seems to indicate a cone of influence around the facility that might be attributable to the subsurface drainage flowing to the Turbine Building sump	
Data Gaps: • Ground Penetrating Radar data are not available at the time of Revision 0 to assist in determining possible void areas at the facility.	

Conclusion

<u>Significance</u>

Potential for Degradation/Direct Floodwater Impact

MH-5 was continually pumped during the flood event and created a point of head differential that created a potential direct path along the electrical duct bank for subsurface erosion. In addition, areas of pavement distress were observed in the corridor between the Intake Structure and the Service Building that might be tied to MH-5 pumping. Thus, a direct potential source for subsurface erosion is linked to the system and potential indicators of subsurface erosion are located in the region of the duct bank alignment.

The Turbine Building sump, reference Key Distress Indicator 4.1, also creates a potential subsurface erosion path that could affect the electrical bank where it is located closest to the facility. Groundwater monitoring well readings seem to indicate that there is a zone of influence that can be attributed to drawdown from a deep source such as the Turbine Building sump. Due to high groundwater conditions, high head conditions created the potential for increased subsurface erosion to points of zero pressure (i.e., pumped locations) during the 2011 flood event.

The potential for degradation is considered high.

Implication

The underground cable bank is a structural entity. The cables in the duct bank are flexible and some minor deflection can be tolerated. Small signs of distress due to this CPFM might be noticeable to experienced OPPD employees who work installing cables. A large-scale failure of the duct bank and shearing of the cables would likely only be possible in the case of a very large void. Large underground voids usually present surface indications of underground distress. Therefore, the implication of degradation for these CPFMs is low.

<u>Confidence</u>

Information on the duct bank is limited to inspection information gathered from observations made along the duct bank alignment and visual observations made through the top of MH-5 and MH-31. Detailed information was not available from an inside inspection of the manholes or from information provided by OPPD employees. Therefore, the confidence in the above assessment is low. "Low Confidence" indicates that additional information and studies are required to increase the confidence in the above findings.

<u>Summary</u>

For CPFMs 3a and 3c, as discussed above, the combined consideration of the potential for degradation and the implications of that degradation to the system puts it in the "significant" category. As discussed, the potential for degradation is composed of two parts. The potential for subsurface erosion appears to be high based on flood-induced conditions and data regarding the Turbine Building sump and MH-5. However, the potential for subsurface erosion impacting the underground duct bank to a point of failure without visible signs of distress prior to failure of the system appear to be low. 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 inspections might be necessary to draw a conclusion.

Triggering Mechanism 3 – Subsurface Erosion/Piping

CPFM 3d – Undermining and settlement of shallow foundation/slab (due to river drawdown)

CPFM 3f – Undermined buried utilities (due to river drawdown)

This CPFM is similar to CPFMs 3a and 3c, but instead of pumping, the gradient is created by rapidly receding river level.

The Triggering Mechanism and CPFMs could then occur as follows: river level drops faster than pore water pressure in the soil/foundation can dissipate. A gradient is created that moves water and soil into existing defects and enlarges voids along the cable bank and through the soil toward the river via piping features or networks. Other consequences include damage to adjacent structures such as fire protection piping, raw water piping, and the Trenwa.

Field observations and data that support the likelihood of these CPFMs are as follows:

- Field observation of the river bank has not been completed since the river release rate stabilized at 40,000 cfs at FCS on October 4, 2011. The nearest utility installations have not been observed on a regular basis to inspect for developing conditions or distress indicators.

Field observations and data on site conditions that indicate this CPFM is unlikely are as follows:

- 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 the FCS on October 4, 2011.
- The Main Underground Cable Bank is offset from the river bank. This offset reduces the likelihood that rapid drawdown and related subsurface piping to the river bank will impact the Main Underground Cable Bank.
- Soils in the area of the Main Underground Cable Bank and to the east are backfill materials that were placed and compacted during construction of site improvements and, therefore, would be expected to be less susceptible to rapid drawdown impacts.
- Void spaces created by subsurface erosion would have to be significant to create conditions to cause the duct bank to fail.

Data Gaps (data have yet to be acquired to assess these CPFMs):

- Inspection of the riverbank following drawdown to normal river elevations.
- Geophysical surveys (GPR, seismic refraction and refraction micro-tremor) in the protected area. (Test reports were not available at the time of Revision 0.)
- Geotechnical test borings in the protected area. 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.)

The following table describes observed distress indicators and factors that would increase the risk associated with these CPFMs and factors that would make these CPFMs less likely.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
Floodwaters inundated the site for an extended period of time and totally saturated site soils.	The existing river bank is protect and armored. No history of river bank failure has been noted at the site due to past flood events.
	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 the FCS on October 4, 2011.
Data Gaps: • Inspection of the riverbank following drawdown to normal river elevations	

Conclusion

<u>Significance</u>

Potential for Degradation/Direct Floodwater Impact

The nearest installation of the Main Underground Cable Bank system to the river bank is MH-31 located at the southwest corner of the Intake Structure. The structure is located on the west side of the structure and a direct connection from the manhole to the river bank is not possible.

The river bank is armored and has historically protected and stabilized the existing river bank. The potential for degradation is reduced due to these improvements.

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 the FCS on October 4, 2011. Groundwater levels had thus started to stabilize between the termination of drawdown reduction and the time of Revision 0. The potential for development of subsurface erosion due to river drawdown decreases with the time due to stabilization between groundwater elevations and river elevations. The potential for this CPFM thus decreases with time as long as subsurface erosion has not instigated and created a flow path that will be subject to future impacts.

As groundwater elevations and river elevations stabilize, the head potential between the two conditions will decrease and the possibility of subsurface erosion will also decrease correspondingly. In addition, the stabilized river embankment reduces the likelihood of these CPFMs.

Overall, the potential for degradation is considered low for these CPFMs.

Implication

The underground cable bank is a structural entity. The cables in the duct bank are flexible and some minor deflection can be tolerated. Small signs of distress due to this CPFM might be noticeable to experienced OPPD employees who work installing cables. A large-scale failure of the duct bank and shearing of the cables would likely only be possible in the case of a very large void. Large underground voids usually present surface indications of underground distress. Therefore, the implication of degradation for these CPFMs is low.

Confidence

Data are not available to make a determination on subsurface erosion due to river drawdown. Time between the termination of the steady reduction of dam release rates and the most current time without indications of subsurface erosion does not decrease the likelihood that damage is not present. Thus, confidence with the assessment is low.

Summary

For CPFMs 3d and 3f, as discussed above, the combined consideration of the potential for degradation and the implications of that degradation to the system put it in the "not significant" category. As discussed, the potential for degradation is considered low because the potential for highly elevated groundwater elevations versus river elevations is unlikely due to stabilized river levels, structural soil backfill on the site, and the protected nature of the existing bank. 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 make a final assessment.

Triggering Mechanism 4 – Hydrostatic Lateral Loading (water loading on structures)

CPFM 4c – Wall failure in flexure
CPFM 4d – Wall failure in shear
CPFM 4e – Excess deflection

The Triggering Mechanism and CPFMs could occur as follows: water level rises and imposes additional unbalanced lateral pressure on manhole walls exceeding shear or flexure capacity of the wall and/or causing excessive deflection or failure. Alternatively, the wall transfers load to supporting elements, overloading them. The supporting elements fail allowing below-grade walls to fail. These CPFMs are credible only for possible degradation to manhole MH-5. The remainder of the system is non-structural (a poured concrete encasement with no walls, floors, or roof structures) or was not exposed to hydrostatic loading beyond design standards (MH-31 was flooded and therefore balanced as regards hydrostatic loading).

Following are field observations and data that support the likelihood of these CPFMs:

- MH-5 was pumped for the duration of flooding to remove water coming in from duct banks extending between the Auxiliary Building and MH-31. Floodwaters outside the Aqua Dam perimeter were above grade and possibly created a hydraulic head condition greater than the design standard for underground structures (i.e., hydraulic loading to the ground surface).

Following are field observations and data that indicate these CPFMs are unlikely:

- No movement or distress of MH-5 concrete cover was observed.
- After pumping MH-5 dry on September 14, 2011, no visible water inflow was noted over a 1 hour and 10 minute time period.

Following are observations and data still required to assess these CPFMs:

- Visual inspection and photographs of the inside of MH-5.
- Visual inspection of the inside of MH-31 was not made. Insulation on the sides of the manhole prevents access and visual inspection.
- Basis of design/design assumptions for the manhole vault.

The following table describes observed distress indicators and factors that would increase the risk associated with these CPFMs and factors that would make these CPFMs less likely.

Adverse (Degradation/Direct Floodwater Impact More Likely)	**Favorable (Degradation/Direct Floodwater Impact Less Likely)**
MH-5 was continually pumped.	Manhole structures and underground utilities are designed for groundwater conditions and forces.
Ground was saturated when the Aqua Dam was in place	No leakage was noted after observing MH-5 get pumped dry with high groundwater conditions still existing.
Data Gaps: • Visual inspection and photographs of the inside of MH-5 • Visual inspection of the inside of MH-31	

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

Indicators for initiation of CPFMs 4c, 4d, and 4e on only the MH-5 element of the Main Underground Cable Bank have been observed. These include continual pumping from manhole MH-5 and floodwater elevations above the ground surface outside the Aqua Dam perimeter, resulting in hydraulic head conditions greater than the design standard for MH-5. However, MH-5 is designed for high groundwater conditions and forces. The possible additional forces related to about 3 ft of additional head from floodwaters outside the Aqua Dam perimeter are not believed to be sufficient to cause degradation of MH-5 due to these CPFMs. In addition, following pumping MH-5 dry on September 14, 2011, no visible water inflow was noted over a 1 hour and 10 minute time period. Therefore, the potential for degradation to the Main Underground Cable Bank system due to CPFMs 4c, 4d, and 4e is low.

Implication

As stated, a couple of CPFM 4c, 4d, and 4e indicators have been observed supporting low (or unlikely) potential for degradation to the MH-5 element of the Main Underground Cable Bank system. The occurrence of CPFMs 4c, 4d, and 4e on a large scale could result in degradation of MH-5 including wall failure in flexure, shear, or deflection. For degradation from these CPFMs to impact service (i.e., damage that renders electrical cables carried by the system inoperable), degradation would need to result in complete failure of supporting elements of MH-5 and this is not deemed likely. Therefore, the implication of degradation for these CPFMs is low.

Confidence

Currently, evidence supporting possible degradation of the MH-5 element of the Main Underground Cable Bank system is based on possible forces that are not supported by visual observations of physical site conditions as discussed above. Geophysical reports including information obtained through geophysical surveys completed at or in the vicinity of the MH-5 element of the Main Underground Cable Bank system were not available at the time of Revision 0. Therefore, the confidence in the above assessment is low. "Low Confidence" indicates that additional information and studies are required to increase the confidence in the above findings.

Summary

For CPFMs 4c, 4d, and 4e, as discussed above, the combined consideration of the potential for degradation and the implications of that degradation to the system puts it in the "not significant" category. The data currently collected are not sufficient to rule out or confirm these CPFMs and more data or continued monitoring and inspections might be necessary to draw a conclusion.

Triggering Mechanism 6 – Buoyancy, Uplift Forces on Structures

CPFM 6b – Cracked slab, loss of structural support

CPFM 6c – Displaced structure/broken connections

The Triggering Mechanism and CPFMs could occur as follows: water level rises and water is pumped from MH-5 causing an uplift force. This uplift force exceeds the weight of the structure, causing structure slabs to crack and buckle. Additional damage could include structure displacement and broken utility connections.

Following are field observations and data that support the likelihood of these CPFMs:

- MH-5 was pumped for the duration of flooding to remove water coming in from duct banks extending between the Auxiliary Building and MH-31 and possible other sources. This created a head differential.
- Water levels outside the Aqua Dam perimeter created hydrostatic uplift forces on MH-5 while it was being pumped that were potentially greater than the hydrostatic forces that the manhole was designed to resist.

Following are field observations and data that indicate these CPFMs are unlikely:

- No movement or distress of MH-5 concrete cover was observed.
- After MH-5 was emptied, observations were made to determine if inflow of water could be observed. No drainage into the manhole was observed during the initial 15 minutes after the manhole was emptied. Approximately 1 hour later, no additional water accumulation was observed.

Following are observations and data still required to assess these CPFMs:

- Visual inspection and photographs of the inside MH-5.
- Visual inspection of the inside of MH-31 was not and cannot be made. Insulation on the sides of the manhole prevents access and visual inspection.
- Basis of design data for the system are unknown.

The following table describes observed distress indicators and factors that would increase the risk associated with these CPFMs and factors that would make these CPFMs less likely.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
	No indications of upward displacement were observed in the field.
	A steel pipe extension above the manhole access opening and stacked sandbags around the manhole extension added ballast to the top of the structure that offset the affects of increased buoyancy on the structure.
Data Gaps: • Visual inspection and photographs of the inside of MH-5 • Visual inspection of the inside of MH-31	

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

MH-5 was located inside the Aqua Dam perimeter and was pumped continually during the flood event. High water levels existed outside the Aqua Dam perimeter, creating a hydraulic head condition. Paving in the corridor within the Aqua Dam perimeter created a barrier that prevented the water from equalizing on the inside of the Aqua Dam. The confined water potentially transmitted uplift forces to structures in the area inside of the Aqua Dam perimeter including MH-5 which was pumped during the same time as the high hydrostatic forces. The potential for degradation due to flood conditions was increased above design norms. The potential for buoyancy forces and chances of degradation was offset by the weight of sandbags and other materials on top of the manhole. Overall, the potential for degradation is considered low for these CPFMs.

Implication

Underground structures are normally designed for groundwater conditions and will experience buoyancy forces. In addition, sandbag installation on top of MH-5and a pipe extension connected to the manhole opening that extended above the hydrostatic head conditions helped weigh down the structure and offset buoyancy induced by flood conditions. No indications of movement or distress were noted from surface observations. Since groundwater levels have dropped with river drawdown, the implication of degradation related to these CPFMs occurring is considered low.

Confidence

As discussed, the potential for degradation is considered low because the potential for impacts due to buoyancy is no longer a factor. Since no apparent distress was noted and none is expected due to the groundwater elevations at the present time, confidence in our assessment results is high.

Summary

For CPFMs 6b and 6c, as discussed above, the combined consideration of the potential for degradation and the implications of that degradation to the system puts it in the "not significant" category. As discussed, the potential for degradation is considered low because the potential for buoyancy impacts from flood conditions no longer exists. Our confidence in the above assessment is high.

Triggering Mechanism 12 – Rapid Drawdown

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

CPFM 12b – Lateral spreading

The Triggering Mechanism and CPFMs could occur as follows: the river level drops faster than pore water pressure in the soil can dissipate. The saturated soil is elevated above the dropping river level. The sloped bank of the river provides no lateral pressure support for the saturated soil. At some point there is insufficient support on the river side to support the saturated soils. At that point, the soils experience slope movements or even failure. Generally, slope failures associated with rapid drawdown are relatively localized and shallow in nature; however, deeper failures can occur.

The river stage level has receded and stabilized at a level corresponding to the nominal normal river level at 40,000 cfs as of October 4, 2011. At the time of Revision 0, the groundwater levels had not yet stabilized to nominal normal levels. Therefore, it is possible that new distress indicators could still develop. Field observation of the river bank area has not been performed since the river level has dropped.

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 Underground Cable Bank, Auxiliary Building to Intake Structure.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
The Main Underground Cable Bank is in close proximity to the river.	No distress was observed at the time of HDR's site inspection.
Elevated saturated soils and elevated flood levels provided a water source.	

Data Gaps:

- Observations of the riverbank following drawdown to nominal normal river elevations.
- Geophysical investigation data to address any observed concerns.
- Inclinometer readings which that will provide an indication of slope movement.

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

The river stage level has receded and stabilized at a level corresponding to the nominal normal river level at 40,000 cfs as of October 4, 2011. Rapid drawdown has been controlled and continued river drawdown is not expected to occur at a rate that would initiate this CPFM. The potential for degradation for this CPFM is considered low.

Implication

The occurrence of this CPFM on a large scale could negatively impact the integrity of the cables in the trench. No distress has been observed during our inspections, however. Therefore, the implication of the potential degradation for this CPFM is low.

Confidence

Although no distress has been observed to date, the river bank has not been inspected for signs of degradation and slope failure. Therefore, the confidence for this CPFM is low.

Summary

For CPFMs 12a and 12b, 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 "not significant" category. The river bank has not been inspected for signs of degradation and slope failure, therefore we cannot rule out this CPFM and the confidence is low, which means continued monitoring and inspections might be necessary to draw a conclusion.

5.19.5 Results and Conclusions

The CPFMs evaluated for the Main Underground Cable Bank, Auxiliary Building to Intake Structure 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**	CPFM 3a CPFM 3c	
Potential for Failure **Not Significant**	CPFM 3d CPFM 3f CPFM 4c CPFM 4d CPFM 4e CPFM 12a CPFM 12b	CPFM 6b CPFM 6c

5.19.6 Recommended Actions

Certain actions are recommended for the Main Underground Cable Bank, Auxiliary Building to MH-3T to address CPFMs 3a, 3c, 3d, 3f, 4c, 4d, 4e, 6a, and 6b. These actions are discussed, separately as appropriate, in the following paragraphs.

Actions to address CPFMs 3a, 3c, 3d, and 3f:

- Further forensic investigations and physical modifications are recommended to address CPFMs 3a and 3c for the Main Underground Cable Bank. These CPFMs are associated with unfiltered flow of groundwater into the Turbine Building basement drain piping system (Key Distress Indicator #1). These recommendations are described in detail in Section 4.1.
- CPFM 3a, 3c, 3d, and 3f are associated with the distress in and near the Paved Access Area between the Service Building and the Intake Structure (Key Distress Indicator #2). These recommendations are described in detail in Section 4.2.

Actions to address CPFMs listed:

- Continued monitoring is recommended to include a continuation of the elevation surveys of the previously identified targets on this structure and surrounding the site. The purpose is to monitor for signs of structure distress and movement or changes in soil conditions around the structure. The results of this monitoring will be used to increase the confidence in the assessment results. Elevation surveys should be performed weekly for 4 weeks and biweekly until December 31, 2011. At the time of Revision 0, groundwater levels had not yet stabilized to nominal normal levels. Therefore, it is possible that new distress indicators could still develop. If new distress indicators are observed before December 31, 2011, appropriate HDR personnel should be notified immediately to determine whether an immediate inspection or assessment should be conducted. Observation of new distress indicators might result in a modification of the recommendations for this structure.

- Inspect the interior of MH-5, including walls, floor, cover, joints, and duct bank penetrations. Obtain photographic record of conditions.
- Inspect the interior of MH-31 as practical.
- Have OPPD initiate a procedure to monitor for problems during cable pulling operations. Unusual/non-typical conditions encountered or noted during cable pulling operations should be documented, reported, and evaluated for additional investigation, as appropriate (i.e., if strong resistance is encountered during cable pulling, then consider video camera inspection of the problem and adjacent ducts.)
- Perform a detailed analysis of the pavement subgrade and trench alignments if the pavement in the corridor between the Intake Structure and the Service Building is replaced.
- Perform detailed geophysical analysis (GPR and/or seismic surveys) of the system subgrade and trench alignments if failure is suspected or if adjacent/nearby site improvements indicate failure due to subsurface erosion or piping.
- Review geophysical and geotechnical reports to evaluate the data as they pertain to the Underground Cable Bank.
- Observe the river bank for signs of degradation and slope failure.

5.19.7 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.

5.19.7.1 Additional Data Available

The following additional data were available for the Main Underground Cable Bank 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 falling weight deflectometer investigation by American Engineering Testing, Inc. (see Attachment 6).
- Results of geophysical investigation by Geotechnology, Inc. (see Attachment 6).
- Results of geotechnical investigation by Thiele Geotech, Inc. (see Attachment 6).
- Data obtained from inclinometers by Thiele Geotech, Inc. (see Attachment 6).

- Results of continued survey by Lamp Rynearson and Associates (see Attachment 6).
- Inspection reports for MH-5 and MH-31.

5.19.7.2 Additional Analysis

The following analysis of additional data was conducted for the Main Underground Cable Bank:

- 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 falling weight deflectometer investigation by American Engineering Testing, Inc.

  Falling Weight Deflectometer 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, Inc.

  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, Inc.

  Six test borings were drilled with continuous sampling of the soil encountered, to ground truth the Geotechnology, Inc. 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 feet 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 Lamp Rynearson and Associates.

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.

- Results of Inspection report by OPPD for MH-5:

  The results of the inspection indicate no apparent damages caused by 2011 flooding.

- Results of Inspection report by OPPD for MH-31 (OPPD CR 2011-8477):

  Pictures of exposed concrete surfaces did not show indications of significant cracks or damage to the concrete walls and floor. Steel conduit support framing members were extremely corroded. The corrosion damage was generated of years and was not related to the 2011 flood.

Triggering Mechanism 3 – Subsurface Erosion/Piping

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

CPFM 3c – Undermined buried utilities (due to pumping)

<u>Significance</u>

Potential for Degradation/Direct Floodwater Impact

Except for Turbine Building sump, conditions inductive to subsurface erosion no longer exist due to present site and flood conditions. Site pumping sources have been removed and high groundwater conditions no longer exist. The potential for this CPFM to occur only exists in conjunction with KDI#1. Some conditions produced by subsurface erosion might still exist from site pumping sources. Areas identified by forensic investigations with indications of subsoil or subsurface issues have been addressed for further investigation and repair as necessary. Recommended actions in conjunction with KDI#2 address a majority of the areas in question as part of the "Paved Access Area." Therefore, with known issues being addressed and further investigated by OPPD, the implication of the potential degradation due to this CPFM is low.

Implication

The underground cable bank is a structural entity. The cables in the duct bank are flexible and some minor deflection can be tolerated. Small signs of distress due to this CPFM might be noticeable to experienced OPPD employees who work installing cables. A large-scale failure of the duct bank and shearing of the cables would likely only be possible in the case of a very large void. Large underground voids usually present surface indications of underground distress. Therefore, the implication is low.

<u>Confidence</u>

With investigations and repairs associated with KDI #1 and #2 handling known issues, and contingencies for expanding investigations and repairs as needed and directed by geotechnical inspectors, confidence in addressing issues associated with this CPFM is high.

Summary

Forensic test results received since the issuance of the Rev 0 report have narrowed and defined probable areas impacted by this CPFM. Recommended actions associated with the results of the forensic reports and site inspections will address known problem areas and allow the direction and expansion of proposed investigations or repairs as necessary. The combined consideration of the potential for degradation and the implications to that structure or system puts it in the "not-significant" category.

Triggering Mechanism 3 – Subsurface Erosion/Piping

CPFM 3d – Undermining and settlement of shallow foundation/slab (due to river drawdown)

CPFM 3f – Undermined buried utilities (due to river drawdown)

Significance

Potential for Degradation/Direct Floodwater Impact

Based on groundwater monitoring data taken in conjunction with river drawdown and on a continuing weekly basis, groundwater levels have been dropping at a rate that closely follows the river drawdown rate. Thus, the differential head necessary to create subsurface erosion due to river drawdown has not occurred. The area most conducive to create this CPFM is nearest the river. River bank inspections made since the issuance of the Rev 0 report show no indications of this CPFM. The "Paved Access Area between the Intake Structure and the Service Building" is the developed area nearest the river bank and includes most of the utility services that are critical to the operation of the facility. Recommended actions in association with KDI #2 will address issues that are encountered in the area. This will include instances of subsoil erosion that could have been induced (however unlikely) by river drawdown. The potential for degradation for this CPFM to occur is considered low.

Implication

The underground cable bank is a structural entity. The cables in the duct bank are flexible and some minor deflection can be tolerated. Small signs of distress due to this CPFM might be noticeable to experienced OPPD employees who work installing cables. A large-scale failure of the duct bank and shearing of the cables would likely only be possible in the case of a very large void. Large underground voids usually present surface indications of underground distress. Therefore, the implication is low.

Confidence

With groundwater data indicating the absence of a high head condition and the instigation of recommendations associated with KDI#2, confidence in the assessment associated with this CPFM is high.

Summary

Based on the above discussion items, the combined consideration of the potential for degradation and the implications to that structure or system puts it in the "not-significant category" in the assessment matrix.

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

Significance

Potential for Degradation/Direct Floodwater Impact

Based on groundwater monitoring data taken in conjunction with river drawdown and on a continuing weekly basis, groundwater levels have been dropping at a rate that closely follows the river drawdown rate. Thus, hydrostatic loading conditions due to the flood no longer exist and the structures are designed for normal groundwater conditions. The structure most susceptible to this CPFM would have been MH-5. From visual external inspection of the manhole, no indications of this CPFM were apparent. The potential for degradation due to this CPFM of having occurred is low since hydrostatic loads above those of standard design conditions were limited. The manhole is intact, appears structurally sound, and showed no signs of leakage at the time of previous inspections. Internal inspections of MH-5 did not reveal significant degradation due to the 2011 flood. Thus the potential for degradation due to this CPFM is considered low.

Implication

As stated, a couple of CPFM 4c, 4d, and 4e indicators have been observed supporting low (or unlikely) potential for degradation to the MH-5 element of the Main Underground Cable Bank system. The occurrence of CPFMs 4c, 4d, and 4e on a large scale could result in degradation of MH-5 including wall failure in flexure, shear, or deflection. For degradation from these CPFMs to impact service (i.e., damage that renders electrical cables carried by the system inoperable), degradation would need to result in complete failure of supporting elements of MH-5 and this is not deemed likely. Therefore, the implication of degradation for these CPFMs is low.

Confidence

Groundwater levels based on recent monitoring well readings are now down to an elevation near or below the base of MH-5. Confidence is high that no additional impacts due to flooding conditions will occur based on groundwater elevations and on inspections of MH-5 that indicate the structure is sound.

Summary

For CPFMs 4c through 4e, based on these discussion items, the combined consideration of the potential for degradation and the implications to that structure or system puts it in the "not-significant category" in the assessment matrix.

Triggering Mechanism 12 – Rapid Drawdown
CPFM 12a – River bank slope failure and undermining surrounding structures
CPFM 12b – Lateral spreading

The groundwater monitoring well data and river level data indicate that excess pore pressures due to river drawdown had generally dissipated by about October 14, 2011. Field observations of the River Bank on October 20, 2011, did not identify deformation of the River Bank that could be attributed to slope failure or lateral spreading. Therefore, neither slope failure nor lateral spreading occurred due to the 2011 flood.

5.19.7.3 Revised Results and Recommendations

The CPFMs evaluated for the Main Underground Cable Bank from the Auxiliary Building to the Intake Structure are presented in the following matrix, which shows the rating for the estimated significance and the level of confidence in the evaluation.

CPFMs 3a and 3c for the Main Underground Cable Bank from the Auxiliary Building to the Intake Structure are associated with Key Distress Indicator #1. Section 4.1 presents the results of additional forensic investigation that was conducted to ascertain whether these CPFMs 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 these CPFMs are ruled out. Therefore, assuming that no further concerns are identified through the monitoring program for the Main Underground Cable Bank from the Auxiliary Building to the Intake Structure (discussed in Section 5.19.6 and continuing until December 31, 2011), these CPFMs are moved to the quadrant of the matrix representing "No Further Action Recommended Related to the 2011 Flood."

CPFMs 3d and 3f for the Main Underground Cable Bank from the Auxiliary Building to the Intake Structure are associated with Key Distress Indicator #2. Section 4.2 presents the results of additional forensic investigation that was conducted to ascertain whether these CPFMs could be ruled out. The results of the additional forensic investigation show that these CPFMs are ruled out. Therefore, assuming that no further concerns are identified through the monitoring program for the Main Underground Cable Bank from the Auxiliary Building to the Intake Structure (discussed in Section 5.19.6 and continuing until December 31, 2011), these CPFMs are moved to the quadrant of the matrix representing "No Further Action Recommended Related to the 2011 Flood."

CPFMs 4c, 4d, and 4e for the Main Underground Cable Bank from the Auxiliary Building to the Intake Structure are not associated with Key Distress Indicators. Groundwater monitoring data have been gathered since the Revision 0 report and indicate groundwater levels have dropped below a level that can hydrostatically load the system and create these CPFMs. Impacts due to the effects of pumping and high hydrostatic head conditions were assessed by internal inspection of MH-5. The internal assessment of MH-5 found no indications of flood damage and the results of the additional forensic investigation show that these CPFMs are ruled out based on present site conditions. Therefore these CPFMs move to the quadrant of the matrix representing "No Further Action Recommended Related to the 2011 Flood."

CPFMs 12a and 12b for the Main Underground Cable Bank from the Auxiliary Building to the Intake Structure are not associated with Key Distress Indicators. River bank inspections have been made and groundwater monitoring data have been gathered since the Revision 0 report. The results of the additional forensic investigation show that these CPFMs are ruled out. Therefore, assuming that no further concerns are identified through the monitoring program for the Main Underground Cable Bank from the Auxiliary Building to the Intake Structure (discussed in Section 5.19.6 and continuing until December 31, 2011), these CPFMs 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**		
Potential for Failure **Not Significant**		CPFM 3a CPFM 3c CPFM 3d CPFM 3f CPFM 4c CPFM 4d CPFM 4e CPFM 6b CPFM 6c CPFM 12a CPFM 12b

5.19.7.4 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 Main Underground Cable Bank from the Auxiliary Building to the Intake Structure other than CPFMs 3a, 3c, 3d, 3f, 4c, 4d, 4e, 6b, 6c, 12a, and 12b had been ruled out prior to Revision 1, because CPFMs 4c, 4d, 4e, 6b, 6c, 12a, and 12b have been ruled out as a result of the Revision 1 findings, because CPFMs 3d and 3f were ruled out by the results of the KDI #2 investigations, and because CPFMs 3a and 3c will be ruled out when the physical modifications recommended for KDI #1 in Section 4.1 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Main Underground Cable Bank from the Auxiliary Building to the Intake Structure. 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.

Section 5.20

Meteorological Tower and Miscellaneous Structures

Omaha Public Power District

5.20 Meteorological Tower and Miscellaneous Structures

5.20.1 Summary of Meteorological Tower and Miscellaneous Structures

Baseline information for the Meteorological Tower and Miscellaneous Structures is provided in Section 2.0, Site History, Description, and Baseline Condition.

The Meteorological Tower is located to the far north of the owner-controlled property. The tower is a three-post truss tower extending 360 ft above grade. The base of the tower is supported at a single center point that is pinned to a 7-ft by 7-ft by 4-ft, 6-in.-deep spread footing that extends 4 ft below grade. Guy wires are used to support the tower against lateral loads. The tower is supported by multiple wires in three directions at 120° intervals. The tower is supported at seven vertical points by wires in each of the three directions. The top four wires extend to a deadman 290 ft from the base of the tower. The bottom three wires extend to a smaller deadman 145 ft from the base of the tower. The larger deadman is 8 ft by 6 ft by 4 ft deep and is located 4 ft below grade. The smaller deadman is 8 ft by 4 ft by 3-ft-deep and is located 4 ft below grade.

There is a weather tower Instrumentation Shelter located southeast of the Meteorological Tower. The building is about 11.3 ft by 11.3 ft and is constructed on a 6-in. concrete slab with a 1.5-ft thickened edge. The walls are constructed with approximately 0.7-ft masonry units.

5.20.2 Inputs/References Supporting the Analysis

Table 5.20-1 lists references provided by OPPD and other documents used to support HDR's analysis.

Table 5.20-1- References for Meteorological Tower and Miscellaneous Structures

Document Title	OPPD Document Number (if applicable)	Date	Page Number(s)
Location or 100 Meter Weather Tower ME-1	16957	Unknown	F-4000
110 Meter Weather Tower Electrical & Communication	16958	Unknown	F-4001
Model T-36 Series Section "20 ft"	22775	8/9/1971	C-036-020-012
Model T-36X Section	22774	8/24/1973	C-036-020-014
10ft Boom Mounting Detail	22776	3/26/1976	C-100-145-760326
Base and Anchor Details	22784	2/26/1976	D-100-036-760218-1
360ft T-36 Tower	22785	2/18/1976	D-100-036-760218
Plan & Details of Weather Tower Instrumentation Shelter	41304	Unknown	D-4685
Naval Facilities Engineering Command, Design Manual 7.01, Soil Mechanics		9/1986	All

Detailed site observations—field reports, field notes, and inspection checklists—for the Meteorological Tower and Miscellaneous Structures are provided in Attachment 8.

Observed performance and pertinent background data are as follows:

- Soils around the Meteorological Tower were found to be soft when probed with a fiberglass T-probe. It was possible to plunge the probe into the ground up to handle depth with little force.
- There is a large area north and west of the Meteorological Tower that is lower in elevation than the surrounding area and it still had standing water during observation.
- Several of the guy wire anchors are covered by a significant number of vines growing up the wires, or have small trees growing around the anchor locations. Vegetation appeared to have been present prior to flooding. The vines growing up the guy wires are well established and the trees that are growing are large, indicating that they have been growing for several years.
- There is a several-inch-thick layer of sediment covering the access road to the Meteorological Tower and Instrumentation Shelter; however, there was no observed damage to the road.
- The maximum surveyed flood elevation for the Meteorological Tower is not known; however, observation indicates the maximum depth was approximately 4.5 ft above existing grade at the Meteorological Tower. The maximum flood elevation at the Instrumentation Shelter was approximately 2.5 ft above finish floor.
- Observation inside the Instrumentation Shelter was not done due to large quantities of mold growing inside, visible through a window in the structure. No signs of structure distress were noted.
- Design drawings show the tops of the deadman anchors to be under [illegible] ft of fill. During the visual inspection, the grade was probed at the locations of the deadman anchors and one of the anchors was found to be only 2 ft under the soil. There were no signs of erosion in the area. Areas that were observed nearby have several inches of deposited sediment.
- There is fencing around the Meteorological Tower structure, excluding the guy anchor locations, and the Instrumentation Shelter. Information on the height of the fence is not available. However, based on observation, it is approximately 8 ft tall with three strands of barbed wire at the top. Minimal debris was deposited around the base of the fencing.

5.20.3 Assessment Methods and Procedures

5.20.3.1 Assessment Procedures Accomplished

Assessments of the Meteorological Tower and Miscellaneous Structures include the following:

- The Meteorological Tower, Instrumentation Shelter, and surrounding grades were visually inspected in September 2011 for signs of distress.
- A review of as-built plans and geotechnical reports to determine possible weak points in the construction that could be affected by the flood.
- Probe of surrounding grade to determine softness and consistency of soils near the structures.

5.20.3.2 Assessment Procedures Not Completed

Assessments of the Meteorological Tower and Miscellaneous Structures that were not completed include the following:

- A review of survey data to-date for indications of trends in the movement of structures. Requested survey information for the Meteorological Tower is not yet available.

5.20.4 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. 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 results of available geotechnical, geophysical, and survey data were analyzed, a number of CPFMs were ruled out as discussed in Section 5.20.4.1. The CPFMs carried forward for detailed assessment is discussed in Section 5.20.4.2.

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

The ruled-out CPFMs are 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

<u>Reason for ruling out:</u>

- No surface erosion was visible during the inspection. Several inches of deposited sediment were observed in surrounding areas.

Triggering Mechanism 3 – Subsurface Erosion/Piping
CPFM 3a – Undermining and settlement of shallow foundation/slab/surfaces (due to pumping)

<u>Reason for ruling out:</u>

- The structures were not pumped, nor were they near pumping.

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

<u>Reasons for ruling out:</u>

- Flows and velocities in the area observed were small, which is supported by the lack of scouring. Sediment deposits several inches thick were observed on top of the pavement surrounding the Meteorological Tower and the Instrumentation Shelter. No damage from debris was observed. The Meteorological Tower, excluding the guy anchor locations, and the Instrumentation Shelter are surrounded by fencing that protected them from moving objects. A minimal amount of debris was observed around the fencing.

- The Meteorological Tower and Instrumentation Shelter are no longer inundated and no signs of distress have been observed.

Triggering Mechanism 10 – Machine/Vibration-Induced Liquefaction
CPFM 10a – Cracked slab, differential settlement of shallow foundation, loss of structural support

Reason for ruling out:

- Permanent equipment or temporary equipment that has the capacity to produce significant dynamic forces due to vibration was not operated near the Meteorological Tower or Instrumentation Shelter during a saturated condition. During inspection, the vehicle being used was not observed to cause liquefaction.

Triggering Mechanism 10 – Machine/Vibration-Induced Liquefaction
CPFM 10b – Displaced structure/broken connections

Reason for ruling out:

- Permanent equipment or temporary equipment that has the capacity to produce significant dynamic forces due to vibration was not operated near the Meteorological Tower or Instrumentation Shelter during a saturated condition. During inspection, the vehicle being used was not observed to cause liquefaction.

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

Reason for ruling out:

- Visual observations show no structure movement. Therefore, degradation that can be attributed to this CPFM did not occur near the Meteorological Tower.

Triggering Mechanism 12 – Rapid Drawdown
CPFM 12a – River bank slope failure and undermining surrounding structures

Reason for ruling out:

- Both structures are at a sufficient distance away from the river to not be influenced by this CPFM.

Triggering Mechanism 12 – Rapid Drawdown
CPFM 12b – Lateral spreading

Reason for ruling out:

- Power and signal cables used by the structures are at a sufficient distance away from the river to not be influenced by this CPFM.

Triggering Mechanism 13 – Submergence
CPFM 13b – Corrosion of structural elements

Reason for ruling out:

- The structures have not been subjected to a corrosive environment that would be considered beyond normal conditions. The structure has been in operation for more than 30 years and has been exposed to environmental conditions over this time.

Triggering Mechanism 14 – Frost Effects
CPFM 14a – Heaving, crushing, or displacement

Reasons for ruling out:

- The Meteorological Tower foundation is below frost depth.
- The Instrumentation Shelter is on a 6-in. concrete slab and is subject to heave from frost conditions. However, the conditions the Instrumentation Shelter will be subject to are not different than what would have occurred before the flood.

5.20.4.2 Detailed Assessment of Credible Potential Failure Modes

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

Triggering Mechanism 7 – Soil Collapse (first time wetting)
CPFM 7c – General site settlement

The Triggering Mechanism and CPFM could occur as follows: the soils become saturated, reducing the capability of the soil to provide passive pressure resistance. The overall capacity of the deadman anchor is reduced below the design capacity.

Soils around the Meteorological Tower were found to be soft when probed with a fiberglass T-probe. It was possible to plunge the probe into the ground up to handle depth with little force. Typical design practices for determining the capacity of the deadman anchors against the demand created by wind forces use passive soil pressures in conjunction with the self weight of the deadman and soil overburden pressures. The soft soils found around the site could reduce the passive pressure resistance of the soils due to loss of shear strength, resulting in a reduction in overall capacity of the deadman anchors.

This PFM does not apply to the Instrumentation Shelter.

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 Meteorological Tower.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
Soft soils around the deadman anchors.	
The Meteorological Tower design is a failure-critical structure.	
Data Gaps: • Design assumptions used for the passive pressure resistance for the deadman anchors are unknown due to detailed design information not being readily available. • Information on the soils from past geotechnical reports was not readily available except as discussed in the baseline information.	

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

Soft soil conditions were observed near the foundations which could reduce the passive pressure resistance of the soils and, in turn, reduce the capacity of the deadman anchors. Since the soils around the deadman anchors were saturated, the potential for degradation due to this CPFM is high.

Implication

The occurrence of this CPFM could negatively impact the capacity of the deadman anchors. This could lead to movement of the anchors and negatively impact the integrity or intended function of the Meteorological Tower. Therefore, the implications of the potential degradation for this CPFM are high.

Confidence

Design assumptions for the soils could not be compared with existing conditions; therefore, the data at hand are not sufficient to rule out this CPFM, or lead to a conclusion that physical modification must be done to ensure that the support for the Meteorological Tower is functioning as intended.

Summary

For CPFM 7c, as discussed above, the combined consideration of the potential for degradation and the implications of that degradation to the structure puts it in the "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 could be necessary to draw a conclusion.

5.20.5 Results and Conclusions

The CPFMs evaluated for the Meteorological Tower and Miscellaneous Structures 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	CPFM 7c	
Potential for Failure Not Significant		

5.20.6 Recommended Actions

The following actions are recommended for the Meteorological Tower and Miscellaneous Structures:

Given the Low Confidence Rating for this CPFM, continued monitoring is recommended to include elevation surveys on this structure. The purpose is to monitor for signs of structure distress and movement or changes in soil conditions around the building. The results of this monitoring will be used to increase the confidence in the assessment results. Elevation surveys should be performed weekly for 4 weeks and biweekly until December 31, 2011. At the time of Revision 0, groundwater levels had not yet stabilized to nominal levels. Therefore, it is possible that new distress indicators could still develop. If new distress indicators are observed before December 31, 2011, appropriate HDR personnel should be notified immediately to determine whether an immediate inspection or assessment should be conducted. Observation of new distress indicators could result in a modification of the recommendations for this structure.

In addition, OPPD should provide information on how the deadmen for the Meteorological Tower were designed (i.e., was passive pressure used or just the dead load of the anchor?). If the tower was designed using just the dead load of the anchor, then the potential for degradation does not remain significant indicating that the recommended survey schedule can be ceased.

5.20.7 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.

5.20.7.1 Additional Data Available

The following additional data were available for the Meteorological Tower for Revisions 1 and 2 of this Assessment Report:

- Additional groundwater monitoring well and river stage/level data from OPPD.
- Results of continued survey by Lamp Rynearson and Associates (see Attachment 6).
- An Assessment Team from HDR visited the Meteorological Tower on October 27, 2011, to document current conditions in that area.

5.20.7.2 Additional Analysis

Analysis of the additional data listed above has clarified the significance and confidence of the assessment. The following analysis of additional data was conducted for the Fuel Oil Storage Tanks and Piping:

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

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

- Results of continued survey by Lamp Rynearson and Associates.

  Survey data to date compared to the original baseline surveys have exceeded the accuracy range of the surveying equipment. The significance of this fact is discussed below.

Triggering Mechanism 7 – Soil Collapse (first time wetting)
CPFM 7c – General site settlement

The follow-up assessment for Revision 1 of this Assessment Report indicated that the soils were soft in the upper 6 to 12 in., but there were stiffer soils below this layer that required a substantial effort to insert the probe rod to its full depth. These soils are within expected stiffness levels for a farmed field in an alluvial setting and indicate that the soils are less saturated than when they were inspected for Revision 0 of the report.

The data available for the survey points that have been established are outside of the accepted range; however, there is no constant trend that has formed. Visual inspection of the survey points on the guy wires noted that the points were located on the turnbuckles of the wires. The wires are easily affected by wind movement. It was also noted that standing on a vine next to the south guy wires pulled on the wire lowering the survey point. Either of these observations could account for the movement outside the accepted tolerance. Three of the four locations being surveyed do not show movement outside of the accepted tolerance when reviewing the first and last measurement taken; indicating any additional movement outside the tolerance should not be expected. The groundwater elevation measured in monitoring wells closely followed the river level as the floodwater receded. The data indicate that groundwater elevation was about 2 ft above the river level near the beginning of October 2011 and receded to the river level by about October 14, 2011. Therefore the differential head created by the river drawdown was insufficient to facilitate subsurface erosion.

Significance

Potential for Degradation/Direct Floodwater Impact

The initial field assessment noted that soft soils were present around the deadman anchors. This was accomplished by probing surrounding soils to the full depth of the probe with little or no resistance. The follow-up assessment for Revision 1 of this Assessment Report indicated that, though the soils could still be considered soft, substantial effort was needed to insert the probe rod to its full depth. Due to the soils becoming less saturated and firmer the potential for degradation due to this CPFM is low.

Implication

The occurrence of this CPFM could negatively impact the capacity of the deadman anchors. This could lead to movement of the anchors and negatively impact the integrity or intended function of the Meteorological Tower. Therefore, the implications of the potential degradation for this CPFM are high.

Confidence

The follow-up assessment for Revision 1 of this Assessment Report indicates that soils are becoming less saturated and firmer. Survey data available for this revision are outside of the accepted range but are not showing a constant trend. The analysis of the survey data indicates any additional movement outside of the accepted tolerance is not expected. Overall, the data available suggest that soil conditions have improved. Therefore, the confidence for this CPFM is high.

Summary

For CPFM 7c, as discussed above, the combined consideration of the potential for degradation and the implications of that degradation to the structure put it in the "not significant" category. The data collected since Revision 0 are sufficient to rule out this CPFM. Therefore, the confidence in the above assessment is high.

CPFM 7c for the Meteorological Tower is not associated with Key Distress Indicators. The follow-up assessment for Revision 1 of the Assessment Report indicates that the soils at the Meteorological Tower are less saturated and firmer. Passive pressure capacity of the deadmen is no longer reduced as much as it would have been when the soils were more saturated. The results of the additional forensic investigation as of this revision show that this CPFM is ruled out. However, the monitoring program discussed in Section 5.20.6 should continue. Therefore, assuming that no further concerns are identified through the monitoring program for the Meteorological Tower (discussed in Section 5.20.6 and continuing until December 31, 2011), this CPFM is moved to the quadrant of the matrix representing "No Further Action

Recommended Related to the 2011 Flood." In addition, the information requested in Section 5.20.6 regarding the design capacity of the deadman anchors and a review of any geotechnical data will no longer be needed.

5.20.7.1 Revised Results

The CPFM evaluated for the Meteorological Tower is 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**		CPFM 7c

5.20.7.2 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 Meteorological Tower other than CPFM 7c had been ruled out prior to Revision 1, and because CPFM 7c has been ruled out as a result of the Revision 1 findings, no Triggering Mechanisms and their associated PFMs remain credible for the Meteorological Tower. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Meteorological Tower because the potential for failure of this structure due to the flood is not significant.

Section 5.21

Original Steam Generator Storage Building (OSGS)

Omaha Public Power District

5.21 Original Steam Generator Storage Building

5.21.1 Summary of Original Steam Generator Storage Building

Baseline information for the Original Steam Generator Storage Building (OSGS) is provided in Section 2.0, Site History, Description, and Baseline Condition.

5.21.2 Inputs/References Supporting the Analysis

Table 5.21-1 lists references provided by OPPD and other documents used to support HDR's analysis.

Table 5.21-1 - References for Original Steam Generator Storage Building

Document Title	OPPD Document Number (if applicable)	Date	Page Number(s)
Original Steam Generator Storage Facility Finish Grade	60579	2/9/2005	25036-C-022
Original Steam Generator Storage Facility Sheet 4	61397	9/13/2005	25036-C-053
Original Steam Generator Storage Facility Rough Grade	60578	Unknown	25036-C-021
Naval Facilities Engineering Command, Design Manual 7.01, Soil Mechanics		9/1986	All

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

Observed performance and pertinent background data are as follows:

- The OSGS is a reinforced-concrete structure that rests on a concrete mat foundation. No construction documents exist for this structure; therefore, all available information about its construction was derived from a single sheet construction repair for the mat foundation and visual inspections.
- Top of slab elevation for the OSGS is 1022 ft.
- The peak flood elevation in 2011 was approximately 1006.9 ft.
- The OSGS is the farthest structure from the Missouri River.
- The OSGS is at the highest surface elevation from the river.

5.21.3 Assessment Methods and Procedures

5.21.3.1 Assessment Procedures Accomplished

Assessments of the OSGS include the following:

- Visual inspection of the exterior of the structure.
- Assessment of collected survey data to-date for indications of trends in the movement of the structure.

5.21.3.2 Assessment Procedures Not Completed

Assessments of the OSGS that were not completed include the following:

- Visual inspection of the interior of the structure was not completed because access to the structure is not possible. However, inspection of the interior of the structure is not necessary to reach a confident final conclusion.

5.21.4 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. 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 determined to be "not applicable" to the OSGS; therefore, none were carried forward for detailed assessment.

5.21.5 Results and Conclusions

Due to the OSGS' relative proximity to the Missouri River, its elevation relative to high floodwaters, and type of construction, there is no PFM related to the 2011 flood event that is applicable to the OSGS.

5.21.6 Recommended Actions

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. There were no applicable CPFMs identified for the OSGS. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the OSGS because the potential for failure of this structure due to the flood is not significant.

Section 5.22

Switchyard

5.22 Switchyard

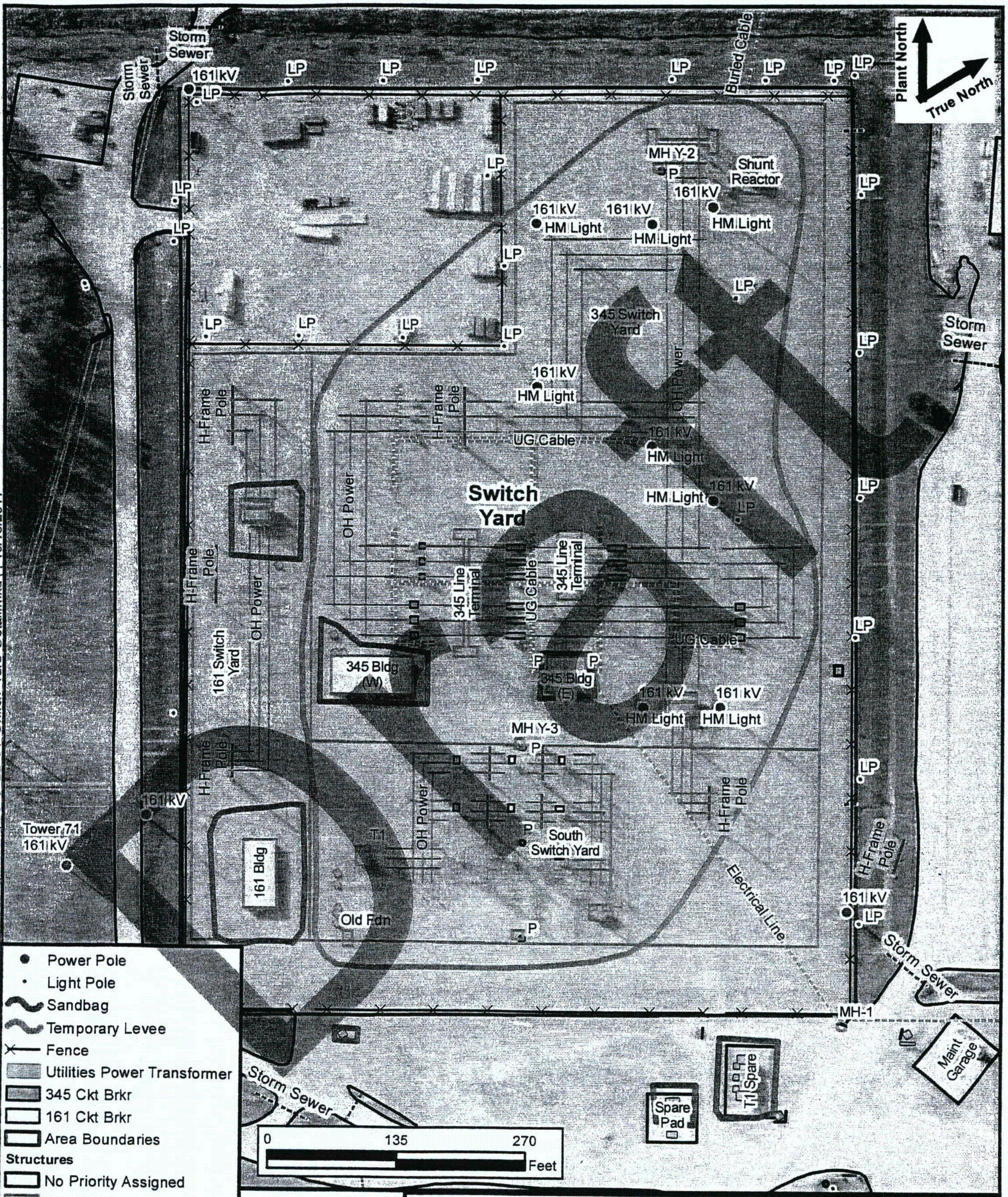
5.22.1 Summary of Switchyard

Baseline information for the Switchyard is provided in Section 2.0, Site History, Description, and Baseline Condition.

The Switchyard is located west of the Old Warehouse Building between two drainageways to its east and west. The drainage is channeled flowing north into culverts draining to Fish Creek. Ground surface elevations within the Switchyard vary from approximately 1002 ft along the drainage swales to a crown ridgeline of 1007 ft. A temporary levee with an approximate top at el 1010 ft was constructed around most of the Switchyard to protect it from the floodwater. The Switchyard will be discussed in four categories: the 161-kilovolt (kV) Switchyard, the 345-kV Switchyard, the South Switchyard, and general site surfacing/security fencing.

The 161-kV Switchyard is in the western section outside the temporary levee (see Figure 5.22-1). A 161-kV Building is located in the southwest corner of the yard. A temporary earthen berm with a 12-ft accessible top width surrounds the 161-kV Building connecting into the levee. The 161-kV Building has a finished floor elevation of 1005.6 ft. The earthen berm allowed construction of a second sandbag berm constructed closer to the structure. The sandbag berm was above floodwater elevation and was covered with plastic to reduce infiltration. Farther north, a transformer structure (T4) had a temporary sandbag berm around it, enclosed by the levee. Remnants of an oil containment berm comprised of rock reside inside the sandbags. The sandbag berm was above floodwater elevation and was covered with plastic to reduce infiltration. Overhead Switch Towers and Transmission Towers outside the levee were subjected to floodwaters. Underground utilities between the structures were subjected to percolating floodwaters. Storm drain pipes carrying flow from the area inside the containment berm were plugged due to inundation of the outlet pipes. Parts of the storm intake were observed at the southwest containment area. Floodwater seeping into the protective sandbag berms at the 161-kV Building and the T4 transformer structure was controlled by numerous sump pumps.

The South Switchyard is in the southern portion of the site (see Figure 5.22-1). All facilities in the South Switchyard are inside the temporary levee. A transformer structure (T1) is located in the southwest corner. A pre-existing oil containment berm comprised of rock surrounds the transformer. Storm drain pipes carrying flow from the area inside the containment berm were plugged due to inundation of the outlet pipes. Parts of the storm intake were observed at the southwest containment area. A second transformer structure (T2) is located in the southeast corner. An oil containment berm comprised of rock surrounds the transformer. Storm drain pipes carrying flow from the area inside the containment berm were plugged due to inundation of the outlet pipes. An erosion channel in the west bank of the drainageway to the east was observed as possibly the outlet for the storm outlet pipe. Parts of the storm intake were observed at the northeast containment area. The South Switchyard area has overhead Switch Towers and Transmission Towers that were subjected to saturated subgrades. Underground utilities between the structures were subjected to percolating floodwaters. A manhole structure southwest of T2 had the lid removed and was being pumped at the time of the inspection. A precast trench heads west from the manhole to another vault in the southwest corner of the Switchyard. The lids from the precast trench have been removed and are adjacent to the trench. The precast trench opening into the manhole is open. The trench is nearly full of sediment the farther the distance from the manhole, with water up to the top surface at the west end. The visual appearance of the sediment in the trench suggests that the manhole pump pulled in the sediment from around the trench until the pump was turned off and the water drained out, leaving the sediment. Low areas inside the levee on the south and east end have ponded water up to a few inches deep.



Projects\OPPD\164565 FCS 2011 Flood Services\Map Docs\Figures\Figure 5 22 01 Switch Yard Detail.mxd , 10/13/2011

OPPD
Omaha Public Power District

Switch Yard Detail
Fort Calhoun Station

Plant and Facility Geotechnical and Structural Assessment

HDR

DATE
Oct 2011

FIGURE
5.22-1

The 345-kV area of the Switchyard is the largest area. All facilities in the 345-kV Switchyard are inside the temporary levee. In the southwest section of the Switchyard is the 345-kV West Building. To the east of this building is the 345-kV East Building. The 345-kV West Building has a finished floor elevation of 1005.75 ft. The 345kV East Building has a finished floor elevation of 1007.5 ft. Sandbag berms were constructed around the 345-kV East Building and the 345-kV West Building even though they are inside the levee. A 161-kV transformer and towers are situated slightly east of 345-kV East Building. An oil containment berm comprised of rock surrounds the transformer. Parts of a storm intake were observed at the southeast containment area. A Shunt Reactor is situated in the northeast corner of the 345-kV area. An oil containment berm comprised of rock surrounds the Shunt Reactor. Storm drain pipes carrying flow from the area inside the containment berm were plugged due to inundation of outlet pipes. A crushed corrugated metal pipe daylighting in the drainageway to the east was observed after water levels subsided. Parts of the storm intake were observed at the southeast containment area. The 345-kV Switchyard area has overhead Switch Towers and Transmission Towers that were subjected to saturated subgrades. Underground utilities between the structures were subjected to percolating floodwaters. Because there is now no provision for interior drainage, low areas inside the levee on the east end have ponded water up to 2 ft deep. Low areas inside the levee on the western edge had shallow ponded water. Numerous sump pumps were utilized inside the berms and the levee to remove infiltration.

No drawings are available to determine if the rock surfacing has subgrade improvements completed prior to placement. It could not be determined if the crushed rock had been placed on a geotextile fabric. The Switchyards (161-kV, 345-kV, and South) are surrounded by security fencing. Parts of the fencing had been reworked due to flood measures. The gate and fencing at the southeast corner of the Switchyard was removed to construct the temporary levee. A temporary gate and fence were placed after the construction of the temporary levee. Security fencing was removed along the entire north end of the Switchyard starting near the northeast corner of the 161-kV Switchyard where the temporary levee was constructed. Temporary fence fabric was constructed outside the levee from the 161-kV permanent fencing to the corner post at the northeast corner of the Switchyard. The temporary fence accumulated debris including wood poles, tree branches, wooden pallets, and trash from floodwaters coming into the site. Some of the fabric was damaged by sump pump piping strung over the top of the fabric carrying pumped floodwaters to Fish Creek.

5.22.2 Inputs/References Supporting the Analysis

Table 5.22-1 lists references provided by OPPD and other documents used to support HDR's analysis.

Table 5.22-1 - References for Switchyard

Document Title	OPPD Document Number (if applicable)	Date	Page Number(s)
Site Plan Topography	45711	Unknown	11405-S-251, Sheets 2,3
Switchyard Area Grading Plan		8/23/1968	11405-S-279
Plan General Site Grading		8/23/1968	11405-S-283
Naval Facilities Engineering Command, Design Manual 7.01, Soil Mechanics		9/1986	All

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

Observed performance and pertinent background data are as follows:

- For the duration of the 2011 flood event, the 161-kV Switchyard area was inundated by floodwaters. The temporary levee construction access blocked water from flowing across the Switchyard. The 161-kV Building and transformer structure had sandbag berms constructed to protect these structures from inundation. Sump pumps continually pumped seepage water back over the berms.
- For the duration of the 2011 flood event, the 345-kV and South Switchyard areas were protected by the temporary levee. Security fencing along the northern edge of the Switchyard was reworked due to flooding. Some of the permanent fencing was removed to construct the levee. Temporary security fencing along this perimeter collected floating debris in the floodwaters coming in to the site.
- The Shunt Reactor, T1 through T4 Transformers, and the spare GSU Transformer are founded on augered cast-in-place piles supporting a mat foundation.
- The other Switchyard structures are supported by 2- to 5-ft-diameter drilled piers 5 to 25 ft long.
- The buildings are supported by shallow continuous spread footings extending to frost depth with a grade-supported slab.

5.22.3 Assessment Methods and Procedures

5.22.3.1 Assessment Procedures Accomplished

Assessments of the Switchyard included the following:

- A visual inspection of the site in general to observe sinkholes and soft subgrade areas.
- A visual inspection of the interior of the buildings.
- A visual inspection of the exterior of the buildings and structures.
- An assessment of collected survey data to-date for indications of trends in the movement of the structure.
- A review of previously documented condition reports, as-built building plans, and geotechnical reports to determine possible weak points in the buildings' construction that could be affected by the flood.

Additional investigations were performed. These included the following non-invasive geophysical and invasive geotechnical investigations:

- Geotechnical investigations including test borings with field tests (SPT and CPT) and laboratory tests were completed near the Switchyard. Note that OPPD required vacuum excavation for the first ten feet of proposed test holes to avoid utility conflicts. Test reports will thus not address soil conditions in the upper ten feet of site and locations where shallow utilities exist. (Test reports were not available at the time of Revision 0.)

5.22.3.2 Assessment Procedures Not Completed

Assessments of the Switchyard that were not completed include the following:

- Pump water out of underground utilities for further investigation. Floodwater elevations are not sufficiently below grade to allow pumping utilities dry without continued infiltration. Priority of staff is pumping Protected Area utilities.
- Geophysical testing such as GPR or seismic refraction was not considered necessary for the Switchyard.

5.22.4 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. 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 detailed design review for each structure, the structure inspections, and the results of available geotechnical, geophysical, and survey data were analyzed, a number of CPFMs were ruled out as discussed in Section 5.22.4.1. The CPFMs carried forward for detailed assessment are discussed in Section 5.22.4.2.

5.22.4.1 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
CPFM 2b – Loss of lateral support for pile foundation
CPFM 2c – Undermined buried utilities

Reasons for ruling out:

- The majority of the Switchyard was protected by the temporary levee or sandbag berms. The northwest corner of the 161-kV Switchyard was inundated, but there was no flow over the site.
- No significant surface erosion was observed during the field assessments.

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

Reason for ruling out:

- The Switchyard is a sufficient distance from the river to be outside the zone of influence of the CPFM.

Triggering Mechanism 3 – Subsurface Erosion/Piping
CPFM 3f – Undermined buried utilities (due to river drawdown)

Reason for ruling out:

- The Switchyard is a sufficient distance from the river to be outside the zone of influence of the CPFM.

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 majority of the Switchyard was protected by the temporary levee or sandbag berms. The northwest corner of the 161-kV Switchyard was inundated, but there was no flow over the site.

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:

- There was potential for first time wetting for some of the fills above el. 1003.3; however, no settlement was observed.

Triggering Mechanism 10 – Machine/Vibration-Induced Liquefaction
CPFM 10a – Cracked slab, differential settlement of shallow foundation, loss of structural support
CPFM 10b – Displaced structure/broken connections
CPFM 10d – Pile/pile group instability

Reason for ruling out:

- The Switchyard has not been subjected to machine vibrations, and no liquefaction was observed on site. Therefore, machine/vibration-induced liquefaction failures are not credible.

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 11d – Pile/pile group instability

Reason for ruling out:

- Liquefaction 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

Reason for ruling out:

- The Switchyard is located a sufficient distance away from the river bank and therefore is outside the zone of influence of a bank slope failure.

Triggering Mechanism 13 – Submergence

CPFM 13a – Corrosion of underground utilities
CPFM 13b – Corrosion of structural elements

Reason for ruling out:

- The Switchyard has not been subjected to corrosive circumstances that would be considered beyond the normal conditions.

Triggering Mechanism 14 – Frost Effects

CPFM 14a – Heaving, crushing, or displacement

Reasons for ruling out:

- The Switchyard structures foundation systems are below frost level. Therefore, frost effects have been discounted.
- Flooding did not change the frost and foundation conditions. The structures have always been subjected to freezing temperature with moist to saturated soils.

5.22.4.2 Detailed Assessment of Credible Potential Failure Modes

The following CPFMs are the only CPFMs carried forward for detailed assessment for the Switchyard 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)
CPFM 3b – Loss of lateral support for pile foundation (due to pumping)
CPFM 3c – Undermined buried utilities (due to pumping)

The Triggering Mechanism and CPFMs could occur as follows: the site soils are erodible, and some of the gradients may be sufficient to facilitate erosion. If seepage is unfiltered and infiltration continues unarrested, voids could develop. Due to the proximity of known pumping points throughout the site, voids that develop could result in undermined foundations.

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 Switchyard.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
A substantial amount of sand was observed inside electrical trenches that were connected to a manhole that was being pumped.	The majority of the Switchyard structures were surrounded by an earth berm.
Voids at conduit locations around the 161-kV Building were observed in the general vicinity of pump locations.	The Switchyard elevations range from 1002 ft to 1007 ft. Flood elevations reached approximately 1006.9 ft. Floods were not significantly higher than general site grades.
Voids were observed around the 161-kV transformer pad.	Survey data to-date does not identify measurable movement.
Data Gaps: • Site grade construction is not well known.	

Conclusion

Significance

*Potential for Degradation/*Direct Floodwater Impact

Many of the indicators for these CPFMs have been observed. The sand in the trench after pumping ceased appeared to come from the soils surrounding the trench, therefore, the potential that degradation due to these CPFMs has occurred due to the 2011 flood is high.

Implication

The occurrence of these CPFMs on a large enough scale could negatively impact the trench structure. This could lead to excessive trench unit movement and negatively impact the integrity of the utility. Therefore, the implication of the potential degradation for these CPFMs is high

Confidence

The extent of subsurface erosion and its potential impact to the utilities in the Switchyard is not known due to the lack of data gathered on subsurface conditions. Since there is not enough information on the subsurface conditions at this time and the pumping on site could have caused undermining and/or settlement, the confidence for these CPFMs is low.

Summary

For CPFMs 3a through 3c, 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. There is low confidence that there has been significant degradation to the soil surrounding the Switchyard due to the lack of test data available at this time. More data or continued monitoring and inspections are needed.

5.22.5 Results and Conclusions

The CPFMs evaluated for the Switchyard 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**	CPFM 3a CPFM 3b CPFM 3c	
Potential for Failure **Not Significant**		

5.22.6 Recommended Actions

The following actions are recommended for the Switchyard:

Given the Low Confidence Rating for these CPFMs, continued monitoring is recommended to continue elevation surveys on this structure. The purpose is to monitor for signs of structure distress and movement or changes in soil conditions around the building. The results of this monitoring will be used to increase the confidence in the assessment results. Elevation surveys should be performed weekly for four weeks and biweekly until December 31, 2011. At the time of Revision 0, groundwater levels had not yet stabilized to nominal levels. Therefore, it is possible that new distress indicators could still develop. If new distress indicators are observed before December 31, 2011, appropriate HDR personnel should be notified immediately to determine whether an immediate inspection and/or assessment should be conducted. Observation of new distress indicators may result in a modification of the recommendations for this structure.

5.22.7 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.

5.22.7.1 Additional Data Available

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

- Additional groundwater monitoring well and river stage level data from OPPD.
- Results of geotechnical investigation by Thiele Geotech Inc. (see Attachment 6).
- Results of continued survey by Lamp Rynearson and Associates (see Attachment 6).

5.22.7.2 Additional Analysis

The following analysis of additional data was conducted for the Switchyard:

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

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

- Results of geotechnical investigation by Thiele Geotech, Inc.

  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 feet to protect existing utilities.

- Results of continued survey by Lamp Rynearson and Associates.

  Survey data to date compared to the original baseline surveys have exceeded the accuracy range of the surveying equipment. The significance of this fact is discussed below.

Three CPFMs were identified in Revision 0. Since Revision 0, additional data have become available which has clarified the significance and confidence for these CPFMs. The following presents the previously identified CPFMs and the new interpretation of its significance and confidence based upon the new data.

Triggering Mechanism 3 – Subsurface Erosion/Piping

CPFM 3a – Undermining and settlement of shallow foundation/slab/surfaces (due to pumping)
CPFM 3b – Loss of lateral support for pile foundation (due to pumping)
CPFM 3c – Undermined buried utilities (due to pumping)

The data available for survey points have shown no movement outside the accepted tolerance levels except the following point: TW 29. TW 29 is a 161-kV pole in the southeastern corner of the Switchyard. The data for TW29 show that there was an elevation change between the first and second survey. Data have held steady since. The original base survey data point was taken when the area around the pole was flooded. Based on the consistency of follow-on data point elevations in non-flooded conditions, we believe that the base survey point elevation does not correlate with later data and is an error.

SPT and CPT test results did not identify substantial changes to the soil strength and stiffness. SPT and CPT test results were not performed in the top 10 feet to protect existing utilities.

The groundwater elevation measured in the monitoring wells closely followed the river level as the floodwater receded. The data indicate that groundwater elevation was about 2 ft above the river level near the beginning of October 2011 and receded to the river level by about October 14, 2011.

CPFMs 3a through 3c for the Switchyard are not associated with Key Distress Indicators. Results of survey data, nearby geotechnical data, groundwater monitoring, and nearby field inspections do not indicate signs of structure movement or other adverse effects that could be attributed to these CPFMs. The results of the additional forensic investigation show that these CPFMs are ruled out. Therefore, assuming that no further concerns are identified through the monitoring program for the Switchyard (discussed in Section 5.22.6 and continuing until December 31, 2011), these CPFMs are moved to the quadrant of the matrix representing "No Further Action Recommended Related to the 2011 Flood."

5.22.7.1 Revised Results

The CPFMs evaluated for the Switchyard 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**		CPFM 3a CPFM 3b CPFM 3c

5.22.7.2 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 Switchyard other than CPFMs 3a, 3b, and 3c had been ruled out prior to Revision 1, and because CPFMs 3a, 3b, and 3c have been ruled out as a result of the Revision 1 findings, no Triggering Mechanisms and their associated PFMs remain credible for the Switchyard. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Switchyard because the potential for failure of this structure due to the flood is not significant.

Section 5.23

Transmission Towers

5.23 Transmission Towers

5.23.1 Summary of Transmission Towers

Baseline information for the Transmission Towers is provided in Section 2.0, Site History, Description, and Baseline Condition.

The following three types of transmission towers reside on the property:

- 345kV Lattice Transmission Towers

  There are four 345 kV lattice transmission towers labeled T2 through T5 on the property. The superstructure is constructed of a tapered steel truss frame that extends to an unknown height due to the lack of available drawings. The trusses are supported on a pier at each of the four columns. The piers are founded on pile caps below grade which are supported on varying pile group arrangements. Piles are 12 in. in diameter and the pile material/type and capacity are unknown. Pile depths below the pile cap range from 20 to 69 ft. Drawings for the foundations indicate an uplift piling option that may be implemented on certain columns of the towers. The exact pile group type and uplift piling location for each tower unknown.

- 161kV Single Pier Transmission Towers

  There are numerous single column transmission towers on the property. The superstructures are single-tapered galvanized steel columns that extend to an unknown height due to lack of available drawings. The columns of the 161 kV transmission towers between the Turbine Building South Switchyard and the Switchyard are supported on a single drilled pier that is advanced to depths varying from 27 ft to 35.5 ft. The piers have vertical and horizontal reinforcing for the full depth. Pier diameters vary from 5.5 ft to 6.5 ft. The detailed design information for the 161kV transmission towers located west and south of the switchyard and north of the site is unknown.

- Double Post Wood Transmission Towers

  Several double-column wooden post towers exist on the property. No drawings are available for these. However, from what is known on the standard installation of these towers, they are presumed to be supported by a direct embed application of the wood pole in soil. Bottom portions of the wood poles are encased in a metal sleeve.

5.23.2 Inputs/References Supporting the Analysis

Table 5.23-1 lists references provided by OPPD and other documents used to support HDR's analysis.

Table 5.23-1 - References for Transmission Towers

Document Title	OPPD Document Number (if applicable)	Date	Page Number(s)
161kV Transmission Line Anchor Bolt Foundations	C-8140-1	5/26/2004	
Transmission Plan & Profile Lines 70 & 76 Circuit		2/3/2011	N/A
345kV Foundations for Lattice Towers	E-4600	6/17/1968	

Table 5.23-1 - References for Transmission Towers			
Document Title	**OPPD Document Number (if applicable)**	**Date**	**Page Number(s)**
345kV Foundations for Lattice Towers Pile Foundation Table	E-4602	6/17/1968	
Naval Facilities Engineering Command, Design Manual 7.01, Soil Mechanics		9/1986	All
Figure 5.23-1		8/2011	N/A

Detailed site observations—field reports, field notes, and inspection checklists—for the Transmission Towers are provided in Attachment 8.

Observed performance and pertinent background follows below.

- The towers were inundated with water for the duration of the flood except the following (see Figure 5.23-1, Sheets 1 through 3):
  - Tower #70, which is located on the south embankment of the entrance drive to the plant;
  - Tower #45, which is located on a hill south of Transmission Tower T2;
  - Tower STS #18-5, which had water inundation in the surrounding area but showed no visible water marks on the tower or pier and vegetation is present. And
  - Tower STS #18-4, which had water inundation in the surrounding area but showed no visible water marks on the tower or pier and vegetation is present.
- Some towers were still inundated with water and unable to be reached for observation during the site inspection (see Figure 5.23-1, Sheets 1 through 3).
- The posts of the double wood post Transmission Tower PRH9 22L 10 08 appeared saturated extending several feet above grade.
- Soils around the towers, with the exception of those in paved areas and those that were not in inundated areas, were found to be soft when probed with a fiberglass probe. The probe was plunged into the ground (up to handle depth) with little force.
- Some of the towers are supported by guy anchors. The towers with guy anchors were observed to have dead man anchor except Towers STS #12, STS #13, STS #14, and STS #25 which have helical anchor foundations.
- Little surface erosion was noted in the observed areas. Most areas had deposited sediments.
- Tower foundations are designed for submergence.

5.23.3 Assessment Methods and Procedures

5.23.3.1 Assessment Procedures Accomplished

Assessments of the Transmission Towers included the following:

- The towers and surrounding grades were visually inspected in August and September of 2011for signs of distress.
- An assessment was made of collected survey data to-date for indications of trends in the movement of the structures.

Section 5.24

Main Underground Cable Bank, MH-1 to Auxiliary Building

Omaha Public Power District

5.24 Main Underground Cable Bank, MH-1 to Auxiliary Building

5.24.1 Summary of Main Underground Cable Bank, MH-1 to Auxiliary Building

Baseline information for the Main Underground Cable Bank from MH-1 to the Auxiliary Building is provided in Section 2.0, Site History, Description, and Baseline Condition.

The portion of the Main Underground Cable Bank system covered under this section extends from MH-1 to the Auxiliary Building. MH-1 is located near the southeast corner of the Switchyard. A duct bank from the switchyard connects to the north wall of MH-1. MH-2 is located east of MH-1 and west of the old warehouse. The duct bank between MH-1 and MH-2 is routed beneath the northwest corner of the new Maintenance Garage and King Tut Wall. From MH-2 it is routed east and extends to MH-3, which is located inside the Rad Waste Building. Between MH-2 and MH-3, the duct bank crosses beneath the old warehouse addition, the site perimeter and security fences, and the "Trenwa" cable trench. From MH-3 the duct bank is routed to the south and out of the Rad Waste Building and to MH-4. At MH-4, the cabling turns east 90° and extends east to the point where it turns 90° and terminates outside of the Auxiliary Building. Outside of the Auxiliary Building the duct bank turns vertically upward and terminates above grade in a pull box. The top of the ducts that terminate in the pull box adjacent to the Auxiliary Building are set at el. 1005.0 ft. according to drawing 11405-E-320. The duct bank between MH-4 and the Auxiliary Building runs adjacent to the face of the Auxiliary Building. A "Missile Shield Room" addition to the Auxiliary Building was built subsequent to construction of the duct bank and is located directly over the Main Underground Cable Bank.

5.24.2 Inputs/References Supporting the Analysis

Table 5.24-1 lists references provided by OPPD and other documents used to support HDR's analysis.

Table 5.24-1: References for Main Underground Cable Bank, MH-1 to Auxiliary Building

Document Title	OPPD Document Number (if applicable)	Date	Page Number(s)
Underground Duct System	60184	12/13/2002	CE-79-3
Diesel Generator Enclosure Plan & Details SH-1	24002	Unknown	13007.18-EC-18A-1
Site Plan Underground Ducts – Manholes-Outdoor Lighting-Fence Grounding	12582	Unknown	11405-E-319
Underground Ducts & Manholes Sections & Details, SH 1	12583	Unknown	
Underground Ducts & Manhole Sections & Details, SH 2	12584	Unknown	11405-E-321, SH. 2
Underground Ducts & Manhole Sections & Details	12585	Unknown	11405-E-322, SH. 3
Naval Facilities Engineering Command, Design Manual 7.01, Soil Mechanics		9/1986	All

Detailed site observations—field reports, field notes, and inspection checklists—for the Main Underground Cable Bank from MH-1 to the Auxiliary Building, are provided in Attachment 8.

Observed performance and pertinent background data are as follows:

- Groundwater was observed flowing into the basement sump of the Turbine Building from floor and condensate drain pipes not designed to intercept groundwater. This condition has a recorded history dating back to 1997. For further information see Section 5.8. A more detailed discussion of this Key Distress Indicator is presented in Section 4.1.
- Settlement of a column in the Maintenance Building, north of the Turbine Building, was documented by OPPD and HDR personnel. A CR describing the event, condition, and related issues was created by OPPD and is on record. The Turbine Building and the Maintenance Building are located east of the Auxiliary Building. A more detailed discussion of this Key Distress Indicator is presented in Section 4.3
- The Main Underground Cable Bank (MH-4 to the Auxiliary Building) extends under the Auxiliary Building Missile Shield Room.
- The Main Underground Cable Bank alignment, where it passes beneath the Missile Shield Room, is located adjacent to fuel oil tank 1 (FO-1) and the associated fuel supply piping.
- A sand boil/piping feature was observed (originally reported in CR 2011-7265) near the southwest corner of the Auxiliary Building, in the Missile Shield Room. This room is located along the south wall of the Auxiliary Building and has an unfinished, pea gravel floor surface. Fuel oil storage tank FO-1 is located outside the Missile Shield Room, with fuel oil piping entering the room below floor elevation near the observed boil/piping feature.
- The Aqua Dam surrounding the facility crossed the Main Underground Cable Bank.
- The Aqua Dam failed for a short period of time due to being damaged, allowing floodwater to enter the area inside the Aqua Dam perimeter. Surfaces above the Main Underground Cable Bank were inundated with water when the Aqua Dam failed.
- King tut blocks (20 to 25 thousand pounds per block) located adjacent to the Protected Area fence at the northeast end of the site were loaded onto trucks (two blocks per load) and removed from this area on September 14, 2011. The assessment team observed and photographed this operation. Pavement displacement or deflection was not observed during the lifting or removal of these blocks. Additionally, deformation of the soil was not observed where loaded trucks crossed various utility alignments when exiting the site.
- MH-1 was opened and pumped out by OPPD employees on Wednesday, September 7, 2011. The water level prior to beginning pumping activities was level to the bottom of the manhole concrete cover according to OPPD employees questioned while observing pumping operations.
- MH-1 was also opened and pumped out by OPPD employees on Monday, September 13, 2011. An OPPD employee entered MH-1 and photographed the interior walls once the manhole was emptied. The employee noted that cracks adjacent to the cable duct openings were a pre-existing condition that existed prior to the 2011 flood event.
- MH-1 pump discharge was routed to a large swale located along the east side of the switchyard. The water level was significantly lower than the rim and cover of the manhole at the time of initial pumping. Water levels in the swale had dropped an additional 1 ft or 2 ft lower at the time of the second pumping.
- Pumping operations to empty the manhole required emptying the connecting duct banks and adjoining manholes to the level of the connecting ducts.
- OPPD employees pumping MH-1 the first day stated that MH-2 had been pumped dry the day prior.
- Manhole pumping operations were performed after flood waters had receded to the point where the manholes were accessible.

- A swale crosses the duct bank east of MH-2. Minor localized surface erosion was observed along the banks of the swale north of the Maintenance Garage and where it crosses the duct bank.
- On September 13, 2011, Thiele Geotechnical Services was hydro-excavating for soil borings south of the new, six-bay, Maintenance Garage. At the time of field observations, vacuum excavations had proceeded to a 2-ft depth and exposed a reinforced gravel road section composed of Geo-grid installed in 6-in. layers. Four layers of Geo-grid were visible at the time of field observations. The lateral extents of the Geo-grid reinforcement in the gravel surfaced areas are not known at this time.

5.24.3 Assessment Methods and Procedures

5.24.3.1 Assessment Procedures Accomplished

Assessments were made by walking the cable bank alignment and observing surface features of the system (manholes) and the ground surface overlying the underground cable bank. The surface assessment included using a 4-ft-long, 0.25-in.-diameter, steel-tipped fiberglass T-handle soil probe to hand probe the ground surface along the utility alignments and adjacent areas to determine relative soil strength. The assessment focused on identifying conditions indicative of potential flood-related impacts or damage to the utility as follows:

- Ground surface conditions overlying and immediately adjacent to the utility and its backfilled trench including scour, subsidence or settlement, lateral spreading, piping, and heave.
- Soft ground surface areas (native soil, engineered fill, and/or limestone gravel pavement) as determined by probing.
- Water accumulations and flows in subsurface system components (manholes and concrete cable encasement pipes).
- Damage to at-grade or above-grade system features and equipment.
- Variance from normal installation conditions, including settled, tilted, or heaved system features and equipment.
- 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:

- GPR. (Test reports were not available at the time of Revision 0.)
- Paved areas were evaluated with GPR and dynamic deflection methods (i.e., drop weight deflectometer). (Test reports were not available at the time of Revision 0.)

5.24.3.2 Assessment Procedures Not Completed

Assessments of the Main Underground Cable Bank from MH-1 to the Auxiliary Building that were not completed include the following:

- The interior of underground cable bank manholes and connecting concrete-encased cable ducts were not inspected except for visual observations that were possible from above and behind temporary safety railings. Manholes are a confined space as defined by Occupational Safety and Health Administration (OSHA) regulations. In accordance with these regulations and OPPD Fort Calhoun Station (FCS) safety procedures, manhole entry is requires a confined space entry permit and can only be performed by appropriately trained OPPD personnel.

- No excavation to inspect underground systems and conditions was performed. Unless field conditions are observed that might indicate problems, this assessment is not warranted.

5.24.4 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 walkdown 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 results of available geotechnical, geophysical, and survey data were analyzed, a number of CPFMs were ruled out as discussed in Section 5.24.4.1. The CPFMs carried forward for detailed assessment are discussed in Section 5.24.4.2.

5.24.4.1 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
CPFM 2c – Undermined buried/utilities

<u>Reasons for ruling out:</u>

- No surface erosion was observed at the Main Underground Cable Bank manholes or on the ground surface overlying the alignment of this system's underground concrete cable encasements.
- Only localized and limited surface erosion was observed on the ground surface across the facility. The Main Underground Cable Bank system is constructed at depths sufficiently below potential scour depths indicated by surface erosion features observed in other areas.

Triggering Mechanism 4 – Hydrostatic Lateral Loading (water loading on structures)

CPFM 4c – Wall failure in flexure
CPFM 4d – Wall failure in shear
CPFM 4e – Excess deflection

<u>Reasons for ruling out:</u>

- This segment of the Main Underground Cable Bank system was not pumped while the site was inundated with water. Manholes in this segment (MH-1, MH-2, and MH-4) were not pumped until flood waters had receded to below ground surface elevations and the manholes were vehicle accessible. Prior to pumping, the system was flooded and not susceptible to hydrostatic loads.
- Underground structures are designed for hydrostatic pressures as a standard practice.
- According to OPPD staff, this system was pumped on numerous occasions in the past due to high groundwater conditions.

Triggering Mechanism 6 – Buoyancy, Uplift Forces on Structures

CPFM 6b – Cracked slab, loss of structural support
CPFM 6c – Displaced structure/broken connections

Reason for ruling out:

- This segment of the cable bank was not pumped while the site was inundated by flood water. Manholes in this segment (MH-1, MH-2, and MH-4) were not pumped until the water level had receded. Prior to pumping, the system was flooded and therefore it was not susceptible to uplift forces.

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:

- Soil supporting and surrounding the Main Underground Cable Bank system has been previously wetted. The peak flood elevation prior to 2011 was 1003.3 ft, which occurred in 1993.

Triggering Mechanism 10 – Machine/Vibration-Induced Liquefaction

CPFM 10a – Cracked slab, differential settlement of shallow foundation, loss of structural support
CPFM 10b – Displaced structure/broken connections
CPFM 10c – Additional lateral force on below-grade walls

Reasons for ruling out:

- Machine vibrations from the facility (turbine and various pumps) have historically occurred and no indications of these CPFMs are evident.
- Pumps used on-site during the flood event were too small to cause ground or structure vibrations sufficient to initiate soil liquefaction. Visible indications of liquefaction were not observed around the areas where the pumps were operating, and no evidence of liquefaction was reported to HDR.
- No structure movements indicative of soil liquefaction and resultant settlement were observed; no structure cracking or lateral movements were observed.

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:

- Static liquefaction results from a relatively small disturbance which precedes an unstable condition that allows a liquefaction failure to occur and produce large, rapid movements. Indications of liquefaction have not been observed on site.

Triggering Mechanism 12 – Rapid Drawdown

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

Reason for ruling out:

- This condition pertains to slope instability associated with rapid drawdown of the river level. Since this segment of the Main Underground Cable Bank cable is well away from the river, the potential for these CPFMs are remote and therefore are ruled out.

Triggering Mechanism 13 – Submergence

CPFM 13a – Corrosion of underground utilities

Reason for ruling out:

- Underground utilities and structures are located below the design flood elevation for the facility. Groundwater elevations controlled by Missouri River water elevations, percolation of storm precipitation, and winter snowmelt would be expected to contact underground improvements, including constructed steel and concrete facility elements. As such, steel and concrete site improvements are assumed to be designed to withstand the corrosive environment of groundwater and wetted soil.

Triggering Mechanism 14 – Frost Effects

CPFM 14a – Heaving, crushing, or displacement

Reasons for ruling out:

- Utility cabling is not rigid and not subject to major damage due to frost-induced displacement.
- Manholes and the bottom of the duct banks are founded below frost level.
- Saturated soil conditions have occurred in the past. Conditions have not been changed due to flood conditions.

5.24.4.2 Detailed Assessment of Credible Potential Failure Modes

The following CPFMs are the only CPFMs carried forward for detailed assessment for the Main Underground Cable Bank from MH-1 to the Auxiliary Building 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)

CPFM 3c – Undermined buried utilities (due to pumping)

The Triggering Mechanism and CPFMs could occur as follows: multiple potentially connected seepage paths exist in the soil backfill at the site, including soil backfill in utility trenches, granular trench bedding, broken building floor and condensate drains pipes, pre-existing defects/voids under pavement, etc. The paths may be exposed at some locations to the river flood waters (e.g., open ground along areas outside the Aqua Dam perimeter). This network of seepage paths is connected to several pumping sources: the sump pit in the Turbine Building, Manhole MH-5, and a series of surface pumps located along the interior of the Aqua Dam perimeter. The pumps were operated for an extended period of time, maintaining a head differential on the seepage path networks. Gradient was sufficient to begin erosion of surrounding soil. The potential damage includes settlement of the Main Underground Cable Bank and manholes causing a loss of electrical connectivity.

Pumping of MH-1, MH-2, and MH-4 after floodwaters receded created temporary and minor drawdown effects. The temporary drawdown would cause a head differential on the seepage path networks already created under higher head conditions, thus causing additional incremental or cyclical damages.

Below are field observations and data that support the likelihood of these CPFMs:

- Groundwater flows were observed flowing into the basement sump of the Turbine Building from floor and condensate drain pipes not designed to intercept groundwater. This condition has a recorded history dating back to 1997. The Main Underground Cable Bank terminates at the southeast corner of the Auxiliary Building, which is directly adjacent to the Turbine Building.
- The area inside the Aqua Dam was pumped dry and created a hydrostatic head between the inside and outside the Aqua Dam perimeter. The inside the Aqua Dam perimeter was pumped from several locations, creating locations where suction increased the potential head differential between the area inside and the area outside the Aqua Dam perimeter.
- A sand boil or piping condition was observed within the exposed floor of the auxiliary building.
- Manholes were pumped to remove water that accumulated due to the flood event. This created a head differential.

Below are field observations and data that indicate these CPFMs are unlikely:

- Trench settlement along the alignment of the duct banks was not observed.
- Soil probing along the duct bank alignments indicated soils were generally firm and stable.

Data Gaps (data yet required to assess these CPFMs):

- GPR data and reports have not been delivered for assessment of subsurface conditions.

The following table describes observed distress indicators and other data that would increase or decrease the potential for degradation associated with these CPFMs for the Main Underground Cable Bank from MH-1 to the Auxiliary Building.

Adverse (Degradation/Direct Floodwater Impact More likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
The southwest corner of the Turbine Building is located adjacent to the termination point of the duct bank.	
Water was pumped from several manholes.	Manholes were inundated during the flood event and were not pumped until flood waters had receded and the manholes were accessible The manholes were only pumped for a short duration of time.
The area inside the Aqua Dam perimeter was pumped from several locations.	
Sand boil/piping feature observed in Auxiliary Building Missile Shield Room.	
Data Gaps: • GPR data were not available at the time of Revision 0 to assist in determining possible void areas or paths at the facility.	

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

Indicators for this CPFM have been observed in the Turbine Building and Auxiliary Building which is directly adjacent to the Main Underground Cable Bank. The voids below the base slab in the Turbine Building are known to exist with heavy flows of water being pumped from the sump. Since the 2011 flood caused increased flow through the broken drain pipes, the potential that the 2011 flood caused further and more rapid degradation due to these CPFMs is high.

Implication

The occurrence of these CPFMs could potentially cause the collapse of the Main Underground Cable Bank. However, the integrity of system of cables in the trench may not be impacted due to the flexibility of the cables. Therefore, the implication of the potential degradation for this CPFM is low.

Confidence

The extent of subsurface erosion and its potential impact to the Main Underground Cable Bank is not known due to the lack of data gathered on subsurface conditions. Since there is not enough information on the subsurface conditions at this time and the pumping in the Turbine Building could have caused subsurface erosion, the confidence for these CPFMs is low.

<u>Summary</u>

For CPFMs 3a and 3c, as discussed above, the potential for degradation is high because the pumping in the Turbine Building and the sand boil/piping feature in the Auxiliary Building. This degradation could have caused enough erosion to impact the integrity or intended function of the structure. 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 these CPFMs. Therefore, the confidence in the above assessment is low, which means more data or continued monitoring and inspections may be necessary to draw a conclusion.

5.24.5 Results and Conclusions

The CPFMs evaluated for the Main Underground Cable Bank from MH-1 to the Auxiliary Building 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**	CPFM 3a CPFM 3c	

5.24.6 Recommended Actions

Further forensic investigations and physical modifications are recommended to address CPFM 3a and 3c for the Main Underground Cable Bank. CPFM 3a and 3c are associated with unfiltered flow of groundwater into the Turbine Building basement drain piping system (Key Distress Indicator #1). These recommendations are described in detail in Section 4.1.

Also, a review of the geophysical data when available should be done. The results of this review will be used increase the confidence in the assessment results. At the time of Revision 0, groundwater levels had not yet stabilized to nominal normal levels. Therefore, it is possible that new distress indicators could still develop. If new distress indicators are observed before December 31, 2011, appropriate HDR personnel should be notified immediately to determine whether an immediate inspection and/or assessment should be conducted. Observation of new distress indicators may result in a modification of the recommendations for this structure.

5.24.1 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.

5.24.1.1 Additional Data Available

The following additional data were available for the Main Underground Cable Bank from MH-1 to the Auxiliary Building for Revisions 1 and 2 of this Assessment Report:

- Results of KDI #1 forensic investigation (see Section 4.1).
- Additional groundwater monitoring well and river stage level data from OPPD.
- Results of geophysical investigation by Geotechnology, Inc. (see Attachment 6).
- Results of geotechnical investigation by Thiele Geotech, Inc. (see Attachment 6).

5.24.1.2 Additional Analysis

The following analysis of additional data was conducted for the Main Underground Cable Bank from MH-1 to the Auxiliary Building:

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

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

- Results of geophysical investigation report by Geotechnology, Inc.

  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, Inc.

  Six test borings were drilled, with continuous sampling of the soil encountered, to ground truth the Geotechnology, Inc. 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 feet to protect existing utilities.

Triggering Mechanism 3 – Subsurface Erosion/Piping

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

CPFM 3c – Undermined buried utilities (due to pumping)

Significance

Potential for Degradation/Direct Floodwater Impact

Indicators for this CPFM have been observed in the Turbine Building and Auxiliary Building, which is directly adjacent to the Main Underground Cable Bank. The voids below the base slab in the Turbine Building are known to exist with heavy flows of water being pumped from the sump. Since the 2011 flood caused increased flow through the broken drain pipes, the potential that the 2011 flood caused further and more rapid degradation due to this CPFM is high. The Turbine Building Sump drainage is labeled as KDI#1 as part of this report and recommendations to address this issue have been made and implemented. In addition, a sand boil/piping feature in the Auxiliary Building Missile Shield room was noted during post flood inspections. Based on implementation and repair of issues associated with KDI#1 and instigation of assessment and necessary repairs in the Missile Shield room, the potential for degradation of this system is low.

Implication

The occurrence of this CPFM could cause the collapse of the Main Underground Cable Bank. However, the integrity of system of cables in the trench might not be impacted due to the flexibility of the cables. Therefore, the implication of the potential degradation for this CPFM is low.

Confidence

The groundwater elevations have dropped to a level where they no longer can impact the system. Based on maintenance and repair activities planned in conjunction with KDI#1 and in the Missile Shield room, confidence is high that problems associated with these CPFMs will be addressed by OPPD.

Summary

As discussed, the potential for degradation is low because the pumping in the Turbine Building and the sand boil/piping feature in the Auxiliary Building are being addressed based on the recommendations for each. The combined consideration of the potential for degradation and the implications of that degradation to a structure of this type put it in the "not significant" category. The data currently collected are sufficient to rule out this CPFM. Therefore, the confidence in the above assessment is high.

5.24.1.1 Revised Results and Recommendations

The CPFMs evaluated for the Main Underground Cable Bank from MH-1 to the Auxiliary Building are presented in the following matrix, which shows the rating for the estimated significance and the level of confidence in the evaluation. CPFMs 3a and 3c for the Main Underground Cable Bank from MH-1 to the Auxiliary Building are associated with Key Distress Indicator #1. Section 4.1 presents the results of additional forensic investigation that was conducted to ascertain whether these CPFMs 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, assuming that no further concerns are identified through the monitoring program for the Main Underground Cable Bank from MH-1 to the Auxiliary Building (discussed in Section 5.24.6 and continuing until December 31, 2011), these CPFMs are 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**		
Potential for Failure **Not Significant**		CPFM 3a CPFM 3c

5.24.1.2 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 Main Underground Cable Bank from MH-1 to the Auxiliary Building other than CPFMs 3a and 3c have been ruled out, and because CPFMs 3a and 3c will be ruled out when the physical modifications recommended for KDI #1 in Section 4.1 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Main Underground Cable Bank from MH-1 to the Auxiliary Building. 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.

SECTION 7.0
SUMMARY AND CONCLUSIONS

7.0 SUMMARY AND CONCLUSIONS

7.1 Scope and Purpose

The FCS Plant and Facility Geotechnical and Structural Assessment has been completed to identify and describe the effects of the 2011 flood on Structures at the site. Specifically, the objective of this Assessment Report is to present HDR's assessment of changes to the soil or rock that supports the structures at FCS that may have negatively impacted those structures.

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. Revision 1 of this Assessment Report was submitted to OPPD on November 28, 2011 and provided updated information related to Priority 1 Structures. These assessments were incomplete in Revision 0 and Revision 1 because the forensic investigations and/or monitoring for most of the Priority 1 Structures was not completed by the submittal date. Revision 2 of this Assessment Report includes updated results for Priority 1 Structures to include additional monitoring data and the results of additional forensic investigations for the Key Distress Indicators. Revision 2 also presents the results of the assessments for each of the Priority 2 structures.

This section of the report provides a brief summary of the process used to conduct the structure assessments. Conclusions and recommendations are then presented regarding the geotechnical conditions at the FCS site, the Key Distress Indicators, and the Priority 1 and Priority 2 structures.

7.2 Summary of the Assessment Process

The Flood of 2011 inundated portions of the FCS site for nearly three months. Peak flood depths across the site generally averaged between 3 and 4 feet, and flood velocities over the site were generally less than two feet per second. The effects of this flooding were assessed by first conducting a systematic and thorough visual observation of each structure to identify any outward signs of distress caused by the flood. After the visual observations, data on the 2011 flood, including the areal extent, water depths, water velocities, and the effect on groundwater at the FCS site, were compiled. Baseline data for the geology, geomorphology, geotechnical, and design conditions prior to the 2011 flood were also compiled. A list of flood-induced triggering mechanisms (Triggering Mechanisms) was identified. Triggering Mechanisms could have caused degradation to the soil and/or rock that supports the FCS structures and/or caused direct impacts to structures due to the force of the floodwaters (Triggering Mechanisms). Examples of Triggering Mechanisms include settlement, erosion, stability, hydraulic actions, and frost actions. Using the list of potential Triggering Mechanisms, a list of PFMs was developed. PFMs are the ways in which a structure might fail. Failures are any errors or defects, and can be potential or actual. Examples of PFMs include undermining and settlement of shallow foundation/slab, undermined buried utilities, and loss of lateral support for pile foundations. A detailed list of Triggering Mechanisms and PFMs is presented in Table 7-1.

Table 7-1 – Triggering Mechanisms and Potential Failure Modes

Triggering Mechanism No.	Triggering Mechanism	PFM No.	Potential Failure Mode
1	River Bank Erosion/Scour	1a	Undermining shallow foundation/slab
		1b	Loss of lateral support for pile foundation
		1c	Undermined buried utilities pipes/cables
		1d	Additional lateral force on piles
2	Surface Erosion	2a	Undermining shallow foundation/slab
		2b	Loss of lateral support for pile foundation
		2c	Undermined buried utilities
3	Subsurface Erosion/Piping	3a	Undermining and settlement of shallow foundation/slab (due to pumping)
		3b	Loss of lateral support for pile foundation (due to pumping)
		3c	Undermined buried utilities (due to pumping)
		3d	Undermining and settlement of shallow foundation/slab (due to river drawdown)
		3e	Loss of lateral support for pile foundation (due to river drawdown)
		3f	Undermined buried utilities (due to river drawdown)
		3g	Sinkhole development due to piping into karst voids
4	Hydrostatic Lateral Loading (water loading on structures)	4a	Overturning
		4b	Sliding
		4c	Wall failure in flexure
		4d	Wall failure in shear
		4e	Excess deflection
5[A]	Hydrodynamic Loading	5a	Overturning
		5b	Sliding
		5c	Wall failure in flexure
		5d	Wall failure in shear
		5e	Damage by debris
		5f	Excess deflection
6	Buoyancy, Uplift Forces on Structures	6a	Fail tension piles
		6b	Cracked slab, loss of structural support
		6c	Displaced structure/broken connections
7	Soil Collapse (first time wetting)	7a	Cracked slab, differential settlement of shallow foundation, loss of structural support
		7b	Displaced structure/broken connections
		7c	General site settlement
		7d	Piles buckling from down drag
8	Soil Solutioning	8a	Not applicable
9	Swelling of Expansive Soils	9a	Cracked slab, differential heave of shallow foundation, loss of structural support
		9b	Displaced structure/broken connections
		9c	Fail tension piles
		9d	Additional lateral force on below-grade walls

Table 7-1 – Triggering Mechanisms and Potential Failure Modes			
Triggering Mechanism No.	Triggering Mechanism	PFM No.	Potential Failure Mode
10	Machine/Vibration-Induced Liquefaction	10a	Cracked slab, differential settlement of shallow foundation, loss of structural support
		10b	Displaced structure/broken connections
		10c	Additional lateral force on below-grade walls
		10d	Pile/pile group instability
11	Loss of Soil Strength due to Static Liquefaction or Upward Seepage	11a	Cracked slab, differential settlement of shallow foundation, loss of structural support
		11b	Displaced structure/broken connections
		11c	Additional lateral force on below-grade walls
		11d	Pile/pile group instability
12	Rapid Drawdown	12a	River bank slope failure and undermining surrounding structures
		12b	Lateral spreading
13	Submergence	13a	Corrosion of underground utilities
		13b	Corrosion of structural elements
14	Frost Effects	14a	Not applicable
15	Karst Foundation Collapse	15a	Piles punching through karst voids due to additional loading

[A] - Triggering Mechanism 5 applies to only the Missouri River. There was low velocity of flow over the FCS site.

Using the knowledge compiled for the baseline on each structure's design standard (for example, shallow or deep founded building or buried utility), a list of applicable PFMs was compiled for each structure. These PFMs were screened to determine if they were "credible" (CPFMs), which means a particular PFM could have occurred or could be in progress due to the changes caused by the 2011 flood. This included a determination of whether the Triggering Mechanisms for the CPFMs could have been or were actually initiated by the flood (potential for degradation/direct floodwater impact). As a result, some PFMs were determined to be non-credible. For example, PFMs arising from river bank erosion were eliminated because no evidence of bank erosion was observed. A detailed list of PFMs eliminated from detailed study is presented in Section 3.6.

During detailed assessment, when additional data was available including the results of the systematic visual observations, a secondary screening took place to rule out more of the CPFMs. This might have resulted in the elimination of all of the CPFMs initially identified for a particular structure, or there could be remaining CPFMs, which are discussed in detail in this Assessment Report. Also, the PFMs screened out as non-credible in the initial screening described above were reviewed again in light of the additional available data to determine if they should be added back to the list of CPFMs. The remaining CPFMs were evaluated to determine first the potential for degradation to the soil or rock that supports the structure and/or the direct floodwater impacts due to the 2011 flood and then the implications of that degradation to a structure of that particular design type. The combination of the potential for degradation/direct floodwater impact and the implications of that degradation/impact is termed the "potential for failure" and is then categorized as "significant" or "not significant." The final step in the analysis was to evaluate the "confidence" in the potential-for-failure significance determination as either "low" or "high."

7.3 Principal Findings of the Comparative Geotechnical Analysis

Comparison of geotechnical data for pre-flood and current investigations indicates that there was no observable difference in the overall geotechnical conditions at the site and that the foundation materials have not been disturbed or significantly weakened by the prolonged inundation caused by the 2011 flood. Comparison of seismic refraction data from the pre-flood and current investigations reveals similar magnitude of seismic wave velocities over the full depth of the overburden soils, and no observable differences between pre- and post-flood conditions were identified from this work.

Based on these findings and evaluations, the overall geotechnical conditions at the site have not been significantly altered due to the sustained high water. The observed scatter of data points is consistent with the relatively wide range of strength and stiffness and corresponding blow counts typically encountered in the alluvial soils within the Missouri River valley. Additional test borings are planned at the FCS site, and data from these SPTs will be incorporated into this assessment when available. However, these findings are considered applicable only to those soils present below a depth of 10 feet at the site. The upper 10 feet were hydro-excavated to avoid damaging buried utilities. This upper layer may have been disturbed from underseepage beneath the temporary levees or from the settlement of utility backfill during drawdown of the river level and groundwater.

7.4 Key Distress Indicators

During the site visual assessments, three problem areas were observed that potentially indicated that the 2011 flood had changed the site's geotechnical and physical character. These observed problem areas, referred to as Key Distress Indicators (KDIs), are the following:

1. Increased groundwater flow into the Turbine Building sump
2. Pavement failure and sinkhole in the paved access area between the Intake Structure and Service Building
3. Column settlement in the Maintenance Shop

The locations of these KDIs are shown in Figure 4-1. Each of the observed KDIs was evaluated using PFM analysis to determine the associated Triggering Mechanism, to identify the CPFMs, to identify other structures that could be affected by the same PFM, and to recommend remedial measures intended to restore the KDIs to their pre-flood condition.

7.4.1 Turbine Building Sump

7.4.1.1 Summary of Analysis

The Turbine Building basement floor drilling and subgrade testing identified both a number of significant voids/soft spots as well as zones of competent soil. Table 4-2 provides the drill-hole number (see Figure 4-3 for drill-hole locations), depth to void and thickness of soft zone (per DCP). The lateral extent and interconnectedness of identified voids can only be inferred from the available data. However, some zones such as the voids encountered in DCP 2-6, DCP 1-4, DCP 1-5 and DCP 2-8 are both significant enough and close enough in lateral distance that we conclude that these voids are part of a connected void system. All of these voids are close to where both the 10-inch and 6-inch drain lines run adjacent to each other and have multiple bends where joints may be more susceptible to cracking or separation in the pipe. In this scenario, significant groundwater inflow into the drainage system is likely. There also are, however, zones where there is little to no evidence of voids or subgrade deterioration such as in testing locations 2-10, 2-11, 2-12, 1-8, 2-14, and 2-18. Overall the data support the following conclusions:

- The Triggering Mechanism of subsurface piping of soil material due to the sump operation and seepage/flow into the drainage system pipes is occurring.
- Voids are significant and interconnected.
- The foundation subgrade is not affected uniformly by this Triggering Mechanism.

Regarding CPFM 3b - Loss of lateral pile support due to subsurface erosion and piping (due to pumping) for the Turbine Building. As discussed in Section 5.8, the thickness of the void and the potential effects on lateral pile support were considered. The maximum void thickness is 6.54 feet in DCP test location 2-8 and the elevation of the bottom of this void is 980.63 ft. The deepest void in DCP test location 1-6 is 3.79 feet thick with the bottom at elevation 976.54. For the worst case in the collected data, pile support could be lost in limited areas to elevation 976.54. The maximum length of loss of lateral piling support due to a void, calculated from the bottom of the pile cap at elevation 983.5 to the lowest void bottom elevation at 976.54, is 7 feet. There are a total of 10 locations were zero blow count zones exist at elevation greater than three feet below the bottom of slab elevation of approximately 987 (bottom of pile cap elevation 984). Of these 10 zero blow count zones, only five are greater in thickness than 1 foot. The remainder of the drill-hole locations have competent or greater than 1 blow per two inch material to within 3 feet of the bottom of the foundation slab or at the bottom of the pile cap elevation (el. 984).

Based on the available information and without a quantitative analysis we find that the loss of lateral piling support shown by the collected data under the Turbine Building, over the limited areas suggested by the collected data, does not infer that a significant risk of piling failure is present in static conditions due to the presence of the existing voids. Therefore, we have ruled out CPFM 3b for the Turbine Building. It should be noted that the subsurface erosion piping Triggering Mechanism is ongoing and that lateral pile support could be compromised in the future if void thickness and extent continues to increase. Seismic considerations have not been assessed for this report and we do not make any conclusion with respect to the effect of voids on lateral pile support during seismic loading.

The data from the Turbine Building sub-slab investigations cannot be used to rule out CPFM 3b for other pile-supported structures in the vicinity of the Turbine Building, including: Containment Building, Auxiliary Building, Service Building, Circulating Water System, Turbine Building South Switchyard, and the Fuel Oil Storage Tanks and Piping.

Two other CPFMs associated with KDI #1 and Triggering Mechanism #3 have not been ruled out by the Turbine Building sub-slab investigations and have the potential to continue to affect structures other than the Turbine Building. They are:

- CPFM 3a – Undermining and settlement of shallow foundation/slab/surfaces (due to pumping)
- CPFM 3c – Undermined buried utilities (due to pumping)

Structures potentially affected include: Technical Support Center, Fire Protection System, Raw Water Line, Security BBRE's, Maintenance Shop, Underground Cable Trench (Trenwa), Waste Disposal Piping, Main Underground Cable Bank, Blair Water System, Demineralized Water System, Turbine Building South Switchyard, Fuel Oil Tanks and Piping, PA

Paving/Sidewalks/Outdoor Drives, Sanitary Sewer System, and Condensate Storage Tank (buried utilities portion of system). For this Triggering Mechanism to affect these structures, a void would have had to progress beyond the Turbine Building Basement foundation and extend under the Structures listed above. The fact that the flow into the broken pipes has been occurring for many years makes the hypothesis that the voids could have extended beyond the Turbine Building foundation and under the Structures listed above more plausible. The collected data showing that voids were found at the perimeter of the Turbine Building basement between the pile caps at 11 locations also suggests that piping of material from beyond the Turbine Building Basement subgrade may have occurred.

The Triggering Mechanism of subsurface erosion/piping of soil from beneath the Turbine Building basement and perhaps beyond continues as long as the drain system piping remains unrepaired. Voids, soft zones, and associated groundwater and piping flow paths will continue to enlarge and extend out from the drainage and sump system over time unless the flow of water into the sump system is stopped. Therefore, CPFMs 3a, 3b and 3c for the Structures listed above cannot be ruled out and remain credible until the following remedial recommendations are implemented to stop the Triggering Mechanism.

7.4.1.2 Recommendations

OPPD should perform remedial work to stop the uncontrolled drainage of the groundwater into the broken Turbine Building basement drainage system piping and fill the voids beneath the basement floor slab. The first priority is to stop the drainage of groundwater into the drainage system as quickly as possible to stop the Triggering Mechanism. The quickest and easiest way to stop the flow of groundwater into the sump is to block the drainage system pipes at their termination points into the sump. An alternative to the repair of the existing drainage system is to abandon the existing system entirely, and replace it with an above-structural-floor-slab system. One option to implement this alternative would be to construct a new system that is entirely above basement floor that would utilize pump(s) to remove water from the existing floor drains and the turbine drains. Another option would be to trench cut the 7 inch concrete topping on the structural slab to allow space for installation of new drain pipes. Both these options would facilitate monitoring and access to the system should repairs be necessary.

In addition to drainage system repair, the voids created by the subsurface erosion/piping should be filled. These voids were apparently caused by groundwater flow through the broken drainage system pipes. Because the extent of the voids cannot be defined beyond the perimeter of the Turbine Building, the volume of the material required to fill the voids should be measured to provide a proof of the extent of the voids.

The repair/replacement of the drainage system and filling of the voids to return the foundation soils and subgrade to pre-pipe break condition will allow us to rule out CPFMs 3a, 3b, and 3c for the Structures listed in Section 4.1.3. To fill the voids and determine the volume of the voids a grouting program should be implemented.

The grouting program design should include:

- Specifications for a grout mix that has the proper rheologic and chemical properties to ensure a balanced, stable mix that will maximize penetration and long-term performance.
- Specifications for a grout mix that can displace very soft disturbed zones and that can provide long term support for the piles, footing, and slabs.

- Identification of the grout pressure(s) necessary to provide for maximum grout penetration into voids, and soft zones within the subgrade soil material.
- Identification of the maximum grouting pressure allowable to avoid damage to any structures and utilities. Particular attention should be given to the under-slab drain pipes in the event that they are repaired and re-used.
- A plan for real-time, full-time, monitoring and recording of:
  - Grout volumes and pressures under the direction of a qualified engineer at the time of the grouting.
  - Any movement of key Structures during grouting operations.
  - Groundwater elevations outside of the Turbine Building Basement during and after the grouting operation.
- A sequence/logic tree for grout program progression.
- A plan for the drilling of verification holes to include permeability tests to assess the affect of the grouting program on the subgrade soils.
- A grouting acceptance protocol by the Engineer.
- A system to report all of the grouting and monitoring data on a daily basis to the Engineer.
- A final report including all data, results and conclusions developed by the grouting contractor. This should include data on grouting locations, grout takes for each location, verification holes and results, and monitoring and any other data that would support the conclusion that the subsurface voids have been filled.

As mentioned previously, OPPD should consider abandoning the existing drainage pipes that are in place below the Turbine Building basement floor slab. Attempting to grout the voids after the existing drainage pipes have been repaired will likely damage or even crush the pipes and complicate the grouting process to the detriment of the overall remediation.

This specialized type of grouting operation is necessary both to properly treat the subsurface voids and soft zones and to provide verification and documentation that the program was a success. We recommend the selection of a specialty grouting contractor experienced in performing this type of work. Pre-bid selection criteria should be developed and potential bidders should be pre-qualified based on the selection criteria.

At the time of the writing of this report, it was not certain that a grouting contractor could be found that could implement a program that would yield the data necessary to rule out the remaining CPFMs described above. Discussions with specialty grouting contractors will be scheduled as soon as possible in the future to ascertain if they have the capability to provide the data necessary to rule out the remaining CPFMs.

7.4.2 Paved Access Area

7.4.2.1 Summary of Analysis

Forensic investigations were performed where observed pavement distress was most prominent, at locations coincident with shallow underground structures and utilities, and where recent seismic surveys identified low velocity features (locations where potential for degradation related to the Triggering Mechanisms and CPFMs associated with KDI #2 was identified).

Excavation and subgrade testing identified no evidence of piping erosion, voids, or subsidence of site fills. Field SCP testing of the exposed subgrade indicated that stiff to very stiff soils were generally encountered in the upper 3 feet below the ground surface or pavement. Based on the observations made and tests results obtained, the fill soils in the locations exposed and tested are compact, cohesive soils that are not susceptible to piping erosion. SPT borings did not identify voids or very soft/very loose conditions that might indicate piping or related material loss nor did they identify changes in soil relative density following the 2011 flood. Inclinometer and survey monitoring indicates that movement of on-site subsurface soils or structures has not occurred.

Possible Triggering Mechanisms and related CPFMs identified for KDI #2 and the PAA include:

- Subsurface Erosion and Piping (due to pumping), CPFMs 3a, 3b, and 3c.
- Subsurface Erosion and Piping (due to rapid river drawdown), CPFMs 3d, 3e, and 3f.

Based on the observations and test results, the individual distress indicators that comprise KDI #2 are not attributed to the possible Triggering Mechanisms identified for KDI #2: Subsurface Erosion and Piping (due to pumping); and, Subsurface Erosion and Piping (due to rapid river drawdown).

Our investigation for KDI #2 also indicates that the Triggering Mechanism of Subsurface Erosion and Piping (due to rapid river drawdown) was not initiated by the 2011 flood and that the CPFMs related to this Triggering Mechanism, including CPFM 3d, 3e, and 3f, are not credible.

However, the Triggering Mechanism of Subsurface Erosion and Piping (due to pumping) and the CPFMs related to this Triggering Mechanism, including CPFM 3a, 3b, and 3c cannot be ruled out for all structures associated with the PAA. Even though this Triggering Mechanism does not appear to have caused the distresses observed in the PAA, their root cause (damaged Turbine Building sub-floor drain pipes and sump pumping) as identified by investigations in the Turbine Building basement continues. A number of other Priority 1 and Priority 2 structures have been assigned CPFMs that are related to this remaining credible Triggering Mechanism and its related CPFMs. These other structures differ from KDI #2 and the PAA in that no strong evidence of distress has been identified or documented through assessment observations or ongoing survey monitoring.

Priority 1 Structures in this category include:

- Security BBREs
- Turbine Building South Switchyard
- Condensate Storage Tank
- Underground (TRENWA) Cable Trench
- Circulation Water System
- Demineralized Water System (line)
- Raw Water Piping
- Fire Protection System Piping
- Waste Disposal Piping
- Fuel Oil Storage Tanks and Piping

- Main Underground Cable Bank, Auxiliary Building to Intake Structure
- Blair Water System
- River Bank

Priority 2 Structures in this category include:

- Service Building
- Sanitary Sewer System

The potential for impact to the above Priority 1 and Priority 2 Structures from the Triggering Mechanism of Subsurface Erosion and Piping (due to pumping) exists and the CPFMs related to this Triggering Mechanism remain credible until the recommendations related to KDI #1 as presented below are implemented and completed. Continued monitoring of the above structures will be required after these recommendations are implemented and completed to evaluate if the recommended actions were effective and the CPFMs are therefore no longer deemed credible.

HDR concluded that the Subsurface Erosion/Piping Triggering Mechanism (due to pumping) most-likely did not extend outside the perimeter of the Seismic investigation lines taken around the power block. This conclusion supports the ruling out of the Subsurface Erosion/Piping (due to pumping) CPFMs associated with this Triggering Mechanism for the following Structures:

- Security Building
- Intake Structure
- River Bank

7.4.2.2 Recommendations

The results of this KDI #2 forensic investigation have ruled out potential Triggering Mechanisms and associated CPFMs that could have been the cause of the observed distress. However, it could not be used to entirely rule out CPFMs associated with KDI #1, which is associated with the uncontrolled drainage of the groundwater into the broken Turbine Building basement drainage system piping. These CPFMs will only be ruled out when the physical modifications presented for KDI #1, as presented in Section 4.1 of this Assessment Report, are implemented.

7.4.3 Maintenance Shop

7.4.3.1 Summary of Analysis

Forensic investigation consisting of concrete floor slab drilling and field and laboratory subgrade testing was completed in the Maintenance Shop to evaluate subsurface conditions near Key Distress Indicator (KDI) #3. This Key Distress Indicator consists of differential settlement of Building Column MG-15, presumed differential settlement of the nearby floor slab, and cracked nearby masonry partition walls. These building distresses were observed at the southwest corner of the building immediately adjacent to the north side of the Turbine Building during facility assessments.

Possible Triggering Mechanisms identified for KDI #3 include:

- Subsurface Erosion and Piping (due to pumping); and
- Soil Collapse (due to first time wetting).

Observations of the conditions underlying the floor slab in the vicinity of Column MG-15 confirm that the subgrade has subsided and a void space has developed. The void space ranges from about none to 8.5 inches in depth below the bottom of the floor slab and extends about 15 feet to the north, east and west-northwest of Column MG-15. The lateral extent of void beneath the floor slab to the south, southeast and southwest was not determined by this investigation.

Field testing including SCP and DCP tests on the subgrade soil below the floor slab did not identify the presence of voids or soft soils below the top of subgrade at tested locations. Field observations and laboratory testing from this investigation and from the previous GSI investigation are in general agreement and indicate that the fine grained loess derived fill in the vicinity of Column MG-15 consists of medium stiff to stiff, low plasticity silt that has allowable bearing pressure of 2,000 psf or greater. Neither field observations nor field and laboratory testing performed for this investigation indicated poor fill placement or conditions that would result in subgrade or column settlement of the magnitude observed.

Based on these observations and field and laboratory test results, the subsidence and resultant void identified below the floor slab and the column settlement and apparently related settlement cracking expressed in nearby masonry walls is not attributed to the Triggering Mechanism of Soil Collapse (due to first time wetting). As such, the CPFMs associated with this Triggering Mechanism; 7a - Cracked Slab/Differential Settlement of Shallow Foundation, and Loss of Structural Support; 7b - Displaced Structure/Broken Connections; and 7c - General Site Settlement, are ruled out for the Maintenance Shop.

In addition to the distress in the Maintenance Shop, cracks have recently been observed and documented in the Technical Support Building in areas located south, southwest, and west of the Maintenance Shop distress area (area of subgrade void, settled column, and wall cracking). The results of the assessment for the Technical Support Center (see Section 5.5) indicate that this distress is associated with KDI #3. Therefore, the Triggering Mechanism of Soil Collapse and its associated CPFMs listed above are also ruled out for the Technical Support Center.

The results of this KDI #3 forensic investigation show that the Triggering Mechanism of Subsurface Erosion and Piping (due to pumping) is likely responsible for the subsidence and related void and settlement distress in the Maintenance Shop and the distress (cracked walls) in the Technical Support Center. Voids, material loss, and material movements have been identified by investigations in the Turbine Building Basement (KDI #1) including along the north wall of the Turbine Building which is a shared/adjoining wall with the Maintenance Shop. The voids/subgrade settlement and distress observed in the Maintenance Shop are believed to be directly related to deep subsurface piping erosion and soil losses occurring at and radiating out from damaged subfloor drain pipes in the Turbine Building subgrade.

Based on the KDI #1 investigation, it appears that material has been removed below the Turbine Building north wall through piping as a result of the hydraulic gradient created by the breaks in the subfloor drain pipes. Piping has been evidenced by depressed groundwater levels, measured voids below the Turbine Building basement floor slab, and sediment accumulated in the Turbine Building sump pit. The depressed groundwater levels and void conditions are more prominent near the northwest portion of the Turbine Building adjacent to the observed KDI #3 structural distresses. We presume that the piping and void conditions extend north beyond the extents of the Turbine Building basement floor slab and below portions of the Maintenance Shop (and Technical Support Center). The soil column above the presumed piping and void condition is thought to be subsiding as a block unit, or column and translating to the ground surface resulting in the void space observed below the floor slab. It should be noted that our investigation was not exhaustive. Subgrade void space was not delineated to the south, southeast, or southwest (see Figure 4-11), which are toward the locations of observed/measured groundwater flow, groundwater lows, and voids below the Turbine Building basement. It should also be noted that wall cracking expressed in the Maintenance Shop masonry walls of the Men's restroom appears to be expanding (crack aperture appears larger than previously noted during structure observations in August/September 2011).

7.4.3.2 Recommendations

The results of the KDI #3 forensic investigations have found that the distress observed in both the Maintenance Shop (failed column) and the Technical Support (cracked walls) are not associated with the Triggering Mechanism 7 - Soil Collapse (due to first time wetting). Therefore the CPFMs associated with this Triggering Mechanism (7a-7c) were ruled out by this forensic investigation. The results show that the distress in both the Maintenance Shop and the Technical Support Center are connected to KDI #1, which is associated with the uncontrolled drainage of the groundwater into the broken Turbine Building basement drainage system piping. KDI #1 is associated with the Triggering Mechanism of Subsurface Erosion/Piping (due to pumping) and the CPFM applicable to the Maintenance Shop and Technical Support Center is 3a - Undermining and settlement of shallow foundation/slab (due to pumping). This CPFM will only be ruled out when the physical modifications presented for KDI #1, as presented in Section 4.1 of this Assessment Report, are implemented.

It is recommended that OPPD implement physical modifications to remediate the distress in the Maintenance Shop as planned (helical piers and jacking). This may or may not affect adjacent masonry walls exhibiting settlement cracking. However, this does nothing to mitigate the likely cause of the observed Maintenance Shop distresses, Subsurface Erosion and Piping. Nor does it ensure that further distress will not be realized in other structural components of the building in nearby areas that may also be affected by Subsurface Erosion and Piping but not yet expressing any observable distress. Future distress could include other building support columns, the adjacent elevator shaft, and other nearby masonry walls (load bearing or not). It should be noted that our investigation did not determine the extent of settlement or voids to the south, southeast, or southwest of settled Column MG-15.

No further investigations are recommended for the purposes of this Assessment Report. However, further investigations could be undertaken by the owner as part of the design for the remedial work to repair the Maintenance Shop and Technical Support Center distress. This could include investigation of the subgrade below the floor slab in the Maintenance Shop to the south, southeast, and southwest of Column MG-15 to include drilling, coring, SCP and DCP tests, soil sampling, and laboratory testing as appropriate to delineate the area of subsiding subgrade and identify other structural building elements at risk. It is further recommended that the physical modifications outlined in the KDI #1 forensic investigations be competed before the physical modifications to remediate the distress in the Maintenance Shop and Technical Support Center are implemented. This is to ensure that the subsurface erosion/piping associated with the broken pipes under the Turbine Building basement slab is halted. Continued subsurface erosion/piping would most likely reduce the efficacy of any physical modifications designed to remediate the distress in the Maintenance Shop and the Technical Support Center.

7.5 Status of Priority 1 Structural Assessments

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. The results of the Assessment are detailed for each of the Priority 1 Structures in the paragraphs below.

7.5.1 Intake Structure

Because all CPFMs for the Intake Structure other than CPFMs 12a and 12b had been ruled out prior to Revision 1, and because CPFMs 12a and 12b have been ruled out as a result of the Revision 1 findings, no Triggering Mechanisms and their associated PFMs remain credible for the Intake Structure. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Intake Structure because the potential for failure of this structure due to the flood is not significant.

7.5.2 Auxiliary Building

Because all CPFMs for the Auxiliary Building 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 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Auxiliary Building. 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.

7.5.3 Containment

Because all CPFMs for the Containment 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 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Containment. 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.

7.5.4 Rad Waste Building

Because all CPFMs for the Rad Waste Building other than CPFMs 7b and 7d had been ruled out prior to Revision 1, and because CPFMs 7b and 7d have been ruled out as a result of the Revision 1 findings, no Triggering Mechanisms and their associated PFMs remain credible for the Rad Waste Building. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Rad Waste Building because the potential for failure of this structure due to the flood is not significant.

7.5.5 Technical Support Center

Because all CPFMs for the Technical Support Center other than CPFMs 3a, 6b, 6c, 7a, 7b, and 7c had been ruled out prior to Revision 1, because CPFMs 6b, 6c, 7a, 7b and 7c had been ruled out as a result of the Revision 1 findings, and because CPFM 3a will be ruled out when the physical modifications recommended for KDIs #1 and #3 in Section 4.1 and 4.3 are implemented, no Triggering Mechanisms and their associated PFMs remain credible for the Technical Support Center. 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.

7.5.6 Independent Spent Fuel Storage Installation

Because all CPFMs for the ISFSI have been ruled out, no Triggering Mechanisms and their associated PFMs remain credible for the ISFSI. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the ISFSI because the potential for failure of this structure due to the flood is not significant.

7.5.7 Security Building

Because all CPFMs for the Security Building other than CPFMs 3a, 3d, 12a, and 12b had been ruled out prior to Revision 1, and because CPFMs 3a, 3d, 12a, and 12b have been ruled out as a result of the Revision 1 findings, no Triggering Mechanisms and their associated PFMs remain credible for the Security Building. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Security Building because the potential for failure of this structure due to the flood is not significant.

7.5.8 Turbine Building

Because all CPFMs for the Turbine Building other than CPFM 3b had been ruled out prior to Revision 1, and because CPFM 3b has been ruled out by the additional forensics investigations for KDI #1 (see Section 4.1), no Triggering Mechanisms and their associated PFMs will remain credible for the Turbine Building. 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.

7.5.9 Security Barricaded Ballistic Resistant Enclosures

Because all CPFMs for the Security BBREs other than CPFMs 3a and 3d had been ruled out prior to Revision 1, and because CPFMs 3a and 3d will be ruled out when the physical modifications recommended for KDI #1 in Section 4.1 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Security BBREs. 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.

7.5.10 Turbine Building South Switchyard

Because all CPFMs for the Turbine Building South Switchyard other than CPFMs 3a, 3b, and 3c had been ruled out prior to Revision 1, because CPFM 3a will be ruled out upon completion of the remediation to the switch foundation slab described in Section 5.10, and because CPFMs 3b and 3c will be ruled out when the physical modifications recommended for KDI #1 in Section 4.1, no Triggering Mechanisms and their associated PFMs will remain credible for the Turbine Building South Switchyard. 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.

7.5.11 Condensate Storage Tank

Because all CPFMs for the Condensate Storage Tank other than CPFMs 2b, 3c, 3e, and 3f had been ruled out prior to Revision 1, because CPFMs 2b, 3e, and 3f have been ruled out as a result of the Revision 1 findings, and because CPFM 3c will be ruled out when the physical modifications recommended for KDI #1 in Section 4.1 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Condensate Storage Tank. 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.

7.5.12 Underground Cable Trench

Because all CPFMs for the Underground Cable Trench (Trenwa) other than CPFMs 3a, 3c, 3d, 3f, and 14a had been ruled out prior to Revision 1, because CPFMs 3d, 3f, and 14a have been ruled out as a result of the Revision 1 findings, and because CPFMs 3a and 3c have been ruled out using the results of the KDI #2 investigation presented in Section 4.2, no Triggering Mechanisms and their associated PFMs remain credible for the Underground Cable Trench. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Underground Cable Trench because the potential for failure of this structure due to the flood is not significant.

7.5.13 Circulating Water System

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 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.

7.5.14 Demineralized Water Tank, Pump House, and RO Unit

Because all CPFMs for the Demineralized Water Tank, Pump House, and RO Unit other than CPFMs 3a and 14a had been ruled out prior to Revision 1, and because CPFMs 3a and 14a have been ruled out as a result of the Revision 1 findings, no Triggering Mechanisms and their associated PFMs will remain credible for the Demineralized Water Tank, Pump House, and RO Unit. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Demineralized Water Tank, Pump House, and RO Unit because the potential for failure of this structure due to the flood is not significant.

7.5.15 Raw Water Piping

Because all CPFMs for the Raw Water Piping System other than CPFMs 3a, 3c, 3d, and 3f had been ruled out prior to Revision 1, because CPFMs 3d and 3f were ruled out using the results of the KDI #2 investigation presented in Section 4.2, and because CPFMs 3a and 3c will be ruled out when the physical modifications recommended for KDI # 1 in Section 4.1 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Raw Water Piping 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.

7.5.16 Fire Protection System Piping

Because all CPFMs for the Fire Protection System Piping other than CPFMs 3a, 3c, 3d, 3f, 12a, and 12b had been ruled out prior to Revision 1, because CPFMs 12a and 12b have been ruled out as a result of the Revision 1 findings, because CPFMs 3d and 3f were ruled out using the results of the KDI #2 investigation presented in Section 4.2, and because CPFMs 3a and 3c will be ruled out when the physical modifications recommended for KDI # 1 in Section 4.1 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Fire Protection System Piping. 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.

7.5.17 Waste Disposal Piping

Because all CPFMs for the Waste Disposal Piping other than CPFMs 3a, 3c, 3d, and 3f had been ruled out prior to Revision 1, because CPFMs 3d and 3f were ruled out using the results of the KDI #2 investigation presented in Section 4.2, and because CPFMs 3a and 3c will be ruled out when the physical modifications recommended for KDI # 1 in Section 4.1 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Waste Disposal Piping. 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.

7.5.18 Fuel Oil Storage Tanks and Piping

Because all CPFMs for the Fuel Oil Storage Tanks and Piping other than CPFMs 3b, 3c, 3e, and 3f have been ruled out prior to Revision 1, because CPFM 3c has been ruled out assuming the implementation of the recommended physical modifications presented in Section 5.18, and because CPFMs 3b, 3e, and 3f will be ruled out when the physical modifications recommended for KDIs #1and #3 in Sections 4.1 and 4.3 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Fuel Oil Storage Tanks and Piping. 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.

7.5.19 Main Underground Cable Bank, Auxiliary Building to Intake Structure

Because all CPFMs for the Main Underground Cable Bank from the Auxiliary Building to the Intake Structure other than CPFMs 3a, 3c, 3d, 3f, 4c, 4d, 4e, 6b, 6c, 12a, and 12b had been ruled out prior to Revision 1, because CPFMs 4c, 4d, 4e, 6b, 6c, 12a, and 12b have been ruled out as a result of the Revision 1 findings, because CPFMs 3d and 3f were ruled out by the results of the KDI #2 investigations, and because CPFMs 3a and 3c will be ruled out when the physical modifications recommended for KDI #1 in Section 4.1 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Main Underground Cable Bank from the Auxiliary Building to the Intake Structure. 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.

7.5.20 Meteorological Tower and Miscellaneous Structures

Because all CPFMs for the Meteorological Tower other than CPFM 7c had been ruled out prior to Revision 1, and because CPFM 7c has been ruled out as a result of the Revision 1 findings, no Triggering Mechanisms and their associated PFMs remain credible for the Meteorological Tower. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Meteorological Tower because the potential for failure of this structure due to the flood is not significant.

7.5.21 Original Steam Generator Storage Building

There were no applicable CPFMs identified for the OSGS. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the OSGS because the potential for failure of this structure due to the flood is not significant.

7.5.22 Switchyard

Because all CPFMs for the Switchyard other than CPFMs 3a, 3b, and 3c had been ruled out prior to Revision 1, and because CPFMs 3a, 3b, and 3c have been ruled out as a result of the Revision 1 findings, no Triggering Mechanisms and their associated PFMs remain credible for the Switchyard. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Switchyard because the potential for failure of this structure due to the flood is not significant.

7.5.23 Transmission Towers

Because all CPFMs for the Transmission Towers other than CPFM 7c had been ruled out prior to Revision 1, and because CPFM 7c has been ruled out as a result of the Revision 1 findings, no Triggering Mechanisms and their associated PFMs remain credible for the Transmission Towers. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Transmission Towers because the potential for failure of this structure due to the flood is not significant.

7.5.24 Main Underground Cable Bank, MH-1 to Auxiliary Building

Because all CPFMs for the Main Underground Cable Bank from MH-1 to the Auxiliary Building other than CPFMs 3a and 3c have been ruled out, and because CPFMs 3a and 3c will be ruled out when the physical modifications recommended for KDI #1 in Section 4.1 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Main Underground Cable Bank from MH-1 to the Auxiliary Building. 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.

7.5.25 River Bank

Because all CPFMs for the River Bank other than CPFMs 3a, 3d, 12a, and 12b had been ruled out prior to Revision 1 and because CPFMs 3a, 3d, 12a, and 12b have been ruled out as a result of the Revision 1 findings, no Triggering Mechanisms and their associated PFMs remain credible for the River Bank. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the River Bank because the potential for failure of this structure due to the flood is not significant.

7.5.26 Blair Water System

Because all CPFMs for the Blair Water System other than CPFMs 3a, 3c, 7a, 7b, and 7c have been ruled out, because CPFMs 7a, 7b, and 7c will be ruled out as a result of the Revision 1 findings and the implementation of the physical modifications recommended in Section 5.26, and because CPFMs 3a and 3c will be ruled out when the physical modifications recommended for KDIs #1 and #3 in Section 4.1 and 4.3 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Blair 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.

7.5.27 Demineralized Water System

Because all CPFMs for the Demineralized Water System other than CPFM 3c had been ruled out prior to Revision 1, and because CPFM 3c will be ruled out when the physical modifications recommended for KDIs #1 and #3 in Section 4.1 and 4.3 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Demineralized 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.

7.5.28 Camera Towers and High Mast Lighting

Because all CPFMs for the Camera Towers and High Mast Lighting other than CPFMs 3a, 3d, 12a, and 12b had been ruled out prior to Revision 1, and because CPFMs 3a, 3d, 12a, and 12b have been ruled out as a result of the Revision 1 findings, no Triggering Mechanisms and their associated PFMs remain credible for the Camera Towers and High Mast Lighting. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Camera Towers and High Mast Lighting because the potential for failure of this structure due to the flood is not significant.

7.6 Status of Priority 2 Structure Assessments

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. The results of the Assessment are detailed for each of the Priority 2 Structures in the paragraphs below.

7.6.1 New Warehouse

Because all CPFMs for the New Warehouse have been ruled out, no Triggering Mechanisms and their associated PFMs remain credible for the New Warehouse. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the New Warehouse because the potential for failure of this structure due to the flood is not significant.

7.6.2 Service Building

Because all CPFMs for the Service Building other than CPFM 3b had been ruled out prior to Revision 2, and because CPFM 3b will be ruled out when the physical modifications recommended for KDI #1 in Section 4.1 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Service Building. 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.

7.6.3 Chemistry/Radiation Protection Building

Because all CPFMs for the CARP Building have been ruled out, no Triggering Mechanisms and their associated PFMs remain credible for the CARP Building. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the CARP Building because the potential for failure of this structure due to the flood is not significant.

7.6.4 Maintenance Shop

Because all CPFMs for the Maintenance Shop other than CPFM 3a have been ruled out, and because CPFM 3a will be ruled out when the physical modifications recommended for KDIs #1 and #3 in Section 4.1 and 4.3 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.

7.6.5 Maintenance Fabrication Shop

Because all CPFMs for the Maintenance Fabrication Shop have been ruled out, no Triggering Mechanisms and their associated PFMs remain credible for the Maintenance Fabrication Shop. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Maintenance Fabrication Shop because the potential for failure of this structure due to the flood is not significant.

7.6.6 PA Paving, PA Sidewalks, and Outdoor Drives

Because all CPFMs for the PA Paving, PA Sidewalks, and Outdoor Drives other than CPFMs 2a, 3a, 7a, 7b, and 7c have been ruled out, and because CPFMs 3a will be ruled out when the physical modifications recommended for KDI #1 in Section 4.1 are implemented, and because CPFMs 2a, 7a, 7b, and 7c will be ruled out when OPPD completes their pavement restoration work, no Triggering Mechanisms and their associated PFMs will remain credible for the PA Paving, PA Sidewalks, and Outdoor Drives. 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 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.

7.6.7 Potable Water Piping

Because all CPFMs for the Potable Water Piping other than CPFM 7c have been ruled out, and because CPFM 7c will be ruled out as a result of placing engineered fill in locations where soil subsidence has occurred (detailed in Section 6.7), no Triggering Mechanisms and their associated PFMs will remain credible for the Potable Water Piping. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Potable Water Piping because the potential for failure of this structure due to the flood is not significant.

7.6.8 Sanitary Sewer System

Because all CPFMs for the Sanitary Sewer System other than CPFMs 3a and 3c have been ruled out, and because CPFMs 3a and 3c will be ruled out when the physical modifications recommended for KDI #1 in Section 4.1, and the physical modifications to MH-1(detailed in Section 6.8)are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Sanitary Sewer 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.

7.6.9 Maintenance Storage Building

Because all CPFMs for the Maintenance Storage Building have been ruled out, no Triggering Mechanisms and their associated PFMs remain credible for the Maintenance Storage Building. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Maintenance Storage Building because the potential for failure of this structure due to the flood is not significant.

7.6.10 Old Warehouse

Because all CPFMs for the Old Warehouse have been ruled out, no Triggering Mechanisms and their associated PFMs remain credible for the Old Warehouse. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Old Warehouse because the potential for failure of this structure due to the flood is not significant.

7.6.11 Training Center

Because all CPFMs for the Training Center have been ruled out, no Triggering Mechanisms and their associated PFMs remain credible for the Training Center. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Training Center because the potential for failure of this structure due to the flood is not significant.

7.6.12 Administration Building

Because all CPFMs for the Administration Building have been ruled out, no Triggering Mechanisms and their associated PFMs remain credible for the Administration Building. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Administration Building because the potential for failure of this structure due to the flood is not significant.

7.6.13 Hazardous Material Storage Building

Because all CPFMs for the Hazardous Material Storage Building have been ruled out, no Triggering Mechanisms and their associated PFMs remain credible for the Hazardous Material Storage Building. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Hazardous Material Storage Building because the potential for failure of this structure due to the flood is not significant.

7.6.14 Maintenance Garage

Because all CPFMs for the Maintenance Garage have been ruled out, no Triggering Mechanisms and their associated PFMs remain credible for the Maintenance Garage. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Maintenance Garage because the potential for failure of this structure due to the flood is not significant.

7.6.15 Tertiary Building

Because all CPFMs for the Tertiary Building (Boat Storage) have been ruled out, no Triggering Mechanisms and their associated PFMs remain credible for the Tertiary Building (Boat Storage). Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Tertiary Building (Boat Storage) because the potential for failure of this structure due to the flood is not significant.

7.6.16 Spare Transformer Pads

Because all CPFMs for the Spare Transformer Pads have been ruled out, no Triggering Mechanisms and their associated PFMs remain credible for the Spare Transformer Pads. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Spare Transformer Pads because the potential for failure of this structure due to the flood is not significant.

7.6.17 Shooting Range

Because all CPFMs for the Shooting Range other than CPFM 2a have been ruled out, and because CPFM 2a will be ruled out when the physical modifications recommended in Section 6.17 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Shooting Range. 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 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.

7.6.18 Gravel Parking Lots

Because all CPFMs for the Gravel Parking Lots have been ruled out, no Triggering Mechanisms and their associated PFMs remain credible for the Gravel Parking Lots. Therefore, HDR has concluded that the 2011 Missouri River flood did not impact the geotechnical and structural integrity of the Gravel Parking Lots because the potential for failure of this structure due to the flood is not significant.

7.6.19 Sewage Lagoons

Because all CPFMs for the Sewage Lagoons other than CPFMs 6c, 7b, and 7c have been ruled out, and because CPFMs 6c, 7b, and 7c will be ruled out when the physical modifications recommended in Section 6.19 are implemented, no Triggering Mechanisms and their associated PFMs will remain credible for the Sewage Lagoons. 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 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.

SECTION 9.0
ATTACHMENTS

9.0 ATTACHMENTS

9.1 Attachment 1 – Deaggregation Plots
9.2 Attachment 2 – Structural Baseline References
9.3 Attachment 3 – FCS Site Inspection Checklists
9.4 Attachment 4 – Triggering Mechanisms and Potential Failure Modes by Structure
9.5 Attachment 5 – Supporting Data for Comparative Evaluation of Geotechnical Analyses
9.6 Attachment 6 – Geotechnical Data from Subconsultants and OPPD
9.7 Attachment 7 – Photo Documentation
9.8 Attachment 8 – Field Reports, Field Notes, and Inspection Checklists