

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 gallons per minute (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.

Document Title	OPPD Document Number (if applicable)	Date	Drawing Number/ Page Number(s)
Underground Piping Extension	FC-UG-1A (#44740)	8/23/1990	
Underground Fire Loop	E-4182 (#41428)	Unknown	

Document Title	OPPD Document Number (if applicable)	Date	Drawing Number/ Page Number(s)
Fire Protection	SDBD-FP-115	3/9/2011	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 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.
- As early as 1993, excessive flow into a sump in the Turbine Building basement was observed. Subsequently, this flow was attributed to unfiltered groundwater entering breaks in drainage pipes under the Turbine Building basement floor slab. The Turbine Building is west of the corridor, and utilities are located between the Intake Structure and the Service Building.
- In 1997 a void, estimated to be approximately 10 x 8 x 1 ft, was documented below the basement floor slab in the Turbine Building. For further information see Section 5.8. A more detailed discussion of this KDI is presented in Section 4.1.
- Settlement of a column in the Maintenance Shop, north of the Turbine Building, has been documented. The Turbine Building and the Maintenance Shop are west of the corridor and associated utility alignments within the corridor.
- The Aqua Dam that surrounded much of the PA crossed the alignment of the fire protection system 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 because it was damaged, which allowed floodwater to enter the area inside the perimeter of the Aqua Dam. All surfaces above the fire protection system piping were inundated when the 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 much of the PA. 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.
- 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 fiberglass T-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 the 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., FWD). (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 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 floodwater (e.g., a surficial void 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 inside the 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 unabated. 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 areas inside and outside the perimeter of 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, 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.
- 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 floodwater.
- 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 Attachment 5, General Field Reports, FR 118). 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 floodwater has receded from the facility. The system is pressurized and operational. (Isolated cases of failure can be assessed as condition reports 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 CPM 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

Adverse (Degradation/Direct Floodwater Impact More likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
The Turbine Building sump pit has a history of groundwater inflows. Flood conditions increased the hydraulic head of water flowing into the sump.	
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.	
Data Gaps: <ul style="list-style-type: none"> • GPR data were not available at the time Revision 0 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 ReMi). • OPPD condition reports 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 were 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 the valve was opened 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 encircles the entire facility and is located in close proximity to many other utilities and structures. Because the fire protection system is highly pressurized, failure of the system could 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 floodwater has 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 encircles 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 GPR 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 floodwater has 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 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.

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 dropping 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.

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Below are 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.

Below are 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 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)
Floodwater 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:	
<ul style="list-style-type: none"> • 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 are apparent from pavement distress indicators and fire service line failures nearest the river. The installations of the fire protection system nearest the river bank are the connection points on 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 Structure 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 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.

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 dropped 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 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: <ul style="list-style-type: none"> • Observations of the riverbank following drawdown to nominal normal river elevations • Geophysical investigation data to address any observed concerns • Inclinator readings that will monitor for possible slope movements 	

ConclusionSignificance*Potential for Degradation/Direct Floodwater Impact*

The river stage level has dropped and stabilized at a level corresponding to the nominal normal river level at 40,000 cfs as of October 4, 2011. Rapid drawdown has been controlled, and continued river drawdown is not expected to occur at a rate that would initiate these CPFMs. Because 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 site 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, these CPFMs cannot be ruled out, and the confidence in the above assessment 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 (KDI #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 (KDI #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 these reports become available.

OPPD should initiate a procedure to monitor for problems during cable pulling operations. Problems associated with cable pulling operations to and from MHI-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 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.

5.16.7 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 FWD investigation by AET (see Attachment 6B).
- Results of geophysical investigation by Geotechnology (see Attachment 6C).
- Results of geotechnical investigation by Thiele Geotech (see Attachment 6A).
- Data obtained from inclinometers by Thiele Geotech (see Attachment 6A).
- Results of continued survey by LRA (see Attachment 6E).

5.16.7.2 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 show that the river and groundwater have returned to nominal normal levels.
- Field observations of river bank
No significance distress from the 2011 flood was observed.
- Results of FWD investigation by AET
FWD and associated GPR testing performed in the Paved Access Area identified anomalies such as soft clay and broken pavement. Additional ground truthing of the investigation results were performed as part of the KDI #2 additional investigations.
- Results of geophysical investigation by Geotechnology
Seismic refraction and seismic ReMi tests performed around the outside perimeter of the power block as part of KDI #2 identified deep anomalies that could be gravel, soft clay, loose sand, or possibly voids.
- Results of geotechnical investigation by Thiele Geotech
Six test borings were drilled, with continuous sampling of the soil encountered, to ground truth the Geotechnology seismic investigation results as part of the KDI #2 forensic investigation. Test bore holes were located to penetrate the deep anomalies identified in the seismic investigation. The test boring data did not show any piping voids or very soft/very loose conditions that might be indicative of subsurface erosion/piping or related material loss or movement.
Results of SPT and CPT tests conducted for this Assessment Report were compared to similar data from numerous other geotechnical investigations that have been conducted on the FCS site in previous years. This comparison did not identify substantial changes to the soil strength and stiffness over that time period. SPT and CPT test results were not performed in the top 10 ft to protect existing utilities.
Data from inclinometers to date, compared to the original baseline measurements, have not exceeded the accuracy range of the inclinometers. Therefore, deformation at the monitored locations since the installation of the instrumentation has not occurred.

- Results of continued survey by LRA

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

Triggering Mechanism 3 – Subsurface Erosion/Piping

CPFM 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

Except for the flow of groundwater into the Turbine Building sump, conditions that 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 these CPFMs is low.

Implication

The occurrence of these CPFMs could impact sections of the fire protection yard piping system and adjacent utilities or structures. The fire protection pipe system encircles the entire facility and is located in close proximity to many other utilities and structures. Because the fire protection system is highly pressurized, failure of the system could 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 floodwater has 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 KDIs #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 these CPFMs is high.

Summary

Forensic test results received since the issuance of Revision 0 have narrowed and defined probable areas impacted by these CPFMs. Recommended actions associated with the results of the forensic reports and site inspections will address known problem areas and will allow the direction of the expansion of proposed investigations and repairs as necessary to address the conditions created by these CPFMs. 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 these CPFMs is nearest the river. River bank inspections made since the issuance of Revision 0 show no indications of these CPFMs. 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 these CPFMs 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 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 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

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 these CPFMs 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.

Triggering Mechanism 12 – Rapid Drawdown

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

CPFM 12b – Lateral spreading

Significance*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 USACE, and continued river drawdown is not expected to occur at a rate that would initiate these CPFMs. Groundwater monitoring well measurements have been taken since floodwater has 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 these CPFMs is 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 site inspections. Therefore, the implication of the potential degradation for these CPFMs is low.

Confidence

Based on recent data and observations, these CPFMs were not created or initiated by the flood conditions associated with the 2011 flood, and confidence in the assessment associated with these CPFMs 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.

5.16.7.3 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 KDIs. 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 fire protection system are associated with KDI #1. Sections 4.1 and 8.3 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, 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 KDI #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 12a CPFM 12b

5.16.7.4 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 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 Sections 4.1 and 8.3 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.