5.25 River Bank

5.25.1 Summary of River Bank

The River Bank is considered the bank of the river adjacent to the PA and the bank of the river from the Security Building to the Tertiary Building. This area consists of about 900 lineal feet of bank. The normal river level is about el. 992 ft. The normal bottom of river elevation is about 975 ft.

The river channel was moved eastward to its present location by USACE in the 1950s. Revetment placed along the bank by USACE consisted of 3-pile clumps (dolphin tails) staggered every 7.5 ft and stone fill. The pile clumps consist of timber pile driven to about 25 ft below the bottom of the river with a cutoff elevation of 999 ft. The stone fill was placed from the river bottom to el. 994.5 ft with side slopes of 1H:1¼V. Soil fill was placed behind the stone fill, as necessary, to the ground surface elevation (about el. 995 ft prior to construction of the FCS plant).

Construction of the Intake Structure required about 400 ft of cofferdam to protect the excavation. The cofferdam consisted of nine main cells with connecting arcs between each main cell. The cells consisted of MP-101 sheets installed to el. 944 ft with a top elevation of 1004 ft. Soil fill was placed inside the cells to the top elevation. Excavation for the Intake Structure extended to about el. 964.5 ft. The revetment installed by USACE was removed within the limits of the cofferdam.

Upon completion of the Intake Structure, new revetment was placed and the cofferdam removed. The new revetment, consisting of stone fill extending a minimum of 10 ft into the bank, was placed from the river bottom to el. 994.5 ft with side slopes of 1H:1¼V. Soil fill was placed behind the stone fill, as necessary, and sloped at 3H:1V to el. 1003.5 ft.

5.25.2 Inputs/References Supporting the Analysis

Table 5.25-1 lists references provided by OPPD and other documents used to support HDR's analysis.

Table 5.25-1 - References for River Bank

Document Title	OPPD Document Number (if applicable)	Date	Page Number(s)
Elevations and Sections, River Bank, Sheet 1	13007.01-EA-1B, Rev. 5 (#11294)	7/26/2001	
Report of Subsoil Investigation	80-5-2	7/26/1977	
Report of Subsoil Investigation for Addition	76E013	5/1/1986	
SDBD-STRUC-504, River Bank	SDBD-STRUC-504	10/9/2009	N/A
Excavation and Grading, Building Area	11405-S-272 (#16504)	1/18/1975	
Excavation and Grading, Cross Sections	11405-S-273 (#16505)	1/17/1975	
Site Grading Plan	11405-S-402 (#16574)	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 River Bank are provided in Attachment 8.

Observed performance and pertinent background data are as follows:

Above about el. 994.5 ft, current revetment was observed to consist of the following:

- A sheet pile wall from the Intake Structure to about 150 ft north
- A sheet pile wall around the Condensate Storage Tank
- Geotextile and riprap north of the sheet pile wall
- Geotextile and riprap south of the Security Building
- Concrete-filled fabric bags between the Intake Structure and the Condensate Storage Tank
- Concrete-filled fabric bags between the Condensate Storage Tank and the Security Building

Several pipes exit the revetment and discharge into the river. No backflow plugs were evident on the observed pipes. No flow was observed discharging from the pipes.

Additional pipes are anticipated to become visible as the river recedes.

Apparent erosion beneath the geotextile fabric was observed north of the Intake Structure.

Sediment was observed deposited along a majority of the bank.

5.25.3 Assessment Methods and Procedures

5.25.3.1 Assessment Procedures Accomplished

Assessments of the River Bank included the following:

- Visual inspection of the bank from the shore line. (The river was at about el. 996 ft.)
- Probe accessible areas of the bank. (The bank was not probed south of the Intake Structure.)
- Bathymetric survey of the river bottom (July 2011).

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

- Seismic surveys (seismic refraction and refraction micro-tremor) in the PA. (Test reports were not available at the time of Revision 0.)
- Geotechnical test borings in the PA. Note that OPPD required vacuum excavation for the first 10 ft of proposed test holes to avoid utility damage. 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.)

5.25.3.2 Assessment Procedures Not Completed

Assessments of the River Bank that were not completed include the following:

- Inclinometers installed along the River Bank to identify lateral movement. (Inclinometers were not installed at the time of Revision 0.)

5.25.4 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 5.25.4.1. The CPFMs carried forward for detailed assessment are discussed in Section 5.25.4.2.

5.25.4.1 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:

- Minimal surface erosion was observed on the River Bank.
- Observed surface erosion was considered inconsequential.

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

Reason for ruling out:

- The bathymetric survey did not indicate significant surface erosion around the pile clumps.

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

Reasons for ruling out:

- Pumping was a sufficient distance away from the piles to be outside the zone of influence of the CPFM.
- The stone fill revetment is not an erodible material.

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

Reasons for ruling out:

- The soils laterally supporting the piles are always below the river level.
- The stone fill revetment is not an erodible material.

Triggering Mechanism 5 – Hydrodynamic Loading
CPFM 5e – Damage by debris

Reason for ruling out:

- Damage to the River Bank by debris was not observed during the field assessments.

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 documented in 1993 as 1003.3 ft, which would indicate that soils below and surrounding the building were saturated at that time. Due to the elevation of the top of the bank (1003.5 ft), this was not the first time that wetting of the soil bank soils occurred.

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

Reasons for ruling out:

- Liquefaction was not observed to have occurred at the site.
- Distress that can be attributed to the CPFMs was not observed during the field assessments.

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 to have occurred near the River Bank.
- Distress that can be attributed to the CPFMs was not observed during the field assessments.

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

Reason for ruling out:

- The conditions the River Bank will be subjected to during the winter months are not different than what would have occurred before the flood.

5.25.4.2 Detailed Assessment of Credible Potential Failure Modes

The following CPFMs are the only CPFMs carried forward for detailed assessment for the River Bank 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 structures in the general vicinity of the River Bank that were pumped during the flood due to groundwater infiltration included:

- Manhole MH-5
- The Turbine Building sump pit
- The Trenwa near the Security Building
- Locations at low points adjacent to the Aqua Dam that surrounded much of the PA

Some of the site storm sewers that typically discharge into the river are currently not draining because the outfalls are below the river surface or have been plugged.

The Triggering Mechanism and CPFM could then occur as follows: once the river surface drops and the pipes are unplugged, groundwater could remain high enough to potentially infiltrate into open joints or holes in the sewer pipes, potentially resulting in an erosion potential situation similar to pumping.

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 River Bank:

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
Some erosion was observed below geotextile fabric north of the Intake Structure.	
Data Gaps: • The extent of subsurface erosion due to groundwater pumping is not known. • Subsurface conditions and how they may facilitate the CPFM are not well understood. • Some of the storm sewer outlets may be clogged or are below the river level.	

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

One of the indicators for the CPFM has been observed at the Intake Structure. However, voids due to pumping may 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. The potential that degradation due to this CPFM has occurred is low.

Implication

The occurrence of this CPFM below the River Bank could negatively impact the performance of the River Bank revetment. This would manifest as surficial voids, which could negatively impact the integrity or intended function of isolated areas of the River Bank but is unlikely to impact a substantial area. Therefore, the implication of the potential degradation for this CPFM is low.

Confidence

The data at hand are not sufficient to rule out this CPFM or to lead to a conclusion that the River Bank revetment has or may become undermined because of this CPFM. Therefore, the confidence in the above assessment is low, which means more data are necessary to draw a conclusion.

Summary

For CPFM 3a, as discussed above, the potential for degradation is low. The implication of this degradation to the integrity or intended function of the River Bank 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 this CPFM. 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.

Triggering Mechanism 3 – Subsurface Erosion/Piping

CPFM 3d – Undermining and settlement of shallow foundation/slab (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.

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 River.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
Some erosion was observed below geotextile fabric north of the Intake Structure.	Previous flooding of the river has not resulted in slope failure.
Data Gaps: • Subsurface conditions and how they may facilitate the CPFM are not well understood.	

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

One of the indicators for the CPFM has been observed at the structure. However, voids due to river drawdown may not have been evident at the time of the field assessments. The potential that degradation due to this CPFM has occurred is low.

Implication

The occurrence of this CPFM below the River Bank could negatively impact the performance of the River Bank revetment. This would manifest as surficial voids, which could negatively impact the integrity or intended function of isolated areas of the River Bank but is unlikely to impact a substantial area. Therefore, the implication of the potential degradation for this CPFM is low.

Confidence

The data at hand are not sufficient to rule out this CPFM or to lead to a conclusion that the River Bank revetment has or may become undermined because of this CPFM. Therefore, the confidence in the above assessment is low, which means more data are necessary to draw a conclusion.

Summary

For CPFM 3d, as discussed above, the potential for degradation is low. The implication of this degradation to the integrity or intended function of the River Bank 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 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 may be necessary to draw a conclusion.

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 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 mass of the slope (driving force) and decreased shear strength (resisting force). The saturation of previously unsaturated soils decreases the soils' shear strength, and loss of effective stress below the river decreases the soils' shear strength. This shear strength will be regained once the excess water in the soil is allowed to drain. If the driving force exceeds resisting force, the slope will fail. Generally, slope failures associated with rapid drawdown are relatively localized and shallow.

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 River Bank.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
	Previous flooding of the river has not resulted in slope failure.
	The riverbank is protected by revetment.
Data Gaps: • Subsurface conditions and how they may facilitate the CPFM are not well understood.	

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

None of the indicators for these CPFMs has been observed at the structure. However, slope movement due to river drawdown may not have been evident at the time of the field assessments. The potential that degradation due to these CPFMs has occurred is low.

Implication

The occurrence of these CPFMs below the River Bank could negatively impact the performance of the River Bank revetment. This would manifest as movement of the River Bank, which could negatively impact the integrity or intended function of several areas of the River Bank. Therefore, the implication of the potential degradation for these CPFMs is high.

Confidence

The data at hand are not sufficient to rule out these CPFMs or to lead to a conclusion that the River Bank has or may move 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 12a and 12b, as discussed above, the potential for degradation is low. The implication of this degradation to the integrity or intended function of the River Bank is high. 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 may be necessary to draw a conclusion.

5.25.5 Results and Conclusions

The CPFMs evaluated for the River Bank 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 3d CPFM 12a CPFM 12b	

5.25.6 Recommended Actions

The following actions are recommended for the River Bank.

A review of the geotechnical and geophysical data and an assessment of the impact on the River Bank are recommended.

Additional field assessments of the River Bank once the river level has dropped to nominal normal levels and the groundwater elevation has stabilized are recommended to address CPFM 3a, 3d, 12a, and 12b.

Continued monitoring is recommended to include a continuation of elevation surveys of the previously identified targets on the surrounding site. The purpose is to monitor for signs of 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.

USACE reduced Missouri River Mainstem System releases to 40,000 cfs on October 2, 2011, which will result in a nominal normal flow at FCS. USACE plans to hold the release level at 40,000 cfs until mid-December. River levels corresponding to the 40,000 cfs release stabilized at FCS on October 4, 2011. Stabilization of groundwater levels at the site will lag the reduction in river stage. HDR estimates that groundwater levels will stabilize at a level corresponding to the nominal normal river level at 40,000 cfs within 2 to 4 weeks.

5.25.7 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.

5.25.7.1 Additional Data Available

The following additional data were available for the River 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 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)

5.25.7.2 Additional Analysis

The following analysis of additional data was conducted for the River Bank:

- 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 the River Bank

  No significance distress from the 2011 Flood was observed.

- 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.

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

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

- Results of continued survey by LRA

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

Triggering Mechanism 3 – Subsurface Erosion/Piping

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

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

Field observations of the River Bank on October 27, 2011, did not identify deformation of the River Bank that could be attributed to undermining and settlement of shallow foundations, slabs, or surfaces. 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. Effects due to pumping in the vicinity of the riverbank during flooding would be apparent at this time. Therefore, undermining and settlement of shallow foundations, slabs, or surfaces did not occur due to the 2011 flood.

Significance

Potential for Degradation/Direct Floodwater Impact

The potential that degradation due to these CPFMs has occurred is low due to the amount of time elapsed since pumping was stopped and subsequent field inspections of the River Bank.

Implication

The occurrence of these CPFMs below the River Bank could negatively impact the performance of the River Bank revetment. This would manifest as surficial voids, which could negatively impact the integrity or intended function of isolated areas of the River Bank but is unlikely to impact a substantial area. Therefore, the implication of the potential degradation for these CPFMs is low.

Confidence

The data at hand are sufficient to rule out these CPFMs. Therefore, the confidence in the above assessment is high, which means more data are not necessary to draw a conclusion.

Summary

For CPFMs 3a and 3d, as discussed above, the potential for degradation is low. The implication of this degradation to the integrity or intended function of the River Bank 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 sufficient to rule out these CPFMs due to the 2011 flood. Therefore, the confidence in the above assessment is high, which means no more data or continued monitoring and inspections will be necessary to draw a conclusion.

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 27, 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.

Significance

Potential for Degradation/Direct Floodwater Impact

The potential that degradation due to these CPFMs has occurred is low.

Implication

The occurrence of these CPFMs below the River Bank could negatively impact the performance of the River Bank revetment. This would manifest as movement of the River Bank which could negatively impact the integrity or intended function of several areas of the River Bank. Therefore, the implication of the potential degradation for these CPFMs is high.

Confidence

The data at hand are sufficient to rule out these CPFMs. Therefore, the confidence in the above assessment is high, which means more data are not necessary to draw a conclusion.

Summary

For CPFMs 12a and 12b, as discussed above, the potential for degradation is low. The implication of this degradation to the integrity or intended function of the River Bank is high. 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 sufficient to rule out these CPFMs due to the 2011 flood. Therefore, the confidence in the above assessment is high, which means no more data or continued monitoring and inspections will be necessary to draw a conclusion.

5.25.7.3 Revised Results

The CPFMs evaluated for the River Bank are presented in the following matrix, which shows the rating for the estimated significance and the level of confidence in the evaluation. CPFMs 3a, 3d, 12a and 12b for the River Bank are not associated with any KDIs. The data currently collected are sufficient to rule out these CPFMs due to the 2011 flood. Therefore, 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 3d CPFM 12a CPFM 12b

5.25.7.4 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 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.