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- Attachment 10 Technical Memoranda

Acronyms and Abbreviations

Acronyms and Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
AET	American Engineering Testing, Inc.
ALARA	As Low As Reasonably Achievable
ANSS	Advanced National Seismic System
API	American Petroleum Institute
Assessment Report	Fort Calhoun Station Plant and Facility Geotechnical and Structural Assessment Report
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
BBRE	Barricaded Ballistic Resistant Enclosure
Blair Water	City of Blair's municipal water system
Boat Storage	Tertiary Building
BTOS	below top of subgrade
CARP	Chemistry/Radiation Protection Building
CBR	California bearing ratio
CEUS	Central and Eastern United States
cfs	cubic feet per second
CHDPE	corrugated high density polyethylene
cm	centimeter(s)
CME	Central Mine Equipment
CMP	corrugated metal pipe
CMU	concrete masonry unit
CPFM	credible potential failure mode
CPT	cone penetration test
CQE	Critical Quality Element

Acronyms and Abbreviations

CR	Condition Report
DCP	dynamic cone penetrometer
el.	elevation
EM	electromagnetic
EPDM	ethylene propylene diene monomer
EPS	Elite Pipeline Services
FAA	Federal Aviation Administration
FCS	Fort Calhoun Station
FEMA	Federal Emergency Management Agency
fps	feet per second
FRP	fiberglass reinforced plastic
ft	feet
FW	Force Water
FWD	falling weight deflectometer
Geotechnology	Geotechnology, Inc.
GHz	gigahertz
gpm	gallons per minute
GPR	ground-penetrating radar
HAF	Head Assembly Facility
Hazmat Shed	Hazardous Material Storage Building
HDR	HDR Engineering, Inc.
HVAC	heating, ventilation, and air conditioning
ICF	insulated concrete form
in.	inch(es)
ISFSI	Independent Spent Fuel Storage Installation
ISO	International Organization for Standardization

Acronyms and Abbreviations

KDI	Key Distress Indicator
kg	kilogram(s)
ksi	kips per square inch
kV	kilovolt(s)
LRA	Lamp Rynearson & Associates, Inc.
MAF	million acre-feet
Met	Meteorological
MH	Manhole
MW	Monitoring Well
NAS	negatively affected soil
NAVD 88	North American Vertical Datum of 1988
NGA	Next Generation Attenuation
NGVD 29	National Geodetic Vertical Datum of 1929
NOUE	Notification of Unusual Event
NQA-1	Nuclear Quality Assurance
OPPD	Omaha Public Power District
OS&Y	outside screw and yoke
OSGS	Original Steam Generator Storage Building
OSHA	Occupational Safety and Health Administration
P&ID	pipng and instrumentation diagrams
PA	Protected Area
PBD	Program Basis Document
pcf	pounds per cubic foot
PFM	potential failure mode
PGA	peak ground acceleration
psf	pounds per square foot

Acronyms and Abbreviations

psi	pounds per square inch
psig	pounds per square inch gauge
PVC	polyvinyl chloride
QA	Quality Assurance
QC	Quality Control
QCP	Quality Control Plan
RCP	reinforced concrete pipe
ReMi	refraction microtremor
RM	River Mile
RO	reverse osmosis
RP	Radiation Protection
RQD	rock quality designation
SCP	static cone penetrometer
SP	spontaneous potential surveying
SPT	standard penetration test
Thiele Geotech	Thiele Geotech, Inc.
Trenwa	Underground Cable Trench
U.S.	United States
USACE	U.S. Army Corps of Engineers
USAR	Updated Safety Analysis Report
USDA-NRCS	U.S. Department of Agriculture, Natural Resource Conservation Service
USGS	U.S. Geological Survey
VCP	vitriified clay pipe
WOH	weight of hammer

Definitions

Definitions

Class I	Class I indicates a system, structure, or component, including instruments and controls, whose failure might cause or increase the severity of an accident that could result in an uncontrolled release of radioactivity. This classification also includes components and structures vital to safe shutdown and isolation of the reactor.
Confidence	Confidence is an opinion regarding the need for additional information.
Credible PFMs (CPFMs)	CPFMs were those that were significant enough to demand further investigation and evaluation or studies that would increase the confidence in the findings or change the conclusion.
Critical Quality Element (CQE)	CQEs are structures, systems, components, or items whose satisfactory performance is required to prevent or mitigate the consequences of postulated accidents that could cause undue risk to the health and safety of the public.
Degradation	Degradation is a negative change to the soil or rock that supports a structure, caused by the sustained inundation of the FCS site during the summer of 2011, which could materially and negatively impact the integrity or intended function of the structure.
Key Distress Indicator	A Key Distress Indicator is an observed problem area that potentially indicated that the 2011 flood had changed the site's geotechnical and physical character.
Non-credible PFMs	Non-credible PFMs are those that were clearly so remote that they were considered negligible risk contributors.
Potential Failure Mode (PFM)	PFMs are the ways in which a structure might fail. Failures are any errors or defects, and can be potential or actual.
Potential for degradation/direct floodwater impact	a determination of whether the Triggering Mechanisms for the CPFMs could have been or were actually initiated by the flood.
Priority 1 Structures	Priority 1 Structures are those structures and systems that directly support plant operations.
Priority 2 Structures	Priority 2 Structures are those structures and systems that do not directly support plant operations.
Significance	Significance is determined by the combined consideration of two elements. The first element is the potential for degradation as described above. The second is the implications of that degradation to a structure built to its specific design standard.

Definitions

Triggering
Mechanism

Triggering Mechanisms are flood-induced triggering mechanisms that could have caused degradation of the soil and/or rock that supports the FCS structures and/or could have caused direct impacts on structures due to the force of the floodwater. Triggering Mechanisms could lead to a potential failure mode (PFM).

OPPD

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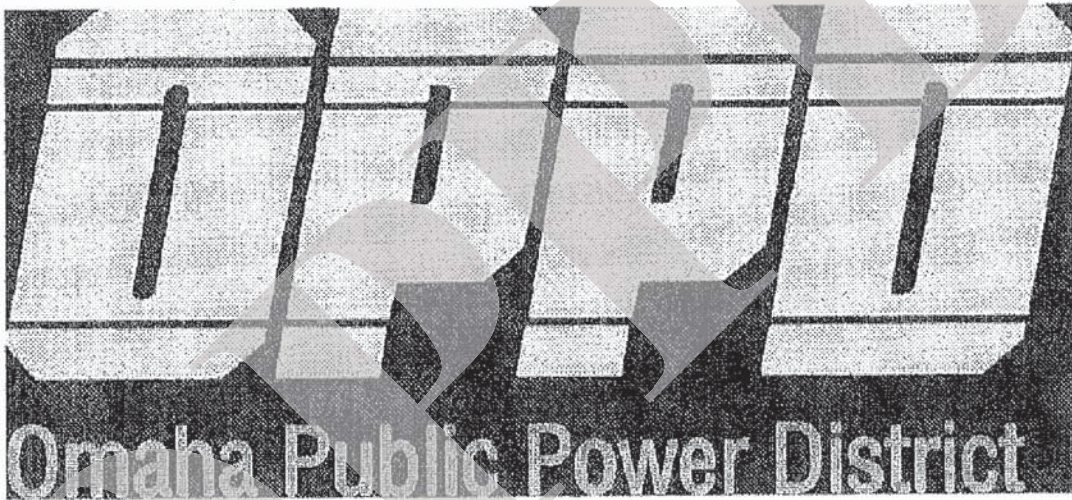
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SECTION 1.0

INTRODUCTION



OPPD

Introduction

1.0 INTRODUCTION

Omaha Public Power District's (OPPD's) Fort Calhoun Station (FCS) is a 484-megawatt nuclear power plant (OPPD, September 25, 2011). FCS is located on the west bank of the Missouri River in northeastern Washington County, Nebraska. FCS is located approximately 4 miles southeast of Blair, Nebraska, and approximately 19 miles north of Omaha, Nebraska.

Massive flooding in the Missouri River basin occurred in 2011, as described in Section 1.3, Background. Because FCS is located along the Missouri River, floodwater encroached on the FCS site. In June 2011, OPPD contracted HDR Engineering, Inc. (HDR) to provide professional engineering services in support of OPPD's Fort Calhoun Station Flooding Recovery Action Plan. HDR provided specialized engineering services for the assessment of geotechnical and structural changes caused by the 2011 Missouri River flood.

The flooding of the Missouri River during the summer of 2011 "significantly challenged" the operation of FCS (OPPD, August 10, 2011). In response to this event, OPPD prepared a Flooding Recovery Action Plan that documented the actions necessary for the repair and restoration of FCS operations. This Fort Calhoun Station Plant and Facility Geotechnical and Structural Assessment Report (Assessment Report) has been prepared in response to FCS Flooding Recovery Action Plan 4.1 Element, Plant and Facility Geotechnical and Structural Assessment.

1.1 Scope and Purpose

The FCS Plant and Facility Geotechnical and Structural Assessment has been completed to identify and describe the geotechnical and structural effects of the 2011 flood on 28 Priority 1 Structures and 19 Priority 2 Structures at the FCS site. The Priority 1 Structures are those structures and systems that directly support plant operations. These structures are listed in Table 1-1. Priority 2 Structures are those structures and systems that do not directly support plant operations. These structures are listed in Table 1-2. Specifically, the purpose of this Assessment Report is to present HDR's assessment of changes to the soil and/or rock that supports the structures at FCS due to the 2011 Missouri River flood and/or the direct impacts of floodwater that may have negatively impacted those structures.

Introduction

Table 1-1 – Priority 1 Structures (Must Be Assessed Prior to Plant Restart)	
Class I (Seismic) Structures	Non-Class I Structures Outside Protected Area
Intake Structure	Original Steam Generator Storage Building (OSGS)
Auxiliary Building	Switchyard
Containment	Transmission Towers
Rad Waste Building	Meteorological Tower
Technical Support Center	Demineralized Water Tank, Pump House, and Reverse Osmosis (RO) Unit
Non-Class I Structures Inside Protected Area	Underground Utilities
Independent Spent Fuel Storage Installation (ISFSI)	Blair Water System
Security Building	Main Underground Cable Bank, MH-1 to Auxiliary Building (MH-1, MH-2, MH-3, MH-4)
Turbine Building	
Security Barricaded Ballistic Resistant Enclosures (BBREs)	River Bank
Turbine Building South Switchyard	
Condensate Storage Tank	
Underground Utilities	
Underground Cable Trench (Security Trenwa)	
Circulating Water System	
Demineralized Water System	
Raw Water Piping	
Fire Protection System Piping	
Waste Disposal Piping	
Fuel Oil Storage Tanks and Piping (only FO-1, FO-10, and FP-1B)	
Main Underground Cable Bank, Auxiliary Building to Intake Structure (Manhole [MH]-5, MH-31)	
Camera Towers and High Mast Lighting	
Source: OPPD. August 10, 2011. <i>Flooding Recovery Action Plan, Revision 0</i> . Document number LIC-11-0090.	

Introduction

Table 1-2 – Priority 2 Structures (Do Not Directly Support Plant Operations)	
Non-Class I Structures Inside Protected Area	Non-Class I Structures Outside Protected Area
New Warehouse	Maintenance Storage Building (Maintenance Shed)
Service Building	Old Warehouse
Chemistry/Radiation Protection (CARP) Building	Training Center
Maintenance Shop	Administrative Building
Maintenance Fabrication Shop	Hazardous Material Storage Building (Hazmat Shed)
Protected Area Paving and Sidewalks	Maintenance Garage
Underground Utilities	Tertiary Building (Boat Storage)
Potable Water	Spare Transformer Pads
Sanitary Sewer	Shooting Range
	Gravel Parking Lots
	Outdoor Concrete Slabs and Driveways
	Underground Utilities
	Potable Water
	Sanitary Sewer
	Sewage Lagoons
Source: OPPD. August 10, 2011. <i>Flooding Recovery Action Plan, Revision 0</i> . Document number LIC-11-0090.	

1.2 Assessment Report Organization, Content, and Revision History

1.2.1 Document Organization

This Assessment Report is organized as follows:

- Section 1.0, Introduction
- Section 2.0, Site History, Description, and Baseline Condition
- Section 3.0, Assessment Process, Procedures, and Methods
- Section 4.0, Geotechnical Testing, Key Distress Indicators, and Geotechnical Comparative Analysis
- Section 5.0, Priority 1 Structures
- Section 6.0, Priority 2 Structures
- Section 7.0, Status of Structures After 2011 Investigations
- Section 8.0, 2012 Investigations
- Section 9.0, Summary and Conclusions
- Section 10.0, References
- Section 11.0, Attachments

1.2.2 Document Content

This report presents the findings, conclusions, and recommendations for the geotechnical, structural, and civil aspects of HDR's inspection completed at the FCS site. It has been prepared in accordance with generally accepted engineering practice and in a manner consistent with the level of care and skill

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required for this type of project within this geographical area. No warranty, expressed or implied, is made.

The findings, conclusions, and recommendations presented herein are based on systematic and thorough visual observations and reconnaissance, review of available design and construction information provided by others, the results of field exploration and laboratory materials testing, the results of engineering evaluations, and HDR's experience and engineering judgment.

Geotechnical engineering and the geologic sciences are characterized by uncertainty. Professional judgments presented herein are based partly on HDR's understanding of the past construction at the FCS site, information gathered during the site inspections, HDR's general experience, and the state of the practice at the time of this writing.

For structures that were impacted by the 2011 inundation of the FCS site, this Assessment Report presents recommendations for 1) additional monitoring, or 2) physical modifications. This Assessment Report is not intended to modify the accepted design basis of each structure, or to modify any accepted emergency action plan for FCS.

1.2.3 Revision History

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. After October 14, 2011, additional surveys and site monitoring activities were conducted that changed the assessment results for some structures. This was documented in Revision 1 of this Assessment Report, which was submitted to OPPD on November 28, 2011. Revision 2 presents the results of post-Revision-1 forensic investigations for Key Distress Indicators and the assessment results for Priority 2 Structures. Table 1-3 summarizes the revision history of this document.

Revision Number	Date of Issuance	Changes
0	October 14, 2011	NA
1	November 28, 2011	Incorporates results of the following: <ul style="list-style-type: none"> • Geotechnical summary, including the majority of the data from subconsultants • Geotechnical comparative analysis • Additional site monitoring
2	May 4, 2012	Incorporates results of the following: <ul style="list-style-type: none"> • Forensic investigations for Key Distress Indicators • Assessment of Priority 2 Structures

1.3 Background

FCS shut down on April 9, 2011, for a scheduled maintenance and refueling outage. The maintenance and refueling activities proceeded until a combination of above-normal snowpack in the plains in the Northern United States (U.S.), above-normal snowpack in the mountains above Fort Peck and Garrison dams¹ on the Missouri River, and excessive upstream spring rains in eastern Montana and North and

¹ Fort Peck Dam and Garrison Dam are the uppermost two in a system of six mainstem dams on the Missouri River.

Introduction

South Dakota resulted in massive flooding in the Missouri River basin. The U.S. Army Corps of Engineers (USACE) estimated that runoff above Sioux City in 2011 was 61 million acre-feet (MAF). This is the highest amount of runoff since 1898, eclipsing the previous high runoff of 49 MAF. USACE began releasing record discharges from Gavins Point Dam² in late May 2011, as shown in Table 1-4. The hydrologic background of this Missouri River flood event is explained in Section 2.3 of this Assessment Report.

Date	Water Released^A
End of January 2011	19,000 cfs
End of February 2011 to end of March 2011	21,000 cfs
End of April 2011	45,000 cfs
May 30, 2011	71,000 cfs ^B
June 27, 2011, through July 30, 2011	160,000 cfs
August 3-19, 2011	150,000 cfs
September 1-19, 2011	90,000 cfs
October 4, 2011, through December 8, 2011	40,000 cfs
December 15, 2011	22,000 cfs

^A - cfs = cubic feet per second
^B - This release set a new record; the previous record System release was 70,000 cfs in 1997.

On June 6, 2011, when the plant was still in cold shutdown, FCS entered Notification of Unusual Event (NOUE) status as floodwater on the site exceeded an elevation of 1004 feet (ft).³ After this declaration, the Missouri River continued to rise as increasing amounts of water were released from upstream dams. Floodwater covered much of the FCS site, reaching a maximum elevation of approximately 1006.9 ft. The average elevation of the site surrounding the Containment, Turbine Building, and Auxiliary Building is approximately 1004 ft. FCS remained in an NOUE status until August 29, 2011, when floodwater fell below elevation (el.) 1004 ft. The site was in an NOUE status for 84 days. A variety of steps were taken to prevent floodwater from entering any critical buildings on site. The measures taken to protect the Priority 1 and Priority 2 structures are listed in Tables 1-5 and 1-6, respectively.

Priority 1 Structure	Method of Flood Protection
Intake Structure	Structural flood-proofing, walkway access
Auxiliary Building	Aqua Dam ^A
Containment	Aqua Dam
Rad Waste Building	Aqua Dam
Technical Support Center	Aqua Dam
Independent Spent Fuel Storage Installation (ISFSI)	None
Security Building	HESCO barrier ^B
Turbine Building	Aqua Dam

² Gavins Point Dam is the lowermost of six mainstem dams on the Missouri River.

³ All elevations are expressed in National Geodetic Vertical Datum of 1929 (NGVD 29), also known as the Sea Level Datum of 1929.

Introduction

Table 1-5 – Summary of Flood Protection Measures Taken for Priority 1 Structures	
Priority 1 Structure	Method of Flood Protection
Security Barricaded Ballistic Resistant Enclosures (BBREs)	Varies (see below)
[REDACTED]	[REDACTED]
[REDACTED]	[REDACTED]
[REDACTED]	[REDACTED]
[REDACTED]	[REDACTED]
Turbine Building South Switchyard	Aqua Dam
Condensate Storage Tank	None
Demineralized Water Tank and Pump House	Aqua Dam
Meteorological (Met) Tower and Miscellaneous Structures	None
Original Steam Generator Storage Building (OSGS)	None
Switchyard	Temporary earthen berm/sandbag levee
Transmission Towers	None
^A - An Aqua Dam is an engineered water barrier used to contain, divert, and control the flow of water. It consists of two polyethylene liners contained by a single woven geo-tech outer tube. When the two inner tubes are filled with water, the resulting pressure and mass create a stable, non-rolling wall of water (Layfield Environmental Systems, 2008).	
^B - A HESCO barrier is a collapsible container used to block and control floodwater and debris. Composed of wire-mesh with heavy-duty polypropylene geotextile liner, HESCO barriers are filled with aggregate and placed as temporary dikes or flood defense walls.	

Table 1-6 – Summary of Flood Protection Measures Taken for Priority 2 Structures	
Priority 2 Structure	Method of Flood Protection
New Warehouse	None
Service Building	Aqua Dam ^A
Chemistry/Radiation Protection (CARP) Building	Aqua Dam
Maintenance Shop	Aqua Dam
Maintenance Fabrication Shop	None
Maintenance Storage Building (Maintenance Shed)	None
Old Warehouse	Aqua Dam around northern portion of building
Training Center	Aqua Dam
Administrative Building	Aqua Dam
Hazardous Material Storage Building (Hazmat Shed)	Unknown
Maintenance Garage	None
Tertiary Building (Boat Storage)	None

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Priority 2 Structure	Method of Flood Protection
Spare Transformer Pads	Varies (see below)
T1 Spare Transformer Pad	Earthen berm covered with crushed rock
Spare pad located west of the T1 Spare Transformer Pad	Sandbag levee
Shooting Range	Berm

^A - An Aqua Dam is an engineered water barrier used to contain, divert, and control the flow of water. It consists of two polyethylene liners contained by a single woven geo-tech outer tube. When the two inner tubes are filled with water, the resulting pressure and mass create a stable, non-rolling wall of water (Layfield Environmental Systems, 2008).

Following the 2011 flood, OPPD actively engaged in cleaning up deposited sediment from the parking lots and roadways, removing flood debris, repairing obvious flood damage, and conducting the plant activities necessary to resume generation. Preparation of this Assessment Report is part of these activities.

1.4 Assessment Process

The post-flooding assessment of FCS structures was completed 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 that could have caused degradation to the soil and/or rock that supports the FCS structures and/or could have caused direct impacts on structures due to the force of the floodwater (Triggering Mechanisms) was then developed. Examples of Triggering Mechanisms include settlement, erosion, stability, hydraulic actions, and frost actions. Using the list of potential Triggering Mechanisms, a comprehensive list of potential failure modes (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. 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 corresponding PFMs was compiled for each structure from the comprehensive list of PFMs. A more detailed discussion of the assessment process is provided in Section 3.0 of this Assessment Report.

1.5 Quality Assurance and Control

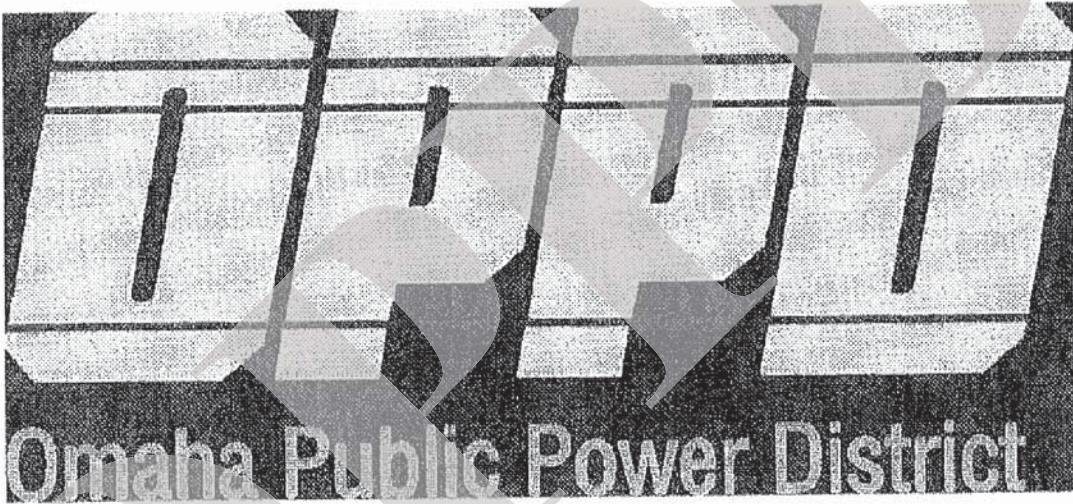
HDR has developed a Quality Control Plan (QCP), which supplements HDR's Quality Assurance/Quality Control (QA/QC) Program Manual, to provide guidance for performing QA evaluations of assessment activities. HDR's program is based on International Organization for Standardization (ISO) 9000 principles. HDR's QA/QC process is not certified as a Nuclear Quality Assurance (NQA-1) program. The Project QCP ensures that QA and QC activities are documented and performed in accordance with written procedures or checklists.

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SECTION 2.0

SITE HISTORY, DESCRIPTION, AND BASELINE CONDITION



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Site History, Description, and Baseline Condition**2.0 SITE HISTORY, DESCRIPTION, AND BASELINE CONDITION**

In order to compare the pre-flood and post-flood conditions at the FCS site, construction documents, as-built drawings, previous reports, and plant performance history were reviewed. Baseline information for the FCS site and structures was compiled to include data on the geology, geomorphology, geotechnical, and design conditions prior to the 2011 flood. In addition, data on the 2011 flood itself, including the areal extent, water depths, water velocities, and the effect on groundwater at the FCS site were compiled. This section of the Assessment Report presents these baseline data.

2.1 Geologic Setting

The surficial geology of the FCS site consists primarily of Missouri River alluvium deposited during the Holocene Epoch after Late Pleistocene, Wisconsin glaciation (Miller, 1964). Because it is thought that the Missouri River did not occupy its current position during the Wisconsin glaciation (Miller, 1964), a sequence of erosion of the Missouri River channel and deposition of the present Holocene alluvium is the sequence that has developed the current site stratigraphy. Post Wisconsin glacial event (Late Pleistocene) to Holocene alluvium overlies the Winterset Member of the Dennis Formation Limestone of the Pennsylvanian Kansas City Group at the site. Glacial and alluvial deposits of Quaternary Age (less than 1.6 million years) are less than 100 ft thick at the site but vary from 300 to less than 100 ft thick within a 5-mile radius of the site (Burchette, et al., 1975). Limestone of the Kansas City Group is described as dark gray to light gray, very thinly bedded to massive, argillaceous, fossiliferous, and containing some pyrite crystals and mica (Burchette, et al., 1975). Bedrock is not exposed at the site. A more specific description of soil and bedrock conditions at the site is presented in Section 2.4, Geotechnical Baseline Condition.

Regional geologic structure includes a gentle dip of bedrock bedding to the west (McBee, 2003). Faults within a 100-mile radius of the site are limited to basement structures such as the Nemaha Fault Zone, do not offset Pennsylvanian strata, and are not recognized as active (McBee, 2003). A more detailed discussion of regional geologic structure and history is presented in OPPD's Updated Safety Analysis Report (USAR) Section 2.6 (May 2, 2011). FCS site geology is discussed in more detail below.

2.1.1 Historical Seismicity

HDR conducted an inventory of recorded historical seismic events that occurred at a magnitude of 2.0 (Richter Scale) or greater within 100 miles of FCS. The location of each event, its magnitude, and its distance from the site are shown in Table 2-1. The investigation of the historical seismicity was conducted using the Advanced National Seismic System (ANSS) at <http://www.ncedc.org/anss/catalog-search.html>. The ANSS is a worldwide earthquake catalog created by merging the master earthquake catalogs of the contributing ANSS member network and can be queried by geographic location. USAR Section 2.4 includes an inventory of Modified Mercalli Intensity Scale events of V or greater within 200 miles of the FCS site. This inventory identified 12 seismic events of Modified Mercalli Intensities of V or greater within 200 miles of the site. USAR Section 2.4 and this Assessment Report independently conclude that no major earthquake has occurred near the FCS site and that the site likely would not experience damaging earthquake motion.

Year	Latitude (decimal degrees)	Longitude (decimal degrees)	Magnitude	Distance from Site (kilometers)
1877	41.00	-97.00	5.0	99
1902	42.00	-97.60	4.5	140
1935	40.3	-96.20	4.7	136
1981	41.520	-97.630	2.7	132
1995	40.51	-94.95	3.1	145
1997	41.79	-97.18	3.4	100
2004	40.63	-95.55	3.5	106
2009	40.41	-95.86	3.6	124
2010	41.35	-97.01	3.3	83

Source: U.S. Geological Survey (USGS). October 26, 2009. "2008 National Seismic Hazard Maps - Fault Parameters." Earthquake Hazards Program. Retrieved September 20, 2011. http://geohazards.usgs.gov/cfusion/hazfaults_search/hf_search_main.cfm.

2.1.2 Regional Seismicity and Faulting

FCS is located within the Central and Eastern United States (CEUS) as delineated by the U.S. Geological Survey (USGS) (Crone and Wheeler, 2000). The CEUS experiences minimal seismic activity with the exception of specific zones such as the New Madrid Seismic Zone and Mears Fault Zone not located in proximity to FCS (Petersen et al., 2008). In conjunction with many local and state agencies, USGS maintains a database of Quaternary faults for the U.S. (USGS, October 26, 2009). These include known faults that are estimated to have undergone movement in the past 1.6 million years (within the Quaternary Period), or since late Cenozoic Age for Class B faults. Active faults generally include Holocene Age faults that have undergone movement in the past 15,000 years. For this study, the database was searched for all fault classifications (A, B, C, and D). The USGS fault classifications are as follows:

- Class A – Geologic evidence demonstrates the existence of a Quaternary fault (within the past 1.6 million years) of tectonic origin.
- Class B – Geologic evidence demonstrates the existence of Quaternary deformation, but either 1) the fault might not extend deeply enough to be a potential source of significant earthquakes, or 2) the currently available geologic evidence is too strong to confidently assign the feature to Class C but not strong enough to assign it to Class A.
- Class C – Geologic evidence is insufficient to demonstrate 1) the existence of tectonic faulting, or 2) Quaternary slip or deformation associated with the feature.
- Class D – Geologic evidence demonstrates that the feature is not a tectonic fault or feature; this category includes features such as joints, landslides, erosional or fluvial scarps, or other landforms resembling fault scarps but of demonstrable non-tectonic origin.

No Class A or B fault exists within a 400-mile radius of FCS. The closest Class A or B fault is the Cheraw fault, which is 450 miles to the southwest in southeastern Colorado. The closest fault system is the Ord escarpment, located approximately 150 miles west of FCS. This fault system is a Class C feature (it is not associated with tectonic processes) and was determined by Machette et al. (1998) as not exhibiting Quaternary movement. The USGS database contains no Class D faults within a

Site History, Description, and Baseline Condition

400-mile radius of FCS. This is consistent with USAR Section 2.4, which briefly discusses the structural geologic setting of the FCS site with respect to historical seismicity. USAR Section 2.4 also states that no faulting is evident in the Pleistocene and recent sediments of the Missouri River Lowlands and that known faults in the vicinity of the FCS site exhibit no evidence of movement in historic times.

2.1.3 Seismic Hazard

Assessment of seismic hazard is based on the earthquake characteristics and the causative fault associated with the earthquake. These characteristics include magnitude of maximum earthquake, distance from the site to the causative fault, fault length, and activity of the fault. The effects of site soil conditions and the mechanism of faulting are accounted for in the attenuation relationships.

The probabilistic strong ground-motion values were developed from USGS gridded databases, developed by Frankel, et al. (1996 and 2002), and with most recently developed Next Generation Attenuation (NGA) relationships by Petersen, et al. (2008). These values were queried from USGS-maintained databases located at <http://gldims.cr.usgs.gov/website/nshmp2008/viewer.htm> and <https://geohazards.usgs.gov/deaggint/2008/>. The results of this analysis are presented in Attachment 1, Deaggregation Plots. Attachment 1 illustrates the regional probabilistic strong ground motion for the 10 percent probability of exceedance in 50 years, 2 percent probability of exceedance in 50 years, 2 percent probability of exceedance in 100 years, and 2 percent probability of exceedance in 200 years. Estimated peak ground acceleration (PGA) is summarized in Table 2-2.

Earthquake Return Period (years)	Approximate Probability of Exceedance in 50 years (%)	Peak Ground Acceleration^A
500	10	0.0142 g
2500	2	0.0431 g
5000	1	0.0669 g
10,000	0.5	0.1020 g

^A - Peak ground acceleration is measured by the acceleration due to gravity (g).
 Source: USGS. July 21, 2011. "2008 Interactive Deaggregations (Beta)." *Geologic Hazards Science Center*. Retrieved September 20, 2011. <https://geohazards.usgs.gov/deaggint/2008/>.

The PGA values presented in Table 2-2 are based on USGS probabilistic seismic hazard analyses for various return periods and are useful for presenting an overall seismic hazard for a geographic area. These values are not for the purpose of establishing seismic design criteria such as the design earthquake (0.08 g) and maximum hypothetical earthquake (0.17 g) that are presented in USAR Section 2.4.3. The USAR values are based on a detailed deterministic seismic hazard analysis that uses site-specific and site-area-specific data to develop PGA values.

2.1.4 Site Geologic Hazards

Several geologic hazards have been identified at the FCS site and discussed in previous design reports by Dames & Moore (January 26, 1967, and January 30, 1968). These hazards include the existence of karst features associated with dissolution of the Winterset Member of the Dennis Formation

Site History, Description, and Baseline Condition

Limestone, liquefaction of the loose poorly graded sands identified at the site, bank slope stability adjacent to the Missouri River, and scour and erosion of near-surface soils.

2.1.4.1 Karst

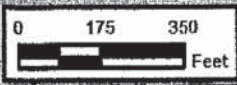
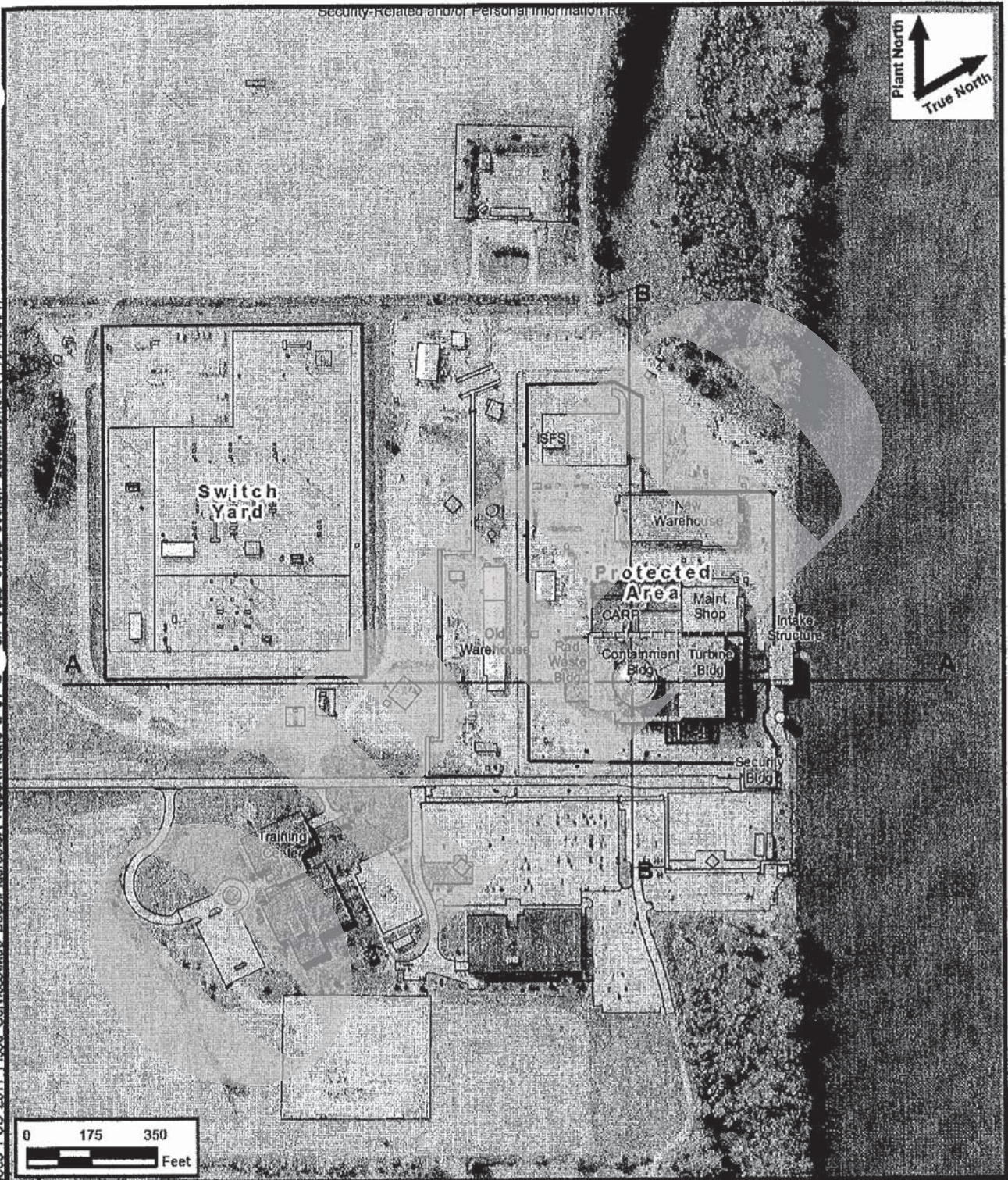
Dames & Moore (January 30, 1968) identified at least two significant karst features in the Winterset Member of the Dennis Formation Limestone that apparently have developed along existing fractures. The features were estimated to be as much as 5 ft wide, 16 ft deep, and 45 ft long and consist of an upper 1.5- to 3-ft void and a lower zone of decomposed limestone and detritus. The approximate location of these features is shown in Figure 2-1, Geotechnical Areas and Cross-Section Locations. Cross-sectional views of the geologic setting are presented in Figures 2-2 and 2-3. Figure 2-2, Section A-A, shows where these karst features approximately intersect the subsurface section.




Pile installation at FCS for the Containment, Auxiliary Building, Turbine Building, and Intake Structure was designed to penetrate any overlying layer of limestone that covers the karst feature and to found the pile on sound rock at the bottom of these features. The potential influence of these karst features on foundation stability is considered minimal. It is likely that additional karst features exist across the site, but the overlying alluvial cover of a minimum of 61 ft offers a buffer to the influence of these features on any structure. Further dissolution of limestone is an assumed process given that the limestone is in contact with groundwater. The most aggressive dissolution of limestone by groundwater occurs in the vadose zone (Myroie, 1984). The fact that the karst features at the FCS site are covered by approximately 60 ft of alluvial material and are in contact with groundwater that has experienced some subsurface residence time dictates that the rate of karst feature development (limestone dissolution) is low. In addition, the karst features encountered in the 1967 Dames & Moore drilling program were primarily filled with decomposed limestone and detritus. The volume of space needed to allow significant collapse of overlying soils is not present. Therefore, within the expected service life of FCS, the process of limestone dissolution is not significant.

A further understanding of the karst features at the FCS site would require drilling and installation of sampling wells to sample water near the limestone and soil contact in order to assess the chemical characteristics of the groundwater at this interface. This effort is not considered necessary as part of this Assessment Report because the plant has functioned without evidence of foundation subsidence due to karst feature collapse and resulting collapse of overlying soil prior to and during the 2011 flood.



Z:\Projects\116-1565 FCS 2011 Flood Services\Map Docs\Figures\SA Report\Figure 2 01 C...sh Areas Cross Section Locations.mxd 10/19/2011



-  Approximate Extent and Orientation of Linear Karst
-  Zone of V broflotation
-  Zone of Pile Installation



Geotechnical Areas and Cross Section Locations
Fort Calhoun Station
 Plant and Facility Geotechnical and Structural Assessment



DATE
Oct 2011

FIGURE
2-1

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