UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

May 26, 2017

Mr. Scott D. Northard
Vice President
Northern States Power Company - Minnesota
Prairie Island Nuclear Generating Plant
1717 Wakonade Drive East
Welch, MN 55089-9642

SUBJECT: PRAIRIE ISLAND NUCLEAR GENERATING PLANT, UNITS 1 AND 2 – STAFF ASSESSMENT OF RESPONSE TO 10 CFR 50.54(f) INFORMATION REQUEST – FLOOD-CAUSING MECHANISM REEVALUATION (CAC NOS. MF7710 AND MF7711)

Dear Mr. Northard:

By letter dated March 12, 2012, the U.S. Nuclear Regulatory Commission (NRC) issued a request for information pursuant to Title 10 of the *Code of Federal Regulations*, Section 50.54(f) (hereafter referred to as the 50.54(f) letter). The request was issued as part of implementing lessons learned from the accident at the Fukushima Dai-ichi nuclear power plant. Enclosure 2 to the 50.54(f) letter requested licensees to reevaluate flood-causing mechanisms using present-day methodologies and guidance. By letter dated May 09, 2016 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML16133A041), Northern States Power Company, a Minnesota corporation (NSPM, the licensee), doing business as Xcel Energy, responded to this request for Prairie Island Nuclear Generating Plant, Units 1 and 2 (Prairie Island).

By letter dated September 16, 2016 (ADAMS Accession No. ML16248A006), the NRC staff sent the licensee a summary of its review of Prairie Island's reevaluated flood-causing mechanisms. The enclosed staff assessment provides the documentation supporting the NRC staff's conclusions summarized in the letter. As stated in the letter, because local intense precipitation at Prairie Island is not bounded by the plant's current design basis, additional assessments of the flood hazard mechanism are necessary.

The NRC staff has no additional information needs at this time with respect to NPSM's 50.54(f) response related to flooding.

This staff assessment closes out the NRC's efforts associated with CAC Nos. MF7710 and MF7711.

Enclosure 1 transmitted herewith contains Security-Related Information. When separated from Enclosure 1, this document is decontrolled.

If you have any questions, please contact me at (301) 415-1617 or e-mail at Frankie.Vega@nrc.gov.

Sincerely,

Frankie Vega, Project Manager
Hazards Management Branch
Japan Lessons-Learned Division
Office of Nuclear Reactor Regulation

Docket Nos. 50-282 and 50-306

Enclosures:
1. Staff Assessment of Flood Hazard Reevaluation Report (Non-public)
2. Staff Assessment of Flood Hazard Reevaluation Report (public)

cc w/encl: Distribution via Listserv

STAFF ASSESSMENT BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO FLOODING HAZARD REEVALUATION REPORT

NEAR-TERM TASK FORCE RECOMMENDATION 2.1

PRAIRIE ISLAND NUCLEAR GENERATING STATION, UNITS 1 AND 2

DOCKET NOS. 50-282 AND 50-306

1.0 INTRODUCTION

By letter dated March 12, 2012 (NRC, 2012a), the U.S. Nuclear Regulatory Commission (NRC) issued a request for information to all power reactor licensees and holders of construction permits in active or deferred status, pursuant to Title 10 of the *Code of Federal Regulations* (10 CFR), Section 50.54(f) (hereafter referred to as the "50.54(f) letter"). The request was issued in connection with implementing lessons learned from the 2011 accident at the Fukushima Dai-ichi nuclear power plant as documented in the Near-Term Task Force (NTTF) report (NRC, 2011a). Recommendation 2.1 in that document recommended that the NRC staff issue orders to all licensees to reevaluate seismic and flooding for their sites against current NRC requirements and guidance. Subsequent staff requirements memoranda associated with SECY-11-0124 (NRC, 2011c) and SECY-11-0137 (NRC, 2011d), directed the NRC staff to issue requests for information to licensees pursuant to 10 CFR 50.54(f) to address this recommendation.

Enclosure 2 to the 50.54(f) letter (NRC, 2012a) requested that licensees reevaluate flood hazards for their respective sites using present-day methods and regulatory guidance used by the NRC staff when reviewing applications for early site permits (ESPs) and combined licenses (COLs). The required response section of Enclosure 2 specified that NRC staff would provide a prioritization plan indicating Flooding Hazard Reevaluation Report (FHRR) deadlines for each plant. On May 11, 2012, the NRC staff issued its prioritization of the FHRRs (NRC, 2012b).

By letter dated May 12, 2016 (Xcel Energy, 2016a), Northern States Power Company (NSPM, the licensee), doing business as Xcel Energy, provided its FHRR for Prairie Island Nuclear Generating Station, Units 1 and 2 (Prairie Island). The NRC staff performed an audit as documented in the audit report (NRC, 2017).

By letter dated September 16, 2016, the NRC issued an interim staff response (ISR) letter to the licensee (NRC, 2016b). The purpose of the ISR letter is to provide the flood hazard information suitable for the assessment of mitigating strategies developed in response to Order EA-12-049 (NRC, 2012b) and the additional assessments associated with NTTF Recommendation 2.1: Flooding. The ISR letter also made reference to this staff assessment, which documents NRC staff's basis and conclusions. The flood hazard mechanism values presented in the letter's enclosures match the values in this staff assessment without change or alteration.

As mentioned in the ISR letter (NRC, 2016b), the reevaluated flood hazard results for the local intense precipitation (LIP) flood-causing mechanism is not bounded by the plant's current design basis (CDB). Consistent with the 50.54(f) letter and amended by the process outlined in COMSECY-15-0019 (NRC, 2015a), Japan Lessons-Learned Division (JLD) Interim Staff Guidance (ISG) JLD-ISG-2012-01, Revision 1 (NRC, 2016b) and JLD-ISG-2016-01, Revision 0 (NRC, 2016c), the NRC staff anticipates that the licensee will perform and document a focused evaluation for LIP and associated site drainage that assesses the impact of the LIP hazard on the site and evaluates and implements any necessary programmatic, procedural, or plant modifications to address this hazard exceedance.

Additionally, for any reevaluated flood hazards that are not bounded by the plant's CDB hazard, the licensee is expected to develop flood event duration (FED) and associated effects (AE) parameters. These parameters will be used to conduct the mitigating strategies assessment (MSA) and focused evaluations or integrated assessments.

2.0 REGULATORY BACKGROUND

2.1 Applicable Regulatory Requirements

As stated above, Enclosure 2 to the 50.54(f) letter (NRC, 2012a) requested that licensees reevaluate flood hazards for their sites using present-day methods and regulatory guidance used by the NRC staff when reviewing applications for ESPs and COLs. This section of the staff assessment describes present-day regulatory requirements that are applicable to the FHRR.

Sections 50.34(a)(1), (a)(3), (a)(4), (b)(1), (b)(2), and (b)(4), of 10 CFR, describe the required content of the preliminary and final safety analysis reports, including a discussion of the facility site with a particular emphasis on the site evaluation factors identified in 10 CFR Part 100. The licensee should provide any pertinent information identified or developed since the submittal of the preliminary safety analysis report in the final safety analysis report.

General Design Criterion 2 in Appendix A of 10 CFR Part 50 states that structures, systems, and components (SSCs) important to safety at nuclear power plants must be designed to withstand the effects of natural phenomena such as earthquakes, tornados, hurricanes, floods, tsunamis, and seiches without the loss of capability to perform their intended safety functions. The design bases for these SSCs are to reflect appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area. The design bases are also to have sufficient margin to account for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

Section 50.2 of 10 CFR defines the design-basis as the information that identifies the specific functions that an SSC of a facility must perform, and the specific values or ranges of values chosen for controlling parameters as reference bounds for design which each licensee is required to develop and maintain. These values may be: (a) restraints derived from generally accepted "state of the art" practices for achieving functional goals; or (b) requirements derived from an analysis (based on calculation, experiments, or both) of the effects of a postulated accident for which an SSC must meet its functional goals.

Section 54.3 of 10 CFR defines the "current licensing basis" (CLB) as "the set of NRC requirements applicable to a specific plant and a licensee's written commitments for ensuring compliance with and operation within applicable NRC requirements and the plant-specific design-basis (including all modifications and additions to such commitments over the life of the license) that are docketed and in effect." This includes 10 CFR Parts 2, 19, 20, 21, 26, 30, 40, 50, 51, 52, 54, 55, 70, 72, 73, 100, and appendices thereto; orders; license conditions; exemptions; and technical specifications, as well as the plant-specific design-basis information as documented in the most recent updated final safety analysis report (UFSAR). The licensee's commitments made in docketed licensing correspondence that remain in effect, are also considered part of the CLB.

Present-day regulations for reactor site criteria (Subpart B to 10 CFR Part 100 for site applications on or after January 10, 1997) state, in part that the physical characteristics of the site must be evaluated and site parameters established such that potential threats from such physical characteristics will pose no undue risk to the type of facility proposed to be located at the site. Factors to be considered when evaluating sites include the nature and proximity of dams and other man-related hazards (10 CFR 100.20(b)) and the physical characteristics of the site, including the hydrology (10 CFR 100.21(d)).

2.2 Enclosure 2 to the 50.54(f) Letter

Section 50.54(f) of 10 CFR states that a licensee shall at any time before expiration of its license, upon request of the Commission, submit written statements, signed under oath or affirmation, to enable the Commission to determine whether or not the license should be modified, suspended, or revoked. The 50.54(f) letter (NRC, 2012a) requested, in part, that licensees reevaluate the flood-causing mechanisms for their respective sites using present-day methodologies and regulatory guidance used by the NRC for the ESP and COL reviews.

2.2.1 Flood-Causing Mechanisms

Attachment 1 Enclosure 2 of the 50.54(f) letter discusses flood-causing mechanisms for the licensee to address in its FHRR (NRC, 2012a). Table 2.2-1 lists the flood-causing mechanisms the licensee should consider and the corresponding Standard Review Plan (SRP) (NRC, 2007) section(s) and applicable ISG documents containing acceptance criteria and review procedures.

2.2.2 Associated Effects

The licensee should incorporate and report associated effects per JLD-ISG-2012-05, "Guidance for Performing the Integrated Assessment for External Flooding" (NRC, 2012c) in addition to the maximum water level associated with each flood-causing mechanism. Guidance document JLD-ISG-2012-05 (NRC, 2012c), defines "flood height and associated effects" as the maximum stillwater surface elevation plus:

- Wind waves and run-up effects
- Hydrodynamic loading, including debris
- Effects caused by sediment deposition and erosion
- Concurrent site conditions, including adverse weather conditions
- Groundwater ingress
- Other pertinent factors

2.2.3 Combined Effect Flood

The worst flooding at a site that may result from a reasonable combination of individual flooding mechanisms is sometimes referred to as a "combined effects flood." It should also be noted that for the purposes of this staff assessment, the terms "combined effects" and "combined events" are synonyms. Even if some or all of these individual flood-causing mechanisms are less severe than their worst-case occurrence, their combination may still exceed the most severe flooding effects from the worst-case occurrence of any single mechanism described in the 50.54(f) letter (see SRP Section 2.4.2, "Areas of Review" (NRC, 2007). Attachment 1 of the 50.54(f) letter describes the "combined effect flood" as defined in American National Standards Institute/American Nuclear Society (ANSI/ANS) 2.8-1992 (ANSI/ANS, 1992) as follows:

> For flood hazard associated with combined events, American Nuclear Society (ANS) 2.8-1992 provides guidance for combination of flood-causing mechanisms for flood hazard at nuclear power reactor sites. In addition to those listed in the ANS guidance, additional plausible combined events should be considered on a site specific basis and should be based on the impacts of other flood-causing mechanisms and the location of the site.

If two less severe mechanisms are plausibly combined per ANSI/ANS-2.8-1992 (ANSI/ANS, 1992), then the licensee will document and report the result as part of one of the hazard sections. An example of a situation where this may occur is flooding at a riverine site located where the river enters the ocean. For this site, storm surge and river flooding are plausible combined events and should be considered.

2.2.4 Flood Event Duration

Flood event duration was defined in JLD-ISG-2012-05 (NRC, 2012c), as the length of time during which the flood event affects the site. It begins when conditions are met for entry into a flood procedure, or with notification of an impending flood (e.g., a flood forecast or notification of dam failure), and includes preparation for the flood. It continues during the period of inundation, and ends when water recedes from the site and the plant reaches a safe and stable state that can be maintained indefinitely. Figure 2.2-1 illustrates flood event duration.

2.2.5 Actions Following the FHRR

For the sites where the reevaluated flood hazard is not bounded by the CDB flood hazard elevation for any flood-causing mechanisms, the 50.54(f) letter requests licensees and construction permit holders to:

- Submit an interim action plan with the FHRR documenting actions planned or already taken to address the reevaluated hazard; and,
- Perform an integrated assessment to: (a) evaluate the effectiveness of the CDB (i.e., flood protection and mitigation systems); (b) identify plant-specific vulnerabilities; and (c) assess the effectiveness of existing or planned systems and procedures for protecting against and mitigating consequences of flooding for the flood event duration.

If the reevaluated flood hazard is bounded by the CDB flood hazard for all flood-causing mechanisms at the site, licensees were not required to perform an integrated assessment.

COMSECY-15-0019 (NRC, 2015) outlines a revised process for addressing cases in which the reevaluated flood hazard is not bounded by the plant's CDB. The revised process describes an approach in which licensees with LIP hazards exceeding their CDB flood will not be required to complete an integrated assessment, but instead will perform a focused evaluation. As part of the focused evaluation, licensees will assess the impact of the LIP hazard on their sites and then evaluate and implement any necessary programmatic, procedural or plant modifications to address the hazard exceedance. For other flood hazard mechanisms that exceed the CDB, licensees can assess the impact of these reevaluated hazards on their site by performing either a focused evaluation or a revised integrated assessment (NRC, 2015 and NRC, 2016a).

3.0 TECHNICAL EVALUATION

The NRC staff reviewed the information provided for the flood hazard reevaluation of the Prairie Island site. The licensee conducted the flood hazard reevaluation using present-day methodologies and regulatory guidance used by the NRC staff in connection with ESP and COL reviews. To provide additional information in support of the summaries and conclusions in the FHRR, the licensee made several calculation packages and engineering analyses referenced available to the NRC staff via an electronic reading room. The NRC staff did not rely directly on these calculation packages in its review; they were found only to expand upon and clarify the information provided in the Prairie Island FHRR, and so those calculation packages were not docketed and cited.

Finally, there were some licensee documents reviewed in connection with the NRC staff's 2016 audit of the Prairie Island FHRR. Many of those documents examined as part of the audit were also not docketed by the licensee; that additional information was made available to the NRC staff via the electronic reading room. Nevertheless, for those documents reviewed by the staff as part that audit, they were cited in the audit summary report (NRC, 2017) prepared by the staff.

3.1 Site Information

The 50.54(f) letter (NRC, 2012a) includes the SSCs important to safety in the scope of the hazard reevaluation. The licensee included pertinent data concerning these SSCs in the Prairie Island FHRR. The NRC staff reviewed and summarized this information in the sections below.

3.1.1 Detailed Site Information

The Prairie Island site is located on the southeastern shore of Prairie Island where Sturgeon Lake merges with the main stem of the Mississippi River; the western flank of the island is bordered by the Vermillion River. The reactor complex (including both the powerblock and the controlled area) encompasses approximately 578 acres adjacent to the Native American Reservation of the Prairie Island Dakota (or Mdewakanton Sioux) in Goodhue County, Minnesota; the reservation extends over 1,068 acres. The reactor site is located at River Mile 798 upstream from the City of Red Wing (at River Mile 789) and downstream from the cities of Hastings (at River Mile 814) and Prescott (at River Mile 810).

Geographically, the reactor site is within the Mississippi River floodplain, a wetlands interior delta that includes lesser lakes, sloughs, and rivers. The topography of the site is relatively level, and ranges in elevation from 675 feet (ft) to 706 ft in the National Geodetic Vertical Datum of 1929 (NGVD29). Unless otherwise stated, all elevations in this staff assessment are given with respect to NGVD29. Rising sharply above the river floodplain are the 'Central Lowlands' of Minnesota, a rural agricultural area generally defined by bluffs of slight topographic relief and numerous small lakes (Martin, 1965). The elevation of those bluffs in the vicinity of the reactor site ranges from 1,000 ft to 1,200 ft NGVD29, and are easily identified by the presence of deeply-eroded coulees. The reactor complex itself is located on a relatively flat location whose natural elevation varies from 695.4 ft to 695 ft NGVD29, and slopes slightly to the southeast towards Sturgeon Lake and the Mississippi River, and southwest to the Vermillion River. Figure 3.1-1 of this assessment shows the Prairie Island site in relation to Sturgeon Lake, the Mississippi River, the Vermillion River, and other local geographic features.

Geologically, the Prairie Island site is underlain by sandy soil that was deposited as glacial outwash (Zumberge, 1952); these soils are mixed with more-recent fluvial sediments. The licensee previously reported these surface deposits vary in thickness from 158 ft to 185 ft below grade (Xcel Energy, 2010). The bedrock surface found at depth is sandstone of the Franconian Formation (Upper Cambrian). Because of their porous nature, the licensee previously noted that overland surface flow conditions in the surficial soils are essentially non-existent.

The water level in the vicinity of the reactor site is regulated by the St. Paul District of the U.S. Army Corps of Engineers (USACE). Regulation of the water level is achieved through the operation of a series of locks and dams intended to maintain minimum-depth navigation channels within the main stem of the Mississippi River. The water level within this so-called "upper pool" (defined primarily by the Mississippi River and Sturgeon Lake – Figure 3.1-1) is controlled by operation of Lock and Dam No. 3 located 1.5 miles (mi) south of the reactor site; the stillwater surface elevation (WSE) of the upper pool is generally 674.5 ft NGVD29. A second lock/dam combination – Lock and Dam Number 2 – is located about 17 mi upstream of the plant site (River Mile 815.2), near Prescott. The difference in the WSE on the river across Lock and Dam No. 2 is 12.2 ft (Xcel Energy, 2016a). The licensee previously noted that failure of the hydroelectric dam at that location would not flood the Prairie Island reactor site (Xcel Energy, 2010). The reactor's Service Water Intake Structure (SWIS) is located on the east bank of the Sturgeon Lake at its confluence with the Mississippi River, and the upper pool serves as the ultimate heat sink for the reactor.

For the purposes of the FHRR analysis, the licensee estimated the size of the drainage area above the Prairie Island reactor site is about 45,000 square miles (mi^2). According to USACE, the highest probable maximum flood (PMF) on record is a 1965 event (recurrence interval was 150 years) whose peak stage at the Lock and Dam No. 3 location was 687.7 ft NGVD29. It is estimated by USACE that a flood having a 1,000-year recurrence interval would have a peak stage of about 693.5 ft NGVD29 at the same location.

Owing to potential seismic hazard concerns (specifically liquefaction), the foundation material for the reactor complex is re-compacted granular fill. The finished plant grade is about 20 ft above the mean upper pool WSE, 7 ft above the 1965 PMF WSE, and 1 ft above the predicted 1,000-yr flood WSE (Xcel Energy, 2010). The licensee previously noted that the reactor site is designed to withstand the effects of a 703.6 ft NGVD29 PMF corresponding to a probable maximum discharge of 910,300 cubic ft/sec (cfs) (Xcel Energy, 2010).

Table 3.0-1 of this assessment summarizes the controlling reevaluated flood-causing mechanisms, including associated effects, the licensee computed to be higher than the powerblock elevation.

The licensee noted that the Reactor Buildings, the Auxiliary and Fuel Handling Building, the Turbine Building, the D5/D6 Diesel Generator Building, and the pump section of the Intake Screenhouse structure for the SWIS are protected against the PMF to an elevation of 703.6 ft NGVD29. The base slabs for these structures are reported to have also been designed to resist the full hydrostatic head associated with the PMF. Tops of substructures and/or superstructure flood protection walls rise to an elevation of 705.0 ft NGVD29, and are also reported to have been designed to resist the PMF. The licensee noted that these structures are capable of withstanding the hydrostatic forces associated with the PMF and associated maximum wave run-up to an elevation equivalent to 706.7 ft NGVD29. All construction joints are keyed and provided with water stops. Penetrations through the foundation base slabs and flood protection walls below 703.6 ft were minimized as an additional flood protection measure (Xcel Energy, 2012).

Temporary passive or active flood protection features reported by the licensee include the use of flood panels, portable pumps, etc. that are intended protect safety-related SSCs from external flooding effects (Xcel Energy, 2012). As these features are temporary in nature, the licensee notes they must be installed prior to advent of the design basis external flood.

3.1.2 Design-Basis Flood Hazards

The CDB flood levels are summarized by flood hazard mechanism in Table 3.1-1 of this assessment. The licensee reported that the bounding CDB flood hazard for the Prairie Island site is flooding due to a PMF. The licensee noted that the Prairie Island site was not previously considered susceptible to floods resulting from LIP, dam breaches or failures, ice-induced dams or jams, channel migration, or a combined effects flood on the Mississippi River and therefore they were not included in the design-basis. The NRC staff documented that some of these flood-causing mechanisms were not specifically addressed by the licensee when the UFSAR for the Prairie Island site was prepared. The NRC staff noted that some of these mechanisms were, nonetheless, screened from further consideration as the licensee determined that the WSEs associated with these flooding mechanisms were bounded by the CDB. The licensee also reported that the Prairie Island site was not in a geographic location subject to certain types of marine-induced flooding scenarios that might occur as a result of surges, seiches, and tsunamis; consequently, these flood-causing scenarios were also be screened-out from further consideration for the purposes of licensing.

The NRC staff reviewed the information provided in the FHRR and determined that sufficient information was provided to be responsive to Enclosure 2 of the 50.54(f) letter.

3.1.3 Flood-Related Changes to the Licensing Basis

The licensee noted that since the issuance of the operating license, no revisions to the flood hazard analysis have occurred and no significant changes to the flood protection strategies described in the current Prairie Island operating license have taken place. During the NRC-requested 50.54(f) flooding walkdown, a deficiency related to the operation of the sump pumps was identified by the licensee (Xcel Energy, 2012). To address that deficiency, the licensee prepared a new plan (procedure) to provide portable sump pumps with power supplies that would be available during a loss-of-offsite power event (Xcel Energy, 2016a). In addition, a site operating procedure (Abnormal Procedure AB-4, "Flood," Revision 50) was revised to describe the process for deploying the sump pumps.

The NRC staff reviewed the information provided in the FHRR and determined that sufficient information was provided to be responsive to Enclosure 2 of the 50.54(f) letter.

3.1.4 Changes to the Watershed and Local Area

The licensee reported that there are no significant changes reported to the Mississippi River watershed and environs in the immediate vicinity of the Prairie Island site since issuance of the UFSAR. The most significant changes to the watershed reported by the licensee include expansion and development of the greater Twin City Metropolitan Area about 26 mi to the northwest of the reactor site. Other, lesser local area changes have been minimal since plant operation began including the expansion of the local Native American tribal community and the additional new, nearby businesses.

Changes consistent with most nuclear plant sites have been made at Prairie Island since operations began, including the addition of the following permanent structures:

- Administration buildings
- Intake Screenhouse Structure
- Security buildings
- Warehouses
- FLEX Equipment Storage Building
- Diesel Generator D3/D4 Building
- Diesel Generators D5 and D6 Building
- Security barriers such as a vehicle barrier system (VBS)

Subsequent to the operation of the reactor, the licensee also received a 10 CFR Part 72 license for an independent spent fuel storage installation to be operated at the site. Any other unreported changes to the terrain would be implicitly accounted for in the hydrologic models used in the FHRR through the use of improved, higher-resolution topographic data for the region and site.

The NRC staff reviewed the information provided in the FHRR and determined that sufficient information was provided to be responsive to Enclosure 2 of the 50.54(f) letter.

3.1.5 Current Licensing Basis Flood Protection and Pertinent Flood Mitigation Features

The Prairie Island site grade is at an elevation of 695 ft NGVD29, which is about 16 ft higher than the maximum recorded high-water level for the main stem of the Mississippi River at this location, and about 0.6 ft higher than the 1,000-yr projected high-water level. In its FHRR (Xcel Energy, 2016a), the licensee reported that certain buildings within the powerblock containing SSCs (i.e., the Reactor Buildings, the Auxiliary and Fuel Handling Building, the Turbine Building, the D5/D6 Diesel Generator Building, and the pump section of the Intake Screenhouse structure) have been designed to resist a PMF in combination with wind effects to an elevation of 706.7 ft NGVD29.

The licensee stated that the site has both incorporated and temporary active and passive barriers (Xcel Energy, 2012). For example, the licensee stated that the Prairie Island site is designed in such a manner that all areas critical to nuclear safety are protected against the effects of a PMF and associated wave run up to an elevation of 706.7 ft NGVD29. The manual actions requiring operator involvement include the installation of flood doors and bulkheads, portable pumps, and the initiation of plant flood operating procedures.

The licensee also stated that plant operating procedures specify flood stage elevations at which plant protective measures must be taken. Implementation of those flood procedures are based on 3-day forecasts of flood stage obtained from the St. Paul District of the USACE at the Lock and Dam No. 3 location. According to the licensee, Operating Procedure AB-4 ("Flood") outlines the specific manual actions to be taken when the three-day flood forecast exceeds a WSE of 678 ft NGVD29. Additional manual actions would take place, based on 3-day flood forecasts, when WSEs of elevations 680, 683, 685, 688, 690, and 692 ft NGVD29. For the design-basis flood (703.6 ft NGVD29), the total time available between the initial 3-day WSE forecast of 678 ft NGVD29 and when the WSE reaches the nominal finished grade of the reactor site (695 ft NGVD29) is approximately 6 days (Xcel Energy, 2012). When the 3-day projections of flood WSEs exceed 693 ft NGVD29, plant operating procedures require placing the reactor units in Mode 3 or "Hot Standby." When the 3-day flood stage projections exceed 693 ft NGVD29, those procedures also require the plant to be placed in Mode 4 based on the High Energy Line Break analysis before flood protection bulkheads are installed. The licensee stated that a critical action during this timeframe is the installation of the flood doors and bulkheads in Operating Procedure AB-4.

The NRC staff reviewed the flood hazard information provided and determined that sufficient information was provided to be responsive to Enclosure 2 of the 50.54(f) letter (NRC, 2012a).

3.1.6 Additional Site Details to Assess the Flood Hazard

In connection with the staff's FHRR review, electronic copies of the computer input/output files used in the numerical modeling of LIP were also provided to the staff in the context of the aforementioned audit process.

3.1.7 Plant Walkdown Activities

The 50.54(f) letter (NRC, 2012a) requested that licensees plan and perform plant walkdown activities to verify that current flood protection systems are available, functional, and implementable. Other parts of the 50.54(f) letter asked the licensee to report any relevant information from the results of the plant walkdown activities (NRC, 2012a).

By letter dated November 26, 2012, the licensee submitted a Flooding Walkdown Report as requested in Enclosure 4 of the 50.54(f) letter for the Prairie Island site (NSPM, 2012). On June 17, 2014 (NRC, 2014), the NRC staff issued its assessment of the Walkdown Report, which documented its review of that licensee action and concluded that the licensee's implementation of the flooding walkdown methodology met the intent of the walkdown guidance.

3.2 Local Intense Precipitation and Associated Site Drainage

The licensee reported that the reevaluated flood hazard for LIP is based on a maximum WSE at five door locations of structures considered important to safety ranging from approximately

695.2 to 695.4 ft NGVD29 (Xcel Energy, 2016a). The maximum inundation depth attributed to LIP-related flooding occurred at the Auxiliary Building/Radioactive Waste Building location.

The effects of wind waves and run-up were not included in the flood hazard reevaluation. The licensee considered the LIP inundation depths and velocities too shallow and low to produce wind/wave effects. This flood-causing mechanism is not discussed in the licensee's CDB and no PMF elevation was reported.

The licensee reevaluated the flood hazard due to an LIP event using the USACE's Hydrologic Engineering Center (HEC) Hydrologic Modeling System (HEC-HMS) (USACE, 2010a) and River Analysis System (HEC-RAS) (USACE, 2010b) software packages. The NRC staff considers the selection of the HEC-HMS and HEC-RAS computer code for LIP modeling to be reasonable.

3.2.1 Site Drainage and Elevations

The licensee reevaluated the flood hazard resulting from LIP due to a storm over an immediate drainage area of about 0.17 mi^2 that included the footprint of the Prairie Island powerblock, the site's VBS, and all contiguous natural drainage areas that could potentially affect flooding of the site. The licensee used a digital terrain model (DTM) to approximate the ground surface topography corresponding to the Prairie Island powerblock site and environs (Figure 3.2-1 of this assessment). Data for that topographic model were acquired from a Light Detection and Ranging (LiDAR) data combined with site survey data; the LiDAR data has a horizontal resolution of about 3.28 ft.

The NRC staff reviewed the licensee's approach to the development of the computation domain for HEC-RAS model against relevant regulatory criteria based on present day methodologies and guidance. The NRC staff considers the general approach described by the licensee to be reasonable.

3.2.2 Local Intense Precipitation

For ESPs and COLs, current NRC guidance for LIP evaluation is to select the appropriate probable maximum precipitation (PMP) event reported in the National Weather Service's Hydrometeorological Reports (or HMRs) applicable to the site (NRC, 2011). Using the National Oceanic and Atmospheric Administration (NOAA) HMR-51 (NOAA, 1982) and HMR-52 (NOAA, 1982) methodology, the 1-hour (h), 1-mi^2 all-season precipitation intensity estimated for the site would be 16.76 in.; for a 6-h, 10-mi^2 event, the precipitation intensity would be 23.60 in. These values also correspond to the precipitation values for the nearby Monticello Nuclear Generating Plant (Monticello).

Alternatively, a site-specific PMP (ssPMP) estimate was derived based on a methodology developed by Applied Weather Associates; the PMP value estimated using that methodology was 13.4 in. for the 1-h, 1-mi^2 event and 21.0 in. for the 6-h, 1-mi^2 event (Parzybok and Tomlinson, 2006). The licensee noted that the LIP evaluation included consideration of both an all-season as well as a cool-season, rain-on-snow storm event. The all-season event was determined to be the controlling LIP event. Therefore, only the all-season storm event analysis is discussed in this section.

The NRC staff reviewed the licensee's use of an ssPMP by examining the sensitivity of the WSE estimate based on the use of an HMR value. In connection with that review, the NRC staff found that the HMR-51/HMR-52 values for the Prairie Island site (Figure 3.2-2 of this assessment) were approximately equivalent to the precipitation values for the nearby Monticello site (Figure 3.2-3 of this assessment). In light of that similarity, as an analysis efficiency, the staff also used the HEC-HMS rainfall hyetographs from the Monticello site as input to the licensee's Prairie Island HEC-RAS computer model. The calculated WSEs based on either an ssPMP or an HMR-derived PMP value were subsequently found to be essentially the same at any safety-related structure location of interest within the Prairie Island powerblock. As a further PMP sensitivity test, the NRC staff increased the magnitude of the flow factor within HEC-RAS model by a factor of two thereby adding additional conservatism to the LIP model and the resulting difference between the WSEs at any safety-related structure from either source was less than 0.1 ft based on rounding.

As a result of these efforts, the NRC staff concluded that the results of the ssPMP flooding scenario described by the licensee are reasonable.

3.2.3 Runoff Analysis

The physical features of the Prairie Island powerblock (e.g., permanent buildings, roadways, the VBS, etc.) incorporated into the licensee's LIP model were described in either the FHRR or the complementary LIP flood calculation packages (discussed during a 2016 audit with the licensee (NRC, 2017)). These documents also summarized key details concerning the LIP model. The licensee divided the HEC-HMS modeling domain into 32 sub-basins covering the power block area, switchyard, parking lots, and some topographically-higher, upstream contributing areas (Figure 3.2-4 of this assessment). In the HEC-RAS model, the model domain covers all 32 sub-basins and was divided into 18 storage areas and 10 conveyance areas. The licensee noted that the decisions on how to define the respective sub-basins were based on an examination of ground elevation data obtained from a LiDAR topographic survey, the elevations of various security barriers within the controlled area, and other as-built structures at the site. The licensee noted that the roofs of permanent buildings and other key structures were elevated in the LIP model to ensure that roof drainage would shed onto adjacent ground surfaces in order to maximize flood-related WSE estimates; moreover, those rooftops provided no rainwater storage. As an additional conservatism, site drainage systems were also assumed to be blocked and non-functional allowing for additional rainwater accumulation. Small gaps in the VBS were also reported to have been ignored in the hydraulic analysis. Lastly, the licensee stated that infiltration by ground surface materials was conservatively not considered. The NRC staff reviewed the LIP model and found that the basins are appropriately delineated, and the model domain covers the entire reactor site.

Having defined the respective sub-basins, the licensee then used the HEC-HMS software to model overland flow within those domains. The U.S. Soil Conservation Service (SCS) unit hydrograph method (SCS, 1986) was used to transform the PMP estimate into a probable maximum flow hydrograph for each of the 32 sub-basins. As a downstream boundary condition in the HEC-RAS model, the licensee assigned a WSE of 689.4 ft NGVD29 corresponding to a 500-year flood on the Mississippi River for all channel reaches discharging into the river. The NRC staff identified and confirmed the locations of buildings and other structures present within the HEC-RAS modeling domain using available aerial imagery for the Prairie Island site. Buildings were modeled as obstructions that completely blocked the surface flow of water. The NRC staff also confirmed that the representation of those features with higher elevations would both promote surface flow away from and/or around those locations. Lastly, the NRC staff confirmed that a stage hydrograph elevation proposed as the Mississippi River downstream boundary condition was reasonable.

In its review of the derived SCS unit hydrographs for the site, the NRC staff noted that the hydrograph may not always represent hydrometeorological conditions that would prevail during the PMF, and thus some non-linearity adjustments to the unit hydrographs could be made by increasing the peaks by 20 percent and reducing the time-to-peak by 33 percent, as recommended in NUREG/CR-7046 (NRC, 2011). In response to an NRC staff's request, the licensee explained that the lag time for the respective LIP sub-basins was chosen based on the minimum time of concentration used in the Technical Release 55 software (USDA, 1986). Based on the recommendations accompanying that software, further reduction of lag time is not necessary due to the small size of the sub-basins in the Prairie Island LIP model. The licensee also indicated that the conservatively-chosen lag time would automatically result in an increase in the unit hydrograph peak discharge, and thus further adjustment in the peak discharge was not warranted. Following the 2016 audit, the NRC staff confirmed that the manner in which the licensee addressed the lag time issue in the LIP model for the site was reasonable. The NRC staff conducted an independent sensitivity analysis using smaller lags time in the model and found that the results do not affect conclusions reached in the FHRR (NRC, 2017).

The HEC-HMS flow hydrographs were used as inflow hydrographs corresponding to reaches and cross sections in the HEC-RAS models. In order to characterize the flowpaths around the powerblock, one reach may extend across multiple sub-basins. The existence of multiple reaches within a particular sub-basin required multiple sets of inflow hydrographs as inputs to the reach. In connection with its FHRR review, the NRC staff had several questions concerning the information transfer between the HEC-HMS hydrographs and the HEC-RAS river reaches, which were discussed with the licensee during an audit (NRC, 2017). For example, the Prairie Island LIP model had 32 subbasins, 10 river reaches, and 18 storage areas. The NRC staff determined that information about the respective modeling interfaces was not discussed in any of the FHRR documents available to the staff. At the NRC staff's request, the licensee provided additional information explaining how mass-flow conservation and continuity were maintained through the transfer process. During the audit (NRC, 2017), the staff confirmed that the information transfer between the LIP-related models was reasonable. The NRC staff also engaged the licensee in other questions related to the licensee's corrected runoff analysis during the audit. Following the audit, the NRC staff independently performed a computer run of the HEC-RAS model with the corrected inflow hydrograph (for reach #210) from the HEC-HMS model and confirmed that the increase in the maximum WSE at the critical door locations of interest were minimal (NRC, 2017).

Lastly, the Prairie Island FHRR stated that Manning's roughness coefficient value n, is a key parameter to determining how flow resistance exerted by the ground surface controls water velocities and WSEs within the LIP model. In the HEC-RAS model, the licensee selected a Manning's value of 0.02 based on the recommendations of Chow (1959) to represent the roughness coefficient for those cross sections extending over surfaces which were mainly asphalt paved roads with some area along the side of the sides of the roads covered with gravel some grass. The NRC staff reviewed the methodology for assigning coefficient value and concluded that both the methodology and coefficient value selected were reasonable and consistent with present-day guidance and methods.

3.2.4 Water Level Determination

The licensee evaluated the flooding hazard due to LIP across the Prairie Island powerblock. For the purposes of the LIP analysis, the site's drainage system was conservatively assumed to be nonfunctional. As a further conservatism, no infiltration was assumed.

The modeling results indicated that the maximum WSEs varied across the powerblock; 14 critical-door locations were considered important-to-safety and identified in Table 2 of the FHRR. Of the 14 critical-door locations, flood water levels could exceed the finished floor levels at 5 door locations (Xcel Energy, 2016a). Figure 3.2-1 of this assessment illustrates those buildings/locations, which include the Intake Screenhouse structure, the Old Administration Building, the Turbine Building, the Turbine Building/Service Building, and the Auxiliary Building/Radioactive Waste Building. Table 3.0-1 of this assessment lists the maximum flood depths and the corresponding WSEs at five critical-door locations. The appendix at the end of this staff assessment contains figures illustrating the critical-door locations in relation to powerblock structures.

After independently executing the licensee's HEC-HMS/HEC-RAS computer code input files, the NRC staff confirmed the depths and locations of the maximum WSEs reported in the FHRR. The NRC staff found that: (a) mass balance errors were acceptably small; (b) flow pathways and areas of inundation appeared reasonable; (c) water velocities were reasonable; and (d) no indication of numerical instabilities nor unexpected supercritical flow conditions were identified near potential flooding pathways associated with the five critical-door locations. Based on these results, the NRC staff confirmed the results of the licensee's LIP simulations. The NRC staff further concluded that the maximum WSEs reported by the licensee were consistent with its independent calculations.

3.2.5 Conclusion

The NRC staff confirmed the licensee's conclusion that the reevaluated flood hazard for LIP and associated site drainage is not bounded by the CDB. Therefore, the NRC staff expects that the licensee will submit a focused evaluation for LIP and associated site drainage for Prairie Island.

3.3 <u>Streams and Rivers</u>

The licensee reported that the reevaluated flood hazard for streams and rivers is based on a PMF whose stillwater surface elevation on the Mississippi River is [redacted] NGVD29. When wind wave and runup effects are considered, the reevaluated flood hazard elevation is estimated at [redacted] NGVD29 (Xcel Energy, 2016a). The CDB elevation for the streams and rivers type of PMF is based on a stillwater surface elevation of 703.6 ft NGVD29 and a wave run-up elevation of 706.7 ft NGVD29.

The reevaluation of the streams and rivers flood-causing mechanism at the Prairie Island site was performed by USACE, and the results subsequently adopted by the licensee for the purposes of its FHRR. Flows on the greater Mississippi River are affected by the presence of a large number of locks and dams, some of which were designed, constructed, and are currently maintained by USACE. To support development of its FHRR, by letter dated March 5, 2014 (NSPM, 2014), the licensee requested NRC assistance in obtaining information related to the performance of those USACE-operated dams, including completed dam failure analyses. In response to this request, the NRC staff contracted with USACE to perform both the PMF and dam failure flooding analyses through Interagency Agreement NRC-HQ-13-I-03-0021, in which USACE assisted the NRC in determining the safety significance of upstream dams that may affect the Prairie Island site. Results applicable to the Prairie Island site and obtained from USACE's analysis were transmitted to the licensee on November 18, 2015 (NRC, 2015b). A non-public meeting was held between the NRC and USACE on July 9, 2015 (NRC, 2015c), to discuss the licensee's questions and comments regarding the USACE PMF and dam failure analyses.

The USACE PMF analysis included three components: (a) the definition of the PMP event; (b) a simulation of the PMF associated with the PMP event; and (c) an evaluation of the effect of combined flooding events. The analysis was limited to that portion of the Mississippi River watershed geographically above the Prairie Island site or about 45,000 mi^2. Overland flow within that sub-basin following a simulated PMP event was achieved using HEC-HMS computer code (USACE, 2010a). Using synthetic unit hydrographs as input, the runoff volumes and discharges at upstream and tributary locations within the sub-basin occupied by the reactor site were estimated. The output from that computer analysis was subsequently used to route the river flow within the Mississippi River and estimate WSEs at the Prairie Island site; this was achieved using the HEC-RAS computer code (USACE, 2010b).

The USACE relied on the standard NOAA approach to estimate PMP using the HMRs applicable to the Prairie Island site (HMR-51 (NOAA, 1982) and HMR-52 (NOAA, 1982)). Following the HMR methodology, the USACE developed a standard depth-area-duration (DAD) curve for the Mississippi River watershed using HMR-52. Two PMP scenarios were considered; one that was all-season and the other limited to the spring time (including snow melt). Those basin-wide PMP estimates for the watershed were then converted to surface runoff (overland flow) using the HEC-HMS computer code (USACE, 2010b). Based on their computer modeling, the USACE determined that the maximum discharge on the main stem of the Mississippi River at the Prairie Island site was [redacted] cfs. Using the calibrated HEC-RAS model, the USACE determined that the maximum stillwater WSE at the reactor site was [redacted] ft NGVD29 (Xcel Energy, 2016a).

The licensee also evaluated wind-wave and runup effects, coincident with a PMF, using the peak WSE of [redacted] ft NGVD29. The licensee used the Automated Coastal Engineering System (Leenknecht, Szuwalski, and Sherlock, 1992) and the Coastal Engineering Manual (USACE, 2008) to estimate those effects. Wind fetch length was estimated for seven fetch directions along the main stem of the river (Figure 3.3-2 of this assessment). Two critical fetch line distances (lines 1 and 7 in the figure) were identified based on the length (approximately 19 mi) and are oriented in such a way that a wind-generated wave would impact on the north-western face of the powerblock. The wave height that could be sustained by the incident wave after it breaks was estimated to be [redacted] ft. Taking that value into account, the licensee also predicted a run-up elevation of 2.72 ft on reactor site structures. The maximum WSE for this combined effects flood was estimated to be [redacted] ft NGVD29, which is less than the CDB. Consequently, the licensee reported that the combined effects PMF on the Mississippi River does not pose a hazard to the reactor site.

The NRC staff reviewed the licensee's wind-wave evaluation for the stream and river flooding and determined that the licensee followed methods consistent with the NRC guidance and with standard engineering practice. The NRC staff also consulted the appropriate hydrologic equations described in the Shore Protection Manual (USACE, 1984) and other sources (e.g., USACE, 1952) for evaluating wind-wave and runup effects. The NRC staff's estimated wave run-up values indicate total water levels similar to, or slightly below, those reported by the licensee. The NRC staff concluded that the licensee's wind-wave estimates were reasonable.

The NRC staff agrees with the licensee's conclusion that the reevaluated flood hazard for streams and rivers is bounded by the CDB flood hazard at the Prairie Island site.

Consequently, the NRC staff determined that flooding due to streams and rivers does not need to be analyzed in a focused evaluation or a revised integrated assessment.

3.4 Failure of Dams and Onsite Water Control/Storage Structures

The licensee reported that the reevaluated hazard for dam-related flooding effects is not applicable to the Prairie Island site. Further, this flood-causing mechanism is not described in the licensee's CDB.

The effects of potential dam breaches and failures at the Prairie Island site were considered by USACE as part of their PMF analysis conducted at the request of the NRC staff (NRC, 2015b). In performing that analysis, USACE noted that it followed JLD-ISG-2013-01 (NRC, 2013b). Upon completion of that analysis and in connection with a July 9, 2015, closed meeting on the findings of that analysis, the USACE stated that "all dams were screened out in terms of flood risk to the power plant site regardless of failure mode" (NRC, 2015b). Based on the information provided by USACE, it can be concluded that potential upstream dam breaches and failures regardless of failure mode do not increase the flood hazard at the Prairie Island site. This conclusion was adopted by the licensee and subsequently reported in the licensee's FHRR as the reevaluated hazard result for this flood-causing mechanism.

The NRC staff agrees with the licensee's conclusion that the PMF from dam failure flood-causing mechanism alone could not inundate the Prairie Island site. Consequently, the NRC staff determined that flooding due to dam failure does not need to be analyzed in a focused evaluation or a revised integrated assessment.

3.5 Storm Surge

The licensee reported that the reevaluated hazard for storm surge-related flooding effects are not applicable at the Prairie Island site. The Prairie Island site is not in a geographic location amenable to the occurrence of marine-driven storms capable of generating a storm surge. The site is inland, in the approximate center of the continent, and is located over 100 mi from the nearest large body of water (Lake Superior, to the north east; the next nearest large body of water capable of generating storm surge is Lake Michigan over 300 mi to the southeast). Consequently, this flood-causing mechanism is not considered physically plausible and thus was not considered in the licensee's CDB. Based on hydrological evidence in the region, the licensee concluded that storm surge will not affect the Prairie Island site.

In connection with its independent examination of the FHRR, the NRC staff reviewed the potential hazard from storm surge-related flooding against the relevant regulatory criteria based on present-day methodologies and regulatory guidance. Based on geographic evidence in the site region, the NRC staff concluded that there is no potential for flooding from storm surge to occur at the Prairie Island site.

The NRC staff confirmed the licensee's conclusion that the PMF due to the storm surge flood-causing mechanism does not impact the Prairie Island site. Consequently, the NRC staff determined that flooding due to storm surge does not need to be analyzed in a focused evaluation or a revised integrated assessment.

3.6 Seiche

The licensee reported that the reevaluated hazard for seiche-related flooding effects are not applicable at the Prairie Island site. The Prairie Island site is not adjacent to any large body of water (marine or non-marine) with a free surface area large enough to generate seiche-driven waves. Consequently, this flood-causing mechanism is not considered physically plausible and thus was not considered in the licensee's CDB. Based on hydrological evidence in the site region, the licensee concluded that seiche-related flooding will not affect the Prairie Island site.

In connection with its examination of the FHRR, the NRC staff reviewed the potential hazard from seiche-related flooding against the relevant regulatory criteria based on present-day methodologies and regulatory guidance. If seiche-like behavior were to occur on Sturgeon Lake, the NRC staff estimates that its effects on the reactor site would be negligible. As a consequence, the NRC staff concluded that there is no potential for seiche-like flooding behavior to occur at the Prairie Island site.

The NRC staff confirmed the licensee's conclusion that the PMF due to seiche-induced flooding does not impact the Prairie Island site. Consequently, the NRC staff determined that flooding due to seiche does not need to be analyzed in a focused evaluation or a revised integrated assessment.

3.7 Tsunami

The licensee reported that the reevaluated hazard for tsunami-related flooding effects is not applicable at the Prairie Island site. The Prairie Island site is not in a geographic location amenable to the occurrence of tsunamis; the reactor site is inland, at essentially a mid-content location and well-away from the coastline where tsunami-like waves can make land after forming following a tectonic disturbance on the ocean floor. The licensee observed that there are anecdotal reports of tsunami-like bores (or solitons) on the Mississippi River that were attributed to the 1811 to 1812 New Madrid earthquakes. The literature describing this earthquake is silent, though, on whether these effects were observed as far north as Minnesota. Consequently, this flood-causing mechanism is not considered physically plausible based on these types of scenarios and thus was not considered in the licensee's CDB. Based on hydrological evidence in the site region, the licensee concluded that tsunami-related flooding will not affect the Prairie Island site.

In connection with its examination of the FHRR, the NRC staff reviewed the potential hazard from tsunami-related flooding against the relevant regulatory criteria based on present-day methodologies and regulatory guidance. Based on geographic evidence in the site region, the NRC staff concluded that there is no potential for tsunami-like phenomena to affect the Prairie Island site. The inland location is isolated from the influence of recognized tsunamigenic sources (e.g., Gutenberg, 1939; Bernard and Robinson, 2009). Although the literature indicates that solitons or soliton-like features occurring on the free surface can travel for great distances (e.g., Russell, 1845, Bartsch-Winkler and Lynch, 1988), it is not apparent that such phenomena occurred on the Mississippi River in the past in connection with the New Madrid earthquakes.

The NRC staff confirmed the licensee's conclusion that flooding from tsunami could not inundate the Prairie Island site. Consequently, the NRC staff determined that flooding from tsunami does not need to be analyzed in a focused evaluation or a revised integrated assessment.

3.8 Ice-Induced Flooding

The licensee reported that the reevaluated flood hazard due to for ice-induced flooding effects is based on a stillwater WSE of 684 ft NGVD29; wind waves and runup effects were not included in the calculation. This flood-causing mechanism was not previously quantified for the purposes of the licensee's CDB.

For the purposes of its FHRR analysis, the licensee first queried the USACE's Cold Regions Research and Engineering Laboratory (CRREL) database for historic reports of ice dams/ice jams in the vicinity of the Prairie Island site. Results of that query indicated that there were two events recorded at the USGS stream gage (No. 05344500) location at Prescott (at River Mile 811), where the St. Croix River converges with the Mississippi River. Both events occurred in 1989 and 1990, and were reported as a WSE based on the height from the river invert (approximately 24.5 ft). There was also a November 1991 report of a 7.2 ft ice obstruction at Minneapolis near USGS stream gage (No. 05288920). In its analysis, the licensee transposed both observations to three locations along the main stem of the Mississippi River: the Lock and Dam Nos. 2 and 3 sites, and the Prairie Island site. The licensee generated six WSE estimates for different flooding scenarios given the two sets of observations; some of those estimates also included consideration of backwater effects. The flooding estimates for all six scenarios were bounded by the CDB; margins to plant grade ranged from 1.1 ft to 19.0 ft. The licensee's preferred scenario for the purposes of FHRR reporting was the one in which the maximum observed obstruction height of 24.5 ft was superimposed onto the river invert elevation at the Prairie Island site; the estimated WSE was 684.0 ft NGVD29 with an 11 ft margin below plant grade. The licensee made the calculation packages of its ice dam/ice jam analysis available to the staff during the 2016 audit for review (NRC, 2017).

The NRC staff independently reviewed the potential for flooding due to ice dams/ice jams on the main stem of the Mississippi River. The NRC staff reviewed the CRREL database and confirmed ice dam/ice jam reports described by the licensee in its FHRR. The CRREL database contains no historic reports of frozen obstructions on the main stem of the Mississippi River at the Prairie Island reactor site. A review of the literature (Paterson and Gamble, 1968) confirmed the information reported in the CRREL database. In the matter of the licensee's flood hazard calculations, the NRC staff independently estimated WSEs based on ice dam/ice jam failures by using a bounding calculation type-of-an approach based on empiric hydraulic equations. The NRC staff estimated dam breach discharges at specified locations above the reactor site using the U.S. Bureau of Reclamation's (USBR's) dam breach flow equations (USBR, 1982 and 1983). Those equations rely on estimating a hypothetical dam breach discharge taking into account the height of the flow obstruction, such as a dam. Having obtained that value, the shallow water wave celerity approximation and the Manning's velocity equation were used to mathematically-estimate a WSE at the Prairie Island site. As a conservatism, no fluid mass losses due to infiltration or attenuation were assumed in the analysis. Two hypothetical dam obstruction scenarios were considered: at the Lock and Dam No. 2 location and at the St. Croix/Mississippi River convergence at Prescott. The observed flood water elevation of 7.2 ft reported at the USGS Prescott river gage was used. At the Lock and Dam No. 2 location, the 7.2 ft observation was added to the 12.2 ft elevation difference reported across the Mississippi River there resulting in a 19.4 ft ice dam/ice jam obstruction. The results of the NRC staff analysis was that the estimated WSE increase due to the failure of an ice dam/jam at either location (Lock and Dam No. 2 or Prescott) was less than the FHRR WSE estimated by the licensee, and below the powerblock site grade.

The NRC staff confirmed the licensee's conclusion that the reevaluated hazard for flooding due to ice dams/ice jams is bounded by the CDB flood hazard at the Prairie Island site. Consequently, the NRC staff determined that ice-induced flooding does not need to be analyzed in a focused evaluation or a revised integrated assessment.

3.9 Channel Migrations or Diversions

The licensee reported that the reevaluated hazard for dam-related flooding effects is not applicable to the Prairie Island site. This flood-causing mechanism is not described in the licensee's CDB.

The licensee examined the potential for this hazard to occur at the reactor site by presenting geomorphic evidence that channel migration and/or diversion is unlikely at the site given that the Mississippi River floodplain is essentially entrained within a broad floodplain bordered by limestone rocks that are 300 ft in relief. The licensee also noted that this portion of the Mississippi River is a waterway that is used for both commerce and recreation, and that the USACE is responsible for maintaining navigability.

NUREG/CR-7046 (NRC, 2011e) acknowledges that there are no well-established predictive models for estimating the potential for channel diversion in a riverine environment. However, the potential for channel migrations or diversions to take place at a particular reactor location can be assessed by visually-inspecting applicable topographic maps such as those prepared by the U.S. Geological Survey (USGS, 2015). Such maps can be examined for what would be considered to be classic topographic/geomorphic evidence of past channel migrations or diversions (Fairbridge, 1968). In its evaluation of the FHRR, the NRC staff examined historic topographic maps of the Mississippi River stem for evidence of channel migration or river meandering phenomenon in the past, as well as more recently-published topographic maps of the area for such evidence subsequent to the initial publication of those maps. Examination of both sets topographic maps of the Prairie Island site area suggest that the course of the Mississippi River has remained relatively fixed for the last century at this location. Moreover, the literature describes the Prairie Island site as an inland delta (Zumberge, 1952), which implies low flow conditions (velocities) and increased sedimentation; such conditions are generally not conducive to promoting migrating channel behavior (Langbein and Leopold, 1966).

The NRC staff confirmed the licensee's conclusion that the reevaluated hazard for flooding due to channel migration or diversions is bounded by the CDB flood hazard at the Prairie Island site. Consequently, the NRC staff determined that channel migration or diversion-related flooding does not need to be analyzed in a focused evaluation or a revised integrated assessment.

4.0 REEVALUATED FLOOD HEIGHT, EVENT DURATION AND ASSOCIATED EFFECTS FOR HAZARDS NOT BOUNDED BY THE CDB

4.1 Reevaluated Flood Height for Hazards Not Bounded by the CDB

Section 3 of this staff assessment documents the NRC staff review of the licensee's flood hazard water height results. Table 4.1-1 contains the maximum flood height results, including wave effects, for flood mechanisms not bounded by the CDB. The NRC staff agrees with the licensee's conclusion that the LIP flood hazard mechanism is not bounded by the CDB.

The NRC staff anticipates the licensee will submit a focused evaluation for LIP and associated site drainage.

4.2 Flood Event Duration for Hazards Not Bounded by the CDB

The NRC staff reviewed information provided in the licensee's 50.54(f) response (Xcel Energy, 2016a) regarding the FED parameters needed to perform the additional assessments of the plant response for flood hazards not bounded by the CDB. The FED parameters for the flood-causing mechanisms not bounded by the CDB are summarized in Table 4.2-1 and Table 4.2-2 of this assessment.

The maximum WSEs generated during the LIP event in excess of the CDB were reported at five locations within the Prairie Island powerblock, as discussed in Table 3.0-1 of this assessment. The licensee reported that the duration of inundation across the powerblock is approximately 1.1 h whereas the time necessary for flood waters to recede from the site would be 5.4 h regardless of the structure or location in question (Xcel Energy, 2016).

The licensee used results from a one-dimensional numerical model, as described in its FHRR (Xcel Energy, 2016a), to determine the inundation and recession durations. The NRC staff confirmed that the licensee's reevaluation of the flood event duration parameters for LIP and associated drainage uses present-day methodologies and regulatory guidance; the NRC staff views the values reported reasonable based on the magnitudes of the estimated flooding hazards.

The licensee is expected to use the estimated LIP FED parameter values reported in the Prairie Island FHRR (Xcel Energy, 2016a) when it conducts additional assessments of plant response.

4.3 Associated Effects for Hazards Not Bounded by the CDB

The NRC staff reviewed information provided in the licensee's 50.54(f) response (Xcel Energy, 2016a) regarding AE parameters needed to perform future additional assessments of plant response for flood hazards not bounded by the CDB. The AE parameters directly related with maximum water elevation, such as wave effects, are provided in Table 4.1-1 of this assessment. The AE parameters not directly associated with total water elevation are listed in Table 4.3-1 of this assessment.

The licensee reported hydrostatic and hydrodynamic loads at impacted door locations due to LIP-related flooding at the Prairie Island site. Based on the relatively low flood depths and slow water velocities, the NRC staff agreed that these associated effects are minimal and the results reported in Table 4.3-1 are reasonable. For the AE parameters provided, the NRC staff confirms the licensee's AE parameter results are reasonable for use in additional assessments.

4.4 Conclusion

Based upon the preceding analysis, the NRC staff confirmed that the reevaluated flood hazard information defined in Section 4 is an appropriate input to the additional assessments of plant response as described in the 50.54(f) letter (NRC, 2012a), COMSECY-15-0019 (NRC, 2015a), and associated guidance.

5.0 CONCLUSION

The NRC staff reviewed the information provided for the reevaluated flood-causing mechanisms for the Prairie Island site. Based on the review of the available information provided in the licensee's 50.54(f) response (Xcel Energy, 2016a), the NRC staff concludes that the licensee conducted the hazard reevaluation using present-day methodologies and regulatory guidance used by the NRC staff in connection with ESP and COL reviews.

Based upon the preceding analysis, the NRC staff confirmed that the licensee responded appropriately to Enclosure 2, Required Response 2, of the 50.54(f) letter, dated March 12, 2012. In reaching this determination, the NRC staff confirmed the licensee's conclusions that: (a) the reevaluated flood hazard result for LIP is not bounded by the CDB flood hazard; (b) additional assessments of plant response will be performed for the LIP flooding mechanism; and (c) the reevaluated flood-causing mechanism information is appropriate input to the additional assessments of plant response as described in the 50.54(f) letter, COMSECY-15-0019 (NRC, 2015a), and associated guidance. The NRC staff has no additional information needs with respect to the licensee's 50.54(f) response.

6.0 REFERENCES

Notes: ADAMS Accession Nos. refers to documents available through NRC's Agencywide Documents Access and Management System (ADAMS). Publicly-available ADAMS documents may be accessed through http://www.nrc.gov/reading-rm/adams.html.

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Table 2.2-1. Flood-Causing Mechanisms and Corresponding Guidance

FLOOD-CAUSING MECHANISM	SRP SECTION(S) AND/OR JLD-ISG
Local Intense Precipitation and Associated Drainage	SRP 2.4.2 SRP 2.4.3
Streams and Rivers	SRP 2.4.2 SRP 2.4.3
Failure of Dams and Onsite Water Control/Storage Structures	SRP 2.4.4 JLD-ISG-2013-01
Storm Surge	SRP 2.4.5 JLD-ISG-2012-06
Seiche	SRP 2.4.5 JLD-ISG-2012-06
Tsunami	SRP 2.4.6 JLD-ISG-2012-06
Ice-Induced	SRP 2.4.7
Channel Migrations or Diversions	SRP 2.4.9

SRP refers to the Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition (NRC, 2007).
JLD-ISG-2012-06 refers to the "Guidance for Performing a Tsunami, Surge, or Seiche Hazard Assessment" (NRC, 2013a).
JLD-ISG-2013-01 refers to the "Guidance for Assessment of Flooding Hazards Due to Dam Failure" (NRC, 2013b).

Table 3.0-1. Summary of Controlling Flood-Causing Mechanism at the Prairie Island site.

REEVALUATED FLOOD-CAUSING MECHANISMS AND ASSOCIATED EFFECTS THAT MAY EXCEED THE POWERBLOCK ELEVATION 695.0 ft NGVD29[1]		WSE (NGVD29)
Local Intense Precipitation		
Turbine Building	*Door 47* [2]	695.2 ft
Auxiliary Building/ Radioactive Waste Building	*Door 100* [3]	695.4 ft
	Door 102 [3]	695.3 ft
	Door 104 [3]	695.4 ft
	Door 164 [3]	695.3 ft

[1] Flood height and associated effects as defined in JLD-ISG-2012-05.
[2] Identified as a roll-up type of door.
[3] Licensee notes that these doors are typically closed during normal operations.

Table 3.1-1. Current Design Basis Flood Hazard Elevations at the Prairie Island Nuclear Power Plant Site. (NGVD29)

FLOOD-CAUSING MECHANISM	STILLWATER ELEVATION	ASSOCIATED EFFECTS	CDB FLOOD ELEVATION	REFERENCE
Local Intense Precipitation and Associated Drainage	Not Included in the CDB	Not Included in the CDB	Not Included in the CDB	FHRR Sections 2.1, 2.13, and Table 4
Streams and Rivers	703.6 ft	3.1 ft	706.7 ft	FHRR Section 1.5.1 and Table 4
Failure of Dams and Onsite Water Control/Storage Structures	676.5 ft	Not Applicable	676.5 ft	FHRR Section 1.5.2 and Table 4
Storm Surge	Not Included in the CDB	Not Included in the CDB	Not Included in the CDB	FHRR Section 1.5 and Table 4
Seiche	Not Included in the CDB	Not Included in the CDB	Not Included in the CDB	FHRR Section 1.5 and Table 4
Tsunami	Not Included in the CDB	Not Included in the CDB	Not Included in the CDB	FHRR Section 1.5 and Table 4
Ice-Induced	Not Included in the CDB	Not Included in the CDB	Not Included in the CDB	FHRR Section 1.5 and Table 4
Channel Migrations or Diversions	Not Included in the CDB	Not Included in the CDB	Not Included in the CDB	FHRR Section 1.5 and Table 4

Table 4.1-1. Reevaluated Flood Hazard Elevations (NGVD29) for Flood-Causing Mechanisms Not Bounded by the Prairie Island CDB

FLOOD-CAUSING MECHANISM	STILLWATER ELEVATION (NGVD29)	ASSOCIATED EFFECTS	REEVALUATED FLOOD HAZARD (NGVD29)	REFERENCE
Local Intense Precipitation	695.4 ft	Minimal	695.4 ft	FHRR Section 2.1.2, and Tables 4 and 5

Note1: Reevaluated hazard mechanisms bounded by the current design basis (see Table 3.1-1) are not included in this table.
Note 2: Reported values are rounded to the nearest one-tenth of a foot.

Table 4.2-1. Flood Event Duration for Flood-Causing Mechanisms Not Bounded by the Prairie Island CDB.

FLOOD-CAUSING MECHANISM	TIME AVAILABLE FOR PREPARATION FOR FLOOD EVENT	DURATION OF INUNDATION OF SITE	TIME FOR WATER TO RECEDE FROM SITE
Local Intense Precipitation and Associated Drainage	NEI 15-05 (NEI, 2015)	1.1 h	5.4 h

Table 4.3-1. Associated Effects Parameters not Directly Associated with Total Water Height for Flood-Causing Mechanisms not Bounded by the Prairie Island CDB

	FLOODING MECHANISM
Associated Effects Parameter	**Local Intense Precipitation and Associated Drainage**
Hydrodynamic loading at plant grade	Minimal
Debris loading at plant grade	Minimal
Sediment loading at plant grade	Minimal
Sediment deposition and erosion	Minimal
Concurrent conditions, including adverse weather	Minimal
Groundwater ingress	Minimal
Other pertinent factors (e.g., waterborne projectiles)	Minimal

Source: Xcel Energy (2016b)

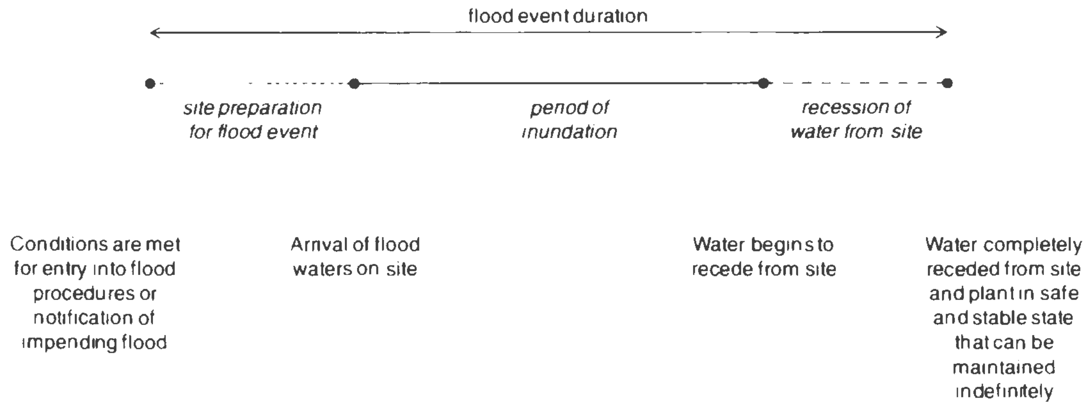


Figure 2.2-1. Flood Event Duration (NRC, 2012e)

Figure 3.1-1. Geography of the Prairie Island Nuclear Generating Plant.
Source: USGS

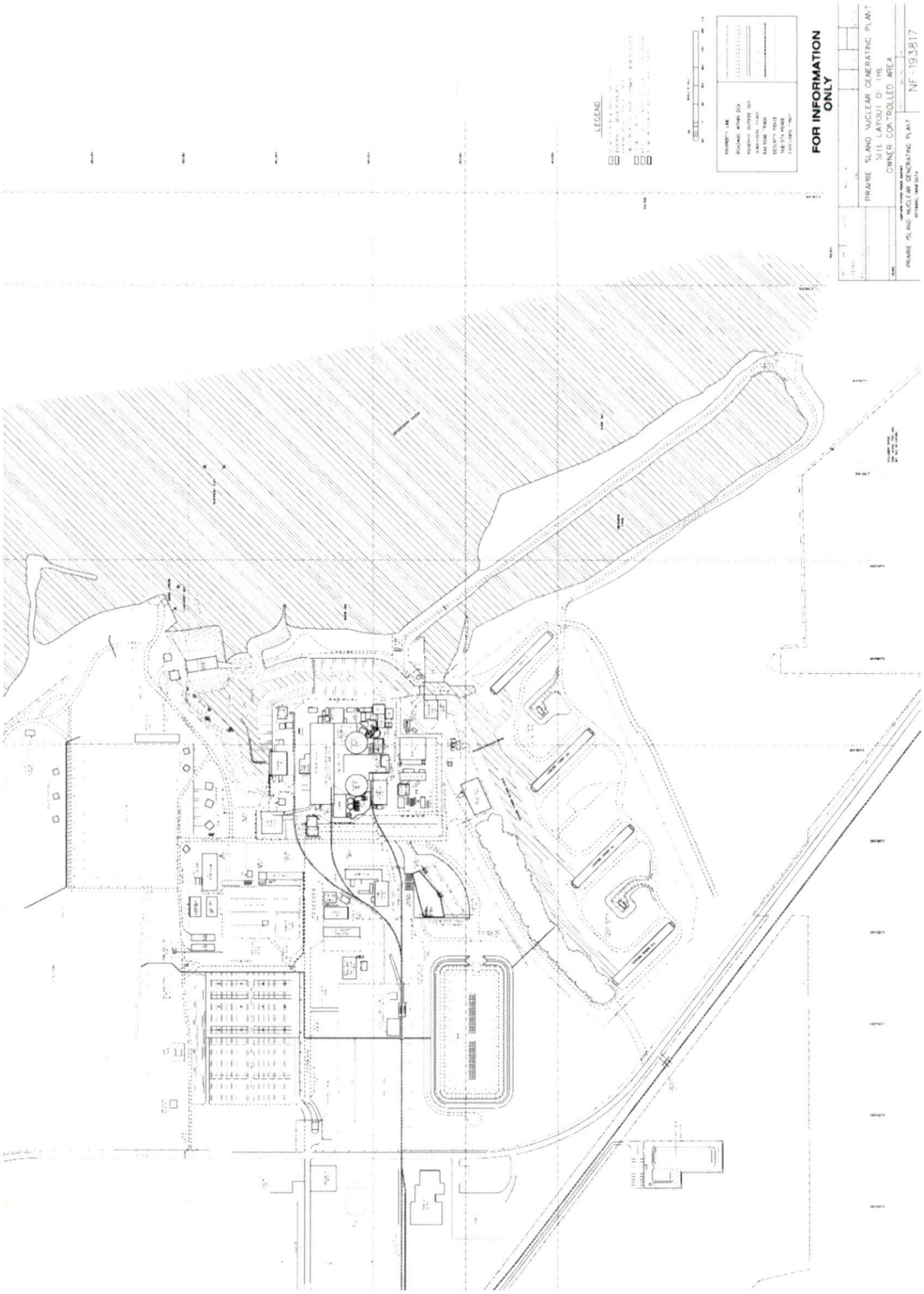


Figure 3.2-1. Prairie Island Powerblock Layout. Source: Licensee

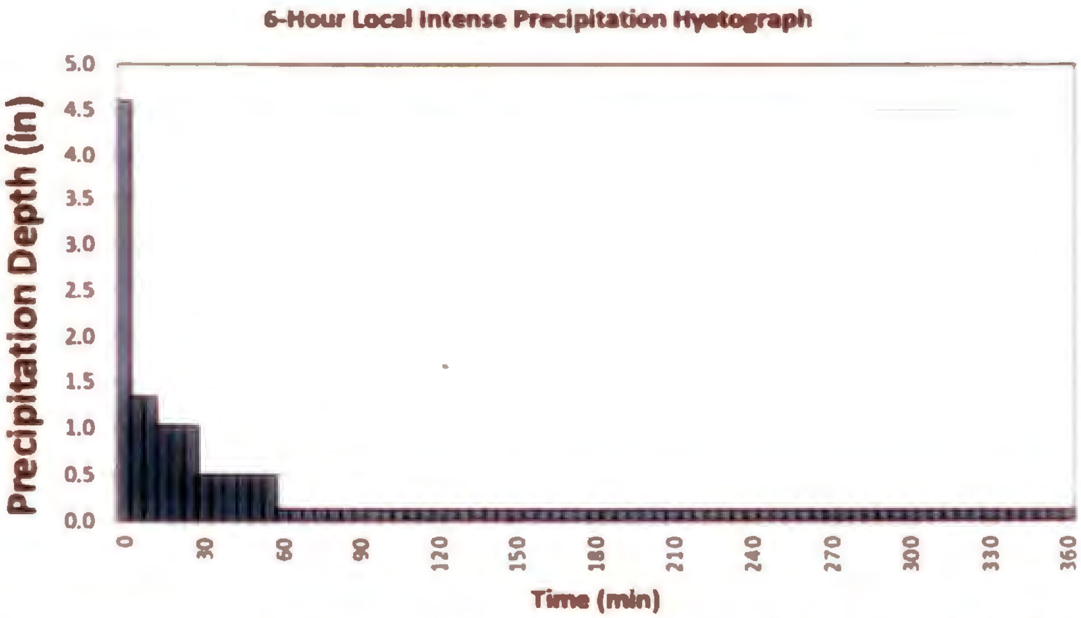


Figure 3.2-2. **All-Season PMP Hyetograph Used in the LIP Analysis for the Prairie Island Nuclear Power Plant Site.** (Xcel Energy, 2016a)

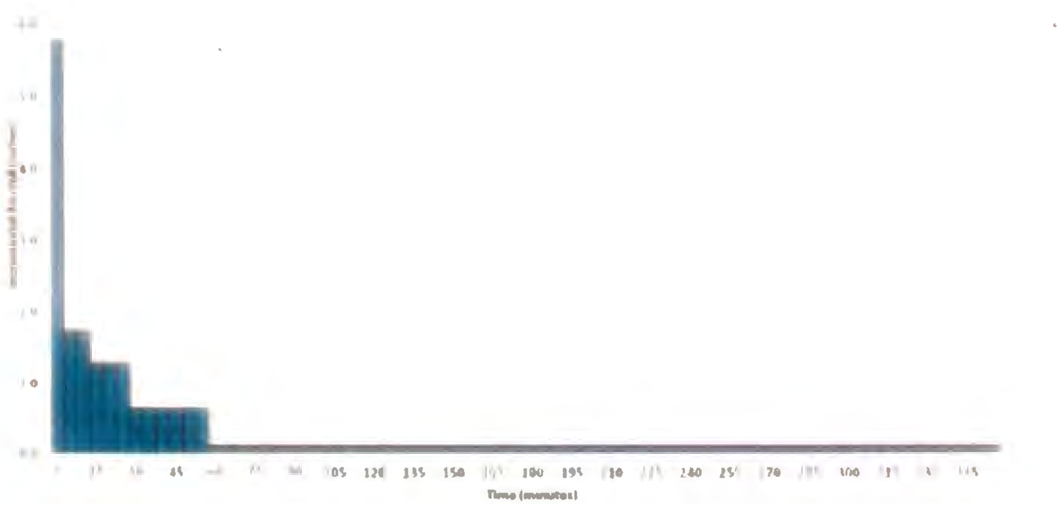


Figure 3.2-3. **All-Season PMP Hyetograph Used in the LIP Analysis for the Monticello Nuclear Power Plant Site.** (Xcel Energy, 2016b)

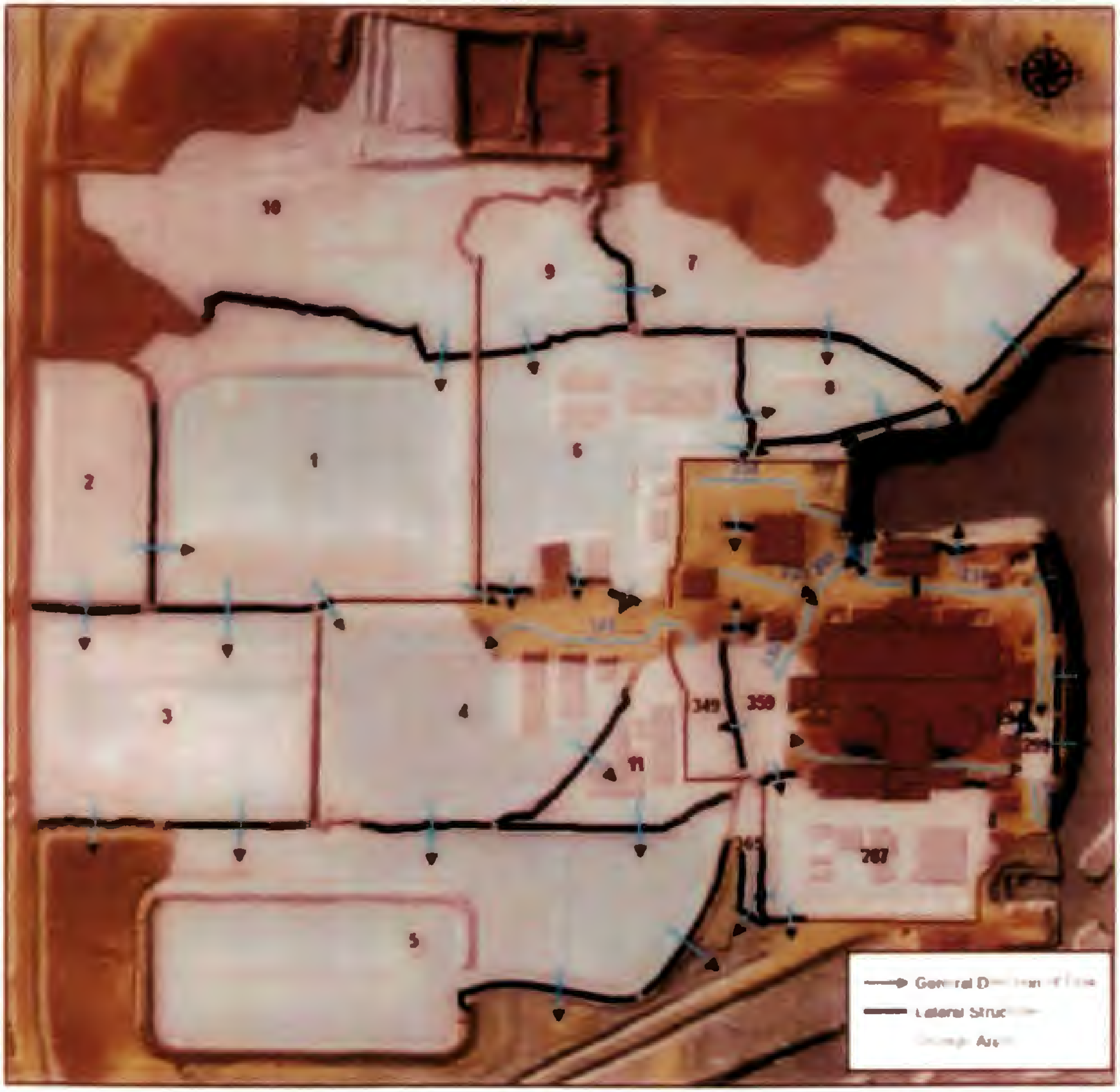


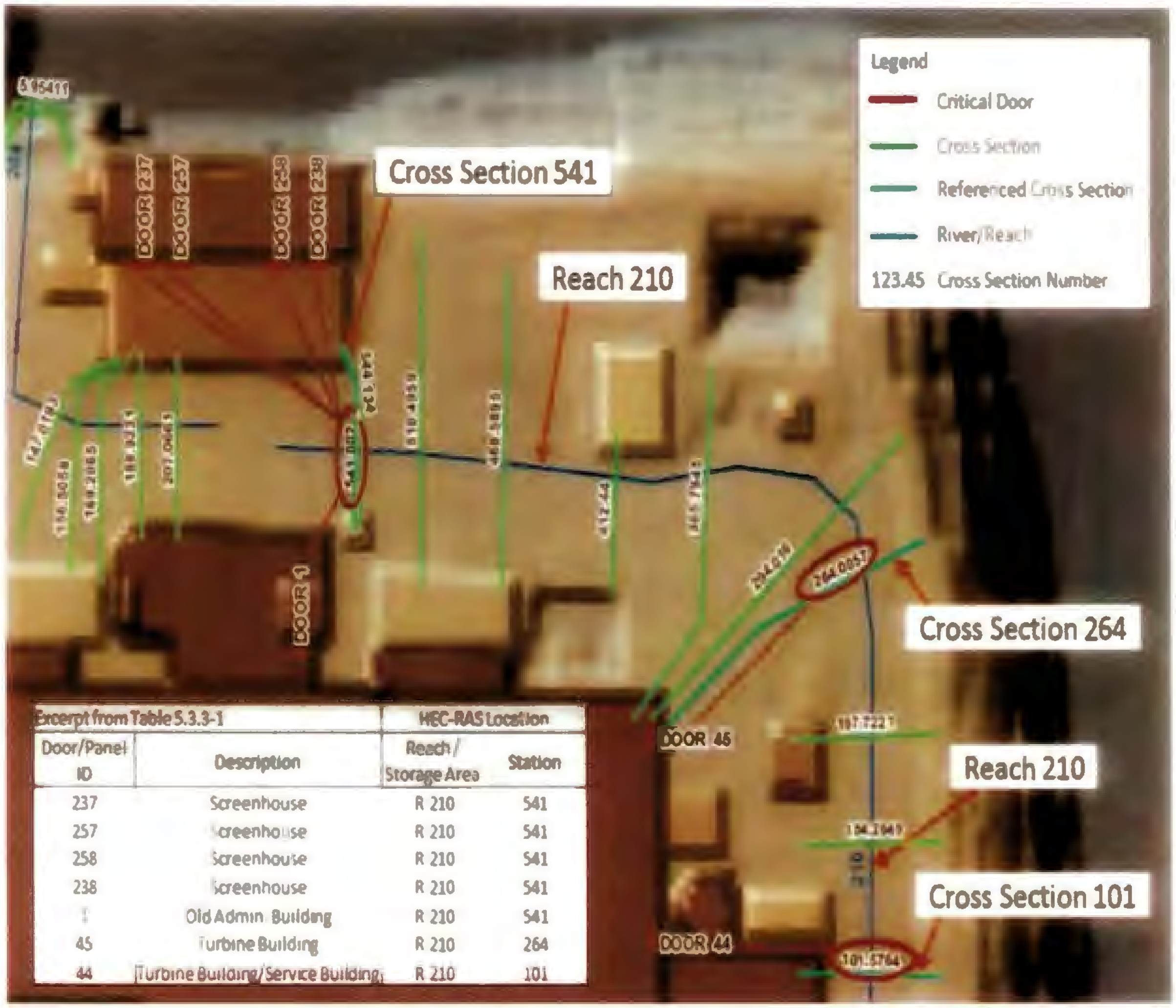
Figure 3.2-4. Drainage Sub-Basins (Areas) and Flow Path Directions Applicable to the Prairie Island LIP Analysis (Xcel Energy, 2016a)

[redacted]

Figure 3.3-2. Fetch Orientations Considered in Connection with the Wind/Wave Analysis for the Streams and Rivers Flood Reevaluation. (Xcel Energy, 2016a)

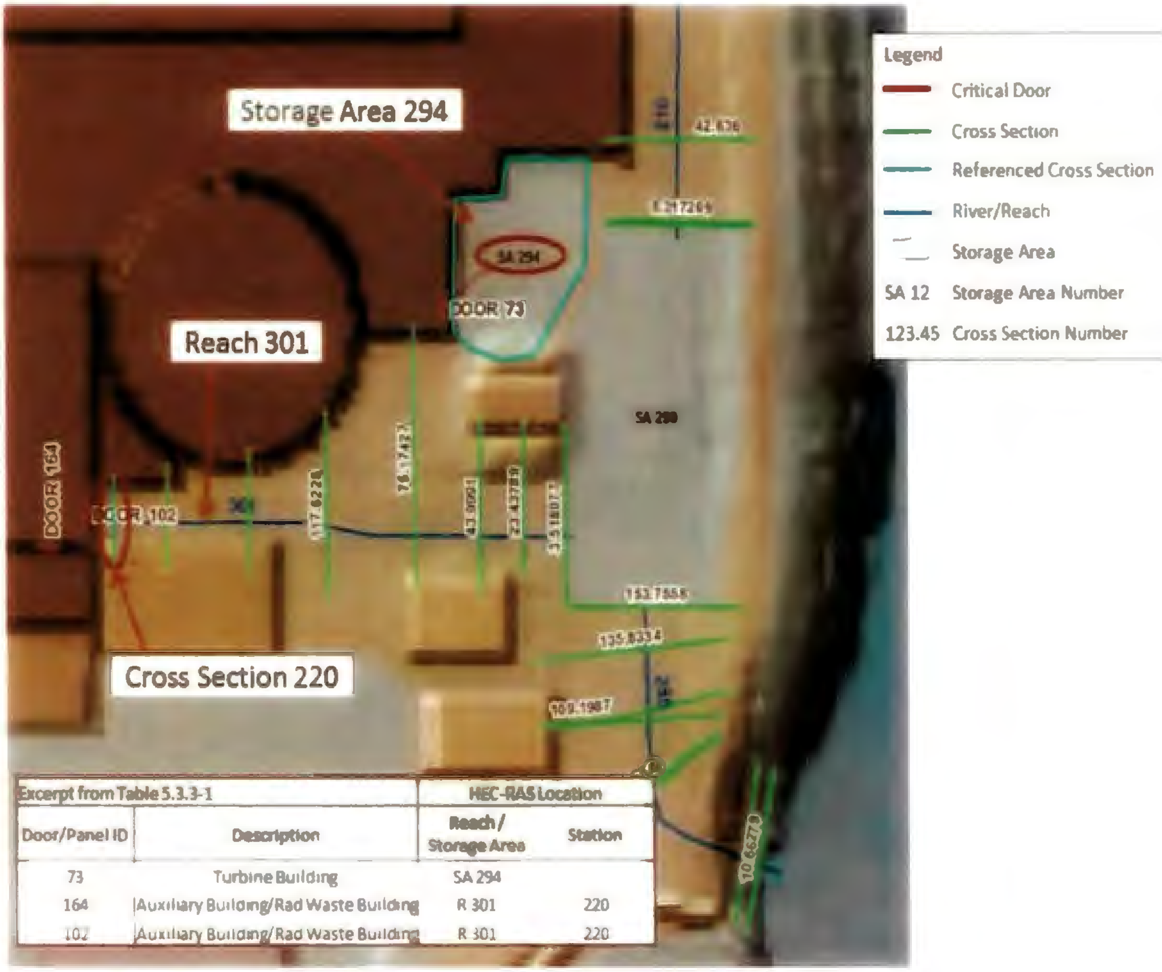
Appendix Containing Figures Illustrating Critical Door Locations Identified in Connection with the Local Intense Precipitation Analysis for the Prairie Island Nuclear Power Plant Site

Figures obtained from Xcel Energy (2016b)



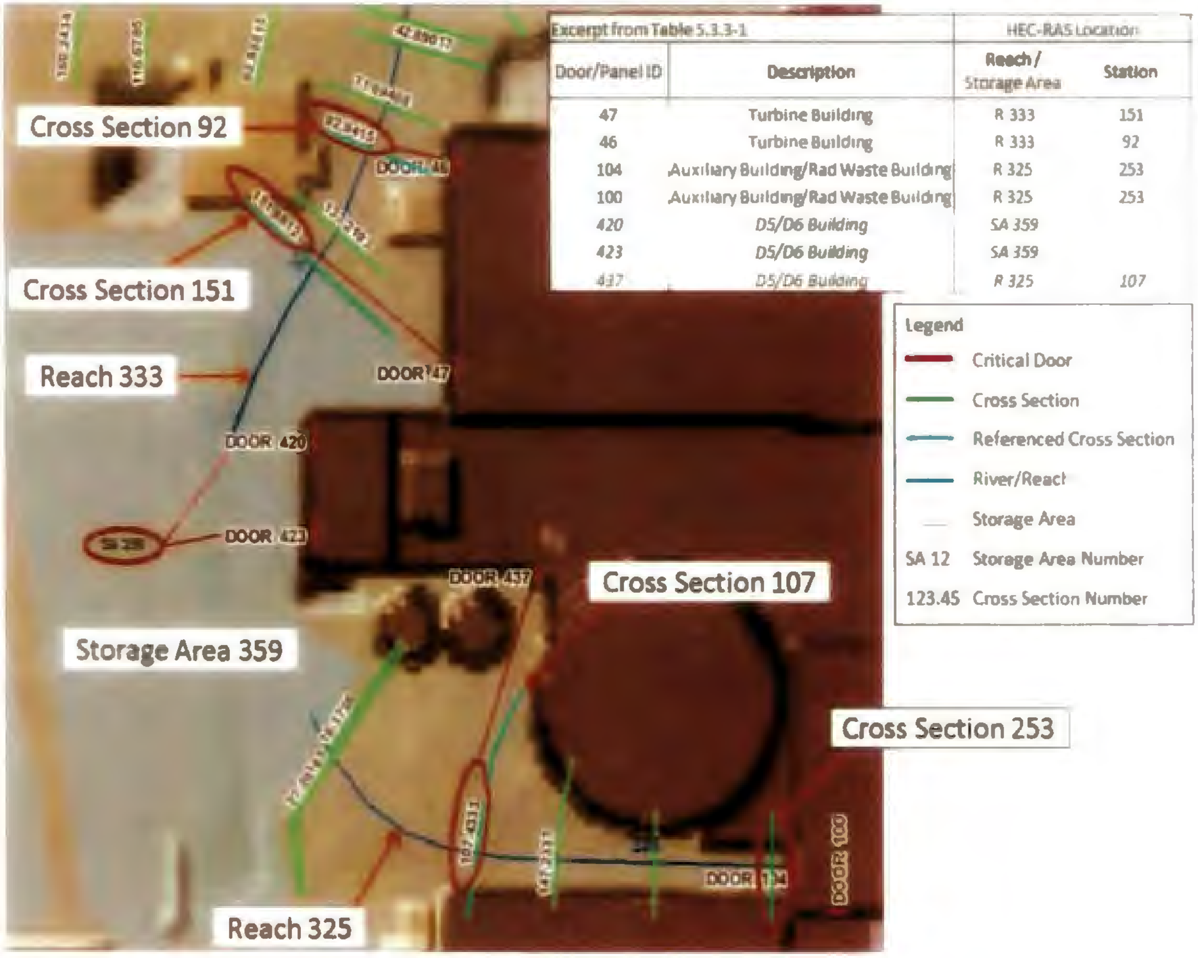
Excerpt from Table 5.3.3-1		HEC-RAS Location	
Door/Panel ID	Description	Reach / Storage Area	Station
237	Screenhouse	R 210	541
257	Screenhouse	R 210	541
258	Screenhouse	R 210	541
238	Screenhouse	R 210	541
1	Old Admin. Building	R 210	541
45	Turbine Building	R 210	264
44	Turbine Building/Service Building	R 210	101

Source: Black & Veatch, Calculation 180461.51.1005 Rev. 1, "Local Intense PMP Hydrology and Hydraulics", 2016



Excerpt from Table 5.3.3-1		HEC-RAS Location	
Door/Panel ID	Description	Reach / Storage Area	Station
73	Turbine Building	SA 294	
164	Auxiliary Building/Rad Waste Building	R 301	220
102	Auxiliary Building/Rad Waste Building	R 301	220

Source: Black & Veatch. Calculation 180461.51.1005 Rev. 1. "Local Intense PMP Hydrology and Hydraulics", 2016



Excerpt from Table 5.3.3-1

Door/Panel ID	Description	HEC-RAS Location: Reach / Storage Area	HEC-RAS Location: Station
47	Turbine Building	R 333	151
46	Turbine Building	R 333	92
104	Auxiliary Building/Rad Waste Building	R 325	253
100	Auxiliary Building/Rad Waste Building	R 325	253
420	D5/D6 Building	SA 359	
423	D5/D6 Building	SA 359	
437	D5/D6 Building	R 325	107

Source: Black & Veatch Calculation 180461.51.1005 Rev. 1. "Local Intense PMP Hydrology and Hydraulics", 2016

PRAIRIE ISLAND NUCLEAR GENERATING PLANT, UNITS 1 AND 2 – STAFF ASSESSMENT OF RESPONSE TO 10 CFR 50.54(f) INFORMATION REQUEST – FLOOD-CAUSING MECHANISM REEVALUATION DATED May 26, 2017

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