UNITED STATES
NUCLEAR REGULATORY COMMISSION
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November 18, 2016

Mr. Bryan C. Hanson
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SUBJECT: QUAD CITIES NUCLEAR POWER STATION, UNITS 1 AND 2– STAFF ASSESSMENT OF RESPONSE TO 10 CFR 50.54(f) INFORMATION REQUEST – FLOOD-CAUSING MECHANISM REEVALUATION (CAC NOS. MF1108 AND MF1109)

Dear Mr. Hanson:

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 March 12, 2013 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML13081A037), Exelon Generation Company, LLC (the licensee) responded to this request for Quad Cities Nuclear Power Station, Units 1 and 2 (Quad Cities).

By letter dated September 4, 2015 (ADAMS Accession No. ML15238B672), the NRC staff sent the licensee a summary of its review of Quad Cities' 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 the local intense precipitation (LIP) and dam failure reevaluated flood hazard mechanisms at Quad Cities are not bounded by the plant's current design-basis, the NRC staff anticipates that the licensee will perform and document a focused evaluation to assess the impact of the LIP hazard on the site,

Enclosure 1 transmitted herewith contains security-related information. When separated from Enclosure 1, this document is decontrolled

and evaluate and implement any necessary programmatic, procedural, or plant modifications to address this hazard exceedance. Additionally, for the dam failure flood-causing mechanism, the NRC staff anticipates that the licensee will submit (1) an integrated assessment or (2) a focused evaluation after confirming the capability of existing flood protection or describing new flood protection capabilities for this mechanism.

This staff assessment closes out the NRC's efforts associated with CAC Nos. MF1108 and MF1109.

If you have any questions, please contact me at (301) 415-6197 or e-mail at Tekia.Govan@nrc.gov.

Sincerely,

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Japan Lessons-Learned Division
Office of Nuclear Reactor Regulation

Docket Nos. 50-254 and 50-265

Enclosure:
Staff Assessment of Flood Hazard
Reevaluation Report

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STAFF ASSESSMENT BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO FLOODING HAZARD REEVALUATION REPORT

NEAR-TERM TASK FORCE RECOMMENDATION 2.1

QUAD CITIES NUCLEAR POWER STATION, UNITS 1 AND 2

DOCKET NOS. 50-254 AND 50-265

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), "Conditions of Licenses" (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, 2011b). Recommendation 2.1 in that document recommended that the NRC staff issue orders to all licensees to reevaluate seismic and flooding hazards for their sites against current NRC requirements and guidance. Subsequent staff requirements memoranda associated with SECY-11-0124 (NRC, 2011b) and SECY-11-0137 (NRC, 2011c), 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 operating licenses (COLs). The required response section of Enclosure 2 specified that NRC staff would provide a prioritization plan indicating the Flooding Hazard Reevaluation Report (FHRR) deadlines for each plant. On May 11, 2012, the NRC staff issued its prioritization of the FHRRs (NRC, 2012c)

By letter dated March 12, 2013, Exelon Generation Company, LLC (Exelon, the licensee), provided its FHRR for Quad Cities Nuclear Power Station, Units 1 and 2 (Quad Cities) (Exelon, 2013). The NRC staff issued requests for additional information (RAIs) to the licensee by letters dated June 25, 2014 (NRC, 2014b), October 17, 2014 (NRC, 2014d), and October 6, 2015 (NRC, 2015d). The licensee responded by letters dated July 3, 2014 (Exelon, 2014b),

Enclosure

October 6, 2014 (Exelon, 2014c), January 13, 2015 (Exelon, 2015a), and October 28, 2015 (Exelon, 2015b).

By letter dated September 4, 2015, the NRC staff issued an interim staff response (ISR) letter to the licensee (NRC, 2015c). 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 Recommendation 2.1: Flooding. The ISR letter also made reference to this staff assessment, which documents the 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, the reevaluated flood hazard results for the local intense precipitation (LIP) and associated site drainage and dam failure flood-causing mechanisms are 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 and Japan Lessons-Learned Division (JLD) Interim Staff Guidance (ISG) JLD-ISG-2016-01, Revision 0 (NRC, 2015b; NRC, 2016b), the NRC staff anticipates that for LIP, the licensee will perform and document a focused evaluation to assess the impact of the LIP hazard on the site, and evaluate and implement any necessary programmatic, procedural, or plant modifications to address this hazard exceedance. For the dam failure flood-causing mechanism, the NRC staff anticipates that the licensee will submit (1) an integrated assessment or (2) a focused evaluation after confirming the capability of existing flood protection or describing new flood protection capabilities for this mechanism.

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 flood-related associated effect (AE) parameters not provided at this time 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 report, 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 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 final safety analysis report. The licensee's commitments made in docketed licensing correspondence, which 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 to 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 that the licensee should consider, and the corresponding Standard Review Plan (SRP) (NRC, 2007) sections and applicable ISG documents containing acceptance criteria and review procedures.

2.2.2 Associated Effects

In reevaluating the flood-causing mechanisms, the "flood height and associated effects" should be considered. JLD-ISG-2012-05 (NRC, 2012e) defines "flood height and associated effects" as the maximum stillwater surface elevation plus:

- Wind waves and runup 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 Effects 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 effect flood." 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 event 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, then the NRC staff 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 should be plausibly combined.

2.2.4 Flood Event Duration

Flood event duration was defined in JLD-ISG-2012-05 (NRC, 2012d) 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 a reevaluated flood elevation is not bounded by the CDB flood hazard for any flood-causing mechanism, the 50.54(f) letter (NRC, 2012a) 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.
- 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, 2015b) 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, licensee 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, 2015b; NRC, 2016b).

3.0 TECHNICAL EVALUATION

The NRC staff reviewed the information provided for the flood hazard reevaluation for the Quad Cities site. 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.

To provide additional information in support of the summaries and conclusions in the Quad Cities FHRR, the licensee made certain calculation packages 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 Quad Cities FHRR, and so those calculation packages were not docketed or cited.

All elevations in this NRC staff assessment are given with respect to the mean sea level (MSL), 1912 adjustment. Hereafter, "MSL" used without qualification refers to this datum. All elevations are rounded to the nearest tenth of a foot. Also note that the Quad Cities FHRR LIP discussion (Exelon, 2014c) references the North American Vertical Datum of 1988 (NAVD88). This is a result of the licensee using NAVD88 topographic data as input for the modeling of LIP. The conversion factor from MSL 1912 Datum to NAVD88 is -0.70 feet (ft) (0.21 meters (m)).

3.1 Site Information

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

3.1.1 Detailed Site Information

The Quad Cities site is located approximately 3 miles (mi) (4.8 km) north of Cordova, Illinois. The 748-acre (3.0 km^2) site is located on the eastern bank of the Mississippi River, near the river's confluence with the Wapsipinicon River and 506.8 mi (815.6 km) upstream of its confluence with the Ohio River (see Figure 3.1-1) (Exelon, 2013). The Quad Cities FHRR states that the U.S. Army Corps of Engineers (USACE) controls the water level on the Mississippi through a system of locks and dams which create a series of near-level pools for navigation. The Quad Cities site is located between Lock and Dam Nos. 13 and 14. According to the Quad Cities FHRR, the normal elevation of the pool near the plant is 572 ft (174.35 m) MSL (Exelon, 2013). A manmade "spray channel," bounded by berms on both sides, surrounds the Quad Cities site on the northern, eastern, and southern edges (see Figure 3.1-2) (Exelon, 2013). The spray channel is no longer used as part of the plant's cooling system (Exelon, 2013). The topographic relief near the Quad Cities site is relatively flat within the river floodplain, with all minor tributaries ultimately discharging to the Mississippi River. The Mississippi River watershed area upstream of the site is approximately 88,000 mi^2 (228,000 km^2) (Exelon, 2013).

The site grade elevation at the Quad Cities powerblock is 594.5 ft (181.20 m) MSL (Exelon, 2013). Table 3.1-1 provides the summary of reevaluated flood-causing mechanisms that the licensee computed to be higher than the powerblock elevation, which includes the wind wave effects.

3.1.2 Design-Basis Flood Hazards

The CDB flood levels for Quad Cities are summarized by flood-causing mechanism in Table 3.1-2. The Quad Cities FHRR stated that the CDB flood elevation is 603 ft (183.79 m) MSL (Exelon, 2013) due to flooding from the Mississippi River. The flooding walkdown report for Quad Cities (Exelon, 2012) refers to an "original" design-basis flood elevation of 589 ft (179.53 m) MSL, based on the "original probable maximum flood (PMF)" that was associated with a 200-year (yr) recurrence interval computed at the time of the plant's design. The flooding walkdown report later refers to elevation 603 ft (183.79 m) MSL as the "PMF elevation," and further discussed the 603 ft (183.79 m) MSL elevation in the context of an elevation to which the plant could mitigate flood effects, but did not explicitly identify 603 ft (183.79 m) MSL as the design-basis flood elevation (Exelon, 2012). The licensee explained that during construction permit reviews, the PMF as defined by the USACE with a corresponding elevation of 603 ft (183.79 m) MSL is the design-basis (Exelon, 2014b). The NRC staff reviewed the information provided 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 reported that there have been no significant changes to the Quad Cities' licensing basis with respect to an external flooding event (Exelon, 2013). In the Quad Cities FHRR, the licensee described two changes made in 1999 to the external flood emergency response to place the plant in a safe shutdown condition in anticipation of a flooding event. The first change revised equipment set-up details to facilitate a more flexible response regarding equipment selection and placement in response to the event, and the second change altered the method and timeline for transferring river water to the boiling water reactor torus during the response to a flooding event (Exelon, 2013). The NRC staff reviewed the information provided in the Quad Cities 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 the most important changes in the local area of the site involve urbanization of the Minneapolis-St. Paul metropolitan area, which constitutes a small proportion of the entire watershed. At least 28 dams have been constructed since the license was issued in 1974, of which three (the Lake Carroll, Smallpox Creek, and Apple Canyon Lake dams) are considered critical and are included in the reevaluated dam failure analysis (Exelon, 2013).

3.1.5 Current Licensing Basis Flood Protection and Flood Mitigation Features

The Quad Cities FHRR stated there are no external flood protection systems in place and that any mode of plant operation is possible at a flood elevation of up to 594.5 ft (181.20 m) MSL. The licensee stated that the USACE controls the water level on the Mississippi through a system of locks and dams and that the plant will receive notice from USACE to perform a safe shutdown when necessary (Exelon, 2013). The shutdown procedure is initiated when the Mississippi River exceeds 586 ft (178.6 m) MSL or when the water levels are expected to exceed 594 ft (181.05 m) MSL in less than 72-hours (h). The NRC staff reviewed the information provided in the Quad Cities FHRR and determined that sufficient information was provided to be responsive to Enclosure 2 of the 50.54(f) letter.

3.1.6 Additional Site Details to Assess the Flood Hazard

Additional site details provided by the licensee include topography and bathymetry of the Mississippi River in the vicinity of Quad Cities site (Exelon, 2014b). The NRC staff reviewed this information as discussed in the following sections.

3.1.7 Results of Plant Walkdown Activities

The 50.54(f) letter requested that licensees perform a plant walkdown to verify that current flood protection systems were available, functional, and implementable.

Other requests described in 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 27, 2012 (Exelon, 2012), Exelon provided the flood walkdown report for the Quad Cities. The NRC staff issued a staff assessment report on June 25, 2014 (NRC, 2014a), to document its review of that report. The NRC staff concluded that the licensee's flooding walkdown methodology met the intent of the 50.54(f) letter.

3.2 Local Intense Precipitation and Associated Site Drainage

The licensee reported in the Quad Cities FHRR that the reevaluated flood hazard for LIP results in maximum stillwater-surface elevations ranging from 596.5 ft (181.81 m) to 598.4 ft (182.39 m) MSL at the main doors and bays of the site buildings. This flood-causing mechanism is not discussed in the licensee's CDB.

3.2.1 Probable Maximum Precipitation

The 1-h, 1-mi^2 probable maximum precipitation (PMP) event was developed using a site-specific analysis (Exelon, 2015a). The PMP was derived following methodologies similar to those used in developing Hydrometeorological Reports (HMR) 51 and 52 (NOAA, 1980; NOAA, 1982); however, various updates to the methodology were used by the licensee's contractor, Applied Weather Associates. The NRC staff along with its contractor, Oak Ridge National Laboratory (ORNL), conducted an audit of Applied Weather Associates' generic methodologies for computing a site-specific PMP (ssPMP) and produced an audit report, "Report for the Audit of Applied Weather Associates, LLC, Regarding Site Specific Probable Maximum Precipitation Development in Support of Near-Term Task Force Recommendation 2.1 Flood Hazard Reevaluations" (hereafter referred to as the NRC ssPMP audit report) (NRC, 2015a), documenting the findings relevant to the review of the licensee's analyses.

The licensee's 1-h, 1-mi^2 ssPMP value was 13.6 in (34.5 cm), which is based on a list of 21 observed LIP-type storms (Exelon, 2015a). Compared to the 1-h, 1-mi^2 PMP derived from HMR 51 and HMR 52 (17.78 in. (45.2 cm)), the ssPMP value is 23.5 percent smaller. The primary difference between the ssPMP and the HMR-derived values stemmed from transposition and maximization of the 1940 Hallett, Oklahoma, storm (Exelon, 2015a). The NRC staff's review of the licensee's ssPMP included a sensitivity analysis related to two points of professional judgment identified during NRC's audit (NRC, 2015a).

The first point relates to the licensee's use of a heuristic for storm representative dew point temperature adjustment. This heuristic was used to adjust historical storms for which only 12-h dew point data were available (Exelon, 2015a). To compare these historical storms to more recent storms that have hourly dew point data, the licensee applied a heuristic developed by the Electric Power Research Institute (EPRI, 1993). This heuristic converts the maximum 12-h persisting dew point values to a maximum-average dew point value by applying a generic +7 °F adjustment for the mid-western United States (EPRI, 1993). In lieu of this generic adjustment, the NRC staff computed a site-specific adjustment by analyzing 11 recent storms from the list of storms developed by Applied Weather Associates, LLC (ORNL, 2015). The NRC staff's heuristic resulted in a different adjustment that, when used, resulted in +2 °F adjustment for converting the maximum 12-h persisting dew point and the maximum 6-, 12-, and 24-hour average dew point (ORNL, 2015). Using this information, a direct comparison can then be made between the maximum average dew point, used by the licensee, and the 12-h persisting dew point (developed by the NRC staff). For each storm, the difference between the maximum averge dew point (using the same 6-, 12-, and 24-h dew point duration specified by the licensee) and 12-hour persisting dew point was calculated (ORNL, 2015) and applied as part of a hydraulic-model sensitivity study discussed below.

The second point relates to the licensee's use of climatological averages for spatially interpolating 100-yr dew point temperature values based on published maps versus a gauge-based approach. A gauge-based approach uses observed meteorological data in the area of LIP-type storms to determine the maximum dew point temperatures. When incorporating the gauge-based approach used by the NRC staff, a sensitivity analysis produced higher individual storm PMP adjustment factors than the licensee's analysis (ORNL, 2015). This resulted in a 10 percent increase (13.6 in. (34.5 cm) to 14.92 in. (37.9 cm)) in the rainfall depth associated with the 1-h, 1-mi^2 PMP, primarily due to changes to the Hallett, Oklahoma storm, which is the licensee's controlling LIP storm event at the Quad Cities site (ORNL, 2015). The combination of NRC staff's gauge-based approach with NRC staff's storm-representative dew point heuristic increased the 1-h, 1-mi^2 PMP depth by 15 percent, to a total of 15.59 inches (ORNL, 2015). The NRC staff's sensitivity results also indicated that the 1926 Boyden, Iowa storm should be the controlling LIP-type storm versus the licensee's 1940 Hallettt, Oklahoma storm (ORNL, 2015).

The NRC staff subsequently applied this increased PMP depth as input to the licensee's hydraulic model (FLO-2D), which is described in Section 3.2.4 below. As expected, the maximum water depths increased at various locations around the site with this larger rainfall depth. However, the water depth increases were small, with the maximum water-depth differences ranging from 2.4 to 4.4 in. (6.1 to 11.1 cm) as compared to the licensee's results (ORNL, 2015). Therefore, the NRC staff concluded that the licensee's ssPMP values are reasonable input to the hydraulic model and site drainage analysis discussed below.

The NRC staff performed a separate sensitivity analysis on the temporal distribution of the rainfall (ORNL, 2015). The sub-hourly PMP depths for the 5-minute (min), 15-min, and 30-min time intervals were calculated by the licensee using ratios obtained from Figures 36, 37, and 38 of HMR 52 (Exelon, 2015a;NOAA, 1982). The rainfall hyetograph was arranged by the licensee using a front-loaded distribution, with the highest rainfall intensity occurring at the event onset (Exelon, 2015a). The licensee stated that the type of storm indicative of an LIP event would likely be a mesoscale convective system, which is associated with a zone of convergence and very intense initial precipitation that would maintain "a decrease in the precipitation after the initial burst as the rear trailing stratiform region with the cold pool moves over the area," thus fitting with a front loaded distribution (Exelon, 2014b). While this statement is true for some historical LIP-scale storms, alternative rainfall distributions have also frequently occurred. The

NRC staff's sensitivity analysis changed the rainfall distribution in the hydraulic model (FLO-2D) to a center weighted temporal distribution, as shown in Figure 3.2-1, and then computed the maximum water surface elevation at various locations around the site (ORNL, 2015). As expected, the results of this sensitivity study did increase the water depths around the site. However, the increases in water depths were small, with differences of 1.1 to 3.4 in. (2.7 to 8.6 cm) of the licensee's results (ORNL, 2015). Therefore, the NRC staff concluded that the licensee's temporal distribution of the ssPMP values is reasonable input to the hydraulic model and site drainage analysis discussed below.

3.2.2 Runoff Analysis

The licensee used the 2009 version of FLO-2D (Build No. 09-13.1.12) to calculate site flooding from the 1-h, 1-mi^2 PMP (FLO-2D, 2009). The model included all site buildings and the concrete barriers along the north, east, and south sides of the site to account for effects on local drainage patterns (Exelon, 2014b; Exelon, 2015a) including gaps, as appropriate. For the multiple adjacent gaps along the east side of the plant, a single 20 ft (6.09 m) gap was used versus simulating ten 2 ft (0.61 m) gaps (Exelon, 2015a). The NRC staff reviewed the location and sizing of the barrier gaps, and determined that they are reasonable for the site drainage analysis.

The licensee created a digital elevation model of the Quad Cities site area based on LiDAR (light detection and ranging) data augmented with field surveys to refine grading, slopes, drainage divides, and other elevations around the site (Exelon, 2015a). The licensee describes a sensitivity analysis that varied the upper and lower range of the Manning's n roughness coefficients in the hydraulic model (Exelon, 2015a). The results of this analysis indicated the model was not sensitive to variations in the roughness coefficient, with maximum water surface elevations variations of ±0.1 ft (0.03 m).

The licensee's modeling analysis also assumed that all passive and active drainage system components were non-functional or blocked during the rainfall event (Exelon, 2015a). The licensee also ignored any rainfall losses due to infiltration, and converted all rainfall into effective runoff (Exelon, 2015a). Based on the licensee's conservative assumptions, review of the licensee's sensitivity study, and review of the model geometry and model layout discussed above, the NRC staff concluded the licensee's hydraulic model for site drainage produced appropriate estimates of water depths at various locations around the Quad Cities site following the PMP event discussed in Section 3.2.1.

3.2.3 Conclusion

The NRC staff reviewed the licensee's PMP rainfall event and runoff analysis model, and confirmed both were reasonable for the purposes of the 50.54(f) letter request. The NRC staff confirms the licensee's reevaluated flood hazard for LIP results in maximum still-water surface elevations that range between 596.5 ft (181.81 m) and 598.4 ft (182.39 m) MSL at the site, and that this hazard is not bounded by the CDB flood hazard. Therefore, the NRC staff expects that the licensee will submit a focused evaluation for LIP consistent with the process and guidance discussed in COMSECY-15-0019 (NRC, 2015b).

3.3 Streams and Rivers

The licensee reported in the Quad Cities FHRR that the reevaluated hazard for site flooding from streams and rivers results in a stillwater-surface elevation of 600.5 ft (183.03 m) MSL at the site (Exelon, 2013). This flood-causing mechanism is described in the licensee's CDB and has a maximum flood elevation of 603 ft (183.79 m) MSL.

3.3.1 Probable Maximum Precipitation

The HMR 51 is limited to watershed areas smaller than 20,000 mi^2 (52,000 km^2). Since the Mississippi River watershed upstream of the Quad Cities site is approximately 88,000 mi^2 (228,000 km^2), the licensee developed an all-season and cool-season (rain on snow event) basin wide ssPMP (Exelon, 2013). The ssPMP methodology was consistent with the HMR 51 methodology and included recent storm events since the publication of the HMR 51. The basin-wide ssPMP also included other adjustments, such as the definition of storm-representative dew point and maximum dew point climatology, which are similar to those applied as part of the LIP ssPMP discussed in Section 3.2.1 and are discussed in the NRC's ssPMP audit report (NRC, 2015a).

By reviewing multiple historical extreme storms that were observed in the neighboring regions of the Quad Cities drainage basin, the licensee developed a list of 31 major storms for the ssPMP calculation. For each of the storms evaluated, the licensee considered transposition limits which could prevent historical storm events from occurring at the basin centroid and each of the 20 grid point locations within the Quad Cities drainage basin for which the ssPMP was evaluated (ORNL, 2015). Various procedures for adjusting historical rainfall events were followed as documented in the NRC ssPMP audit report (NRC, 2015a). Using storm-adjusted rainfall at each grid point, the licensee constructed depth-duration plots to provide the PMP values at each grid point and the basin centroid. The licensee also allowed for movement of the design storm during the PMF calculations, which is different from the stationary storm method used in HMR 52 (Exelon, 2013). The NRC staff observed that the ssPMP values are consistently less than HMR values across various storm durations and drainage areas (ORNL, 2015).

For all drainage basin storms included in the ssPMP study, the storm representative dew point, in-place maximum dew point, and transpositioned maximum dew point values were evaluated using the gauge-based approach described in Section 3.2.1 (ORNL, 2015). While storm representative dew point values were similar between the licensee and the NRC staff, both in-place and transpositioned 100-year dew point values showed large differences. The NRC staff's PMP values tended to be higher than the licensee's PMP values for the cool-season drainage basin PMP. The total adjustment factor is based on values of storm representative dew point, in-place maximum dew point, and transpositioned maximum dew point. The majority of drainage basin PMP storms show higher total adjustment factors under the NRC staff's approach (ORNL, 2015). Since the NRC staff's values exceeded the licensee's values for various area-duration combinations (including those that would impact flooding), the NRC staff performed a sensitivity analysis.

The NRC staff's sensitivity analyses determined the combined impact of the licensee's various ssPMP assumptions by observing the impact of varying the rainfall on the maximum water surface elevation at the Quad Cities site. First, the NRC staff computed an independent estimate of the ssPMP, which included the gauge-based approach to determine maximum dew point temperature discussed in Section 3.2.1 (ORNL, 2015). The NRC staff's independent estimate of the ssPMP was 8.7 percent larger than the licensee's ssPMP depth values (ORNL, 2015). Second, the NRC staff's ssPMP was used as input to the licensee's hydrologic and hydraulic models discussed below. The result of applying an 8.7 percent increase in the rainfall value was a 2.5 ft (0.76 m) increase in the maximum water elevation at the Quad Cities site (ORNL, 2105). This corresponded with a 12 percent increase, or an additional 92,000 cubic feet per second (ft^3/s) (2605.2 cubic meters per second (m^3/s)) in peak Mississippi River discharge at the site (ORNL, 2015). The NRC staff noted this increase in maximum water surface elevation was approximately equal to the difference between the CDB water height and the licensee's reevaluated water height for the streams and rivers flood-causing mechanism. The NRC staff determined that the differences in water surface elevation resulting from the use of an ssPMP, rather than the NOAA HMRs, is not significant enough to warrant additional review. Therefore, the NRC staff concluded that the ssPMP developed by the licensee was reasonable input for the reevaluated flooding analysis.

3.3.2 Modeling of Peak Water Surface Elevation

The licensee-identified three alternatives for the investigation of the PMF as a function of the combined events defined in NUREG/CR-7046 (NRC, 2011d) for floods caused by precipitation events:

> Alternative 1 involved mean monthly base flow, median soil moisture, an antecedent of the subsequent rain which is the lesser of (1) rainfall equal to 40 percent of PMP or (2) a 500-yr rainfall, followed by a 72-h dry period and then the full PMP, including effects from wind waves induced by a 2-yr wind speed applied along the critical direction. Alternative 1 resulted in a maximum water surface elevation of 595.2 ft (181.42 m) MSL with a corresponding flow of 551,800 ft^3/s (15,600 m^3/s), and was not the controlling PMF scenario.

Alternative 2 involved mean monthly base flow, probable maximum snowpack and a 100-yr cool-season rainfall, including effects from wind waves induced by 2-yr wind speed applied along the critical direction. The licensee determined that Alternative 2 was not the controlling PMF scenario by qualitatively comparing the runoff sources between Alternative 2 and 3. The licensee stated that for Alternative 2, the rainfall is much less (100-yr versus PMP), therefore the total effective runoff for Alternative 2 is less than the other alternatives since the majority of the snowmelt would be rain-free (Exelon, 2013). This is because the constant loss rates for each sub-watershed are roughly equivalent to the snowmelt water volume during the rain-free snowmelt processes, so less snowmelt would be available to become effective runoff as compared to Alternative 3 (Exelon, 2013).

Alternative 3 was the controlling PMF scenario. It involved mean monthly base flow, 100-yr snowpack, cool-season PMP, and effects from wind waves induced by 2-yr wind speed applied along the critical direction. Alternative 3 resulted in a maximum PMF (stillwater) elevation at Quad Cities of 600.5 ft (183.03 m) MSL with a corresponding flow of 744,700 ft^3/s (21,100 m^3/s). The maximum duration of flooding above elevation 595 ft (181.36 m) MSL for this scenario was 10 days.

The licensee used the USACE developed Hydrologic Engineering Center - Hydrologic Modeling System (HEC-HMS) software, Version 3.5 (USACE, 2010b) and the ssPMP values to determine the drainage basin runoff using the Clark unit hydrograph and flow routing to the Mississippi River using the Muskingum method (Chow, Maidment, and Mays, 1988; USACE, 2010b). Daily U.S. Geological Survey stream flow data for historical extreme storms were used to calibrate and verify the HEC-HMS model (Exelon, 2013). Base flow was obtained using gage data averaged within each month, with the highest monthly averaged flow from May to November used for the all-season PMF and the March average monthly flow used for cool-season PMF (Exelon, 2013). The licensee considered modifying the calibrated hydrographs to account for nonlinear basin response in accordance with NUREG/CR-7046, by increasing the peak by one-fifth and decreasing the time-to-peak by one-third. However, these adjustments resulted in lower river discharges; hence, in the interest of conservatism, the licensee did not use the nonlinear adjustments in the PMF analysis (Exelon, 2013).

The routing of the PMF resulting from the watershed runoff to the Quad Cities site was accomplished using the unsteady flow module of USACE's Hydrologic Engineering Center – River Analysis System (HEC-RAS) Version 4.1.0; (USACE, 2010a) for both Alternative 1 and Alternative 3 (Exelon, 2013). The cross-section geometry of the hydraulic model is based on USACE's UNET Model Version 4.0 (USACE, 2001). The licensee calibrated the model using observed flood-flow data from river gaging stations by refining the input parameters in HEC-RAS to match the observed flood-flow data to within 0.5 ft (0.152 m) (Exelon, 2013).

The NRC staff reviewed the licensee's modeling of the peak flow using HEC-RAS, and performed sensitivity analyses (ORNL, 2015). The parameters that NRC staff modified were the Manning's n roughness coefficient, watershed infiltration rate, and the cross-sectional geometry of the Mississippi River. The NRC staff determined that variations in these parameters had relatively minor impacts on the maximum water surface elevation at the site (ORNL, 2015). For example, the NRC staff modified the Manning's n roughness coefficient uniformly by 15 percent for all cross-sections, and the change in maximum water surface elevation was less than variations in water surface elevations due to changing the rainfall, as discussed in Section 3.2.1. Therefore, the NRC staff concluded the licensee's hydrologic and hydraulic models produced appropriate estimates of water depths at the Quad Cities site.

3.3.3 Conclusion

The NRC staff confirms the licensee's conclusion that the reevaluated hazard for flooding from streams and rivers results in a reevaluated elevation of 600.5 ft (183.03 m) MSL, which is bounded by the CDB flood hazard elevation of 603 ft (183.79 m) MSL. Therefore, the NRC staff determined that flooding from streams and rivers does not need to be analyzed in a focused evaluation or an integrated assessment.

3.4 Failure of Dams and Onsite Water Control and Storage Structures

The licensee reported in the Quad Cities FHRR that the reevaluated hazard for failure of dams and onsite water control and storage structures results in a stillwater-surface elevation of [[redacted]] MSL, and including wind waves and runup results in an elevation of [[redacted]] MSL at the site. This flood-causing mechanism is not described in the licensee's CDB (Exelon, 2013).

3.4.1 Dam Failure Scenarios

The licensee evaluated dam failure scenarios that combined a subset of dams on tributaries upstream of the Quad Cities site, and cascading (or domino-like) failures of upstream dams on the Mississippi River. The licensee considered hydrologic, sunny-day, and seismically-induced dam failures, and determined that the hydrologic-failure scenario produced the maximum water surface elevation at the Quad Cities site.

The licensee followed the hierarchical hazard assessment methodology in NUREG/CR-7046. The licensee screened-out dams that were more than 100 mi (161 km) from the site, less than 5,000 acre-ft (6,170,000 m^3), had a low head differential of less than 60 ft (18.3 m), and if there were intervening natural or anthropogenic hydraulic controls such as other dams. The dams that did not screen-out were the Lake Carroll Dam, Apple Canyon Lake Dam, and Smallpox Creek Dam, which are north and east of Quad Cities on tributaries of the Mississippi River. The licensee's analysis also included the Eau Galle Reservoir, with a volume of 56,900 acre-ft (70,185,000 m^3), located about 305 mi (491 km) upstream near Spring Valley, WI, which is a tributary to the Mississippi River (the Eau Galle River); the licensee included this dam due to the large size (Exelon, 2013).

The licensee examined three dam failure scenarios using the four dams not screened out, and the PMF discharges discussed in Section 3.3. A hydrologic dam-failure scenario was analyzed using the Alternative 3 PMF flows, assuming all four dams fail under hydrologic conditions, and domino failures of the three lock and dams downstream of the four significant dams. The sunny-day failure scenario assumed the Alternative 1 all-season PMP, and sunny day failures of the Eau Galle Reservoir with downstream domino failures of the remaining significant dams. The seismic dam failure scenario assumed half of the Alternative 3 PMF in rivers concurrent the operating basis earthquake with subsequent failure of all four significant dams (Exelon, 2013).

The NRC staff reviewed the dam failure analysis, including the failure mode, failure parameters, and assumptions. The NRC staff determined that the failure modes selected by the licensee were the most conservative, since all significant dams would fail completely, and domino failures of the smaller lock and dams would produce the largest flood wave at the Quad Cities site because the dam capacities would be added to the flood wave as it moves downstream. The NRC staff concluded that the licensee's dam failure analysis produce reasonable flood elevations at the site.

The sunny-day and seismically-induced dam failure scenarios resulted in peak water surface elevations at the Quad Cities site below site grade, which is 594.5 ft (181.20 m) MSL. The licensee's hydrologic dam-failure scenario produced a water surface elevation that produced the maximum water surface elevation at the Quad Cities site (Exelon, 2013).

3.4.3 Wind Wave and Runup Effects

The licensee evaluated wind-wave and runup effects on water surface elevations for the hydrologic dam failure scenario (referred to as combined effect flood in the FHRR) (Exelon, 2013). The licensee applied equations discussed in USACE Coastal Engineering Manual (USACE, 2008) to estimate the wave state near the site, including the significant wave height, the wave period, and wave length (Exelon, 2013). The licensee reported a total water elevation increase of [[redacted]] on the outside of the safety-related structures due to wind-waves and runup effects (Exelon, 2013; Exelon, 2014a).

The NRC staff reviewed the topography and bathymetry of the wind wave computation, and verified that the licensee's computation was correct and in accordance with the USACE Coastal Engineering Manual. Based on NRC staff's review of the licensee's FHRR and RAI responses, the NRC staff concluded the licensee's value for wind-waves and runup effects is reasonable.

3.4.4 Conclusion

The NRC staff confirms the licensee's reevaluated flood hazard for failure of dams and onsite water control and storage structures, results in a stillwater-surface elevation of [600.9 ft (183.15 m)] MSL (Exelon, 2013). With the inclusion of wind waves and runup effects, the reevaluated water surface elevation is [[redacted]] MSL. This flood-causing mechanism is not described in the licensee's CDB (Exelon, 2013). Therefore, NRC staff expects that the licensee will submit a focused evaluation or an integrated assessment consistent with the process and guidance discussed in COMSECY-15-0019 (NRC, 2015b).

3.5 Storm Surge

The licensee reported in the Quad Cities FHRR that flooding due to storm surge is not a plausible flooding mechanism at Quad Cities, and therefore would not impact the site (Exelon, 2013). This flood-causing mechanism is not discussed in the licensee's CDB.

The Quad Cities FHRR stated that flooding due to storm surge is not plausible due to the location of the site in relation to large bodies of water that could be a source of a storm surge flood event. The NRC staff confirmed the location of the site in relation to large nearby waterbodies and the site is approximately 140 mi from the coast of Lake Michigan, which would be only source of a storm surge, and the topography between the site and Lake Michigan would attenuate a storm surge and the associated wave runup.

The NRC staff confirmed the licensee's conclusion that storm surge is not a plausible flood hazard mechanism at Quad Cities, and would not impact the site. Therefore, the NRC staff has determined that flooding from storm surge does not need to be analyzed in a focused evaluation or an integrated assessment.

3.6 Seiche

The licensee reported in the Quad Cities FHRR that flooding due to seiche is not a plausible flooding mechanism at Quad Cities due to the location of the site in relation to large bodies of water, and therefore does not impact the site (Exelon, 2013). This flood-causing mechanism is not discussed in the licensee's CDB.

The NRC staff confirmed the licensee's conclusion that seiche is not a plausible flood hazard mechanism since the site is approximately 140 mi from the coast of Lake Michigan, which would be only source of a seiche, and the topography between the site and Lake Michigan would attenuate a seiche wave. Therefore, the NRC staff has determined that flooding from storm surge does not need to be analyzed in a focused evaluation or an integrated assessment.

3.7 Tsunami

The licensee reported in the Quad Cities FHRR that flooding due to tsunami is not a plausible flooding mechanism at Quad Cities (Exelon, 2013). This flood-causing mechanism is not discussed in the licensee's CDB.

The NRC staff confirmed the licensee's conclusion that tsunami is not a plausible flood hazard mechanism since the site is approximately 140 mi from the coast of Lake Michigan, which would be only source of a tsunami, and the topography between the site and Lake Michigan would attenuate a tsunami. Therefore, the NRC staff determined that flooding from tsunami does not need to be analyzed in a focused evaluation or an integrated assessment.

3.8 Ice-Induced Flooding

The licensee reported in the Quad Cities FHRR that the reevaluated hazard elevation for ice-induced flooding for the Quad Cities site is 579.8 ft (176.7 m) MSL, and that effects of wind waves and runup were not considered (Exelon, 2013). This flood-causing mechanism is not discussed in the licensee's CDB.

The licensee considered two scenarios in its analysis: (1) the formation of an ice jam at the first bridge upstream of the Quad Cities site followed by a collapse of the ice jam and resulting flood wave, and (2) formation of an ice jam at the first bridge downstream of the Quad Cities site, which would subsequently impound water and flood the site (Exelon, 2013). The licensee reviewed historical events in Illinois and Iowa from the USACE National Ice Jam Database from 1892 through January 2012 (Exelon, 2013). Based on this review, the licensee identified the historic ice-induced flood on December 13, 1945, at Clinton, Iowa. The licensee replicated this event at Quad Cities using HEC-RAS Version 4.1.0 (USACE, 2010a). The resulting maximum water surface elevation from an ice jam occurring upstream (i.e., scenario 1) was 573.7 ft (174.86 m) MSL, which is 21.3 ft (6.49 m) below site grade of 594.5 ft (181.20 m) MSL (Exelon, 2014b). The resulting maximum water surface elevation for an ice jam occurring, downstream (i.e., scenario 2) was 579.8 ft (176.72 m) MSL, which is 15.2 ft (4.63 m) below grade (Exelon, 2014b). The NRC reviewed information provided by the licensee (Exelon, 2014b) and agreed with the location of the ice jams at the first upstream and downstream bridges.

The NRC staff reviewed the licensee's analysis and confirms the licensee's conclusion that the reevaluated hazard from ice-induced flooding would not inundate the site. Therefore, the NRC staff has determined that ice-induced flooding does not need to be analyzed in a focused evaluation or an integrated assessment.

3.9 Channel Migrations or Diversions

The licensee reported in the Quad Cities FHRR that flooding due to channel migrations or diversions is not a plausible flooding mechanism at the Quad Cities site (Exelon, 2013). This flood-causing mechanism is discussed in the licensee's CDB but is not identified as a flooding hazard since it does not impact the site (Exelon, 2013).

The licensee indicated that flooding from channel migration or diversion would not impact the site, since the river flow and geometry are controlled by the USACE navigational structures (Exelon, 2013). The NRC staff noted that the plant is built on Niagran dolomite. Niagran dolomite is a competent bedrock, and most plant structures are above the level of alluvial materials in the river channel (Exelon, 2013). Channel migration is a concern primarily for rivers in alluvial plains, where erosion and deposition of unconsolidated materials may be rapid.

The NRC staff reviewed the licensee analysis and confirms the licensee's conclusion that flooding from channel migrations or diversions is not a plausible flood hazard mechanism at the Quad Cities site. Therefore, the NRC staff has determined that flooding from channel migrations or diversions does not need to be analyzed in a focused evaluation or an integrated assessment.

4.0 REEVALUATED FLOOD HEIGHT, EVENT DURATION, AND ASSOCIATED EFFECTS FOR HAZARDS NOT BOUNDED BY THE CURRENT DESIGN-BASIS

4.1 Reevaluated Flood Elevation 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 elevation results. Table 4.1-1 contains the maximum flood elevation results, including wind waves and runup effects, for flood mechanisms not bounded by the CDB. The NRC staff agrees with the licensee's conclusion that LIP and failure of dams are the only hazard mechanisms not bounded by the CDB.

Consistent with the process and guidance discussed in COMSECY-15-0019 (NRC, 2015b), the NRC staff anticipates the licensee will submit a focused evaluation for LIP and associated site drainage. For the dam failure flood-causing mechanisms, the NRC staff anticipates the licensee will perform additional assessments of plant response, either a focused evaluation or an integrated assessment, as discussed in COMSECY-15-0019.

4.2 Flood Event Duration for Hazards Not Bounded by the CDB

The NRC staff reviewed information provided in Exelon's 50.54(f) responses (Exelon, 2013; Exelon, 2014a; Exelon, 2014b; Exelon, 2014c; Exelon, 2015a; Exelon, 2015b) regarding the FED parameters needed to perform additional assessments of plant response for flood hazards not bounded by the CDB. The FED parameters values for the flood-causing mechanisms not bounded by the CDB are summarized in Table 4.2-1.

For the combined dam failure event, the licensee stated all FED parameters are based on the HEC-RAS hydraulic modeling (Exelon, 2014b). The licensee defined the warning time as the time from when the PMP rainfall ended to the when the flood waters exceeded plant grade (594.5 ft (181.20 m) MSL), which the licensee computed to be 172-h (Exelon, 2014b). The licensee defined the inundation time as the time from when flood waters exceed plant grade to when the flood waters receded below plant grade, which the licensee determined to be 240-h (Exelon, 2014b). Both of these definitions are visually represented in Figure 4.2-1. The NRC staff reviewed the HEC-RAS model, and agreed with these FED parameters, as defined by the licensee. The NRC staff noted that the warning time definition from the licensee is different than the NRC staff definition. However, the NRC staff noted that the licensee definition starts at the end of the PMP event, which is a quantifiable start time, rather than an estimated forecast of when a PMP event may start. Also, forecasts occur before or early in an event, which would result in a longer temporal difference than using the end of the event. Therefore, the NRC staff determined that the 172-h to be a more accurate and more conservative warning time. The licensee did not provide the recession time for the combined dam failure event. The licensee did not provide any FED parameters for LIP flooding.

The licensee is expected to develop FED parameters designated as "Not Provided" in Table 4.2-1 to conduct the MSA or additional assessments of plant response. The NRC staff will review these FED parameters as part of future additional assessments of plant response, if applicable to the assessment and hazard mechanism.

4.3 Associated Effects for Hazards Not Bounded by the CDB

The NRC staff reviewed information provided in Exelon's 50.54(f) responses (Exelon, 2013; Exelon, 2014a; Exelon, 2014b; Exelon, 2014c; Exelon, 2015a; Exelon 2015b) 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 to maximum total water elevation, such as wave height and runup, are presented in Table 4.1-1 of this staff assessment. The AE parameters not directly associated with total water elevation are listed in Table 4.3-1.

The licensee stated that the LIP analysis resulted in hydrodynamic loads ranging between 0.01 and 271.83 pounds per foot (lb/ft) (0.015 and 404.5 kilograms per meter (kg/m)) of width, with loads varying throughout the plant (Exelon, 2014b). The licensee stated that the sediment supply should limit the degree of sediment deposition during a LIP event (Exelon, 2014b). Velocities around the plant during the LIP event range between 0.19 and 6.29 feet per second (ft/s) (0.058 and 1.92 meters per second (m/s)) (Exelon, 2014b), which is below velocities of 12 to 30 ft/s (3.7 to 9.1 m/s) that are capable of disrupting pavement (USACE, 1984). The NRC staff identified from the FHRR Table 2.1.4.1 the maximum flood depth of 1.9 ft (0.56 m) at the cask storage west and the maximum flow velocity of 3.1 m/s (0.94 m/s) at the Unit 2 Doghouse, which are insignificant in terms of hydrostatic and hydrodynamic loadings considered in the safety of plant structures (Exelon, 2013). The NRC staff confirmed, based on the review of the licensee-provided LIP model input and output files that the justifications and discussions related to AE parameters are reasonable and acceptable. Therefore, the NRC staff agrees with the licensee's conclusion for AE parameters associated with LIP in Table 4.2-1.

For the combined dam failure event, the licensee analyzed debris loading using methods in Federal Emergency Management Agency (FEMA) P-259 (FEMA, 2012), which converts hydrodynamic forces for low velocity flow into an equivalent hydrostatic force. A debris weight estimate of 1,000 lbs (454 kg) was obtained from design load standard ASCE/SEI-7-10 (ASCE, 2013) as described in Exelon's FHRR and RAI responses (Exelon, 2013; Exelon, 2014b). The licensee reported a debris load as an equivalent hydrostatic loading (low velocity hydrodynamic force) of 3.6 lb/ft (5.4 kg/m) acting at an elevation 598 ft (182.3 m) MSL (Exelon, 2014b). The impact loading is 480 lb (218 kg) was based on a probable maximum velocity at the site of 0.6 ft/s (0.18 m/s) (Exelon, 2014b). The NRC staff confirmed that the justifications and discussions related to these AE parameters are reasonable and acceptable by verifying that the licensee applied the FEMA and ASCE guidance correctly and appropriately, and by the NRC staff's previous acceptance of the underlying hydraulic modeling.

The licensee evaluated the potential for a barge to impact critical structures during the hydrologic dam failure event. The licensee stated that velocities in the main channel were much higher than overbank velocities at the site. The licensee also noted that the configuration of the river bend in the vicinity of the plant makes direct impact by a barge unlikely, and finally, that topographic features (e.g., levees) between the site and the river would protect the plant. The staff reviewed the velocities from the hydraulic modeling, the morphology and topography in the vicinity of the site, and found this justification to be reasonable and acceptable. The licensee conducted a qualitative evaluation of the influence of sediment deposition and erosion on plant structures. The licensee determined that low overbank velocities would not carry a substantial sediment load nor could they induce scour and erosion around plant structures. The licensee noted that the relatively long duration of the PMF could result in increased groundwater levels.

The licensee is expected to develop AE parameters designated as "Not Provided" in Table 4.3-1 to conduct the MSA or additional assessments of plant response. The NRC staff will review these AE parameters as part of future additional assessments of plant response, if applicable to the assessment and hazard mechanism.

4.4 Conclusion

Based upon the preceding analysis, the NRC staff confirmed that the reevaluated flood hazard information defined in the 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, and associated guidance.

The licensee is expected to develop the missing FED and AE parameters identified as "Not Provided" in Tables 4.2-1 and 4.3-1 to conduct the MSA and the focused evaluations or integrated. The NRC staff will evaluate the missing FED and AE parameters during its review of future additional assessments of plant response, if applicable.

5.0 CONCLUSION

The NRC staff has reviewed the information provided for the reevaluated flood-causing mechanisms for Quad Cities. Based on its review of available information provided in the Exelon's 50.54(f) response (Exelon, 2013; Exelon, 2014a, Exelon, 2014b; Exelon, 2014c; Exelon, 2015a; Exelon, 2015b), 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 confirms 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 confirms the licensee's conclusions that (a) the reevaluated flood hazard results for LIP, and dam failure of dams and onsite water control and storage structures (combined effect which included dam failure, PMF, and wind wave runup) are not bounded by the CDB flood hazard, (b) a focused evaluation of plant response will be performed for LIP, and a focused evaluation or an integrated assessment will be performed for the combined effect dam failure flood-causing 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 and COMSECY-15-0019 (NRC, 2015a), and associated guidance.

The NRC staff has no additional information needs with respect to Exelon'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 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 and 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

Sources: NRC, 2007; NRC, 20013a; NRC 2013b

Notes:

SRP is the Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition

JLD-ISG-2012-06 is the "Guidance for Performing a Tsunami, Surge, or Seiche Hazard Assessment"

JLD-ISFG-2013-01 is the "Guidance for Assessment of Flooding Hazards Due to Dam Failure"

Table 3.1-1: Summary of Flood-Causing Mechanisms that May Exceed the Power Block Elevation

Reevaluated Flood-Causing Mechanisms that May Exceed the Power Block Elevation 594.5 ft (181.2 m) MSL[1]	Elevation, ft (m) MSL
Local Intense Precipitation and Associated Drainage	596.5 to 598.4 (181.8 to 182.4)[2]
Streams and Rivers	600.5 (183.0)
Failure of Dams and Onsite Water Control and Storage Structures	[[redacted]]
Combined Effects (probable maximum flood, dam failure, plus wind-generated waves)	[[redacted]]

Source: Exelon, 2013, Exelon, 2015a

Notes:

[1] Flood height and associated effects as defined in JLD-ISG-2012-05 (NRC, 2012d).

Table 3.1-2. Current Design-Basis Flood Hazard

Flooding Mechanism	Stillwater Elevation	Waves/Waves/ Runup	Current Design-Basis Flood Elevation	Reference
Local Intense Precipitation	Not included in CDB	Not included in CDB	Not included in CDB	FHRR Enclosure 1 Section 2.c
Streams and Rivers	603.0 ft MSL	Not applicable	603.0 ft MSL	FHRR Enclosure 2 Table 1
Failure of Dams and Onsite Water Control and Storage Structures	Not included in CDB	Not included in CDB	Not included in CDB	FHRR Enclosure 2 Table 1
Storm Surge	No impact on the site identified	No impact on the site identified	No impact on the site identified	FHRR Enclosure 2 Table 1
Seiche	No impact on the site identified	No impact on the site identified	No impact on the site identified	FHRR Enclosure 2 Table 1
Tsunami	No impact on the site identified	No impact on the site identified	No impact on the site identified	FHRR Enclosure 2 Table 1
Ice-Induced Flooding	Not included in CDB	Not included in CDB	Not included in CDB	FHRR Enclosure 2 Table 1
Channel Migrations/Diversions	No impact on the site identified	No impact on the site identified	No impact on the site identified	FHRR Enclosure 2 Table 1

Source: NRC, 2015c

4.1-1. Reevaluated Hazard Elevations for Flood-Causing Mechanisms Not Bounded by the CDB

Flood-Causing Mechanism	Stillwater Elevation,	Waves/Runup	Reevaluated Hazard Elevation	Reference
Local Intense Precipitation				
Min-doors by Safety-Related Structures, Systems and Components	596.5 ft MSL	Minimal	596.5 ft MSL	Table 4-2 in Enclosure 2 of the January 13, 2015, Response to Request for Additional Information (ML15021A179)
Max-doors by Safety-Related Structures, Systems, and Components	598.4 ft MSL	Minimal	598.4 ft MSL	Table 4-2 in Enclosure 2 of the January 13, 2015 Response to Request for Additional Information (ML15021A179)
Failure of Dams and Onsite Water Control and Storage Structures				FHRR Enclosure 2, Table 1
Combined Effect (Dam Failure, PMF and Waves)	[redacted]	[redacted]	[redacted]	[redacted]

Source: NRC, 2015c

Table 4.2-1. Flood Event Duration for Flood-Causing Mechanisms Not Bounded by the 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	Not Provided	Not Provided	Not Provided
Failure of Dams and Onsite Water Control and Storage Structures	[[redacted]]	[[redacted]]	Not Provided

Source: Exelon, 2014b

Table 4.3-1. Associated Effects Parameters Not Directly Associated With Total Water Elevation For Flood-causing Mechanisms Not Bounded by the CDB

	Flooding Mechanism	
Associated Effects Factor	**Local Intense Precipitation**	**Combined Event – Riverine, Dam Failure and Waves**
Hydrodynamic loading at plant grade	0.01 to 271.83 lb/ft (0.015 and 404.5 kg/m) of width	Equivalent hydrostatic loading of 3.6 lb/ft (5.4 kg/m) of width acting at 598 ft (182.3 m) MSL[1]
Debris loading at plant grade	Minimal	Impact load of 480 lb (218 kg) acting at surface
Sediment loading at plant grade	Minimal	Minimal
Sediment deposition and erosion	Minimal	Minimal
Concurrent conditions, including adverse weather	Minimal	Minimal
Groundwater ingress	Minimal	Not Provided
Other pertinent factors (e.g., waterborne projectiles)	Not Provided	No impact on the site identified.

Source: Exelon, 2014b

Notes:

[1] Per FEMA P-259 (FEMA, 2012), which converts hydrodynamic forces for low velocity flow into an equivalent hydrostatic force. Units are pound per foot (lb/ft) and kilograms per meter (kg/m).

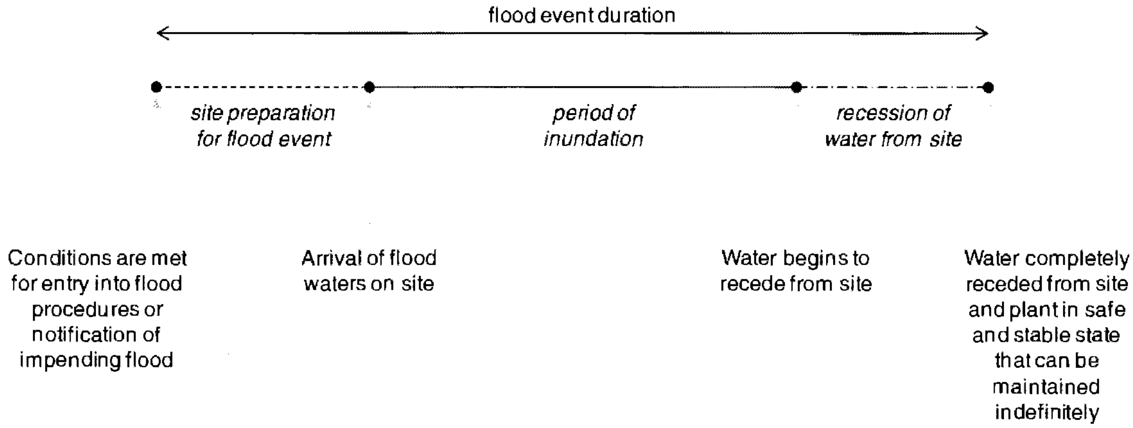

Figure 2.2-1. Flood Event Duration (NRC, 2012d).

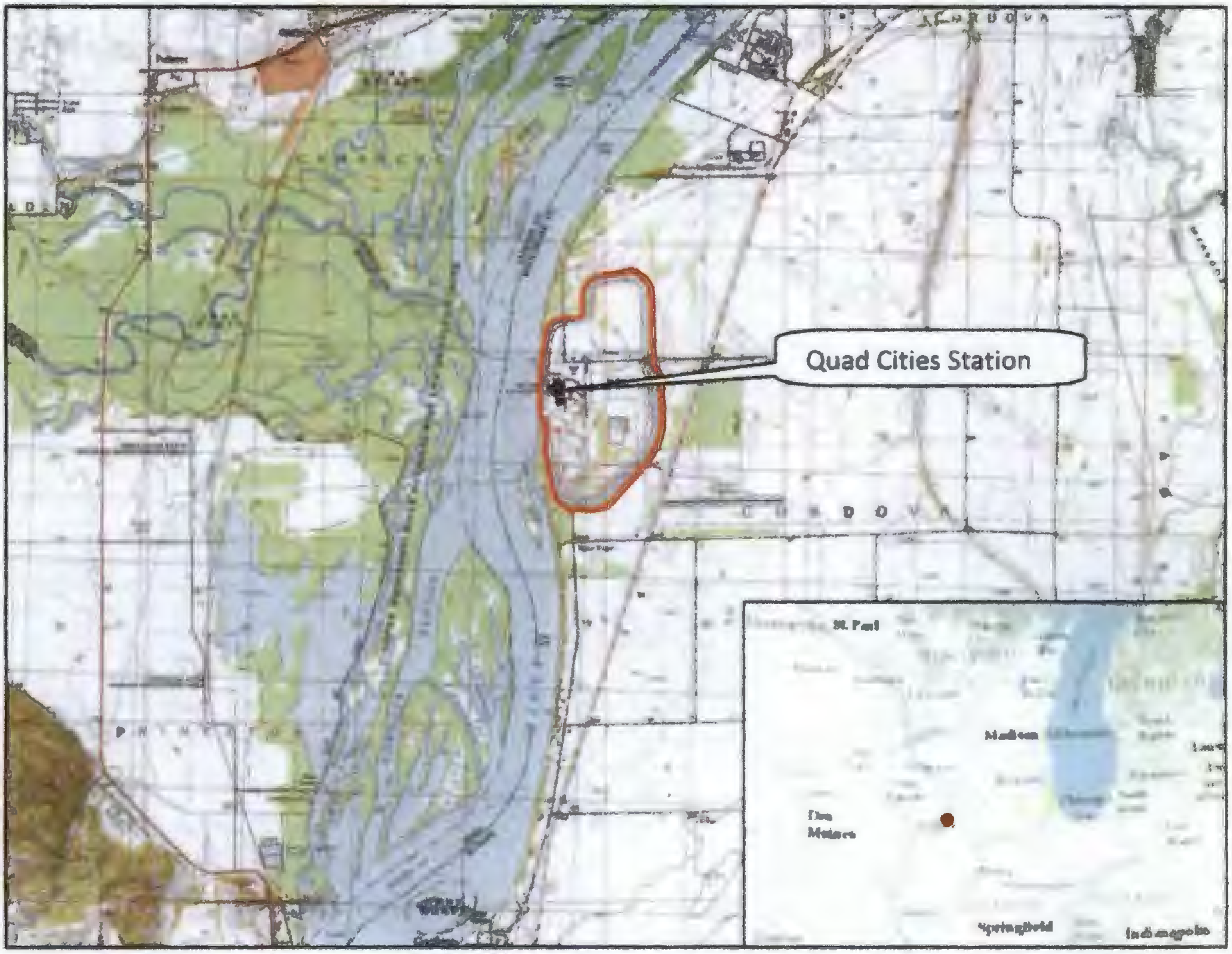

Figure 3.1-1. Quad Cities Nuclear Power Station Location Map (Exelon, 2013)

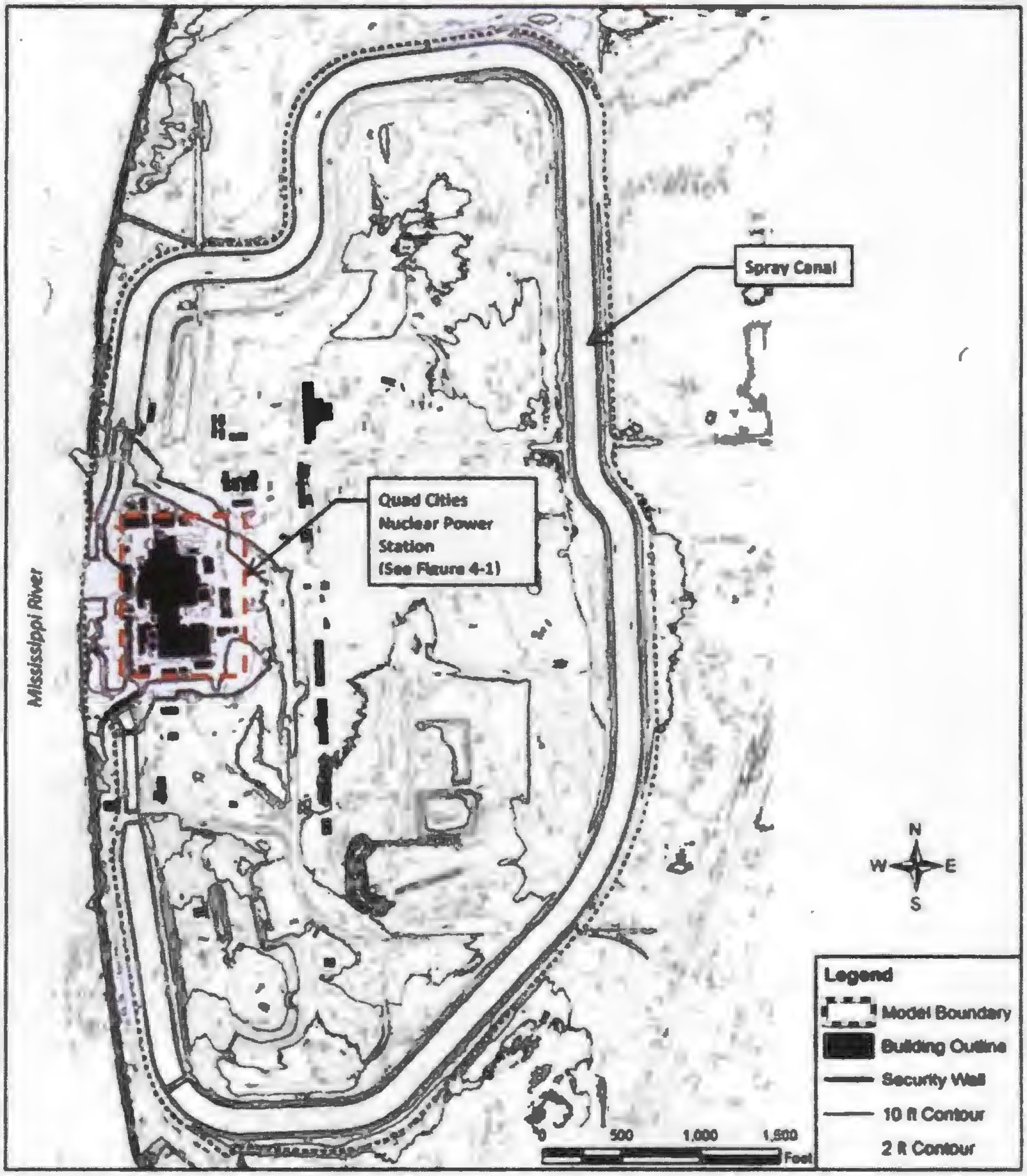

Figure 3.1-2. Quad Cities Nuclear Power Station Site Map (Exelon, 2013)

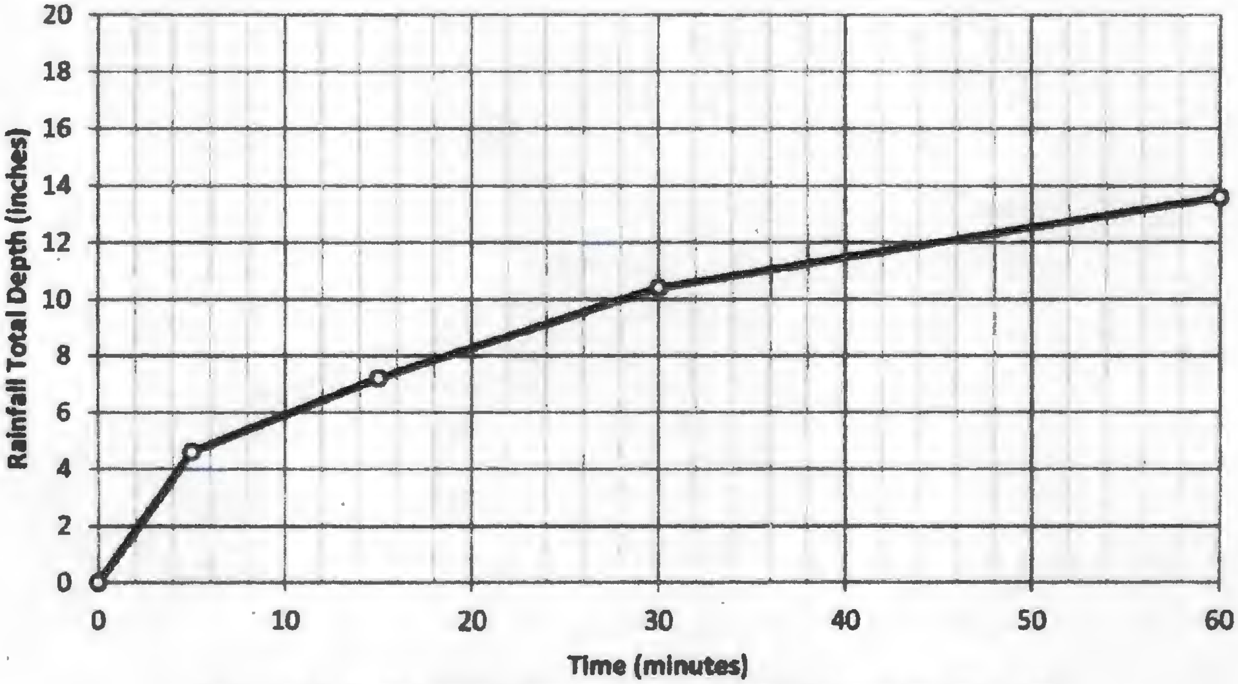

Figure 3.2-1. Probable Maximum Precipitation Distribution at Quad Cities Nuclear Power Station (1-h 1-mi²) (Exelon, 2015a)

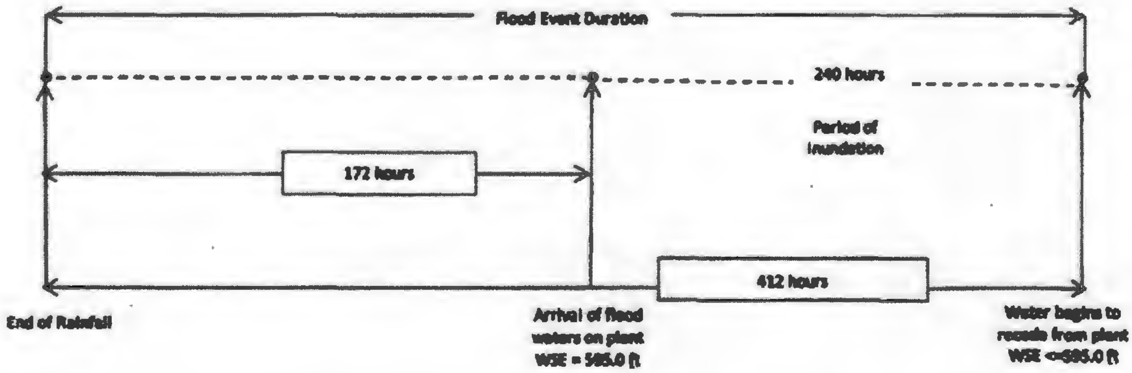

Figure 4.2-1. Flood Event Durations for Failure of Dams and Onsite Water Control and Storage Structures at Quad Cities, Units 1 and 2 (Elevations in MSL) (Exelon, 2015b)

and evaluate and implement any necessary programmatic, procedural, or plant modifications to address this hazard exceedance. Additionally, for the dam failure flood-causing mechanism, the NRC staff anticipates that the licensee will submit (1) an integrated assessment or (2) a focused evaluation after confirming the capability of existing flood protection or describing new flood protection capabilities for this mechanism.

This staff assessment closes out the NRC's efforts associated with CAC Nos. MF1108 and MF1109.

If you have any questions, please contact me at (301) 415-6197 or e-mail at Tekia.Govan@nrc.gov.

Sincerely,
/RA/

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

Docket Nos. 50-254 and 50-265

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Reevaluation Report

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