UNITED STATES
NUCLEAR REGULATORY COMMISSION
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November 28, 2016

Mr. Bryan C. Hanson
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President and Chief Nuclear Officer
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4300 Winfield Road
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SUBJECT: BRAIDWOOD STATION, UNITS 1 AND 2 – STAFF ASSESSMENT OF RESPONSE TO 10 CFR 50.54(f) INFORMATION REQUEST – FLOOD-CAUSING MECHANISM REEVALUATION (CAC NOS. MF3895 AND MF3896)

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, 2014 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML14079A418), Exelon Generation Company, LLC (Exelon, the licensee) responded to this request for Braidwood Station, Units 1 and 2 (Braidwood).

By letter dated September 3, 2015 (ADAMS Accession No. ML15211A363), the NRC staff sent the licensee a summary of its review of Braidwood'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 there are two flood hazard mechanisms at Braidwood that are not bounded by the plant's current design basis, additional assessments of the flood hazard mechanisms are necessary.

As part of the licensee's response to the 50.54(f) letter, the March 12, 2014, submittal contained a limited integrated assessment (IA) that demonstrates protection at the Braidwood site that is permanently installed and passive. The NRC staff has reviewed the limited IA and confirmed that the licensee responded appropriately to Enclosure 2, Required Response 2, of the 50.54(f) letter (ADAMS Accession No. ML16265A214). In reaching this determination, NRC staff confirmed the licensee's conclusions that Braidwood has adequate protection against potential flood water infiltration.

The NRC staff has no additional information needs with respect to Exelon's 50.54(f) response related to flooding. This staff assessment closes out the NRC's efforts associated with TAC Nos. MF3895 and MF3896.

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

Sincerely,

Tekia V. Govan

Tekia Govan, Project Manager
Hazards Management Branch
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Office of Nuclear Reactor Regulation

Docket Nos. 50-456 and 50-457

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

BRAIDWOOD NUCLEAR GENRATING STATION, UNITS 1 AND 2

DOCKET NOS. 50-456 AND 50-457

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, 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 individual plants. On May 11, 2012, the staff issued its prioritization of the FHRRs (NRC, 2012c).

By letter dated March 12, 2014 (Gaston, 2014), Exelon Generation Company, LLC (Exelon, the licensee), provided its FHRR for Braidwood Station, Units 1 and 2 (Braidwood). The NRC staff issued requests for additional information (RAIs) to the licensee (NRC, 2014a and NRC, 2015a). The licensee responded to the RAIs by letters dated July 14, 2014 (Kaegi, 2014), February 17, 2015 (Kaegi, 2015a), and June 24, 2015 (Kaegi, 2015b). The licensee did not identify any interim actions, as discussed in a limited integrated assessment enclosed to the Braidwood FHRR (Exelon, 2014b).

By letter dated September 3, 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 NTTF Recommendation 2.1: Flooding. The ISR letter also made reference to this staff assessment, which documents NRC staff's basis and conclusions. After issuance of the ISR, the NRC staff noted two errors in the ISR letter. The ISR letter incorrectly reported the reevaluated hazard elevation for probable maximum flood (PMF) on the Mazon River under the streams and rivers flood-causing mechanism as not bounded. The error has been corrected in this staff assessment to indicate that hydrologic dam failure plus PMF on the Mazon River under Failure of Dams and Onsite Water Control/Storage Structures is not bounded. Additionally, the reevaluated hazard elevation for PMF on the cooling pond with waves/runup has been corrected in this staff assessment to reflect the elevation reviewed in the Braidwood FHRR by the NRC staff.

As mentioned in the ISR letter (NRC, 2015c), the reevaluated flood hazard results for PMF on the cooling pond is not bounded by the plant's current design basis (CDB). Additionally, as noted in Table 4.1-1 of this staff assessment, the reevaluated flood hazard results for failure of dams plus PMF on the Mazon River is not bounded by the plant's CDB. As part of the licensee's response to the 50.54(f) letter, the Braidwood FHRR contained a limited integrated assessment that demonstrates protection at the Braidwood site that is permanently installed and passive. The NRC staff has reviewed the limited integrated assessment (NRC, 2016c) and confirmed that the licensee responded appropriately to Enclosure 2, Required Response 2, of the 50.54(f) letter. In reaching this determination, NRC staff confirmed the licensee's conclusions that Braidwood has adequate protection against potential flood water infiltration and that the hazard reevaluation was completed using present-day methodologies and regulatory guidance used by the NRC staff.

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 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 the licensee should consider and lists 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

In reevaluating the flood-causing mechanisms, the “flood height and associated effects” should be considered. Guidance document JLD-ISG-2012-05 (NRC, 2012d) 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 effects 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 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 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 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.

2.3 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 (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 local intense precipitation (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, 2015b).

3.0 TECHNICAL EVALUATION

The NRC staff reviewed the information provided for the flood hazard reevaluation of Braidwood (Exelon, 2014a; Kaegi, 2014; Kaegi, 2015a, and Kaegi, 2015b). 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 Braidwood FHRR, the licensee made 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 Braidwood FHRR, and so those calculation packages were not docketed or cited.

All elevations in this staff assessment are reported in mean sea level (MSL). The licensee used the North American Vertical Datum of 1988 (NAVD88) at times in the Braidwood FHRR, and provided a conversion to NAVD88 from MSL as:

NAVD88 = MSL – 0.27 ft (Exelon, 2014a).

3.1 Site Information

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

3.1.1 Detailed Site Information

The Braidwood site is located approximately 2 mi southwest of the city of Braidwood, Illinois, in the Kankakee River and Mazon River watersheds (Exelon, 2014a). The site grade is at 600.0 ft (182.9 m) MSL, and the floor grade is at 601.0 ft (183.2 m) MSL (Exelon, 2014b).

The elevations of the area around the site vary from 595.0 ft (181.4 m) MSL to 605.0 ft (184.4 m) MSL, with relatively flat topography (Exelon, 2014a). In addition to the nearby rivers, a 2,475-acre (1001.6 hectare) cooling pond lies adjacent to the site (Exelon, 2014a). The cooling pond is impounded by a dike with a top elevation that ranges from 600.0 ft (182.9 m) MSL to 602.5 ft (183.6 m) MSL, with the maximum top elevation (602.5 ft (183.6 m) MSL) located at the lake screen house (Exelon, 2014a). Figure 3.1-1 provides a location map of the site and Figure 3.1-2 provides the Braidwood site layout. Both figures are derived from maps in the Braidwood FHRR (Exelon, 2014a).

3.1.2 Design-Basis Flood Hazards

The CDB flood levels are summarized by flood-causing mechanism in Table 3.1-1 of this staff assessment. 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 (NRC, 2012a).

3.1.3 Flood-Related Changes to the Licensing Basis

The licensee reported in the Braidwood FHRR that there have been no flood-related changes to the licensing basis. 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 (NRC, 2012a).

3.1.4 Changes to the Watershed and Local Area

The licensee reported in the Braidwood FHRR that no changes were noted in the watershed or local area that would affect the CDB of the Braidwood site. 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 (NRC, 2012a).

3.1.5 Current Licensing Basis Flood Protection and Pertinent Flood Mitigation Features

The licensee noted that the CDB flood elevations for LIP, PMF on the Kankakee and Mazon Rivers, and PMF for the cooling pond are below elevations that would affect safety-related facilities. Hence, no flood protection or mitigation is credited in the current licensing basis (Exelon, 2014a). 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 (NRC, 2012a).

3.1.6 Additional Site Details to Assess the Flood Hazard

The licensee made available for review electronic copies of the input/output files for the computer models and calculation packages used in connection with the flood hazard reevaluations. The NRC staff reviewed that material and determined that sufficient information had been provided in response to Enclosure 2 of the 50.54(f) letter (Kaegi, 2014 and Kaegi, 2015a).

3.1.7 Results of 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 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 (Kaegi, 2012), the licensee provided the requisite flood walkdown report for Braidwood. The NRC staff issued a staff assessment on June 24, 2014 (NRC, 2014b), which documented its review of the flooding walkdown report and concluded that the licensee's implementation of 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 Braidwood FHRR that the reevaluated flood hazard, including associated effects, for LIP and associated site drainage is based on a stillwater surface elevation that varies at the doors of safety-related facilities from 601.3 ft (183.3 m) MSL to 601.7 ft (183.4 m) MSL (Exelon, 2014a). This flood-causing mechanism is discussed in the licensee's CDB. The CDB PMF elevation for LIP and associated site drainage is based on a stillwater surface elevation of 601.9 ft (193.5 m) MSL (Exelon, 2014a).

The licensee's LIP analysis used the FLO-2D model (FLO-2D, 2013), a two-dimensional hydrodynamic model that uses the dynamic wave momentum equation to route flood hydrographs and rainfall-runoff over unconfined flow surfaces and in channels (Exelon, 2014). The model inputs included the site topography (including existing conditions), a probable maximum precipitation (PMP) hyetograph, roughness coefficients based on land cover which the licensee derived from publically available orthoimagery and land use data. The FLO-2D model used a 10 ft (3 m) by 10 ft (3 m) grid element size (Exelon, 2014a). The licensee identified the obstructions to drainage at the site using both light detection and ranging (LiDAR) data and information collected during a site survey (Exelon, 2014a).

The NRC staff's review of the FLO-2D model included reviewing the depths and velocities at all grid cells, performing sensitivity analysis of the grid size and roughness coefficients, and comparing publically-available aerial photography to the modeled features and structures. The licensee made modifications to their FLO-2D model (Kaegi, 2015b) and the NRC staff determined that all issues were resolved.

For the flood hazard reevaluation, the licensee used a site-specific 1-hr, 1-mi^2 (2.6 km^2) PMP for the LIP event (Exelon, 2014a). The Braidwood FHRR states that the computed site-specific PMP (ssPMP) depth is 14.0 in (35.6 cm) for the LIP event at the Braidwood site. The NRC staff performed a sensitivity analysis of the ssPMP precipitation depth versus a National Oceanographic and Atmospheric Administration (NOAA) Hydrometeorological Report 52 (HMR-52) (NOAA, 1982) maximum precipitation depth. The NRC staff computed a HMR-52 precipitation depth of 17.8 in (45.2 cm) at the Braidwood site. Using the licensee's FLO-2D computer model with the HMR-52 maximum precipitation depth, the NRC staff computed a maximum water surface elevation (WSE) of 601.9 ft (183.5 m) NGVD29, which is 0.2 ft (0.06 m) greater than the ssPMP FLO-2D results provided by the licensee. The NRC staff determined that the ssPMP results are comparable to the HMR-52 results (less than 0.5 ft (0.2 m) in depth); therefore, staff determined that the licensee's ssPMP analysis was reasonable based on this sensitivity analysis.

The NRC staff confirmed the licensee's conclusion that the reevaluated flood hazard for LIP and associated site drainage is bounded by the CDB flood hazard. Therefore, LIP does not need to be analyzed in a focused evaluation or an additional assessment.

3.3 Streams and Rivers

The licensee reported in the Braidwood FHRR that a reevaluated flood hazard for the PMF on streams and rivers was reevaluated for the Mazon River, Granary Creek, and the Kankakee River (Kaegi, 2015b). Additionally, the licensee provided a reevaluated PMF on the cooling pond.

The reevaluated flood hazard for PMF on the Mazon River and Granary Creek is based on a maximum stillwater elevation of 592.7 ft (180.7 m) MSL and 592.9 ft (180.7 m) MSL, respectively (Kaegi, 2015b). The licensee compared the upstream peak flood elevations resulting from the flooding from the Mazon River and Granary Creek analyses and the flooding from upstream dam failure analysis, and determined that the riverine flood is bounded by the upstream dam failure flood in the Mazon River (Kaegi, 2015b). Wind waves and wave runup results are provided for the reevaluated PMF flood hazard with dam failure of the Mazon River and are discussed in Section 3.4. The flood hazard of the Kankakee River was also evaluated by the licensee (Kaegi, 2015b); however, the licensee noted that the peak flow results for the PMF and dam failure in the Kankakee River are bounded by those from the Mazon River.

The PMF flood-causing mechanism on streams and rivers is discussed in the licensee's CDB. The CDB PMF elevation for streams and rivers is based on a stillwater-surface elevation of 582.0 ft (177.4 m) MSL, and includes wind waves and runup results in an elevation of 584.0 ft (178.0 m) MSL.

The PMF flood hazard for the cooling pond was reevaluated by the licensee is a maximum stillwater elevation of 599.4 ft (182.7 m) MSL (Kaegi, 2015b) and includes wind waves and runup results in an elevation of 601.3 ft (183.3 m) MSL. The PMF flood-causing mechanism from the cooling pond is discussed in the licensee's CDB. The CDB PMF for the cooling pond is based on a stillwater surface elevation of 598.2 ft (182.3 m) MSL, and includes wind waves and runup results in an elevation of 602.3 ft (183.6 m) MSL.

The NRC staff reviewed the flooding hazard from streams and rivers and from the cooling pond, including associated effects, against the relevant regulatory criteria based on present-day methodologies and regulatory guidance.

3.3.1 Probable Maximum Flood Alternative Selection

According to the Braidwood FHRR (Kaegi, 2015b), the flooding hazard for the PMF in streams and rivers, as well as the cooling pond, were based on the following three alternatives as defined in NUREG/CR-7046 (NRC 2011e):

- Alternative 1 - a combination of mean monthly base flow; median soil moisture; antecedent of subsequent rain, specifically the lesser of: (1) rainfall equal to 40% of PMP, and (2) a 500-yr rainfall; the PMP for all seasons; and 2-yr wind waves along the critical direction.

- Alternative 2 - a combination of mean monthly base flow; probable maximum snowpack; a 100-yr, snow season rainfall; and 2-yr wind waves along the critical direction.

- Alternative 3 - a combination of mean monthly base flow; a 100-yr snowpack; snow season PMP; and 2-yr wind waves along the critical direction.

The controlling combination for the Kankakee River was identified as Alternative 2 with a 100-yr snow season rainfall and was based on the analysis at the Dresden Nuclear Power Station (Kaegi, 2013). The controlling event combination for the Mazon River watershed was identified as Alternative 1 with a 500-yr rainfall antecedent condition (Kaegi, 2015b). For the cooling pond PMF, the controlling event combination was Alternative 1 with a 500-yr antecedent rainfall condition (Kaegi, 2015b).

The licensee provided discussions of all of the alternatives, which included analyses of PMP using the guidance in HMR 51 and HMR 52 (NOAA, 1978; NOAA, 1982) and HMR 52 software (NOAA, 1982). The NRC staff reviewed the alternatives, including reviewing the inputs and verifying that the guidance was used appropriately and properly. The NRC staff also verified that the results from all of the alternatives were reasonable, and that the alternative selected for further analysis produced the highest PMF flows at the Braidwood site.

3.3.2 Probable Maximum Snowpack and Snowmelt Analysis

The licensee examined available snowpack data for the Braidwood site, though the Braidwood FHRR states that there was inadequate data for use in estimating the probable maximum snowpack. Hence, the licensee assumed an unlimited snowpack depth and obtained the snowpack density from available data (Kaegi, 2015b). The licensee also computed the 100-yr precipitation for a 72-hr duration using NOAA precipitation frequency data from Atlas 14 (Kaegi, 2015b). Snowmelt runoff was computed assuming an unlimited snowpack throughout the 72-hr precipitation period and using the energy budget method of the U.S. Army Corps of Engineers (USACE) (Kaegi, 2015b).

The NRC staff checked the 100-yr precipitation depths against the NOAA Atlas 14 frequency data (NOAA 2015) at the Braidwood site and found they agree with the precipitation data used by the licensee. The snow melt analyses used by the licensee were derived from those computed for the Dresden Nuclear Power Station, which the NRC staff had previously reviewed and had found that "the methodology selected was appropriate, and that the procedures were used appropriately" (NRC, 2015a).

3.3.3 Probable Maximum Precipitation Analysis

According to the Braidwood FHRR (Kaegi, 2015b), the licensee estimated the all-season PMP depth for the location of the Braidwood site and the Mazon River and Granary Creek watersheds using the methods of HMR 51 and 52. The staff notes that the licensee's method for calculating watershed-wide PMP depths at hourly intervals used HMR 52 procedures developed by USACE (1984). The licensee used the same methods for the cooling pond and its drainage area but also included adjustments as appropriate for the watershed area (Kaegi, 2015b). The NRC staff checked the methods and results used by the licensee and found the selected method was applied appropriately.

3.3.4 Probable Maximum Flood Hydrology for Kankakee River

The PMF hydrology was developed previously for the Dresden Nuclear Power Station (Kaegi, 2013), but used the particular storm centering to provide the largest flow at the Wilmington Dam (Kaegi, 2015b). The flow was derived by the licensee based on selection of Alternative 2 (Kaegi, 2015b). The NRC staff checked the methods and results used by the licensee and found the selected method was appropriate and applied appropriately. `

3.3.5 Probable Maximum Flood Hydrology for Mazon River

Precipitation losses from infiltration were computed by the licensee using Natural Resource Conservation Service (NRCS) methods (Kaegi, 2015b). The licensee utilized the Snyder unit hydrograph method to transform the estimated hourly precipitation, including precipitation losses, from the PMP to runoff (Kaegi, 2015b). The licensee used USACE's Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) (USACE, 2010b) to produce flow hydrographs for input into the complimentary Hydrologic Engineering Center-River Analysis System (HEC-RAS) computer model (USACE, 2010a) to determine water surface elevations (Kaegi, 2015b). The NRC staff's examination of the HEC-HMS inputs provided by the licensee shows that the licensee used a PMP storm centered at the centroid of the Mazon River watershed and that peaking of the unit hydrographs was used to account for the effect of nonlinear basin response with extreme precipitation events (Kaegi, 2105b). According to the Braidwood FHRR, the model HEC-HMS was used for the hydrologic analysis of the PMP using the inputs for precipitation depth, precipitation loss, and rainfall transformation to runoff. The licensee used the Muskingum method to route the PMF hydrographs from each subbasin downstream for use in a hydraulic model to estimate PMF elevations (Kaegi, 2015b). The NRC staff checked the methods and results used by the licensee and found the selected method was applied appropriately.

3.3.6 Probable Maximum Flood Water Surface Elevations Kankakee River

The controlling PMF hydrograph at Wilmington from the HEC-HMS PMF model was assigned as an upstream boundary of the HEC-RAS model and the normal depth boundary condition was applied at the downstream boundary of the model. The Braidwood FHRR states that the cross section geometry input to the HEC-RAS model was developed from LiDAR data (Kaegi, 2015b). The NRC staff's examination of the HEC-RAS shows that three bridges are also incorporated into the HEC-RAS model geometry. Manning's roughness coefficients were estimated for the river channel and flood plain from topographic survey and aerial images for the site (Kaegi, 2015b). The maximum WSE at a location upstream of the site is 570.1 ft (173.8 m) MSL. The NRC staff checked the methods and results used by the licensee and found the selected method was applied appropriately. The license conducted further analyses that examined the effect of dam failure on the maximum computed WSE. The result of the analyses is discussed in Section 3.4 of this staff assessment.

3.3.7 Probable Maximum Flood Water Surface Elevations Mazon River and Granary Creek.

The HEC-RAS PMF model, developed by the licensee, shows the input of three hydrographs representing Granary Creek, the Upper Mazon River, and the Lower Mazon River including the cooling pond (Kaegi, 2015b). The FHRR states that the cross section geometry input to the HEC-RAS model was developed from LiDAR data. The NRC staff's examination of the HEC-RAS model shows that three bridges are also incorporated into the HEC-RAS model geometry. Manning's roughness coefficients were estimated for the river channel and flood plain from topographic survey and aerial images for the site (Kaegi, 2015b). The NRC staff's examination of the HEC-RAS shows that a normal depth boundary condition was used at the downstream boundary.

According to the Braidwood FHRR, the computed maximum stillwater PMF elevation for the Mazon River was 592.7 ft (180.7 m) MSL. While a WSE of 592.9 ft (180.7 m) MSL is reported in the Braidwood FHRR for Granary Creek, it is not included in the flood parameter tables. The NRC staff notes that Granary Creek is a vassal stream of the Mazon River, and is upstream of the Braidwood site. The NRC staff checked the methods and results used by the licensee and found the selected method was applied appropriately.

The license conducted further analyses that examined the effect of dam failure on the maximum computed WSE, including the effects of wind wave setup and wave run up. The results of these analyses are discussed in Section 3.4 of this staff assessment.

3.3.8 Probable Maximum Flood Water Surface Elevations Cooling Pond

The NRC staff's examination of the HEC-HMS model for the cooling pond showed that the license calculated the maximum flood WSE assuming direct input of the PMP onto the cooling pond surface, and assumed instantaneous runoff from the watershed. The licensee used the stage-area-volume relationship and the spillway rating curve to calculate the WSE of the cooling pond during the PMP (Kaegi, 2015b). The licensee also accounted for losses of precipitation falling on the land surface portion of the drainage area (Kaegi, 2015b). The NRC staff examination of the HEC-HMS model for the cooling pond showed that the PMF analysis included a three-day antecedent rainfall, followed by 3-day dry period, and the 72-hr PMP. The antecedent rainfall was selected as the 500-yr event, as called for in Alternative 1 scenario (Kaegi, 2015b). According to the Braidwood FHRR, the computed stillwater PMF elevation was 599.4 ft (182.7 m) MSL. As stated in Braidwood FHRR, Table 4.4 (Kaegi, 2105b), the inclusion of wind wave setup and wave runup produces an elevation of 601.3 ft (183.3 m) MSL.

3.3.9 NRC Staff Conclusion

As described previously, the NRC staff reviewed the analyses for a PMF from streams and rivers on the Kankakee and Mazon Rivers. The staff reviewed the various hydrologic and hydraulic models, including review of the inputs, parameters, selection of parameters, and methodologies, which staff compared to present-day methodologies and regulatory guidance. The licensee used the flooding from rivers as the base hydrologic input into the analysis of flooding from upstream dam failure mechanism, with only the inclusion of the additional water volume from the failure of the upstream dams. Since the river flooding and dam failure evaluations, respectively in Sections 3.3 and 3.4 of this staff assessment, are effectively the same except for the additional flood volume from the dam failure, the NRC staff agreed with the licensee's approach that the river flood hazard evaluation did not require evaluation of the associated effects as part of the river flooding hazard analysis. The associated effects were evaluated as part of the dam failure hazard analysis in Section 3.4 of this assessment. The NRC staff agrees with the licensee that the PMF on streams and rivers on the Mazon River is bounded by the reevaluated dam failure analysis.

For the cooling pond PMF, the NRC staff confirmed the licensee's conclusion that the reevaluated hazard are not bounded by the CDB flood hazard. The NRC staff has reviewed the licensee submitted MSA for the cooling pond PMF flood-causing mechanism for the Braidwood site and determined that the mitigation strategies described in the Braidwood MSA are reasonably protected against the reevaluated flood for this hazard.

3.4 Failure of Dams and Onsite Water Control/Storage Structures

The licensee reported in the Braidwood FHRR that the reevaluated flood hazard, including associated effects, for failure of dams and onsite water control or storage structures is based on a stillwater-surface elevation on the Mazon River of 594.3 ft (181.1 m) MSL. Including wind waves and run up results in an elevation of 595.8 ft (182.4 m) MSL. The licensee analyzed the effects of dam failures for Kankakee River and Mazon River watersheds (Kaegi, 2015b). The licensee based the dam failure evaluation on NRC's "Guidance for Assessment of Flooding Hazards due to Dam Failure" (NRC, 2013). The impacts of dam failures on the PMF flow and WSE at the Braidwood were evaluated by simulating dam failure using the HEC-HMS and HEC-RAS models (Kaegi, 2015b).

This flood-causing mechanism is discussed in the licensee's CDB (Kaegi, 2015b), but no PMF elevations were reported. In the Braidwood FHRR discussion of the CDB, the licensee states the Braidwood site is dry because on the Kankakee River, the nearest dam with a normal pool elevation near the plant grade elevation is 15 mi (24.1 km) upstream of the river screen house and that any flood wave would attenuate before reaching the site. Also, in the Braidwood FHRR discussion of the CDB, the licensee states that failure of the cooling pond would not affect safety-related facilities because the maximum pool elevation is lower than the plant site grade.

The licensee located the dams in the Kankakee River and Mazon River watersheds through the USACE National Inventory of Dam (NID) website (Kaegi, 2015b). Based on the location in the watershed, the licensee refined the number of dams within the Kankakee River watershed to 38 and to one within the Mazon River watershed (Kaegi, 2015b). For the 38 dams in the Kankakee River watershed, the licensee used the hydrologic model method to identify potentially critical dams (NRC 2013b) and combined dams within subbasins to create 11 hypothetical dams (Kaegi, 2015b). The Braidwood FHRR states that Method 4 of NRC's "Guidance for Assessment of Flooding Hazards due to Dam Failure" was used (NRC, 2013) and includes each hypothetical dam using the largest height and the total storage from the group of dams with a combined breach width to represent breaches of the individual dams (Kaegi, 2015b). All hypothetical dams were assumed to breach at the time that the subbasin reaches its maximum flow and are assumed to be at full storage at the time of failure. Using an elevation-flow rating curve on the Kankakee River near the Braidwood site, the licensee determined that the maximum WSE would not inundate the plant site. Therefore, all 38 dams in Kankakee River watershed were determined to be noncritical (Kaegi, 2015b). The NRC staff reviewed the USACE NID (USACE, 2013) and verified that the methodology to determine critical dams conformed to the NRC guidance (NRC, 2013) and confirmed the licensee's conclusion.

The Braidwood FHRR states that two dam failure scenarios (hydrologic and seismically-induced dam failures) were evaluated based on NRC guidance (NRC 2013b). The licensee assumed that the sunny-day dam failure was bounded by the seismically-induced dam failure because of the smaller flood magnitude from breaching of a single dam compared with breaching all dams (Kaegi, 2015b).

3.4.1 Hydrologic Dam Failure Analysis

The licensee performed hydrologic dam failure analyses for the Kankakee River and Mazon Rivers. For the Kankakee River, the licensee modeled all 11 hypothetical dams into the HEC-HMS PMF model (see Section 3.3). To maximize the effects of dam failure for each dam, all hypothetical dams were set to fail at the time when the corresponding subbasin reached its maximum flow (Kaegi, 2015b). The NRC staff examined the HEC-RAS model used to evaluate the effect of dam failure on the flood hazard near the site for the Kankakee River PMF. The NRC staff noted in the review of the HEC-RAS model that the inflow hydrograph for the upstream boundary was replaced by the dam failure hydrograph at Wilmington from the HEC-HMS dam failure model. The resultant stillwater elevation was 571.1 ft (174.1 m) MSL (Kaegi, 2015b), which is well below the plant grade elevation of 600.0 ft (182.9 m) MSL. Hence the Braidwood FHRR states that the site is not affected by dam failure on the Kankakee River, and the effects of wind wave activity were not computed. The NRC staff reviewed methods and results used by the licensee found the selected method was appropriate and applied appropriately.

The dam failure in Mazon River was evaluated using the HEC-HMS PMF model for the Mazon River. For the dam failure assessment, the Braidwood cooling pond dam was the only dam found in the Mazon River watershed and was assumed to be potentially critical (Kaegi, 2015b). The hydrologic dam failure was assumed to occur at the peak WSE in the cooling pond to maximize the outflow due to a spillway breach (Kaegi, 2015b). The effect of dam failure on the WSE near the site was analyzed using the HEC-RAS model developed for the Mazon River PMF, but using the flow hydrograph from the HEC-HMS dam failure model. The resulting WSE due to hydrologic dam failure was 594.3 ft (181.1 m) MSL. The licensee included wind wave and wave runup in the analysis of dam failure based on Alternative 1 presented in Section 3.3, which increased the maximum WSE to 595.8 ft (181.6 m) MSL. Therefore, hydraulic dam failure plus the effect of PMF on the Mazon River is not bounded by the CDB.

3.4.2 Seismic Dam Failure Analysis

As for hydrologic dam failure, when reevaluating seismic dam failure, the licensee assumed that all dams upstream of the Braidwood site fail (Kaegi, 2015b). Following the NRC guidance (NRC, 2013b), the licensee used the lesser of 50 percent of the PMF or the 500-yr flood (Kaegi, 2015b). Based on examination of the HEC-HMS files for dam failure, staff found that the licensee used the 50 percent PMF for both the Kankakee and Mazon River watersheds. For analysis of seismic dam failure in both the Kankakee and Mazon Rivers, the staff's examination of the HEC-HMS input files showed the dams in each river were specified to fail at different times, with a short breach time of no greater than 0.5 hr. While the Braidwood FHRR provides no rational for the dam failure sequence, the NRC staff's examination of the HEC-HMS inputs for the seismic failure scenario with 50 percent PMF indicates that dam failure times were set to correspond to the time of peak flow in each subbasin. The NRC staff conducted sensitivity tests assuming simultaneous failure and found the maximum flow was smaller than the dam failure scenario used by the licensee. Hence, the licensee's method was reasonable. As found by the NRC staff's examination of the HEC-HMS and HEC-RAS input and output files, the outflow hydrographs were input to the HEC-RAS model to estimate the maximum WSE. The seismic dam failure was found by staff's examination of the HEC-RAS files to be bounded by hydrologic dam failure for both the Kankakee and Mazon Rivers.

3.4.3 NRC Staff Conclusion

The NRC staff found that hydrologic dam failure mechanism controls the dam failure hazards. For the Mazon River the reevaluated maximum WSE including wind wave effects was found to be 595.8 ft (181.6 m) MSL. For the Kankakee River the reevaluated maximum stillwater WSE was found to be 571.1 ft (174.1 m) MSL. No wind wave effects were computed for the Kankakee River because it is bounded by the results from the Mazon River.

The NRC staff confirmed the licensee's conclusion that the reevaluated hazard from flooding from failure of dams and onsite water control or storage structures is not bounded by the CDB flood hazard. The NRC staff has reviewed the licensee submitted MSA for the dam failure flood-causing mechanism for the Braidwood site and determined that the mitigation strategies described in the Braidwood MSA are reasonably protected against the reevaluated flood for this hazard.

3.5 Storm Surge

The licensee reported in the Braidwood FHRR that the reevaluated hazard for probable maximum storm surge (PMSS) is based on an extreme wind event on the cooling pond. The results of the analysis were calculated for two locations on the cooling pond, south of the plant where the top elevation of the cooling pond dike is 602.5 ft (183.6 m) MSL and southeast of the plant where the top elevation of cooling pond dike is 600.0 ft (182.9 m) MSL. These calculations resulted in a stillwater elevation at the location south of the plant of 598.9 ft (182.5 m) MSL, including wind waves and runup results in an elevation of 601.9 ft (183.6 m) MSL. At the location southeast of the plant the stillwater elevation is 598.0 ft (182.3 m) MSL, with wind waves and runup results in an elevation of 599.8 ft (182.8 m) MSL. The reevaluated flood hazard elevations at both locations were below the top elevations of the cooling pond dike. This flood-causing mechanism is not discussed in the licensee's CDB (Kaegi, 2015b).

In the Braidwood FHRR (Kaegi, 2015b), the licensee noted that an extreme wind event on the cooling pond could be compared to the CDB PMF on the cooling pond. As noted in Section 3.3 of this staff assessment, the CDB PMF on the cooling pond resulted in a stillwater surface elevation of 598.2 ft (182.3 m) MSL; including wind waves and runup results in an elevation of 602.3 ft (183.6 m) MSL.

The licensee noted in the Braidwood FHRR that the reevaluated storm surge analysis is based on guidance outlined in NUREG/CR-7046 (NRC, 2011e), ANS-2.8-1992 (ANSI/ANS, 1992), JLD-ISG-2012-06, and NUREG/CR-6966. The licensee used LiDAR data performed by the Illinois Height Data Modernization program for ground surface elevations. A 100 mi/hr (160.9 km/hr) overwater wind speed was selected based on guidance from ANS/ANSI (1992) and wind data, used to calculate the natural oscillation period of wind events, was obtained from the Chicago/Midway International Airport.

The licensee used the method of Keulegan (Keulegan, 1951) for the estimation of the surge height. The licensee determined that the critical fetch length was 3,025.9 ft (922.3 m) on the south side of the plant and 1672.9 ft (509.9 m) on the southeast side of the plant. The resulting PMSS event produced a storm surge height of 3.19 ft (0.97 m) along the south side of the plant and 2.23 ft (0.7 m) along the southeast side of the plant (Kaegi, 2015b). The NRC staff reviewed the methods and results used by the licensee and found the selected method was applied appropriately.

The NRC staff confirmed the licensee's conclusion that the reevaluated hazard for flooding due to storm surge is bounded by the CDB flood hazard at the Braidwood site. Therefore, the NRC staff determined that flooding from storm surge does not need to be analyzed in a focused evaluation or an additional assessment.

3.6 Seiche

The licensee reported in the Braidwood FHRR that the reevaluated hazard, including associated effects, for seiche was not plausible. The licensee's analysis of the potential for maximum probable seiche determined that the fundamental period for the cooling pond was much shorter than fundamental period computed from available wind data (Exelon, 2014a).

The NRC staff reviewed the information provided by the license and confirms the licensee's conclusion that the flood hazard from seiche is not a plausible flooding mechanism at the Braidwood site. Therefore, the NRC staff determined that flooding from seiche does not need to be analyzed in a focused evaluation or an additional assessment.

3.7 Tsunami

The licensee reported in the Braidwood FHRR that the reevaluated hazard, including associated effects, for tsunami does not inundate the plant site. This flood-causing mechanism is discussed in the licensee's CDB, but was considered not plausible due to the inland location of the Braidwood site which does not connect directly with any bodies of water capable of producing a tsunami (Exelon, 2014a).

The NRC staff reviewed the information provided by the license and confirms the licensee's conclusion that the flood hazard from tsunami is not a plausible flooding mechanism at the Braidwood site. Therefore, the NRC staff determined that flooding from tsunami does not need to be analyzed in a focused evaluation or an additional assessment.

3.8 Ice-Induced Flooding

The licensee reported in the Braidwood FHRR that the reevaluated hazard, including associated effects, for ice-induced flooding on the Kankakee and Mazon Rivers do not inundate the plant site, but did not report PMF elevations (Exelon, 2014a). This flood-causing mechanism is discussed in the licensee's CDB for the Kankakee and Mazon Rivers. For the Kankakee River, the CDB PMF elevation for ice-induced flooding is based on a stillwater-surface elevation of 555.0 ft (169.2 m) MSL (Exelon, 2014a). The CDB does not include wind waves and runup. For the Mazon River, this flood-causing mechanism is discussed in the licensee's CDB, but no PMF elevation was reported. The NRC staff reviewed the flooding hazard from ice-induced flooding, including associated effects, against the relevant regulatory criteria based on present-day methodologies and regulatory guidance.

The licensee used the USACE's national ice jam database (USACE, 2012) to determine the most severe historical ice flooding events (Exelon, 2014a). No historical ice jam data are available for the Mazon River; however, there are historical records for the Kankakee River. For both the Kankakee and Mazon Rivers, the licensee computed maximum WSEs assuming artificial-barrier ice jams and found that they were lower than the PMF WSEs.

The NRC staff reviewed the information provided by the license and confirms the licensee's conclusion that the flood hazard from ice-induced flooding is bounded by the CDB. Therefore, the NRC staff determined that flooding from ice induced flooding does not need to be analyzed in a focused evaluation or an additional assessment.

3.9 Channel Migrations or Diversions

The licensee reported in the Braidwood FHRR that the reevaluated hazard, including associated effects, for channel migrations or diversions does not inundate the plant site. This flood-causing mechanism is discussed in the licensee's CDB, but no PMF elevation was reported (Exelon, 2014a).

For the Kankakee River, the licensee compared historical and current topographic maps spanning a 94 year period and found no evidence of channel migration (Exelon, 2014a). Some migration of the Mazon River channel occurred, but it is attributed to human activities of strip mining and quarrying (Exelon, 2014a). The NRC staff examined U.S. Geological Survey (USGS) topographic maps (USGS, 2015) dating from 1892 to 2012, which confirm that some channel migration of the Mazon River channel occurred prior to 1954, but little channel migration is evident following 1954.

The NRC staff reviewed the information provided by the license and confirmed the licensee's conclusion that the flood hazard from channel migration or diversions is bounded by the CDB. Therefore, the NRC staff determined that flooding from channel migration or diversion does not need to be analyzed in a focused evaluation or an additional assessment.

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

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 elevations results. Table 4.1-1 contains the maximum flood height results, including waves and run-up, for flood mechanisms not bounded by the CDB presented in Table 3.1-1. The NRC staff agrees with the licensee's conclusion that PMF of the cooling pond and failure of dams plus PMF on the Mazon River are the only hazard mechanisms not bounded by the CDB. However, as part of the licensee's response to the 50.54(f) letter, the Braidwood FHRR contained a limited integrated assessment of the PMF of the cooling pond and failure of dams plus PMF on the Mazon River at the Braidwood site. The NRC staff has reviewed the limited integrated assessment and confirmed that the licensee appropriately evaluated the impact of these hazards on the site. In reaching this determination, NRC staff confirmed the licensee's conclusions that Braidwood has adequate protection reliability and margin against potential flood water infiltration.

4.2 Flood Event Duration for Hazards Not Bounded by the CDB

The NRC staff reviewed information provided in the Exelon's 50.54(f) responses (Exelon, 2014a; Kaegi, 2014; Kaegi, 2015a; and Kaegi, 2015b) regarding the FED parameters needed to perform the additional assessments of plant response for flood hazards not bounded by the CDB. The licensee stated that since the site is protected by passive structural features, no actions need to be taken to protect against the PMF of the cooling pond and failure of dams plus PMF on the Mazon River. Therefore, FED parameters for the flood-causing mechanisms not bounded by the CDB were not specifically discussed. The NRC staff agrees with this conclusion.

4.3 Associated Effects for Hazards Not Bounded by the CDB

The NRC staff reviewed information provided in the Braidwood 50.54(f) responses (Exelon, 2014a; Kaegi, 2014; Kaegi, 2015a; and Kaegi, 2015b) regarding the associated effects parameters needed to perform the additional assessments of plant response for flood hazards not bounded by the CDB. The licensee stated that since the site is protected by passive structural features, associated effects do not impact the site. Therefore, the licensee determined that no actions are necessary to protect against PMF of the cooling pond and failure of dams plus PMF on the Mazon River. Therefore, associated effects parameters for the flood-causing mechanisms not bounded by the CDB were not specifically discussed. The staff agrees with this conclusion regarding FED parameters for the Braidwood site.

4.4 Conclusion

Based upon the preceding analysis, 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.

5.0 CONCLUSION

The NRC staff has reviewed the information provided for the reevaluated flood-causing mechanisms of Braidwood. Based on its review of available information provided in Exelon's 50.54(f) response (Exelon, 2014b; Kaegi, 2014; Kaegi, 2015a; and Kaegi, 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 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 the reevaluated flood hazard results for PMF of the cooling pond and failure of dams plus PMF on the Mazon River are not bounded by the CDB flood hazard. The licensee has provided additional assessments of plant response at Braidwood for the PMF of the cooling pond and failure of dams plus PMF on the Mazon River. The NRC staff has reviewed these additional assessments and confirmed the licensee's conclusions that Braidwood has adequate protection reliability and margin against potential flood water infiltration.

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

6.0 REFERENCES

U.S. Nuclear Regulatory Commission Documents and Publications

NRC (U.S. Nuclear Regulatory Commission), 2007, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition", NUREG-0800, 2007. ADAMS stores the Standard Review Plan as multiple ADAMS documents, which are most easily accessed through NRC's public web site at http://www.nrc.gov/reading-rm/basic-ref/srp-review-standards.html.

NRC, 2011a, "Near-Term Report and Recommendations for Agency Actions Following the Events in Japan," Commission Paper SECY-11-0093, July 12, 2011, ADAMS Accession No. ML11186A950.

NRC, 2011b, "Recommendations for Enhancing Reactor Safety in the 21st Century: The Near-Term Task Force Review of Insights from the Fukushima Dai-Ichi Accident," Enclosure to Commission Paper SECY-11-0093, July 12, 2011, ADAMS Accession No. ML111861807.

NRC, 2011c, "Recommended Actions to be Taken Without Delay from the Near-Term Task Force Report," Commission Paper SECY-11-0124, September 9, 2011, ADAMS Accession No. ML11245A158.

NRC, 2011d, "Prioritization of Recommended Actions to be Taken in Response to Fukushima Lessons Learned," Commission Paper SECY-11-0137, October 3, 2011, ADAMS Accession No. ML11272A111.

NRC, 2011e, "Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America," NUREG/CR-7046, November 2011, ADAMS Accession No. ML11321A195.

NRC, 2012a, letter from Eric J. Leeds, Director, Office of Nuclear Reactor Regulation and Michael R. Johnson, Director, Office of New Reactors, to All Power Reactor Licensees and Holders of Construction Permits in Active or Deferred Status, "Request for Information Pursuant to Title 10 of the Code of Federal Regulations 50.54(f) Regarding the Recommendations 2.1, 2.3, and 9.3, of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident," March 12, 2012, ADAMS Accession No. ML12056A046.

NRC, 2012b, letter from Eric J. Leeds, Director, Office of Nuclear Reactor Regulation and Michael R. Johnson, Director, Office of New Reactors, to All Power Reactor Licensees and Holders of Construction Permits in Active or Deferred Status, "Issuance of Order to Modify Licenses with Regard to Requirements for Mitigation Strategies for Beyond-Design-Basis External Events," Order EA-12-049, March 12, 2012, ADAMS Accession No. ML12054A736.

NRC, 2012c, "Guidance for Performing the Integrated Assessment for External Flooding," Japan Lessons-Learned Project Directorate, Interim Staff Guidance JLD-ISG-2012-05, Revision 0, November 30, 2012, ADAMS Accession No. ML12311A214.

NRC, 2013, "Guidance For Assessment of Flooding Hazards Due to Dam Failure," Japan Lessons-Learned Project Directorate, Interim Staff Guidance JLD-ISG-2013-01, Revision 0, July 29, 2013, ADAMS Accession No. ML13151A153.

NRC, 2014a, "Request for Additional Information for Braidwood, Byron, Clinton, and LaSalle Flood Hazard Reevaluation," Email Capture, June 18, 2014, ADAMS Accession No. ML14169A545.

NRC, 2014b, "Braidwood Station, Units 1 and 2 – Staff Assessment of the Flooding Walkdown Reports Supporting Implementation of Near-Term Task Force Recommendation 2.3 Related to the Fukushima-Daichi Nuclear Power Plant Accident," Japan Lessons-Learned Project Directorate, June 30, 2014, ADAMS Accession No. ML14141A133.

NRC, 2015a, "Request for Additional Information: Braidwood Flooding Hazard Reevaluation Report (TAC Nos. MF3895 and MF3896," Japan Lessons-Learned Project Directorate, Email Capture, March 23, 2015, ADAMS Accession No. ML15093A315.

NRC, 2015b, "Closure Plan for the Reevaluation of Flooding Hazard for Operating Nuclear Power Plants," Commission Paper COMSECY-15-0019, June 30, 2015, ADAMS Accession No. ML15153A104.

NRC, 2015c, "Braidwood Nuclear Generating Station, Units 1 and 2 – Interim Staff Response to Reevaluated Flood Hazards Submitted in Response to 10 CFR 50.54(f) Information Request – Flood-Causing Mechanism Reevaluation," September 3, 2015, ADAMS Accession No. ML15211A363.

NRC, 2016a, "Compliance with Order EA-12-049 Order to Modify Licenses with Regard to Requirements for Mitigation Strategies for Beyond-Design-Basis External Events," Interim Staff Guidance JLD-ISG-2012-01, Revision 1 and Comment Resolution, January 22, 2016, ADAMS Accession No. ML15357A142.

NRC, 2016b, "Guidance for Activities Related to Near-Term Task Force Recommendation 2.1, Flooding Hazard Reevaluation; Focused Evaluation and Integrated Assessment," Interim Staff Guidance JLD-ISG-2016-01, Revision 0, July 11, 2016, ADAMS Accession No. ML16162A301.

NRC, 2016c, "Braidwood Station Units 1 and 2 – Flood Hazard Evaluation of Limited Integrated Assessment (CAC Nos. MF3895 and MF3896)," November 1, 2016, ADAMS Accession No. ML16265A214.

Codes and Standards

ANSI/ANS (American National Standards Institute/American Nuclear Society), 1992, ANSI/ANS-2.8-1992, "Determining Design Basis Flooding at Power Reactor Sites," American Nuclear Society, LaGrange Park, IL, July 1992.

Other References

Exelon (Exelon Generation Company, LLC), 2014a, "Flood Hazard Reevaluation Report in Response to the 50.54(f) Information Request Regarding the Near-Term Task Force Recommendation 2.1: Flooding for the Braidwood Generating Station," Revision 0, February 25, 2014, ADAMS Accession No. ML14079A418.

Exelon, 2014b, "Enclosure 1 - Braidwood Generating Station Flooding Hazard Reevaluation Report," Revision 0, March 12, 2014, ADAMS Accession No. ML14079A428.

FLO-2D (FLO-2D Software Inc.), 2013, FLO -2D® Reference Manual, FLO -2D Software, Inc., Nutrioso, Arizona FLO-2D, 2013, Build Number 13.11.06, FLO -2D Software, Inc.

Gaston (Gaston, R. W.) 2014, "Exelon Generation Company, LLC Response to March 12, 2012, Request for Information Enclosure 2, Recommendation 2.1, Flooding, Required Response 2, Flood Hazard Reevaluation Report," RS-14-052. March 12, 2014, ADAMS Accession No. ML14079A418.

Kaegi, 2012, "Exelon Generation Co, LLC 180-day Response to NRC Request for Information Pursuant to 10 CFR 50.54(f) Re: the Flooding Aspects of Recommendation 2.3 of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident," November 27, 2012, ADAMS Accession No. ML12332A378.

Kaegi, Glen T., 2013, "Dresden, Units 2 and 3, Response to March 12, 2012, Request for Information Enclosure 2, Recommendation 2.1, Flooding, Required Response 2, Flooding Hazard Reevaluation Report," ADAMS Accession No. ML13135A120.

Kaegi, Glen T., 2014, "Braidwood, Units 1 & 2, Clinton, Unit 1 and LaSalle, Units 1 & 2, Response to Request for Additional Information Regarding Fukushima Lessons Learned - Flood Hazard Reevaluation Report," July 14, 2014, ADAMS Accession No. ML14293A599.

Kaegi, Glen T., 2015a, "Braidwood Station, Units 1 and 2 - Supplemental Response to Request for Additional Information Regarding Fukushima Lessons Learned – Flood Hazard Reevaluation Report," RS-15-050. February 17, 2015, ADAMS Accession No. ML15055A147.

Kaegi, Glen T., 2015b. "Braidwood, Units 1 and 2 - Response to Request for Additional Information Regarding Fukushima Lessons Learned – Flood Hazard Reevaluation Report," June 24, 2015, ADAMS Accession No. ML15182A237.

Keulegan, G. H., 1951, "Wind Tides in Small Closed Channels," National Bureau of Standards Research Paper No. 2207, F. Res. Nat. Bur. Std., C., 46 (5): 358-381.

NEI (Nuclear Energy Institute), 2015, "Diverse and Flexible Coping Strategies (FLEX) Implementation Guide," NEI 12-06 Revision 2, December 2015, ADAMS Accession No. ML16005A625.

NOAA (National Oceanic and Atmospheric Administration), 1978, "Probable Maximum Precipitation Estimates, United States, East of the 105th Meridian," NOAA Hydrometeorological Report No. 51, June 1978.

NOAA, 1982, "Application of Probable Maximum Precipitation Estimates, United States, East of the 105th Meridian," NOAA Hydrometeorological Report No. 52, August 1982.

SCS (Soil Conservation Service), 1986, "Urban Hydrology for Small Watersheds," Technical Release 55, Soil Conservation Service, U.S. Department of Agriculture, June 1986.

USACE (U.S. Army Corps of Engineers), 1984, "Generalized Computer Program, HMR52 Probable Maximum Storm (Eastern United States), User's Manual," Hydrologic Engineering Center, U.S. Army Corps of Engineer, March 1984, Revised April 1987.

USACE, 2010a, "River Analysis System (HEC-RAS), Version 4.1.0," Hydrologic Engineering Center, January 2010.

USACE, 2010b, "Hydrologic Modeling System (HEC-HMS), Version 3.5.0," Hydrologic Engineering Center, August 2010.

USACE, 2012, "Ice Jam Database," U.S. Army Corps of Engineers, Cold Region Research and Engineering Laboratory (CRREL), available at: http://icejams.crrel.usace.army.mil/. Accessed October 8, 2014.

USACE, 2013, "National Inventory of Dams," accessed from http://nid.usace.army.mil, October 2013.

USGS (U.S. Geological Survey), 2015. The USGS Store. Quadrangles IL_Wilmington_310080 (1892), IL_Wilmington_310074 (1918), IL_Wilmington_309086 (1954), and IL_Wilmington_0822 (2012). Accessed March 4, 2015 at http://store.usgs.gov/b2c_usgs/usgs/maplocator/(xcm=r3standardpitrex_prd&layout=6_1_61_48&uiarea=2&ctype=areaDetails&carea=%24ROOT)/.do.

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/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

Table 3.0-1. Summary of Controlling Flood-Causing Mechanisms (Kaegi, 2015b)

Reevaluated Flood-Causing Mechanisms and Associated Effects that May Exceed the Powerblock Elevation (600.0 ft MSL)[1]	ELEVATION ft MSL)
Local Intense Precipitation and Associated Drainage	601.1
Flooding in Streams and Rivers/Cooling Pond	601.3[2]
Storm Surge	601.9[3]

1. Flood Height and Associated Effects as defined in JLD-ISG-2012-05 (NRC 2012c).
2. Cooling pond PMF plus wind effects (bounded by CDB)
3. Cooling pond Storm Surge (bounded by CDB)

Table 3.1-1. Current Design Basis Flood Hazards (Exelon, 2014a)

Mechanism	Stillwater Elevation	Waves/ Runup	Design Basis Hazard Elevation	Reference
Local Intense Precipitation	601.9 ft MSL	Not applicable	601.9 ft MSL	FHRR Section 2.2.1
Streams and Rivers				
PMF on Mazon River	582.0 ft MSL	2.0 ft	584.0 ft MSL	FHRR Section 2.2.2
PMF on Cooling Pond	598.2 ft MSL	4.1 ft	602.3 ft MSL	FHRR Section 2.2.4
Failure of Dams and Onsite Water Control/Storage Structures	No impact on the site identified	No impact on the site identified	No impact on the site identified	FHRR Section 2.2.3
Storm Surge	No impact on the site identified	No impact on the site identified	No impact on the site identified	FHRR Section 2.2.5
Seiche	No impact on the site identified	No impact on the site identified	No impact on the site identified	FHRR Section 2.2.5
Tsunami	No impact on the site identified	No impact on the site identified	No impact on the site identified	FHRR Section 2.2.6
Ice-Induced Flooding				
Ice jam flooding – Near Intake	555.0 ft MSL	Not applicable	555.0 ft MSL	FHRR Section 2.2.7
Channel Migrations or Diversions	No impact on the site identified	No impact on the site identified	No impact on the site identified	FHRR Section 2.2.8

Note: Reported values are rounded to the nearest one-tenth of a foot

Table 4.1-1: Reevaluated Flood Hazards for Flood-Causing Mechanisms Not Bounded by the CDB

Mechanism	Stillwater Elevation	Waves/ Runup	Reevaluated Hazard Elevation	Reference
Streams and Rivers				
PMF on Cooling Pond	599.4 ft MSL	1.9 ft	601.3 ft MSL	FHRR, Rev. 2 Table 4.4
Failure of Dams and Onsite Water Control/Storage Structures				
Hydrologic Dam Failure plus PMF on Mazon River	594.3 ft MSL	1.5 ft	595.8 ft MSL	FHRR, Rev. 2 Table 4.3

Note 1: 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 CDB

Flood-Causing Mechanism	Time Available for Preparation for Flood Event	Duration of Inundation of Site	Time for Water to Recede from Site
Streams and Rivers – PMF on Cooling Pond	Not applicable	Not applicable	Not applicable
Streams and Rivers – PMF on Mazon River	Not applicable	Not applicable	Not applicable

Source: Exelon, 2014b, and Kaegi, 2015b

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	**PMF on the Cooling Pond**	**Streams and Rivers – PMF on the Mazon River**
Hydrodynamic loading at plant grade	No impact to the site identified	No impact to the site identified
Debris loading at plant grade	No impact to the site identified	No impact to the site identified
Sediment loading at plant grade	No impact to the site identified	No impact to the site identified
Sediment deposition and erosion	No impact to the site identified	No impact to the site identified
Concurrent conditions, including adverse weather	No impact to the site identified	No impact to the site identified
Groundwater ingress	No impact to the site identified	No impact to the site identified
Other pertinent factors (e.g., waterborne projectiles)	No impact to the site identified	No impact to the site identified

Source: Exelon, 2014b, and Kaegi, 2015b

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

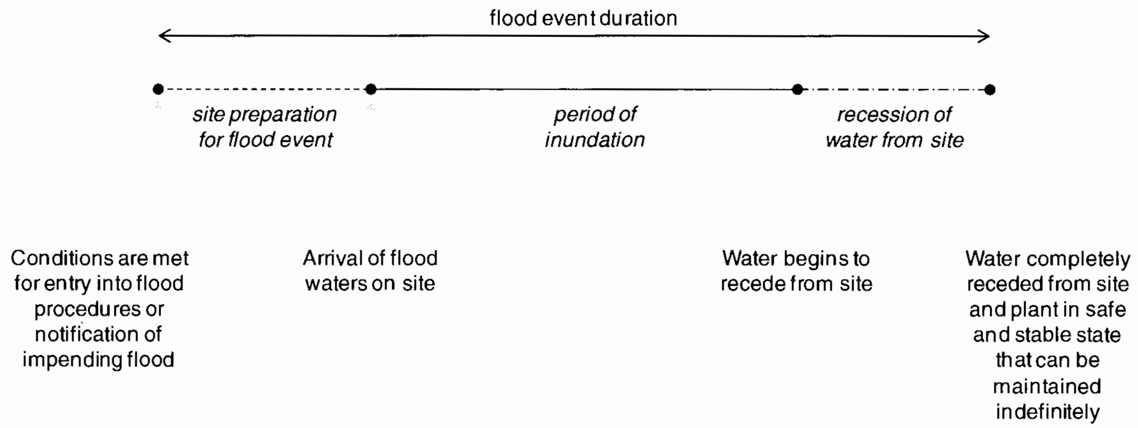
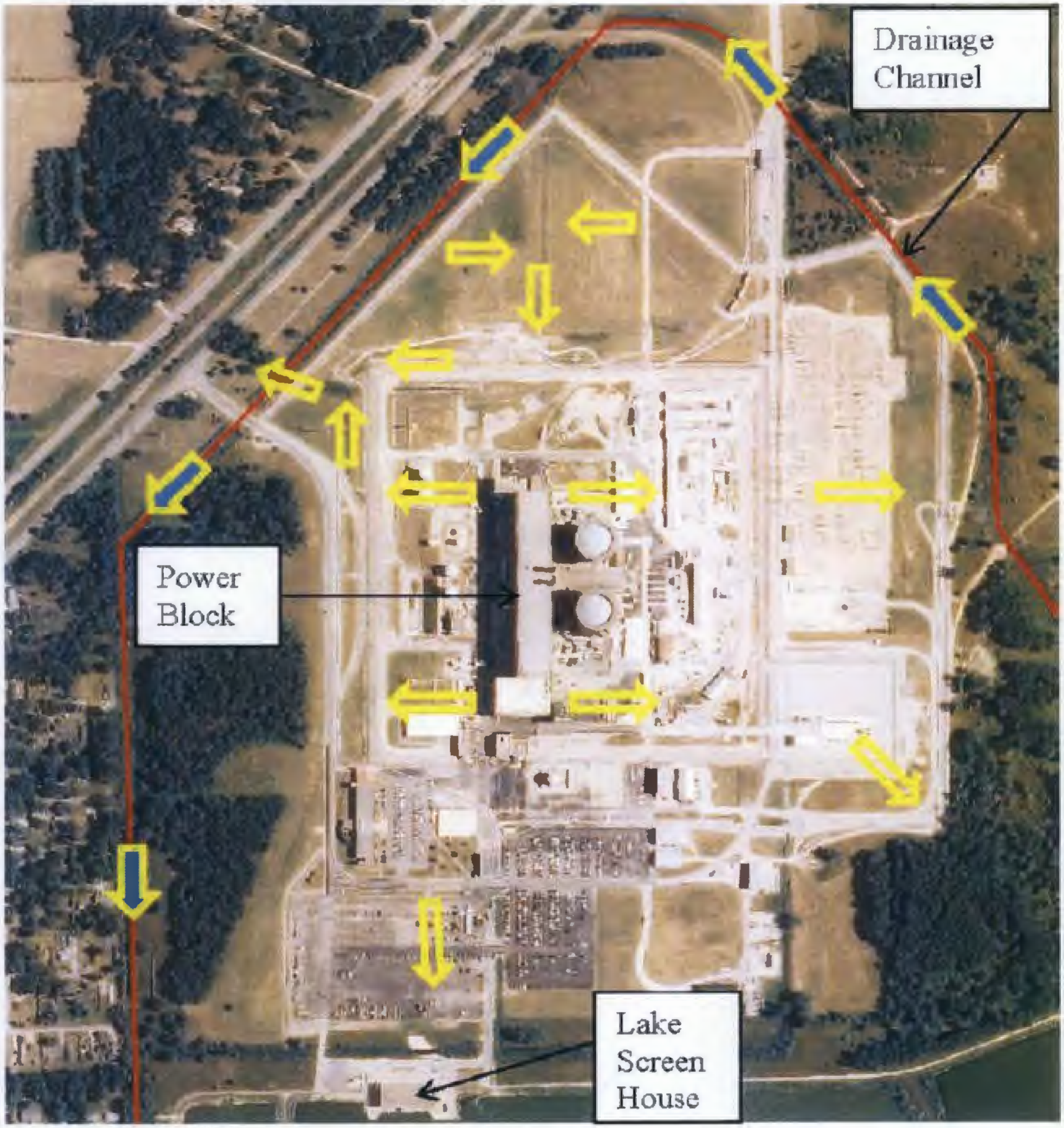


Figure 3.1-1 Braidwood General Site Location (Exelon, 2014a)

Figure 3.1-2 Braidwood Site Layout with Flow Directions (Exelon, 2014a).



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. 50-456 and 50-457

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