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

February 21, 2018

Mr. Bryan C. Hanson
Senior Vice President
Exelon Generation Company, LLC
President and Chief Nuclear Officer
Exelon Nuclear
4300 Winfield Road
Warrenville, IL 60555

SUBJECT: OYSTER CREEK NUCLEAR GENERATING STATION, - STAFF ASSESSMENT OF THE RESPONSE TO 10 CFR 50.54(f) INFORMATION REQUEST – FLOOD-CAUSING MECHANISM REEVALUATION (CAC NO. MF6111; EPID L-2015-JLD-0013)

Dear Mr. Hanson:

By letter dated March 12, 2012 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML12053A340), 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 that licensees reevaluate flood-causing mechanisms using present-day methodologies and guidance. By letter dated March 12, 2015 (ADAMS Accession No. ML15085A046), Exelon Generation Company, LLC (Exelon, the licensee) responded to this request for Oyster Creek Nuclear Generating Station (Oyster Creek).

By letter dated July 21, 2015 (ADAMS Accession No. ML15148A286), the NRC notified Exelon of the staff's plan to perform a regulatory audit of the Flood Hazard Reevaluation Report for Oyster Creek. The technical audit was performed consistent with NRC Office of Nuclear Reactor Regulation, Office Instruction LIC-111, "Regulatory Audits," dated December 29, 2008 (ADAMS Accession No. ML082900195). The audit report was issued by letter dated August 5, 2016 (ADAMS Accession No. ML16165A376).

By letter dated February 9, 2016 (ADAMS Accession No. ML16035A266), the NRC staff sent the licensee a summary of the staff's review of the licensee's reevaluated flood-causing mechanisms. The enclosed staff assessment provides the documentation supporting the NRC staff's conclusions summarized in the February 9, 2016, letter. As stated in the letter, the reevaluated flood hazard result for the following mechanisms were not bounded by the Oyster Creek current design basis (CDB) flood hazard: local intense precipitation and storm surge. The NRC staff notes that for the flood-causing mechanisms that are not bounded by the CDB, the licensee has submitted a mitigation strategies assessment (MSA) by letter December 16, 2016 (ADAMS Accession No. ML16351A219). The NRC staff responded to the MSA by letter dated May 18, 2017 (ADAMS Accession No. ML17082A271). In addition, Exelon submitted a focused evaluation consistent with the process described by NRC letter dated September 1, 2015(ADAMS Accession No. ML15174A257), "Coordination of Requests for Information Regarding Flooding Hazard Reevaluations and Mitigating Strategies for Beyond-

Design-Basis External Events." The NRC staff will provide its assessment of the Oyster Creek focused evaluation in a separate letter. This closes out the NRC's efforts associated with CAC No. MF6111.

If you have any questions, please contact me at (301) 415-1056 or by e-mail at Lauren.Gibson@nrc.gov.

Sincerely,

for

Lauren K. Gibson, Project Manager
Beyond-Design-Basis Management Branch
Division of Licensing Projects
Office of Nuclear Reactor Regulation

Docket No. 50-219

Enclosure:
Staff Assessment of Flood Hazard
Reevaluation Report

cc w/encl.: Distribution via Listserv

STAFF ASSESSMENT BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO FLOODING HAZARD REEVALUATION REPORT

NEAR-TERM TASK FORCE RECOMMENDATION 2.1

RELATED TO THE FUKUSHIMA DAI-ICHI NUCLEAR POWER PLANT ACCIDENT

OYSTER CREEK NUCLEAR GENERATING STATION

DOCKET NO. 50-219

1.0 INTRODUCTION

By letter dated March 12, 2012 (NRC, 2012a), the U.S. Nuclear Regulatory Commission (NRC) issued a request for information to all power reactor licensees and holders of construction permits in active or deferred status, pursuant to Title 10 of the *Code of Federal Regulations* (10 CFR), Section 50.54(f), (hereafter referred to as the "50.54(f) letter"). The request was issued in connection with implementing lessons-learned from the 2011 accident at the Fukushima Dai-ichi nuclear power plant as documented in the Near-Term Task Force (NTTF) report (NRC, 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 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 the Flood Hazard Reevaluation Report (FHRR) deadlines for each plant. On May 11, 2012 (NRC, 2012b), the NRC staff issued its prioritization of the FHRRs.

By letter dated March 12, 2015(Exelon, 2015), Exelon Generation Company, LLC (Exelon, the licensee) provided the FHRR for the Oyster Creek Nuclear Generating Station (Oyster Creek). Following a review of that document, the NRC staff submitted requests for additional information (RAIs) focused principally on the analysis of local intense precipitation (LIP). On August 18, 2015, and January 14, 2016, the NRC staff conducted an audit of the licensee's FHRR submittal at which time the NRC RAIs were discussed. The summary of that audit, including the disposition of the respective RAIs, was summarized in a letter dated August 5, 2016 (NRC, 2016d). The results of that audit have also been factored into this staff assessment. The licensee supplemented their FHRR by e-mail dated January 14, 2016 (Exelon, 2016a), and by letter dated April 15, 2016 (Exelon, 2016b).

On February 9, 2016 (NRC, 2016b), the NRC issued an interim staff response (ISR) letter to the licensee. 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 (NRC, 2016b), the reevaluated flood hazard results for the LIP and storm surge due to a probable maximum hurricane (PMH) 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 (NRC, 2015a), Japan Lessons-Learned Division (JLD) Interim Staff Guidance (ISG) JLD-ISG-2012-01, Revision 1 (NRC, 2016a) and JLD-ISG-2016-01, Revision 0 (NRC, 2016c), the NRC staff anticipated that the licensee would perform and document a focused evaluation for LIP and associated site drainage that assesses the impact of the LIP hazard on the site, and evaluates and implements any necessary programmatic, procedural, or plant modifications to address this hazard exceedance. Additionally, for the storm surge due to a PMH flood-causing mechanism, the NRC staff anticipated that the licensee would submit either (a) a revised integrated assessment or (b) a focused evaluation confirming the capability of existing flood protection or implementing new flood protection consistent with the process outlined in COMSECY-15-0019 (NRC, 2015b) and JLD-ISG-2016-01, Revision 0 (NRC, 2016c). The licensee submitted a focused evaluation for both LIP and storm surge by letter dated April 28, 2017 (Exelon, 2017). It is currently under review by NRC staff.

Additionally, for any reevaluated flood hazards that are not bounded by the plant's CDB hazard, the licensee was expected to develop any flood event duration (FED) and associated effect (AE) parameters. These parameters would be used to conduct the Mitigating Strategies Assessment (MSA) and focused evaluations or revised integrated assessments. By letter dated December 16, 2016 (Exelon, 2016d), the licensee submitted the MSA. The NRC staff's review of the MSA was issued by letter dated May 18, 2017 (NRC, 2017).

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

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

2.2.5 Actions Following the FHRR

For the sites where the reevaluated flood hazard is not bounded by the CDB flood hazard elevation for any of the 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; and

- Perform an integrated assessment to: (a) evaluate the effectiveness of the CDB (i.e. flood protection and mitigation systems); (b) identify plant-specific vulnerabilities; and (c) assess the effectiveness of existing or planned systems and procedures for protecting against and mitigating consequences of flooding for the flood event duration.

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

3.0 TECHNICAL EVALUATION

The NRC staff reviewed the information provided for the reevaluation of the flood hazards at Oyster Creek. The licensee conducted the flood hazard reevaluation using present-day methodologies and regulatory guidance used by the NRC staff in connection with ESP and COL reviews. To provide additional information in support of the summaries and conclusions in the FHRR, the licensee made calculation packages available to the NRC staff via an electronic reading room. When the NRC staff relied directly on any of the calculation packages in its review, they or portions thereof were docketed. Certain other calculation packages were found only to expand upon and clarify the information provided on the docket, and so are not docketed or cited. The licensee also submitted some input/output (I/O) files of modeling used to estimate the reevaluated flood hazard elevation. The staff's review and evaluation is provided below. Licensee-reported values are rounded to the nearest one-tenth of a foot.

3.1 Site Information

The 50.54(f) letter (NRC, 2012a) includes the SSCs important to safety in the scope of the hazard reevaluation. The NRC staff reviewed and summarized this information in the section below.

3.1.1 Detailed Site Information

The nominal grade of the Oyster Creek nuclear reactor site is approximately at elevation 23 feet (ft.) mean sea level (MSL); all elevations in this staff assessment are given with respect to the MSL. Ground surface elevations vary across the site from an elevation maximum of about 35 ft. MSL in the northern part of the site to a low of about 5 ft. MSL in the south. The geology of the reactor site and surrounding region is dominated by alluvial deposits and beach sands and gravels, all of which are unconsolidated. The literature identifies these deposits to be associated with the Kirkwood-Cohansey (unconfined) aquifer system (Zapecza, 1989). The entrances to all site buildings with the exception of the Emergency Diesel Generator (EDG) Building are at elevation 23.5 ft. MSL. The entrances to the EDG Building are at elevation 23 ft. MSL, with protective dikes around the building entrances up to elevation 23.5 ft. MSL. The licensee reported that it also relied on a variety of flood protection measures for various structural features below grade to provide additional protection against flooding effects; those measures include waterproofing, covered or sealed penetrations, water stops, floor drains and sumps. Drains within the power block yard are designed to collect site runoff; however, the licensee previously reported that some ponding will still occur within the powerblock during a thunderstorm in spite of the site's topography and drainage system (NRC, 1991). Table 3.0-1 provides the summary of controlling reevaluated flood-causing mechanisms, including AEs, the licensee computed to be higher than the CDB elevations. Figure 3.2-1 shows the site layout and topography.

The Oyster Creek reactor site is located within the Atlantic Coastal Plain; the site's geology consists of unconsolidated sediments (principally sands) associated that physiographic province. The reactor site is about 2 miles (mi) inland from Barnegat Bay, the principal hydrologic feature of interest. The site is surrounded by wetland vegetation to the east and the Pine Barrens (hardwood swamps) to the west – all of which represent the Barnegat Bay watershed. The reactor site consists of 1,416 acres of which approximately 10 acres are occupied by the powerblock. Barnegat Bay is a relatively shallow, back-water body (lagoon) that trends north-south parallel to the New Jersey coastline. The bay is about 43 mi long, varies in width from 3 to 9 mi, and has a depth that ranges from 3 to 23 ft. It is separated from the Atlantic Ocean by a narrow barrier island and is part of the inter-coastal waterway. The watershed associated with Barnegat Bay estuary is large and extends over 600 square miles (mi^2). Local surface water flow into the estuary near the reactor site is received from Oyster Creek, immediately to the south of the site, and from multiple tributaries of the Forked River located to the north. An important consideration in the evaluation of the flood potential at the reactor site is that the probable maximum stillwater elevation in the marsh and nearby tributaries is generally the same as the water level in Barnegat Bay as they are hydraulically-coupled. As an estuary, water levels within the bay itself are largely controlled by tidal forces and the occasional subtropical cyclone (hurricane). Because of the relative shallowness of Barnegat Bay, normal tidal fluctuations of water level in Oyster Creek were reported to be only 0.5 ft. on a 12.7-hour (h) tidal cycle (Exelon, 2012).

The plant's powerblock is built on an island created by the construction of two canals. The northern and western boundaries of the site (excluding the switchyard) are formed by the outer banks of the intake canal that draws circulating (cooling) water from Barnegat Bay. This canal follows the general course of the south branch of Forked River then curves south to the service water intake structure (SWIS), located 183 ft. west of the Reactor Building. The thermal discharge canal emerges from the SWIS location, curving south and to the west where it intersects the existing Oyster Creek watercourse for a distance of 2 mi where it ultimately discharges into Barnegat Bay. The two canals are approximately 140-ft. wide and 10-ft. deep, and are armored to prevent erosion; the nominal top elevation of the armored berms is about elevation 30 ft. MSL (Exelon, 2009). To the west of the SWIS is the power plant switchyard. Route 9 forms the eastern boundary of the reactor site; beyond Route 9 is the community of Forked River Beach. Surface drainage at the Oyster Creek site is generally managed by the finished topography within the powerblock that consists of man-made (sand) fill. The topography of the site has been configured so that rainwater flows from the center of the island towards the intake canal to the north and west, the discharge canal to the south and west, and Route 9 to the east. The licensee also operates an NRC-regulated independent spent fuel storage installation (ISFSI) that was licensed under 10 CFR Part 72 at a location removed from the powerblock.

Groundwater intrusion is not considered to be a design issue as no groundwater or perched water has been reported at the site (Exelon, 2009). However, the region is generally underlain by an unconfined aquifer; the water table at the reactor site is reported to be at an elevation of

12 ft. MSL under normal conditions, reaching 19 to 22 ft. MSL during storm surge (Exelon, 2012). The licensee noted that all below-grade penetrations are designed to prevent groundwater ingress and be leak-tight (Exelon, 2012).

3.1.2 Design-Basis Flood Hazards

The CDB flood levels are discussed in the licensee's FHRR (Exelon, 2015) and summarized by flood-causing mechanism in Table 3.1.2-1. As noted in that table, the licensee reported that the design-basis flood hazard for the Oyster Creek reactor site is due to LIP and a combined effects storm surge flooding event.

The licensee noted that the Oyster Creek reactor site is not considered susceptible to flooding by streams or rivers, storm surge, tsunami, seiche, dam failures, ice flooding, or channel migration. Although the site is located in a coastal area, it's susceptibility to flooding tsunami or seiche was not previously evaluated by the licensee.

3.1.3 Flood-Related Changes to the Licensing Basis

The licensee noted that the only flood-related change to the reactor site was the installation of a 0.5-ft. high asphalt dike around the EDG Building. The licensee also noted in its FHRR that it was also in the process of implementing unspecified administrative strategies to better cope with the flood-causing mechanisms applicable to the site (Exelon, 2015).

3.1.4 Changes to the Watershed and Local Area

The licensee reported that local changes to the watershed have been minimal since the plant has been licensed to operate. Reported changes within the Oyster Creek reactor site itself include some modification of the site's topography due to the following: the addition of new security features such as a vehicle barrier system (VBS), the construction of new administrative buildings, and the construction of a wall around the EDG Building. These changes were accounted for in the hydrologic models used in the FHRR through the use of improved, higher-resolution topographic data for the region and site. No information was presented to suggest that anthropogenic factors have had an impact on the watersheds encompassing the Oyster Creek reactor site.

3.1.5 Current Licensing Basis Flood Protection and Pertinent Flood Mitigation Features

The licensee stated that there were no changes either to the licensing basis flood elevations or flood protection design features. The licensee noted that the flood protection features for the Oyster Creek were designed to be permanent and were, therefore, not dependent on flood duration. Multiple passive and active flood protection features are credited in the CLB. The passive features consist of the waterfront protection along the respective canals, powerblock location, construction design/characteristics, waterproofing/water stops and penetration seals. Active flood protection features include watertight doors, and a drainage system; many of these features are described in the licensee's walkdown report (Exelon, 2012).

The licensee did note that the SWIS has a deck elevation 6 ft. MSL; this deck supports, apart from the other equipment, the circulating water pumps, service water pumps and the emergency service water pumps. During a PMH type flood, the circulating water, service water pumps and the emergency service water pumps will become inoperable. The licensee noted that emergency plant procedures would then be initiated which require the plant to be shutdown when flood waters reach a predetermined level as to ensure the capability for safe shutdown under either normal or abnormal conditions.

3.1.6 Additional Review Details to Assess the Flood Hazard

In connection with the NRC staff's FHRR review, electronic copies of the computer I/O files used in the numerical modeling of LIP were also provided to the staff in the context of the aforementioned audit process. Requested Information Item 1.c and Attachment 1 to Enclosure 2, Step 6, in the 50.54(f) letter requires licensees to report any relevant information from the results of the plant walkdown activities associated with Enclosure 4 of the 50.54(f) letter. The enclosure to Exelon (2012) identifies and summarizes the issues identified during the Oyster Creek flood protection walkdowns. Minor issues were identified and entered into the Exelon corrective action program. No operability concerns were identified.

3.1.7 Results of Plant Walkdown Activities

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

By letter dated November 19, 2012 (Exelon, 2012), Exelon submitted the Flooding Walkdown report for the Oyster Creek site. On June 16, 2014 (NRC, 2014), the NRC staff issued its assessment of the Walkdown Report, which documented its review of that licensee action and concluded that the licensee's implementation of the flooding walkdown methodology met the intent of the 50.54(f) letter.

3.2 Local Intense Precipitation and Associated Site Drainage

This flood-causing mechanism is discussed in the licensee's CDB. The CDB probable maximum flood (PMF) elevation for LIP and associated site drainage is based on a stillwater-surface elevation of 23.5 ft. MSL (Exelon, 2009). Wind waves and runup effects associated with LIP flooding are not discussed in the licensee's CDB.

The licensee reported that the reevaluated flood hazard for LIP and associated site drainage is based on a stillwater-surface elevation of 24.4 ft. MSL (Exelon, 2016b). The licensee stated that the limited fetch lengths and shallow flow depths within the powerblock would result in negligible wind-wave effects (Exelon, 2015).

3.2.1 Site Drainage and Elevations

The finished plant grade at the Oyster Creek site is 23.0 ft. MSL; the site grade generally slopes away from the nuclear island in all directions. Floor levels and door sills of buildings are generally at an elevation of 23.5 ft. MSL (Exelon, 2009). The licensee stated that entrances to the EDG Building are at an elevation of 23 ft. MSL, and a 6 inch (in.) asphalt dike is provided at these locations to provide flood protection to an elevation of 23.5 ft. MSL. The licensee also stated that the majority of building door sills are at an elevation of 23.5 ft. MSL. However, the four doors associated with the EDG Building are at elevations that range from 23.6 to 23.7 ft. MSL. The licensee noted that these elevations were obtained from an as-built survey drawing of the security features associated with the diesel generator building (Exelon, 2016b).

The licensee obtained the topographic base for the reactor site from a photogrammetric survey performed in 2004 and a supplemental field survey completed in 2012. The photogrammetric data are based on ground stations located approximately 10 to 100 ft. apart; the vertical error in those data was reported to be 0.17 ft. based on the root mean square difference between photogrammetric data and the field survey elevations for the same ground stations (NRC, 2016d). A digital elevation model (DEM) was produced from the survey results and photogrammetric data; the resolution of that DEM was sufficient to produce a 1-ft. contour map of the site (Exelon, 2016b). The licensee relied on a supplemental field survey to identify features not captured in the photogrammetric survey; such features included local topographic depressions and concrete-like Jersey barriers (Exelon, 2016b).

The licensee also performed a physical walkdown of the reactor site that was completed on September 11, 2015, to verify the locations of security barriers and Jersey barriers that could affect site surface drainage (NRC, 2016d). In connection with that walkdown, four different types of security barriers were identified whose heights ranged from 40 to 48 in. The height of the Jersey barriers was 32 in. During the walkdown, the licensee also identified other site features that could affect the free flow of surface water. Those features included an elevated landscaping arrangement and a rock wall near the Office Building and a metal security barrier around the Diesel Generator building.

3.2.2 Local Intense Precipitation

The licensee cited NUREG/CR-7046 (NRC, 2011e) in its decision to select the 1-h, 1-mi2 probable maximum precipitation (PMP) event for the LIP flooding reevaluation (Exelon, 2016b). The licensee selected a 1-h, 1-mi2 PMP depth of 18.07 in. based on the National Weather Service's (NWS) Hydrometeorological Reports (or HMRs – NOAA, 1982), and used multiplier factors from the National Oceanic and Atmospheric Administration (NOAA) (1982) to estimate the 30-, 15-, and 5-min PMP depths for a 1-mi2 drainage area (Exelon, 2016b). Table 3.2-1 provides LIP depths estimated by the licensee. The NRC staff used the location of the Oyster Creek reactor site to verify, from NOAA (1982), that the licensee's LIP depth estimates are reasonable.

The licensee provided a depth-duration plot for the PMP precipitation, shown in Figure 3.2-2. The licensee applied the most intense precipitation during the initial 5-min increment with the precipitation rate decreasing during successive time increments. The NRC staff verified that the licensee followed the example of NUREG/CR-7046 (NRC, 2011e), Appendix B, and that, given the PMP values, the hyetograph used by the licensee would result in the most rapid rise in water levels at the site.

Duration and temporal distribution of an LIP event can affect the intensity of rainfall and the shape of the flood hydrograph. These two LIP properties can have an effect on the available plant response time, the maximum floodwater-surface elevation, and the duration of inundation. The NRC staff concluded that the temporal distribution used by the licensee minimized the response time. As discussed below in Section 3.2.4, the NRC staff concluded that the licensee's LIP event maximizes the flood elevations at the 14 door locations examined, and that a longer duration LIP event would lead to a longer period of inundation at Door Nos. 9 and 14.

3.2.3 Runoff Analysis

The licensee reevaluated the flood hazard from an LIP event using a model developed with the software FLO-2D Pro, Version 2014 (Build No. 14.11.09) (FLO-2D, 2012). FLO-2D computes flows and water-surface elevations on a two-dimensional gridded domain that can include channels, hydraulic structures, and flow obstructions. In connection with the audit of the licensee's FHRR (NRC, 2016d), Exelon provided the FLO-2D model input files used in obtaining the results described in the FHRR. These files were reviewed by the NRC staff to confirm the licensee's model configuration. The licensee used a 10-ft. by 10-ft. grid with 66,664 grid cells over a domain that included the switchyard. The model domain was bounded by the intake and discharge canals and by Route 9, as shown in Figure 3.2-1. Surface elevations for model grid cells were based on the topographic data described above, either interpolated or averaged to the model grid cells.

The licensee represented all barriers and other as-built features within the powerblock that could affect flow as levees in the FLO-2D computer model. The licensee assumed the gaps in the security barriers were blocked if they were smaller than 10 ft. the size of the FLO-2D model grid elements. The licensee also assumed a gap in the northeast side of the metal security barrier around the Diesel Generator Building to be open.

The licensee represented buildings in the FLO-2D computer model using raised grid elevations (NRC, 2016d). The NRC staff determined that model grid elevations for cells corresponding to the Reactor and Turbine Building locations represented the parapet walls on the east and west sides of those buildings' roofs. The licensee stated that the model was configured so that all runoff from the buildings' roofs was conveyed directly to the adjacent ground surface and no credit was taken for roof storage due to parapet walls or runoff diversion from roof drainage systems (NRC, 2016d). Based on the configuration of the licensee's computer model, the NRC staff determined that flow off the building roofs occurs in response to the elevation differences between the roof grid elements and the adjacent grid elements representing the ground surface. The licensee stated that building roofs were flat and set at 10 ft. per building story above the ground elevation, with the exception of the Reactor and Turbine Buildings, which were sloped and had elevations obtained from site drawings (NRC, 2016d). The staff evaluated the licensee's FLO-2D computer model results and determined that flow off the north and south sides of the Reactor and Turbine Buildings was unobstructed, which limited water storage on the roofs and provided conservative flood depths adjacent to those buildings. The NRC staff determined that the licensee's evaluation of roof drainage is consistent with ANSI/ANS (1992).

The licensee assumed that all active and passive drainage system components were non-functional, and ignored runoff losses (Exelon, 2016b). The NRC staff determined that this approach maximizes runoff and is consistent with NUREG/CR-7046 (NRC, 2011e).

The licensee evaluated the land cover types using aerial photos and field verification (Exelon, 2016b). The licensee identified five types of land cover surfaces and assigned Manning's n parameter values from the recommended ranges provided in FLO-2D (2012). Using a previous version of the LIP flood model, the licensee completed a sensitivity analysis using the upper and lower bounds of the recommended ranges of the Manning's n coefficient and determined that the resulting difference in water surface elevation was less than 0.08 ft. The NRC staff completed the Manning's n sensitivity analysis using the model described in Exelon (2016b) and found that the largest increases in maximum water surface elevation (WSE) during the LIP flood were no more than 0.05 ft. Based on this small effect, the NRC staff finds the licensee's approach reasonable.

The licensee used an outflow boundary around the entirety of the model domain, including the outer bank of the intake and discharge canals (see Figure 3.2-1) (NRC, 2016d). The licensee also assumed that the LIP event did not occur coincident with a river flood (Exelon, 2016b).

Flooding in Oyster Creek or the South Branch of the Forked River would result in higher WSEs in the intake and discharge canals forming portions of the FLO-2D computer model boundary. The licensee stated that any overflow from the discharge canals would be directed toward the outer boundaries of the modeling domain because the power block and switch yard areas represent the high-ground topographically within the modeling domain (NRC, 2016d). The licensee also stated that, because of this elevation difference, the modeling choices for the intake and discharge canals and the model boundary would have no effect on the estimated LIP flood elevations in the power block area (NRC, 2016d). The NRC staff used the model files provided by the licensee and determined that the licensee's model configuration resulted in LIP-based flood elevations of about 5 ft. MSL in the intake and discharge canals. The licensee stated that the CDB PMF elevation in Oyster Creek is also about 5 ft. MSL (Exelon, 2009). The licensee discussed reevaluated PMF discharge in the FHRR (Exelon, 2015), but did not provide the corresponding elevation. Because the power block elevation is significantly higher than the PMF elevation in the canals, the NRC staff confirmed that the modeling choices for the canals will have a minimal effect on the LIP flood elevations within the powerblock. Therefore, the NRC staff determined that the licensee's approach to modeling the canals is reasonable.

3.2.4 Water Level Determination

The licensee used the FLO-2D model to evaluate flood elevations and water velocities at the site in response to the LIP event. The licensee reported the range of maximum flood depth and WSEs around each of 15 buildings/facilities (Exelon, 2016b). In addition, the licensee reported the maximum flood depth and water-surface elevation at 14 critical entrances to site buildings (Exelon, 2016b). The corresponding maximum flood depths and water-surface elevations for these critical entrances are given in Table 3.2-1. The licensee's FLO-2D simulations resulted in maximum WSEs ranging from 22.6 to 24.4 ft. MSL at the 14 critical entrance locations, with maximum flood depths from 0.2 to 2.4 ft. The licensee concluded that the maximum reevaluated flood elevation from the LIP event is 24.4 ft. MSL, and that this flood elevation is not bounded by the CDB flood elevation of 23.5 ft. (Exelon, 2016b). The reevaluated LIP flood elevation exceeded the door sill elevation at two of the critical entrances: Door 9 and Door 14 at the Reactor Building.

Using the FLO-2D model files provided by the licensee, the NRC staff confirmed the licensee's results described above and in Exelon (2016a). Maximum flood elevations in the power block area, as calculated from the FLO-2D model, are shown in Figure 3.2-3. The NRC staff determined that the licensee's approach was consistent with and supported by the available information, ANSI/ANS (1992), and NUREG/CR-7046 (NRC, 2011e). The NRC staff confirmed the reevaluated flood hazard elevations provided by the licensee.

3.2.5 Wind-Wave Runup Effects

The licensee stated that wind-wave action associated with flooding due to LIP was not a consideration owing to the limited fetch lengths and flow depths within the powerblock (Exelon, 2015). Maximum flood depths at the critical entrance locations within the powerblock are estimated to be generally less than 1 ft. (see Table 3.2-1). Fetch lengths at the locations of critical entrances with the largest estimated flood depths (Doors 9 and 14) are limited by the presence of other structures (see Figures 3.2-1 and 3.2-3). Based on these factors, the NRC staff concluded that the wave runup effects for LIP-related flooding are minimal.

3.2.6 Conclusion

In summary, the NRC staff confirmed the licensee's conclusion that the reevaluated flood hazard for LIP and associated site drainage is not bounded by the CDB flood hazard at the Oyster Creek site. Therefore, the NRC staff expected that the licensee would submit a focused evaluation for LIP and associated site drainage. The licensee submitted a focused evaluation for both LIP and storm surge by letter dated April 28, 2017 (Exelon, 2017). It is currently under review by NRC staff.

3.3 Streams and Rivers

The licensee reported that the reevaluated flood hazard for streams and rivers does not impact the site. This flood-causing mechanism is discussed in the licensee's CDB and the licensee previously determined that any flooding effects due to a PMF would be inconsequential.

The licensee noted that there is no significant stream flow in either Oyster Creek (the riverine system immediately adjacent to the reactor site[1]) or the three branches of the Forked River. Moreover, the licensee noted that the water levels in nearby Barnegat Bay, and by extension all estuary-based riverine systems just described that discharge into the bay, are influenced solely by tidal action and the occasional Atlantic Ocean storm. The licensee also stated that the CDB PMF elevation in Oyster Creek is about 5 ft. MSL; no PMF elevation was reported for any branches of the Forked River system. Because the power block elevation is significantly higher than the estimated PMF, the licensee considered the PMF within the Oyster Creek watershed to be inconsequential.

The licensee stated that the factors that influence the PMF within the watersheds associated with the Oyster Creek reactor site are the magnitude of the PMP event and the presence of concurrent snowmelt. The licensee's PMF analysis included the following components: (a) delineation of the Oyster Creek and Forked River watersheds that are contiguous with the reactor site; (b) definition of the PMP event associated with those two watersheds; (c) simulation of the PMF associated with the PMP event; and (d) evaluation of the effects of a combined flooding event. The licensee used the U.S. Soil Conservation Service unit hydrograph method (SCS, 1986) to transform the PMP estimate into probable maximum flow hydrographs for each of the two watersheds defining the modeling domain. Overland flow within the riverine modeling domain following a simulated PMP event was achieved using Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) software (USACE, 2010). Using synthetic unit hydrographs produced by the computer software as input, runoff volumes and discharges were computed.

The licensee used the topographic data from multiple sources to define the watershed evaluated for the purposes of the PMP analysis; those sources include the New Jersey Department of Environmental Protection (NJDEP) 10-meter Digital Elevation Grid of the Barnegat Bay Watershed Management Area (designated "WMA 13"), the NJDEP Office of Information Resources Management and Bureau of Geographic Information and Analysis. The NRC staff determined that all of the computer software and data sources described by the licensee reflects accepted engineering practice.

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[1] The average discharge rate estimated by the U.S. Geological Survey (USGS) on Oyster Creek over the last 40 years is less than 40 cubic feet/sec (cfs).

3.3.1 Watershed and Sub-Basin Delineation

The Oyster Creek reactor site is located within the Barnegat Bay watershed whose size is about 660 mi^2 and is comprised of more than a dozen sub-basins. Immediately to the south and west of the site is the Oyster Creek watershed (sub-basin) that extends over an area of about 11.4 mi^2. The reactor's cooling water discharge canal corresponding to the ultimate heat sink was integrated into the existing flow path of Oyster Creek where it ultimately discharges into Barnegat Bay; a gage station (USGS 01409095) operated by the USGS is located on the creek. Within this watershed, the licensee identified two dams of interest; the Wells Mill Reservoir Dam and the so-called Freshwater Impounding Pond Dam. Slightly to the north of the reactor site is the Forked River and its watershed. This river system has three major branches, all of which empty directory into Barnegat Bay; none of these branches are gaged. The South Branch of the Forked River is the closest to the reactor site and has a watershed whose size is on the order of 2.5 mi^2. Within the Forked River watershed, the licensee identified three dams of interest, the Deer Head Lake Dam, the Barnegat Lake Dam, and the Parker Street Dam, all of which are in the community of Forked River (Ocean County, New Jersey) on the North Branch of the Forked River.

The NRC staff reviewed the licensee's delineation of the Oyster Creek and Forked River watershed boundaries and determined that the licensee followed practices commonly used in hydrologic engineering. The NRC staff concluded that the watershed delineation and the differentiation of the respective sub-basins is reasonable.

3.3.2 Probable Maximum Precipitation

For ESPs and COLs, current NRC guidance is to select the appropriate PMP event reported in the HMRs applicable to the site under review (NRC, 2011e). Consistent with that guidance, the licensee selected a PMP event scenario based on the recommendations of HMR-52 (NOAA, 1982).

The licensee used the methods described in HMR-51 (NOAA, 1978), HMR-52 (NOAA, 1982), and the BOSS HMR-52 software (BOSS International, 1988) to develop the PMP distribution over the combined Oyster Creek/Forked River watersheds. The licensee estimated areal average precipitation depth for the 72-h duration event was 39.8 in. for the all-season PMP. Consistent with the guidance found in NUREG/CR-7046 (NRC, 2011e), the licensee also considered a storm whose duration was extended to 6-h. and reported that the PMP estimate for that shorter duration event was 25.4 in. The licensee reported that snowpack/snowmelt was evaluated and determined not be a contributing factor to the PMF at the site (Exelon, 2013). Having defined the respective sub-basins and the magnitude of the PMP estimate, the licensee used the HEC-HMS software to model overland flow within the defined modeling domain. The SCS unit hydrograph method (SCS, 1986) was then used to transform the PMP estimate into probable maximum flow hydrograph for each of the watersheds modeled.

The NRC staff determined that the methods described by the licensee to estimate the PMP reflect current engineering practice.

3.3.3 Probable Maximum Flood

The licensee concluded the reevaluated flood hazard for streams and rivers does not impact the site. The licensee noted that there is no significant stream flow in either Oyster Creek or the three branches of the Forked River and thus no PMF elevation was reported in the FHRR.

The NRC staff agrees with the licensee's conclusion that the PMF from streams and rivers could not inundate the site. There are multiple lines of engineering reasoning to support this position. First, the Oyster Creek site is located within an estuary that is hydraulically-connected to the Barnegat Bay. Barnegat Bay can be considered, in effect, a hydraulic 'sink' of infinite capacity as it communicates hydraulically with the Atlantic Ocean to the east and Manahawkin Bay to the south. The staff confirmed this coupling/connectivity issue by examining tidal gage records for Barnegat Bay. Furthermore, the NRC staff cannot envision any scenario in which discharge entering Barnegat Bay estuary from the streams and rivers that feed that estuary might create backwater effects at the reactor site and inundate that location. Second, Gordon (2004) notes that the presence of wetlands in combination with highly-permeable Coastal Plain sediments in the New Jersey area tend to attenuate peak flow in streams and tributaries due to a rainfall event; such events contribute to sustaining base flow in those riverine systems. The literature also indicates that these deposits are highly transmissive and conductive, capable of yielding large quantities of ground water (Zapecza, 1989). Gordon (2004) further notes that more than 80 percent of the Oyster Creek tributary base flow is attributed to groundwater. In light of these facts, the NRC staff can reasonably conclude that PMP types of events are unlikely to result in flooding of the reactor site due to a PMF on the Oyster Creek tributary.

3.3.4 Conclusion

In summary, the NRC staff confirmed the licensee's conclusion that the reevaluated hazard for flooding due to streams and rivers alone could not inundate the Oyster Creek site. Therefore, the NRC staff determined that flooding from streams and rivers does not need to be analyzed in a focused evaluation or a revised integrated assessment.

3.4 Failure of Dams and Onsite Water Control/Storage Structures

The licensee reported that the reevaluated hazard for dam-related flooding effects does not impact the site. This flood-causing mechanism was considered in connection with the licensee's CDB and it was determined that any flooding effects due to dam failure would be inconsequential.

The licensee reported that there were five dams and other water impoundments present within the watersheds contiguous with the reactor site; two dams within the Oyster Creek watershed, and three dams within the Forked River watershed. The five dams were incorporated into the licensee's HEC-HMS PMF computer model for the Oyster Creek site. The licensee evaluated peak dam discharge estimates attributed to all five dams using the HEC-RAS computer model as an additional flow volume contributing to the PMF estimate. Both sunny day and seismic-induced failure scenarios were considered. The licensee reported that the PMF due to the domino failure of all five dams was bounded by the seismic failure scenario. The licensee reported that the estimated peak WSE attributed to dam failure ranged from 22.7 to 23.2 ft. MSL at multiple locations for both safety- and non-safety-related structures. The entrances to all safety-related site buildings are protected to an elevation 23.5 ft. MSL.

In connection with its independent review of the FHRR, the NRC staff first confirmed that the dams identified by the licensee and the reservoirs they impound co-occupy the watersheds contiguous with the Oyster Creek reactor site. Four of the five dams identified by the licensee were listed in the U.S. Army Corps of Engineers' (USACE's) National Inventory of Dams (NID) database (USACE, 2015b). For these four dams, the NRC staff confirmed that the NID-reported structural heights were the same as those reported by the licensee.

However, the NRC staff did not independently evaluate the calculation packages and computer codes used by the licensee to estimate WSEs at the reactor site due to dam failure. Moreover, the NRC staff limited its analysis to examining the hypothetical failure of only the two dams within the Oyster Creek watershed as this tributary discharges directly into the thermal discharge canal adjacent to the Oyster Creek site. The remaining three dams are located on the North Branch of the Forked River watershed and would discharge directly into Barnegat Bay north of the Oyster Creek site. Based on engineering reasoning, the NRC staff determined that any discharge into Barnegat Bay due to dam failure would be inconsequential because the hydraulic coupling between Barnegat Bay and the Atlantic Ocean suggests that Barnegat Bay has infinite capacity to adsorb additional river discharge. Thus, the NRC staff determined that a detailed review of the licensee's dam failure analysis within the Forked River watershed was not necessary.

Instead, using the licensee-reported dam heights, the NRC staff estimated WSEs due to dam failure at the reactor site using a bounding calculation approach based on empirical hydraulic equations for the Wells Mill Reservoir Dam and the so-called "Freshwater Impounding Pond Dam" that are within the Oyster Creek watershed. Using the Bureau of Reclamation's (1982, 1983) recommended dam breach flow equations to estimate peak outflow, the dam breach outflow independently estimated from the two simultaneous dam failures is instantaneously transferred to the site. The peak outflow mass parameter value was subsequently used in connection with Manning's velocity equation. The NRC staff also determined that the other associated effects at the Oyster Creek reactor site caused by the hydrodynamic loading, debris, sediment, groundwater ingress, or adverse weather condition are insignificant or not applicable to the dam failure flooding scenario. The staff further determined that there were no on-site water control/storage structures that could cause dam failure-related floods within the Oyster Creek powerblock footprint.

The NRC staff confirmed the licensee's conclusion that the PMF from the failure of dams and onsite water control or storage structures alone could not inundate the Oyster Creek site. Therefore, the NRC staff determined that flooding from failure of dams and onsite water control or storage structures does not need to be analyzed in a focused evaluation or a revised integrated assessment.

3.5 Storm Surge

This flood-causing mechanism is described in the licensee's CDB. The CDB for the Oyster Creek site is elevation 22.0 ft. MSL (stillwater) with a maximum wave runup equal to 1.0 ft. The licensee reported that the reevaluated flood hazard for storm surge is based on a WSE of 26.6 ft. MSL (stillwater).

The licensee used a deterministic storm surge methodology for estimating the PMSS flood elevation. The approach follows the current state of practice used by both Federal Emergency Management Agency (FEMA) and the USACE for storm surge inundation analyses (FEMA, 2012 and Resio, 2007) as well as the methodologies presented in NUREG/CR-7134 (NRC, 2012c). Supplemental guidance used by the licensee included Regulatory Guide 1.59 (NRC, 1977), NUREG/CR-7046 (NRC, 2011e), and JLD-ISG-2012-06 (NRC, 2013a). The licensee's analysis consisted of two key phases. The first phase consisted of two components: (a) the collection of historical storm surge data necessary to identify the probable maximum storm surge (PMSS); and (b) the estimation of the meteorological parameters associated with the PMSS. Having derived the parameters associated with the PMSS, the second phase involved the execution of computer models based on those parameters to estimate the likely storm surge elevation at the Oyster Creek site.

3.5.1 Historical Storm Surge Data

In order to identify which storm event would generate the probable maximum surge at the Oyster Creek site, the license collected information on the different types of tropical storms and hurricanes that could potentially impact the Eastern seaboard region in the vicinity of the Oyster Creek site. The licensee identified past storms and associated surges believed to be responsible for generating the highest historically-reported water levels along the New Jersey coastline. The licensee reviewed records of past extreme water level events near the Oyster Creek site that were based on two nearby NOAA co-op stations (at Atlantic City/Station 8534720 and at Sandy Hook/Station 8531680). The licensee also reviewed records of past extreme water level events related to NOAA-predicted hurricane storm surge elevations reported for the two stations just cited.

The NRC staff determined that the methods described by the licensee to collect and evaluate historical storm surge data reflects current meteorological and engineering practice.

3.5.2 Definition of the Probable Maximum Hurricane

Having identified the cohort of storms of interest, the licensee estimated the meteorological parameters (e.g., central pressure, forward speed, etc.) necessary to establish the characteristics of the hurricane necessary for defining the PMH. The licensee used NWS-23 (NOAA, 1979) to define the meteorological parameters consistent with the PMH that would likely occur near the reactor site. For documented hurricanes occurring within both the Atlantic Ocean and the Gulf Coast region during the period 1900 to 1984, the licensee compared the parameters described in NWS-23 (NOAA, 1979) with other comprehensive hurricane climatology statistics that have been published. The licensee stated that some of the PMH parameter ranges presented in NWS-23 appear inconsistent with the current state-of-knowledge. Consequently, the licensee performed site- and region-specific meteorological and climatological statistical analyses of those data to evaluate the applicability of the NWS-23 parameters to the Oyster Creek site and, as necessary, recommend revisions to the ranges in the parameters of interest.

Following a hierarchical hazard approach, the licensee revised the ranges of PMH parameters recommended for use in a deterministic analysis of the coastal flood storm surge, evaluation of the combined flood events, and determination of the flood elevation at the reactor site. The licensee also developed probability distributions for each of the key hurricane parameters. The licensee then convolved data from the National Hurricane Center's HURDAT (HURricane DATabase), Technical Report NWS-38 (Ho et al., 1987), and the National Centers for Environmental Prediction, maintained by NOAA, to analyze distributions of the relevant hurricane parameters required for storm surge simulations. The licensee applied a non-parametric kernel method to form distributions of all relevant parameters and an extreme value distribution for hurricane intensity. The information used to define the PMH included: (a) the meteorological parameter data examined and any discussion concerning the details of the site and region-specific meteorological and climatological study it performed relative to those data; (b) any details concerning the revisions to the ranges of PMH parameters that may have been made based on the review performed; and (c) any details concerning the development of probability distributions it arrived at for each of the key hurricane parameters.

To define the maximum storm forcing system possible at the Oyster Creek site, the NRC staff's independent analysis focused on estimating a reasonable limit for tropical/hybrid cyclones capable of generating extreme storm surges at the site. The approach used was similar to that described in Resio et al. (2012) to estimate asymptotic values at sites along the Gulf of Mexico coastline and south Florida Atlantic coastline. As discussed in that publication, there is a reasonable expectation that an upper limit exists for storm surges along those locations (over the service-life of the power reactor), and that estimate may be performed deterministically. According to Resio et al. (2012), there are three main elements that are to be considered in storm selection and wind forcing of storm set used in detailed numerical simulations to estimate expected PMS levels. Those elements are:

- the specification of storm characteristics associated with maximum surge generation,
- the specification of wind forcing, and
- the behavior of a storm along some track after making land-fall.

Consistent with the recommendations of Resio et al. (2012), the NRC staff derived 32 sets of parameters for use in its independent computer simulations.

3.5.3 Definition of the Probable Maximum Wind Storm

For the purposes of defining the probable maximum wind storm (PMWS), the licensee reported that it estimated the highest storm surge elevation that could be derived from the PMH. Given the storm forcing and water level response dynamics near the reactor site, the NRC staff concluded that evaluating the PMH rather than the PMWS is a reasonable technical approach.

3.5.4 Definition of the Antecedent Water Level

The licensee used a Weibull plotting position equation to statistically estimate the 10 percent exceedance high-tide based recorded tide data obtained from the Sandy Hook co-op station (NOAA Station 8531680). Using a documented offset coefficient from the Sandy Hook location to the Seaside Heights (Station 8533071) co-op station location, the licensee converted the 10 percent exceedance high tide elevation at the Sandy Hook co-op station location to a 10 percent exceedance high-tide elevation at the Seaside Heights location. The licensee deemed the 10 percent exceedance high-tide at the Seaside Heights co-op station location as representative of the 10 percent exceedance high-tide at an open coast nearest to the Oyster Creek site. The licensee estimated the antecedent 10 percent exceedance high-tide was 4.3 ft. MSL.

To estimate the total antecedent water level (AWL) near the reactor site that was subsequently used as input to SLOSH (Sea, Lake and Overland Surges from Hurricanes) computer code for estimating the PMSS, the licensee added a value for the projected sea level rise to the value estimated for 10 percent exceedance high tide over a 10-year (yr) period (or the reported remaining service life of the Oyster Creek power station[2]). The licensee estimated the magnitude of sea level rise from the annual sea level change rates over a 10-yr period at NOAA's Sandy Hook and Atlantic City co-op stations. The NRC staff determined that the methods described by the licensee to estimate the AWL near the reactor site were reasonable and reflected accepted meteorological practice.

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[2] In January 2011, Exelon submitted a letter to the NRC stating that it plans to cease operations no later than December 31, 2019 (ADAMS Accession No, ML110070507).

Using available water level data and sea level rise annual rate at the Atlantic City tidal gaging station, the NRC staff estimated a 10 percent exceedance high tide of 4.1 ft. MSL. This value was combined with a tidal attenuation factor of 0.92 corresponding to the Seaside Heights gaging station location. Mean sea level trend data corresponding to the Atlantic City tidal gaging station indicated a sea level rise of about +/- 0.2 in./yr. The estimated sea level rise derived by the NRC staff was projected to 10 yrs and then added to the attenuated 10 percent exceedance high tide value to obtain an AWL of 3.9 ft. MSL which is in close agreement with the value reported by the licensee. Thus, the NRC staff independently concluded that the licensee's estimate was reasonable.

3.5.5 Storm Surge Model

The licensee's storm surge model involved convolving its surge propagation model with a wind/wave model. In the matter of the surge propagation model, the licensee used the SLOSH computer code (Version 3.97) to produce multiple simulations that it considered to represent the range of meteorological hurricane parameters and storm track directions possible at the Oyster Creek site. The basin bathymetry, topography, and model grid used by the licensee was developed by NOAA.

To perform an independent storm surge analysis, the NRC staff applied the SWAN (Simulating WAves Nearshore; Deltares, 2016) + ADCIRC (ADvanced CIRCulation; Westerink et al., 1994) model developed for the recent FEMA Region II Storm Surge Study (FEMA, 2014). That particular FEMA study relied on a high-resolution ADCIRC mesh, which covers the coastal region that includes portions of New York and New Jersey as well as the Oyster Creek site. Given the efforts expended by FEMA to develop the comprehensive mesh and the goal of providing a platform to allow evaluation of storm surge caused by powerful storms, the Region II mesh provides a reasonable computation platform to use for the purposes of the Oyster Creek storm surge analysis. The mesh provides adequate regional coverage to propagate storm surge from very intense storms that may make landfall near the site or bypass the New Jersey coast. The FEMA Region II study had a regional scope and developed a mesh with resolution limits appropriate for that review. However, to address the NRC staff's FHRR review needs, the resolution of the computational mesh was enhanced by the staff to improve the ADCIRC model's capability to resolve important local features near the Oyster Creek site. This was achieved by decreasing the nodal spacing from 330 ft. in the Region II mesh to 165 ft. in the SWAN+ADCIRC model in the vicinity of the site. Additionally, the NRC staff extended the mesh inland to the 40-ft. North American Vertical Datum of 1988 contour to prevent boundary effects during the most powerful storms. Other enhancements were made by the NRC staff to improve the computational resolution of the Oyster Creek site mesh.

For the wind/wave model, the licensee used the USACE's Coastal Engineering Design Analysis System (CEDAS), Version 4.03 (Veri-Tech, 2009), to estimate coincident wind-wave properties at the reactor site for a combined-effects flooding event. The methods described by the licensee to perform this analysis are reasonable and appear to reflect accepted meteorological practice.

To independently estimate the wind-wave properties at the Oyster Creek site, the NRC staff relied on the SWAN spectral wave computer code coupled with the ADCIRC model.

3.5.6 Estimation of Probable Maximum Flood

The licensee applied the SLOSH (Version 3.97) modeling basin bathymetry and topography and model grid developed and provided by NOAA. The licensee's verification of the SLOSH storm surge model consisted of: (a) review of previous verification studies performed by others, and (b) evaluation of hindcast simulations for two, well-documented historical hurricanes that resulted in storm surge in the vicinity of the Oyster Creek site. The licensee noted that it found an acceptable degree of model accuracy with a minor bias toward over-prediction of the storm surge. The licensee used the SLOSH computer code to determine the maximum surge water levels based on range combinations of PMH parameters, including central and peripheral pressures, forward speed, storm track, and radius of maximum winds. The licensee described the SLOSH computer simulations as having been initially run with a wide range of meteorological parameters, track directions, and landfall strike distances. The results were then compared to identify the model parameters believed to have the greatest effect on estimated storm surge elevation. Using those results, the licensee described a second round of computer simulations in which there was an attempt to refine the range of model parameters, focusing on the most elevation-sensitive ones. For each storm simulation, the licensee evaluated the model results to identify those combinations of meteorological parameters and storm tracks (vectors) that produce the 'worst case' (highest) storm surge elevation. The 'worst case' combination of meteorological hurricane parameters and storm track directions are those that cause the probable maximum surge as it approaches the site along a critical path at an optimum rate of movement.

The NRC staff performed an independent deterministic storm surge analysis using a combined two-dimensional ADCIRC+SWAN computer code. The NRC staff independently-derived deterministic WSEs, including site-specific associated effects (wave runup), to provide data for comparison with the licensee's storm surge CDB at the reactor site. For each storm simulation, the NRC staff developed surge hydrographs for the 'worst case' simulations for the model cells along the plant coastal frontage, including the cooling water canals. Water level and wave height/period results from the SWAN+ADCIRC model were extracted near the site. Using the water level and wave results, an estimate of total water level including wave runup was made in connection with the evaluation of other coincident storm surge effects.

3.5.7 Storm Surge in Combination with Other Flood-Causing Mechanisms

The licensee stated that it followed the guidance in Appendix H.3.2 of NUREG/CR-7046 (NRC, 2011e) in evaluating the potential effects of the reevaluated flood hazard from combined events (APS, 2014). The licensee evaluated the combined effects of dam failure within the Forked River, wind-wave activity coincident a PMSS, and an antecedent 10 percent exceedance high tide. The licensee concluded that the flood hazard from the combined events produced a WSE that ranged from 22.7 to 23.2 ft. MSL at multiple locations within the powerblock and the ISFSI. Wind-wave effects on estimated WSEs varied by location but did not exceed 3.7 ft. The total revised WSE estimated by the licensee due to a combined effects flood taking into account wind/wave effects ranged from 23.1 to 26.6 ft. MSL.

3.5.8 Water Surface Elevations

The licensee calculated the probable maximum wave runup elevation at the Oyster Creek site using the methodology outlined in Chapter VI-5 of the Coastal Engineering Manual (USACE, 2008). Following the steps described above, the licensee estimated a maximum coastal storm surge of 24.6 ft. MSL at the SWIS location and 24.8 ft. MSL within the thermal discharge canal.

These elevations exceed the current CDB. The licensee stated that the WSEs estimated were associated with a storm whose characteristics were forward speed of 30 knots, a radius of maximum winds of 24 nautical miles, a track direction of 90°, and landfall distances of about 0.8 radioactive waste (Rw) to 0.9 Rw nautical miles, where Rw refers to the radius of maximum winds.

The NRC staff relied on its ADCIRC+SWAN computer code to independently evaluate a stillwater WSE, including wave runup effects, at the Oyster Creek site due to a PMSS. The NRC staff's wave runup calculations were also based upon the latest design guidance found in the Coastal Engineering Manual (USACE, 2008). As mentioned earlier in Section 3.5.5, the FEMA Region II model and associated mesh files were applied to the NRC staff's ADCIRC+SWAN computer model to provide additional resolution near the Oyster Creek site. The NRC staff's independent analysis began initially with a series of test simulations based only on the ADCIRC (hydrodynamic) model to expedite run times and allow for a parametric determination as to which tropical storm parameter values have the greatest influence on the estimated WSE results (i.e., which parameters produced the highest WSEs). Those hydrodynamic model test simulation results were then coupled to the SWAN model to allow calculation of wave-induced water level effects near the Oyster Creek site.

The NRC staff performed multiple ADCIRC+SWAN simulations in which certain storm surge parameters were varied to independently estimate WSEs at the reactor site due to this flooding mechanism. Results from those simulations confirmed the licensee's FHRR conclusion that storm surge-based flooding would exceed the Oyster Creek CDB. The staff's simulations also confirmed the reevaluated flood hazard elevations provided by the licensee were reasonable when taking into account the respective differences in the how the reactor site and environs were abstracted for the purposes of modeling, the parameter values selected for use in those models, and the computer programs used to numerically-simulate storm surge effects by the licensee and the NRC staff.

3.5.9 Conclusion

In summary, the NRC staff confirmed the licensee's conclusion that the reevaluated flood hazard for storm surge is not bounded by the CDB flood hazard at the Oyster Creek site. Therefore, the NRC staff expected that the licensee would submit either a focused evaluation or a revised integrated assessment for flooding from storm surge. The licensee submitted a focused evaluation for both LIP and storm surge by letter dated April 28, 2017 (Exelon, 2017). It is currently under review by NRC staff.

3.6 Seiche

This flood-causing mechanism was not described in the licensee's CDB. Seiche-like phenomena occur in connection with enclosed or semi-enclosed water basins such as lakes and bays (Fairbridge, 1966); these geographic features are not present at or immediately adjacent to the Oyster Creek site.

For the purposes of the FHRR analysis, the licensee acknowledged that the most likely location for the formation of seiche-like phenomena would be in Barnegat Bay, 2 mi to the east of the Oyster Creek site. However, upon review, the licensee concluded that the potential for seiche-like behavior to occur in the vicinity of the reactor site is unlikely for the following reasons: (a) that tides and most storm surges and wind-generated waves are not likely to cause seiche standing wave amplitude resonance within Barnegat Bay; (b) that seismic ground displacements capable of generating seiche are very unlikely to occur within the vicinity of Barnegat Bay; and (c) that seiche-like standing waves with crest elevations greater than the elevation of the barrier island located along the eastern margin of the bay will inundate the barrier island (whose maximum elevation is reported to be less than 15 ft.), limiting the maximum seiche amplitude that could be achieved near the reactor site as Barnegat Bay would no longer exist in a closed condition. In its FHRR, the licensee outlined the information and approach used to estimate the fundamental periods of the bay to support its position concerning the likelihood that seiche-like events would not occur near at the reactor site. Using Merian's equation, the licensee reported the fundamental periods of Barnegat Bay near the Oyster Creek site in the longitudinal and transverse directions, for several different tidal stages and flood elevations. The fundamental periods ranged from 3.1 to 6.3 h (longitudinal) to 0.1 to 0.9 h (transverse).

The NRC staff reviewed the hazard from seiche-related flooding against the relevant regulatory criteria based on present-day methodologies and regulatory guidance. Based on geographic/ topographic evidence in the region of the Oyster Creek site, the NRC staff concluded that the only feature potentially capable of generating seiche formation near the Oyster Creek site was in Barnegat Bay. Merian's equation is described in the USACE's Coastal Engineering Manual or CEM (USACE, 2002) and was also used by the NRC staff to calculate the primary and secondary mode periods of the bay taking into account multiple azimuth orientations (of lengths and depths) for the bay near the reactor site. The NRC staff confirmed the licensee's conclusion that the PMF from seiche alone could not inundate the Oyster Creek site.

Within the controlled area but outside of the powerblock is the freshwater impounding pond. This feature is immediately to the south of the switchyard and was previously described as a reservoir containing emergency fire water for the power plant (NRC, 1991). The pond has a 4-acre surface area and receives inflow from the Oyster Creek. Water impoundment is achieved based on a low-head (i.e., 8-ft) dam. The NRC staff concluded that by virtue of its relative location and elevation, should seiche phenomena occur, any resulting flood water would drain to the south into the adjacent marshland, away from the powerblock, following existing gradients and would ultimately be conveyed to the Oyster Creek tributary.

The NRC staff confirmed that the reevaluated hazard for flooding from seiche alone could not inundate the Oyster Creek site. Therefore, the NRC staff determined that flooding due to seiche does not need to be analyzed in a focused evaluation or a revised integrated assessment.

3.7 Tsunami

This flood-causing mechanism was not described in the licensee's CDB. In its UFSAR (Exelon, 2009) the licensee noted that the chance of a tsunami affecting the Oyster Creek site on the east coast of the United States is insignificant; thus, tsunami events were not evaluated.

In evaluating the tsunami hazard at the Oyster Creek site, the licensee relied on the hierarchal hazard assessment approach described in NUREG/CR-6966 (NRC, 2009). The licensee examined the scientific literature to establish the probable maximum tsunami (PMT) at the Oyster Creek site based on published reports. The licensee's review also included a review of the National Geophysical Data Center's tsunami database maintained by NOAA. Next, the licensee performed a numerical tsunami simulation using the FUNWAVE-TVD (Fully Nonlinear Wave – Total Variation Diminishing Scheme) computer code developed by Kirby and others (1998). That computer code considered a range of near-field and far-field seismogenic sources capable of generating a tsunami, and could be used to reconstruct the

WSEs reported in the literature. The seismogenic source-zones (scenarios) considered included a subduction zone event in the Puerto Trench (Caribbean), the collapse of a volcanic cone in the Canary Islands (Atlantic Ocean), and a Currituck-like submarine mass failure (SMF) landslide event on the continental shelf margin (North America) transposed directly offshore of the reactor site. The licensee reported that earlier tsunami analyses performed in connection with NOAA's *National Tsunami Hazard Mitigation Program* suggests that the three PMT scenarios are the ones most likely to have deleterious effects on coastlines within the greater Atlantic Ocean Basin. Upon evaluation of these three scenarios, the licensee reported that the FUNWAVE-TVD computer simulations suggest that the PMT WSE at the Oyster Creek site was due to the collapse of a volcanic cone (specifically the Cumbre Vieja volcano on the island of La Palma) in the Canary Islands. [3]

The run-up values calculated during the FUNWAVE-TVD simulations were reported to account for the 10 percent exceedance high tide at the site, which serves as the static initial water level in the tsunami simulations. The value selected for the 10 percent exceedance high tide was reported as being based on historical observation data from multiple NOAA tidal gage stations in the vicinity of the Oyster Creek reactor site. The license noted that the maximum high tide observed at Barnegat Bay was 7 ft. MSL in a measurement dated in1962 and at a beach location 5 mi from the reactor site.

The NRC staff reviewed the methodologies used by the licensee to determine the magnitude of tsunami phenomena described in the FHRR and noted it was consistent with present day methodologies and guidance. In the context of the above discussion, the NRC staff found that the licensee's analysis (and methodology) to determine the magnitude of a tsunami was reasonable.

The NRC staff conducted an independent analysis to confirm the magnitude of the PMT at the Oyster Creek site. The NRC staff performed numerical modeling of three tsunami sources consisting of both the far field and near field seismogenic source zones as potential PMT generators. In conducting its independent analysis, the NRC staff relied on multiple Boussinesq-based computer models commercially-available to evaluate the three tsunami scenarios described above. In conducting those computer simulations, the NRC staff relied on conservative modeling parameters to provide what it considered to reflect absolute or maximum PMT elevation at the Oyster Creek site. The NRC staff's estimated PMT elevation was 12.1 ft. MSL due to a postulated Canary Island volcanic cone collapse event. After adding antecedent tidal conditions of 5.6 ft., the maximum tsunami wave height independently estimated by the NRC staff was 17.7 ft. MSL. This elevation is about 5.3 ft. below the Oyster Creek site grade. In performing its analysis, the NRC staff concluded that the Barnegat Bay barrier island system has a moderating effect on any tsunami waves approaching the reactor site due the effects of bottom (seafloor) friction and therefore estimated PMT elevations.

The NRC staff confirmed that the reevaluated hazard for flooding from tsunami alone could not inundate the Oyster Creek site. Therefore, the NRC staff determined that flooding from tsunami does not need to be analyzed in a focused evaluation or a revised integrated assessment.

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[3] The NHWAVE computer code (Tehranirad and others, 2012) was also used in connection with the initial modeling of the tsunami wave associated with the SMF scenario.

3.8 Ice-Induced Flooding

The licensee reported that the reevaluated hazard for ice-induced flooding effects does not impact the site. This flood-causing mechanism is discussed in the licensee's CDB, but was not considered to be physically plausible and was screened-out from further consideration. The licensee reported that icing can occur within the intake canal near the cooling water suction pumps, at the trash gate location. However, actual freezing within the intake canal at that location is precluded by the introduction of recirculated (heated) discharge water into the intake bay leading to thermal dilution of any frozen water that might be present.

In connection with the FHRR review, the NRC staff reviewed the hazard potential from ice-induced flooding against relevant regulatory criteria based on present-day methodologies and regulatory guidance. The NRC staff queried the Cold Regions Research and Engineering Laboratory (CRREL) ice jam database maintained by the USACE (2015a). Based on that confirmatory review, the NRC staff concluded that there were no reports of ice jam formation or ice dams on either Oyster Creek or the South Branch of the Forked River. In performing its review, the NRC staff also noted that there is no significant stream flow from either Oyster Creek or the Forked River, thereby implying if freezing where to occur, flooding effects due to ice jams/dams would be inconsequential owing to extensive backwater effects.

The NRC staff confirmed the licensee's conclusion that the reevaluated hazard for ice-induced flooding alone could not inundate the Oyster Creek site. Therefore, the NRC staff determined that ice-induced flooding does not need to be analyzed in a focused evaluation or a revised integrated assessment.

3.9 Channel Migrations or Diversions

This flood-causing mechanism was not described in the licensee's CDB. In its UFSAR (Exelon, 2009), the licensee noted that flooding effects due channel migrations or diversions was not described.

As mentioned earlier, the Oyster Creek site is encircled on three sides by man-made intake and discharge canals that have been connected to the south branch of the Forked River and Oyster Creek, respectively. Both the river and creek have short reaches before they meet Barnegat Bay, about 2 mi to the east of the site. Inspection of aerial photography of the site indicates that the banks of the two canals are armored to prevent erosion and ensure the flow properties of these features are maintained. The engineering adequacy of the canal's protective measures have been previously evaluated in an earlier staff review of the Oyster Creek Safety Analysis Report.

The NRC staff reviewed the flooding hazard potential from channel migrations or diversions against the relevant regulatory criteria based on present-day methodologies and regulatory guidance, as described below. While there are no well-established predictive models for estimating the potential for channel diversion in a riverine environment, the potential for channel migrations or diversions to take place at a particular location can be assessed by reviewing certain types of information such as topographic maps that are generally recognized to reflect evidence of the horizontal movement (meandering) of rivers and streams. If there were evidence of channel migration or river meandering in the past, there would be evidence to that effect present on the topographic maps reviewed of the area. The particular geomorphic features of interest are generally recognized to include river meanders, meander belts, flood plains, oxbow lakes, natural levees, and the like (Salisbury and Atwood, 1908). The NRC staff's review involved using the USGS' s historic topographic map digital data base (USGS, 2015) to identify the earliest maps published for the area and then inspecting those maps for geomorphic evidence of channel diversion including river meandering. After completing that review, the NRC staff inspected more recently-prepared maps of the Oyster Creek site to see if there had been changes in the topography in the intervening years. The NRC staff's review of the USGS's historic data base of topographic maps of the Oyster Creek site and environs did not reveal any evidence of meandering. The NRC staff thus concluded that there is no physical evidence of river meandering and/or channel diversion for at least the last century.

The NRC staff confirmed the licensee's conclusion that channel migration- or diversion-induced flooding alone could not inundate the Oyster Creek site. Therefore, the NRC staff determined that flooding from channel migration or diversions does not need to be analyzed in a focused evaluation or a revised integrated assessment.

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

4.1 Reevaluated Flood Height for Hazards Not Bounded by the CDB

Section 3 of this staff assessment documents the NRC staff's review of the licensee's flood hazard water height results. Table 4.1-1 contains the maximum flood height results, including wave and runup, for flood mechanisms not bounded by the CDB. The NRC staff agrees with the licensee's conclusion that LIP and storm surge are the flood-causing mechanisms not bounded by the CDB. The NRC staff anticipated that the licensee would submit a focused evaluation for LIP, and either a focused evaluation or revised integrated assessment for storm surge. The licensee submitted a focused evaluation for both LIP and storm surge by letter dated April 28, 2017 (Exelon, 2017). It is currently under review by NRC staff.

4.2 Flood Event Duration for Hazards Not Bounded by the CDB

The NRC staff reviewed information provided in Exelon's 50.54(f) response (Exelon, 2016c) regarding the FED parameters needed to perform the additional assessments of the plant response for flood hazards not bounded by the CDB. The FED parameters for the flood-causing mechanisms not bounded by the CDB are summarized in Table 4.2-1 and Table 4.3-1.

4.2.1 Local Intense Precipitation

The licensee reported in its FHRR (Exelon, 2015) that there is no appreciable warning time for LIP-related flooding except that based on a weather (precipitation) forecast. The licensee stated that the storm warning time, the period of site preparation, and the period of inundation are not bounded by the CDB (Exelon, 2015). The NRC staff notes the licensee also has the option to use NEI 15-05 (NEI, 2015) to estimate warning time for LIP.

The licensee used results from 2-dimentional numerical modeling, as described in the FHRR (Exelon, 2016b), to determine the inundation and recession periods. The maximum WSE generated during the LIP event described in the FHRR (Exelon, 2015) exceeds the elevation of two door thresholds within the Oyster Creek powerblock: Doors 9 and 14 at the Reactor Building (Exelon, 2016b). The licensee reported a period of inundation that was on the order of 1.52- and 1.41-h at Doors 9 and 14, respectively. The period of recession or the time necessary for LIP-related flood waters to recede from the Oyster Creek reactor site is estimated to be 6.5-h (Exelon, 2016b).

The NRC staff confirmed that the licensee's reevaluation of the inundation and recession periods for the LIP event were based on present-day methods and regulatory guidance. The NRC staff verified that the maximum WSEs at all critical entrances occurred prior to an elapsed time of 1 h, the duration of the LIP event. The NRC staff concludes that, because the WSEs at the critical entrance locations all reach a maximum prior to the cessation of precipitation at 1 h, longer-duration LIP events would not change the maximum flood elevations. Because the water-surface elevations at Door 9 and Door 14 were still above the building floor elevations when the 1-h LIP event ended, the NRC staff also concludes that longer duration LIP events would increase the duration of flooding at these two critical entrance locations. Based on this review, the NRC staff determined that the licensee's FED parameters for LIP are reasonable and acceptable for use in the MSA.

By letter dated December 16, 2016 (Exelon, 2016d), the licensee submitted the MSA. The NRC staff responded to the MSA by letter dated May 18, 2017 (NRC, 2017).

4.2.2 Storm Surge

The licensee did not report a specific warning time for storm surge-related flooding. In its FHRR, the licensee noted that conventional weather forecasting organizations can be utilized to estimate when an impending hurricane might make landfall at or near the Oyster Creek reactor site (Exelon, 2015). The NOAA hurricane forecasts, for example, are one such source that has reliably predicted hurricanes more than 48-hours in advance making landfall (Exelon, 2015). The NRC staff considers this warning time acceptable for the purposes of the MSA.

In estimating the FED parameters that are not bounded by the CDB, the licensee relied on the SLOSH-based computer model it had developed for the site for the purposes of the FHRR. The licensee relied on flood elevation time plots for the stillwater elevations, along with wave runup height, to determine the duration of flooding due to storm surge. The licensee reported that the warning time is 22.3-hours starting from the onset of the PMH and that the duration of flooding due to storm surge is limited to approximately 0.3-hours in duration (Exelon, 2015); however, no recession time was reported as the licensee observed that the inundation water depth was shallow given the nature of the transient surge-related flooding expected at the site (thus, a minimal recession period).

In connection with the development of the ISR letter (NRC, 2016b), the NRC staff independently reviewed the model-generated storm surge hydrograph provided by the licensee (Exelon, 2015). Based on a review of the storm surge numerical model results, the NRC staff conclude that the licensee's FED parameters are acceptable and reasonable for use as part of the MSA review.

By letter dated December 16, 2016, the licensee submitted itse MSA (Exelon, 2016d). The NRC staff responded to the MSA by letter dated May 18, 2017 (NRC, 2017).

4.3 <u>Associated Effects for Hazards Not Bounded by the CDB</u>

The NRC staff reviewed information provided by the licensee (Exelon, 2015, 2016b, and 2016c) regarding AE parameters for flood hazards not bounded by the CDB. The AE parameters related to water surface elevation (i.e., stillwater elevation with wind waves and runup effects) were previously reviewed by staff, and were transmitted to the licensee via an ISR letter (NRC, 2016b). The AE parameters not directly associated with water surface elevation are discussed below and are summarized in Table 3.2.2-1.

The licensee reported maximum static loads at 15 building/facility locations, with a maximum of 99.9 pound/foot (lb./ft.) at the Turbine Building location (Exelon, 2016b). The maximum static load at the critical entrances reported by the licensee was 74.3 lb./ft. at Door 14 (Exelon, 2016b). Maximum static load at Door 9 was 57.1 lb./ft. (Exelon, 2016b). The NRC staff found that the estimated inundation depths and flow velocities are accurate and that the modeling is reasonable for use in the MSA. The NRC staff agrees with the licensee's conclusion that the AE parameters for LIP are either minimal or will have no impact on the safety-related plant facilities.

For the storm surge event, the licensee reported hydrodynamic loads ranging from 0.7 lb/ft2 to 10.5 lb./ft.^{2}, and the maximum wave load of up to 756.8 lb/ft^2 (Exelon, 2015). These water-borne loads were estimated based on the simulated storm surge depths using a numerical storm surge model. The NRC staff independently reviewed the model-generated storm surge output provided by the licensee (NRC, 2016b). Based on a review of the storm surge numerical model results, the NRC staff conclude that the licensee's hydrodynamic and wave loads are acceptable and reasonable for use as part of the MSA review.

For the storm surge event, the revised FHRR discusses potential debris impact loading from floating woody debris of 2,000 lbs., ice debris of 4,000 lbs., and water-borne boat of 8,125 lbs. (Exelon, 2015). The debris velocity used was the summation of the maximum flow velocity and wave velocity. The FHRR indicates the flow velocities to compute the debris loads range from 2.3 to 8.8 feet/second at different locations within the powerblock and at the SWIS location. The maximum debris load estimated was 64,950 lbs., which was attributed to an impact load from boat debris at the Site Emergency Building location. The NRC staff reviewed the calculation of the debris loads and the maximum velocities applied to the calculation in the FHRR. The NRC staff confirmed that the postulated debris sources and load computation follow the guideline of American Society of Civil Engineers (ASCE) 7-10 (ASCE, 2012). The NRC staff found that the calculation is accurate and the assumptions are conservative. Therefore, the NRC staff concluded that the licensee's estimation of the debris loads are acceptable for use in the MSA.

In summary, the NRC staff determined the licensee's methods were appropriate and the provided AE parameters are reasonable for use in the MSA. By letter dated December 16, 2016, the licensee submitted its MSA (Exelon, 2016d). The NRC staff responded to the MSA by letter dated May 18, 2017 (NRC, 2017).

4.4 Conclusion

Based upon the preceding analysis, the NRC staff confirmed that the reevaluated flood hazard information defined in Section 4.1 is appropriate input to the additional assessments of plant response as described in the 50.54(f) letter (NRC, 2012a), COMSECY-15-0019 (NRC, 2015c), and associated guidance.

5.0 CONCLUSION

The NRC staff reviewed the information provided for the reevaluated flood-causing mechanisms for the Oyster Creek site. Based on the review, 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 confirms the licensee's conclusions that (1) the reevaluated flood hazard results for LIP and storm surge are not bounded by the CDB flood hazards, (2) additional assessments of plant response will be performed for the LIP and storm surge flood-causing mechanisms, and (3) the reevaluated flood-causing mechanism information is appropriate input to additional assessments of plant response, as described in the 50.54(f) letter, COMSECY-15-0019 (NRC, 2015a), and associated guidance. At this time, 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) (NRC, 2008) AND JLD-ISG (NRC, 2007)
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 at the Oyster Creek Site (Exelon, 2015).

REEVALUATED FLOOD-CAUSING MECHANISMS AND ASSOCIATED EFFECTS THAT MAY EXCEED THE POWERBLOCK ELEVATION (23.0FT. MSL)*	ELEVATION (MSL)
Local Intense Precipitation and Associated Drainage	24.4 ft.
Storm Surge	
Service Water Intake Structure Location	24.6 ft.
Turbine Building (Combined Effects Flood)	25.9 ft.
Site Emergency Building (Combined Effects Flood)	26.6 ft.
*Flood Height and Associated Effects as defined in JLD-ISG-2012-05 (NRC, 2012d).	

Table 3.1.2-1. Current Design Basis (CDB) Flood Hazards for the Oyster Creek Site.

FLOODING MECHANISM	STILLWATER ELEVATION	ASSOCIATED EFFECTS	CDB ELEVATION	FHRR REFERENCE
Local Intense Precipitation and Associated Drainage	23.5 ft.	Not discussed in CDB	23.5 ft.	Enclosure 2 Section 2.2
Streams and Rivers	No Impact to the Site Identified	No Impact to the Site Identified	No Impact to the Site Identified t	Enclosure 2 Section 2.2
Failure of Dams and Onsite Water Control/Storage Structure	No Impact to the Site Identified	No Impact to the Site Identified	No Impact to the Site Identified t	Enclosure 2 Section 2.2
Storm Surge	22.0 ft.	1.0 ft.	23.0 ft.	Enclosure 2 Section 2.2
Seiche	Not Discussed in CDB	Not Discussed in CDB	Not Discussed in CDB	Enclosure 2 Section 2.2
Tsunami	Not Discussed in CDB	Not Discussed in CDB	Not Discussed in CDB	Enclosure 2 Section 2.2
Ice-Induced	No Impact to the Site Identified	No Impact to the Site Identified	No Impact to the Site Identified t	Enclosure 2 Section 2.2
Channel Migrations or Diversions	Not Discussed in CDB	Not Discussed in CDB	Not Discussed in CDB	Enclosure 2 Section 2.2

Table 3.2-2. Water-Surface Elevations at Critical Door Locations within the Oyster Creek Nuclear Power Reactor Powerblock.

DOOR ID	POWERBLOCK STRUCTURE	DOOR SILL ELEVATION [a] (ft. MSL)	MAXIMUM FLOOD WATER SURFACE ELEVATION (ft. MSL)	MAXIMUM FLOOD DEPTH (ft.)	FLOOD DEPTH ABOVE DOOR SILL (f.t)	FLOODING DURATION ABOVE DOOR SILL (hr.)
1	Old Machine Shop	23.5	22.7	0.7	N/A [b]	0.0
2		23.5	22.8	0.8	N/A	0.0
3		23.5	22.7	0.7	N/A	0.0
4		23.5	23.2	0.2	N/A	0.0
5	Turbine Building Office	23.5	22.7	0.7	N/A	0.0
6		23.5	23.0	1.0	N/A	0.0
7	Boiler House	23.5	23.1	1.1	N/A	0.0
8	Old Radioactive Waste Building	23.5	23.2	1.2	N/A	0.0
9	Reactor Building	23.5	24.4	1.4	0.9	1.5
14		23.5	24.4	2.4	0.9	1.4
10	Diesel Generator Building	23.6 [c]	22.6	0.6	N/A	0.0
11		23.6 [c]	22.8	0.8	N/A	0.0
12		23.6 [c]	23.6	0.6	N/A	0.0
13		23.7 [c]	23.6	0.6	N/A	0.0

Source: Exelon (2016a), Tables 4 and 5

(a) Door sill elevations taken from Exelon (2009) unless otherwise indicated.
(b) N/A: Not Applicable (water surface elevation is less than door sill elevation).
(c) Door sill elevations taken from Exelon (2016a).

Table 4.1-1. Reevaluated Flood Hazard Elevations for Flood-Causing Mechanisms Not Bounded by the Current Design Basis at the Oyster Creek Reactor Site.

FLOOD-CAUSING MECHANISM	STILLWATER ELEVATION (MSL)	WAVES/RUNUP	REEVALUATED FLOOD HAZARD (MSL)	REFERENCE
Local Intense Precipitation *Max Water Surface Elevation at Door #9 Location*	24.4 ft.	Minimal	24.4 ft.	Correspondence Dated 1/14/16 (ML16015A001)
Storm Surge				
Site Emergency Building Location – Combined Effects Flood	22.9 ft.	3.7 ft.	26.6 ft.	FHRR Enclosure 2, Table 2
Turbine Building Location – Combined Effects Flood	23.2 ft.	2.7 ft.	25.9 ft.	FHRR Enclosure 2, Table 2
Intake Structure Location	23.2 ft.	1.4 ft.	24.6 ft.	FHRR Enclosure 2, Table 2

Note 1: The licensee was expected to develop FED parameters and applicable flood AEs to conduct the MSA. The licensee submitted an MSA by letter December 16. 2016 (Exelon, 2016d). The NRC staff responded to the MSA by letter dated May 18, 2017 (NRC, 2017).
Note 2: Reevaluated hazard mechanisms bounded by the CDB (see Table 3.1.2-1) are not included in this table.
Note 3: Reported values are rounded to the nearest one-tenth of a foot.

Table 4.2-1. Flood Event Durations for Flood-Causing Mechanisms Not Bounded by the Current Design Basis at the Oyster Creek Reactor Site.

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	24 h	≈1 h [(a)]	≈ 0.5 h [(a)]
Storm Surge (Combined Event)	48 h	≈ 23 h [(b)]	< 0.3 h [(b)]

(1) Estimate based on staff's review of the licensee's LIP model (Exelon, 2015).
(2) Estimate based on staff's review of the licensee's SLOSH-based computer model described in the FHRR (Exelon, 2015).

Table 4.3-1. Associated Effects Parameters not directly associated with Total Water Height for Flood-Causing Mechanisms not Bounded by the Current Design Basis at the Oyster Creek Reactor Site.

ASSOCIATED EFFECTS PARAMETER	LOCAL INTENSE PRECIPITATION	STORM SURGE
Hydrodynamic loading at plant grade	99.9 lb./ft. (1)	10.5 lb/ft^2 *(Intake Structure Location)* (2) 24.4 lb./ft.^{2} *(Power Block)* (2)
Debris loading at plant grade	Minimal	< 64,950 lbs. (3)
Sediment loading at plant grade	Minimal	Minimal
Sediment deposition and erosion	Minimal	Minimal
Concurrent conditions, including adverse weather	Minimal	Not Applicable
Groundwater ingress	Minimal	Not Applicable
Other pertinent factors (e.g., waterborne projectiles)	Minimal	Not Applicable

Sources: (Exelon, 2015b, 2016c)

Notes:
(1) Estimate based on staff's review of the licensee's LIP computer model; lb./ft. refers to pounds per linear foot of structure in length.
(2) Estimate based on staff's review of the licensee's FHRR SLOSH-based computer model; lb/ft^2 refers to pounds per square foot.
(3) Due to boat loading (Exelon, 2015)

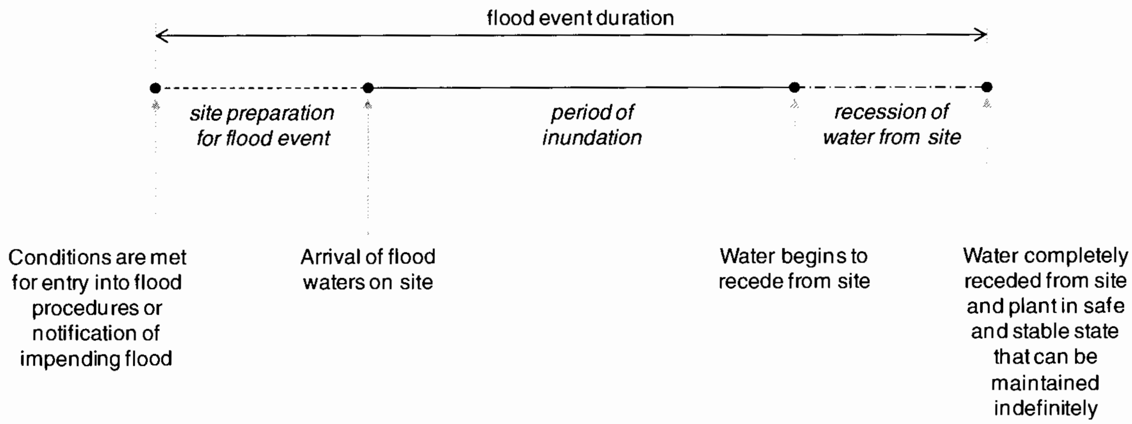

Figure 2.2-1. Flood Event Duration (NRC, 2012c).

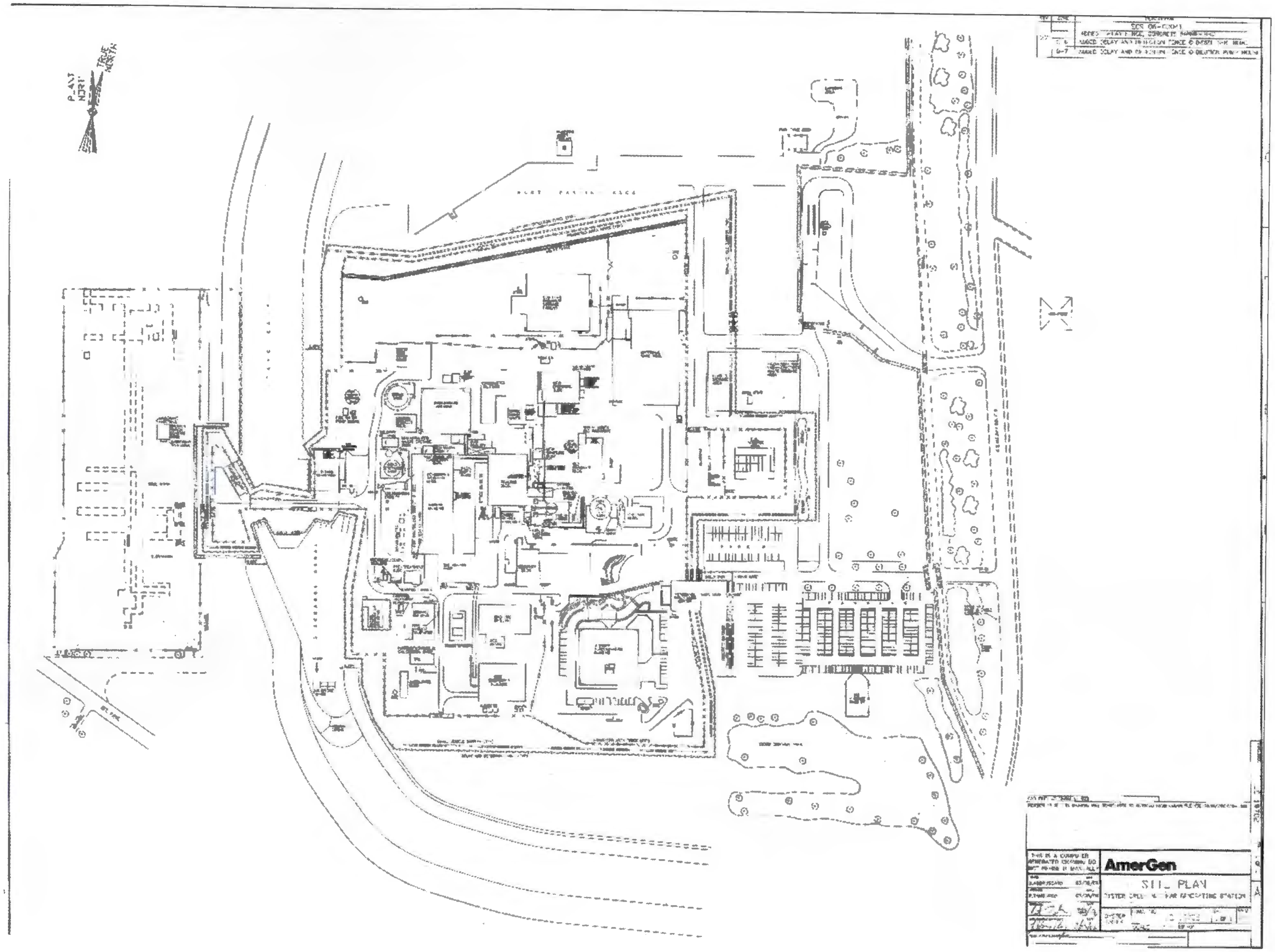

Figure 3.0-1. Map of the Oyster Creek Nuclear Power Reactor Site.

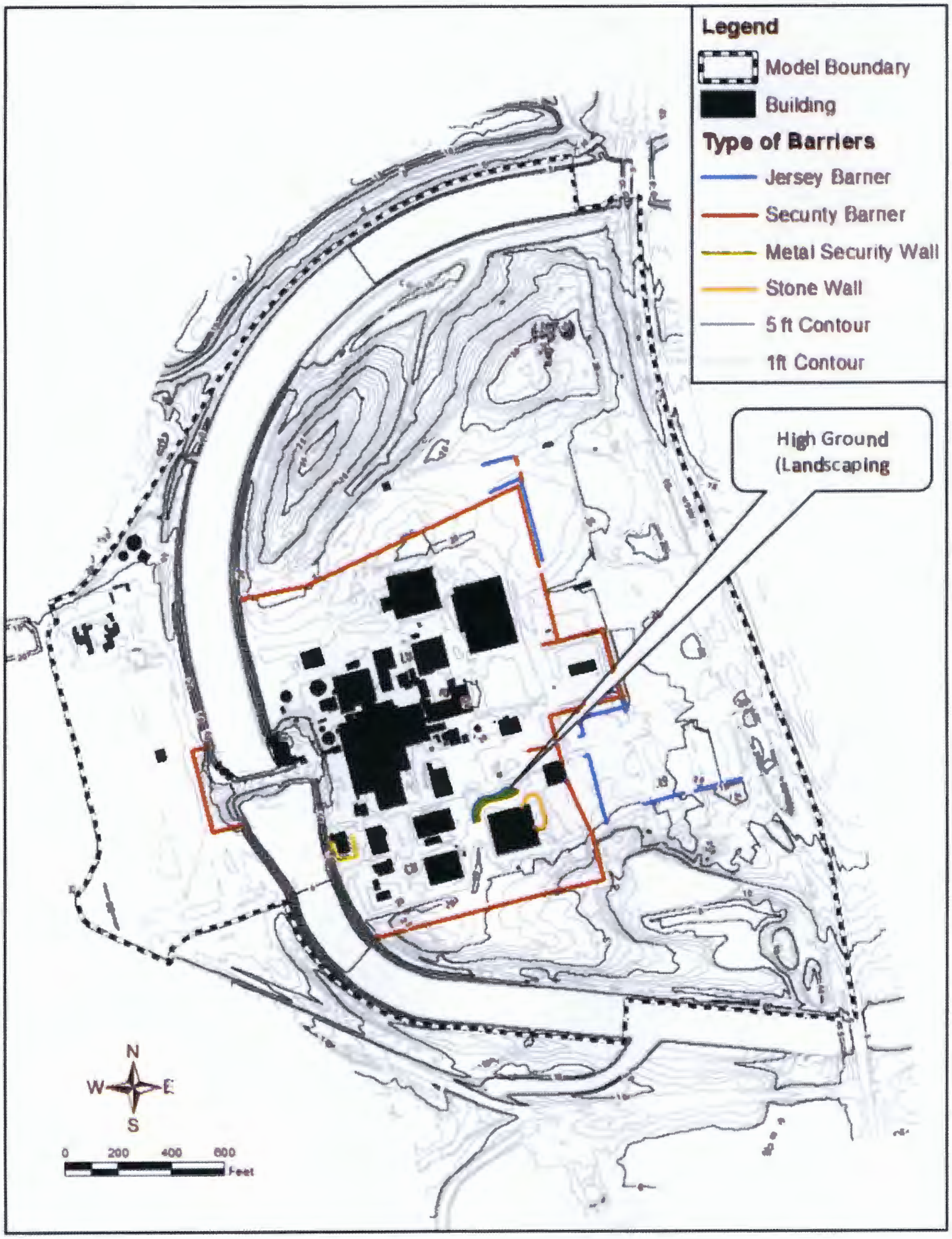

Figure 3.2-1. Site Layout and Topography, Locations of Barriers, and FLO-2D Model Boundary for the Oyster Creek Nuclear Power Reactor Site (modified from Exelon, 2016b, Figure 2).

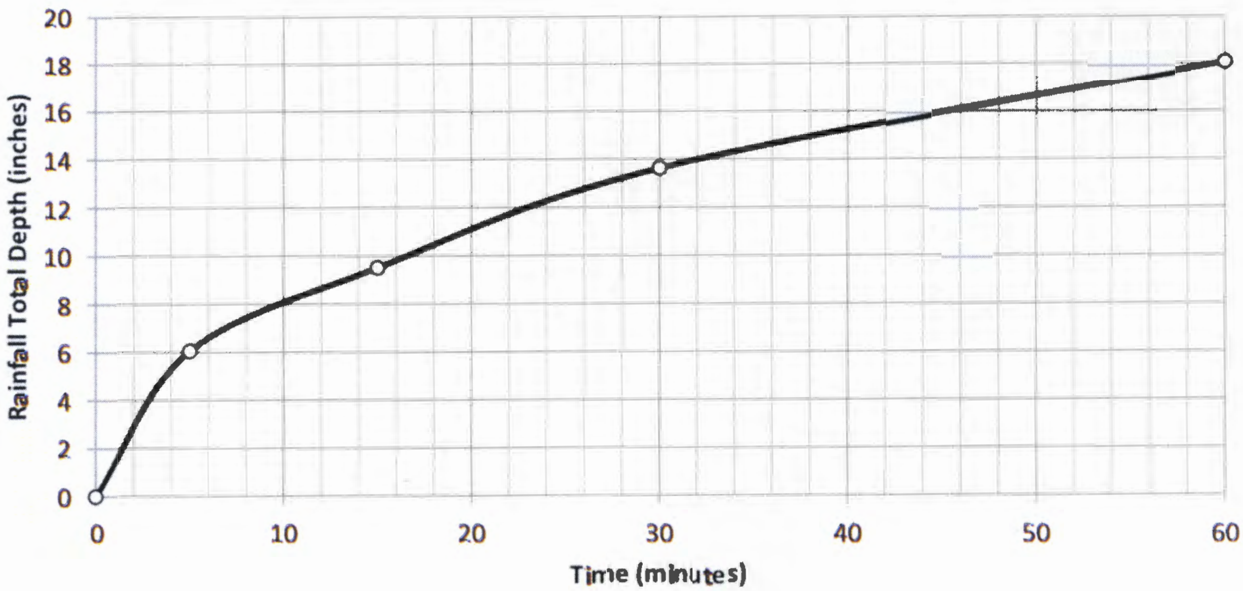

Figure 3.2-2. **Cumulative Rainfall Depth for the 1-hr, 1mi² PMP at the Oyster Creek Nuclear Power Reactor Site (modified from Exelon, 2016a, Figure 3).**

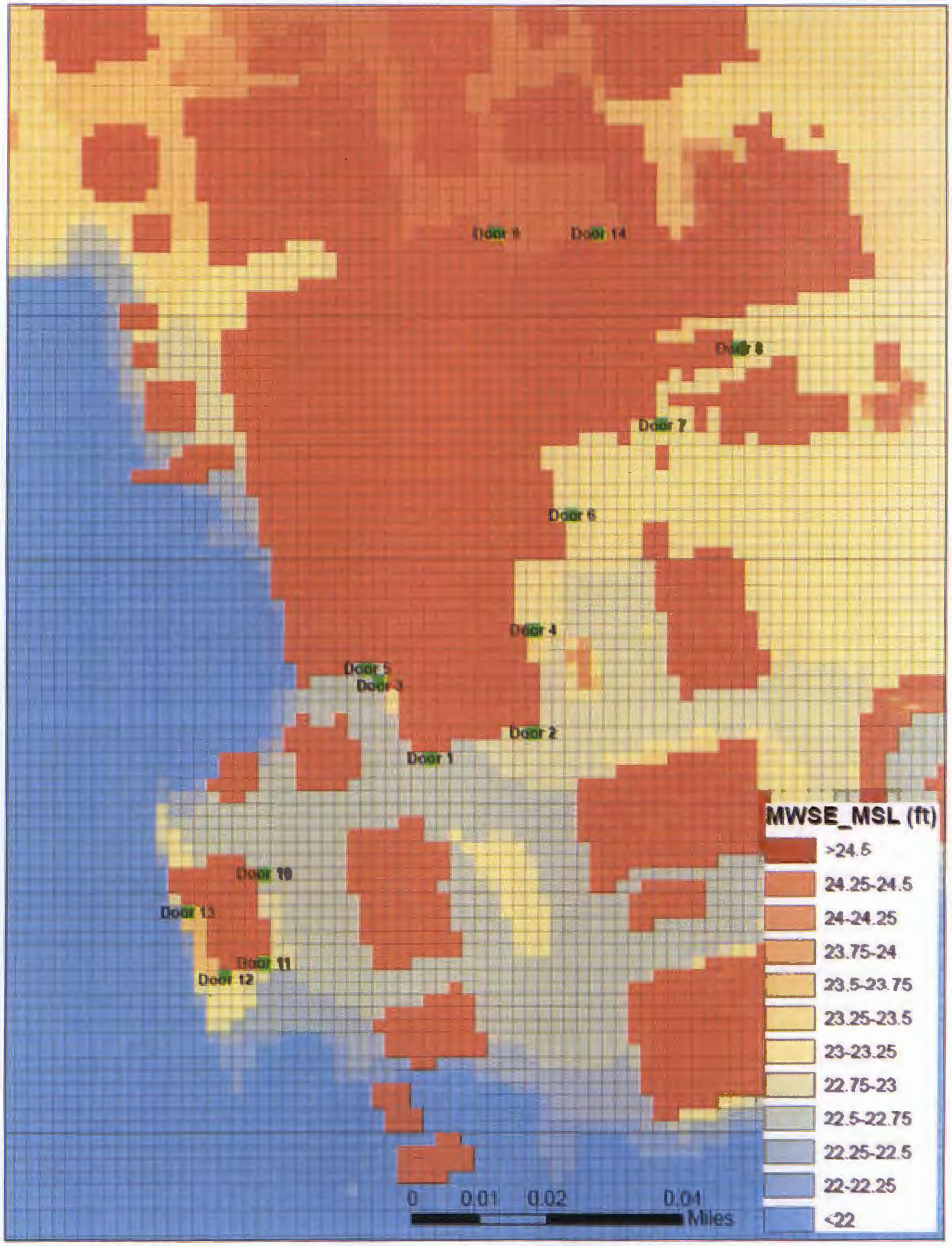

Figure 3.2-3. Maximum Flood Elevation in the Powerblock Area at the Oyster Creek Nuclear Power Reactor Site Calculated using the Licensee's FLO-2D I/O files. Grid cells with elevations greater than 24.5 ft. represent buildings.

SUBJECT: OYSTER CREEK NUCLEAR GENERATING STATION - STAFF ASSESSMENT OF THE RESPONSE TO 10 CFR 50.54(f) INFORMATION REQUEST – FLOOD-CAUSING MECHANISM REEVALUATION (CAC NO. MF6111; EPID L-2015-JLD-0013) DATED February 21, 2018

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