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

May 31, 2018

Vice President, Operations
Entergy Nuclear Operations, Inc.
Indian Point Energy Center
450 Broadway, GSB
P.O. Box 249
Buchanan, NY 10511-0249

SUBJECT: INDIAN POINT NUCLEAR GENERATING UNIT NOS. 2 AND 3 – STAFF ASSESSMENT OF RESPONSE TO 10 CFR 50.54(f) INFORMATION REQUEST – FLOOD-CAUSING MECHANISM REEVALUATION (CAC NOS. MF3313 AND MF3314; EPID L-2013-JLD-0031)

Dear Sir or Madam:

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 December 23, 2013 (ADAMS Accession No. ML13364A005), as supplemented by letter dated December 9, 2014 (ADAMS Accession No. ML14357A052) Entergy Nuclear Operations, Inc. (Entergy, the licensee) responded to this request for Indian Point Nuclear Generating Unit Nos. 2 and 3 (IP2 and IP3).

By letter dated April 25, 2016 (ADAMS Accession No. ML16112A152), 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 letter. As stated in the letter, the reevaluated flood hazard result for the following mechanisms were not bounded by the IP2 and IP3 current design basis (CDB) flood hazard: local intense precipitation, streams and rivers, failure of dams, and storm surge. The NRC staff notes that for the flood-causing mechanisms that are not bounded by the CDB the licensee has performed a flooding mitigation strategies assessment (MSA) dated October 27, 2016 (ADAMS Accession No. ML16305A331). The NRC staff's assessment of the flooding MSA can be found in a letter dated April 10, 2017 (ADAMS Accession No. ML17059C227). In a letter dated October 4, 2017 (ADAMS Accession No. ML17222A239), the NRC deferred the IP2 and IP3 flooding integrated assessment until August 31, 2021.

This closes out the NRC's efforts associated with CAC Nos. MF3313 and MF3314.

Enclosure 1 transmitted herewith contains Security-Related Information and Critical Electric Infrastructure Information (CEII). When separated from Enclosure 1, this document is decontrolled.

If you have any questions, please contact me at (301) 415-1132 or e-mail at Joseph.Sebrosky@nrc.gov.

Sincerely,

Joseph Sebrosky, Senior Project Manager
Beyond-Design-Basis Management Branch
Division of Licensing Projects
Office of Nuclear Reactor Regulation

Docket Nos. 50-247 and 50-286

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

cc w/encl: Distribution via Listserv

STAFF ASSESSMENT BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO FLOODING HAZARD REEVALUATION REPORT

NEAR-TERM TASK FORCE RECOMMENDATION 2.1

INDIAN POINT GENERATING STATION, UNIT NUMBERS 2 AND 3

DOCKET NOS. 50-247 AND 50-286

1.0 INTRODUCTION

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

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

By letter dated December 23, 2013, Entergy Nuclear Operations (Entergy, the licensee) provided the FHRR for the Indian Point Nuclear Generating Unit Nos. 2 and 3 (Indian Point, IP2 and IP3 (Entergy, 2013b). No interim actions were identified by the licensee. Following a preliminary review of the December 2013 version of the FHRR, the NRC staff identified several questions concerning various aspects of the flooding analyses prepared in response to the 50.54(f) request. To address those questions, the NRC staff subsequently conducted an audit of the December 2013 FHHR on May 27-30, 2014, at the reactor site in Buchanan, New York.

Based on the discussions held during the May 2014 FHRR audit, the licensee amended and resubmitted the FHRR on December 9, 2014 (Entergy, 2014e). Following a review of the 2014 reversion of the FHRR, the staff identified additional questions concerning various aspects of the licensee's flooding analyses. In response to the staff's riverine-based questions, the licensee placed information in its electronic reading room (ERR).

Enclosure 2

On April 25, 2016, the NRC issued an interim staff response (ISR) letter to the licensee (NRC, 2016c). The purpose of the ISR letter is to provide the flood hazard information suitable for the assessment of mitigating strategies developed in response to Order EA-12-049 (NRC, 2012b) and the additional assessments associated with NTTF Recommendation 2.1-Flooding. The ISR letter also made reference to this staff assessment, which documents 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, 2016c), the reevaluated flood hazard results for the local intense precipitation (LIP), streams and rivers, dam failure, and storm surge flood-causing mechanisms are not bounded by the plant's current design basis (CDB). The NRC staff notes that for the flood-causing mechanisms that are not bounded by the CDB the licensee has performed a flooding mitigation strategies assessment (MSA) dated October 27, 2016 (Entergy, 2016c). The NRC staff's assessment of the flooding MSA can be found in a letter dated April 10, 2017 (NRC, 2017a).

Consistent with the 50.54(f) letter and amended by the process outlined in COMSECY-15-0019 (NRC, 2015b), and Japan Lessons-Learned Division (JLD) Interim Staff Guidance (ISG) JLD-ISG-2016-01, Revision 0 (NRC, 2016c), the NRC staff anticipates that the licensee will perform and document a focused evaluation for LIP and associated site drainage that assesses the impact of the LIP hazard on the site and evaluates and implements any necessary programmatic, procedural, or plant modifications to address this hazard exceedance. Additionally, for the streams and rivers, failure of dams and onsite water control/storage structures, and storm surge flood-causing mechanisms, the NRC staff anticipates that the licensee will submit (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, 2015) and JLD-ISG-2016-01, Revision 0 (NRC, 2016b). In a letter dated October 4, 2017 (NRC, 2017b), the NRC deferred the IP2 and IP3 flooding integrated assessment until August 31, 2021.

2.0 REGULATORY BACKGROUND

2.1 Applicable Regulatory Requirements

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

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

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

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

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

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

2.2 Enclosure 2 to the 50.54(f) Letter

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

2.2.1 Flood-Causing Mechanisms

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

2.2.2 Associated Effects

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

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

2.2.3 Combined Effect Flood

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

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

If two less severe mechanisms are plausibly combined per ANSI/ANS-2.8-1992 (ANSI/ANS, 1992), then the 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 (FED) was defined in JLD-ISG-2012-05 (NRC, 2012d), as the length of time during which the flood event affects the site. It begins when conditions are met for entry into a flood procedure, or with notification of an impending flood (e.g., a flood forecast or notification of dam failure), and includes preparation for the flood. It continues during the period of inundation, and ends when water recedes from the site and the plant reaches a safe and stable state that can be maintained indefinitely. Figure 2.2-1 illustrates flood event duration.

2.2.5 Actions Following the FHRR

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

- Submit an interim action plan with the FHRR documenting actions planned or already taken to address the reevaluated hazard.
- 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 FED.

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

COMSECY-15-0019 (NRC, 2015b) and JLD-ISG-2016-01, Revision 0 (NRC, 2016b) outline a revised process for addressing cases in which the reevaluated flood hazard is not bounded by the plant's CDB. The revised process describes an approach in which licensees with LIP hazards exceeding their CDB flood will not be required to complete an integrated assessment, but instead will perform a focused evaluation. As part of the focused evaluation, licensees will assess the impact of the LIP hazard on their sites and then evaluate and implement any necessary programmatic, procedural or plant modifications to address the hazard exceedance. For other flood hazard mechanisms that exceed the CDB, licensees can assess the impact of these reevaluated hazards on their site by performing either a focused evaluation or a revised integrated assessment (NRC, 2015 and NRC, 2016b).

3.0 TECHNICAL EVALUATION

The NRC staff reviewed the information provided for the flood hazard reevaluation for Indian Point. The licensee conducted the flood hazard reevaluation using present-day methodologies and regulatory guidance used by the NRC staff in connection with ESP and COL reviews.

To provide additional information in support of the summaries and conclusions in the FHRR, the licensee made several calculation packages and engineering analyses referenced available to the NRC staff via an ERR. The NRC staff did not rely directly on these calculation packages in its review; they were found only to expand upon and clarify the information already provided in the FHRR, and so those calculation packages were not docketed and cited in the staff assessment. However, in a few instances as review questions arose, the staff discussed those in connection with multiple audits conducted with the licensee; the disposition of staff audit questions are documented in the audit summary prepared by the staff (NRC, 2018).[1]

However, in a few instances, the staff requested additional information from the licensee to supplement the December 2014 FHRR (Entergy, 2014e). The licensee provided this additional information by letters dated May 19, 2014 (Entergy, 2014b), and August 18, 2014 (Entergy,

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[1] Some of the staff's questions were points of clarification concerning information described in the FHRR or one of its references. These types of questions are generally not captured in an audit summary.

2014c) which were docketed and are discussed in the appropriate sections in this document.

3.1 Site Information

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

3.1.1 Detailed Site Information

The nominal grade of the Indian Point site is 15 feet (ft.) above mean sea level (MSL) per the National Geodetic Vertical Datum of 1929 (NGVD29).[2] The reactor site is located on the eastern shore of the Hudson River, the dominant hydrologic feature of interest. The reactor site is situated at a riverside location consisting of limestone outcrops. To accommodate those outcrops, the design of the reactor site is terraced; the elevation of the site grade varies from 14 ft. at the shoreline to about 140 ft. inland within the controlled area. Reactor buildings for both units are equidistant from the river's edge; the minimum floor elevation for both buildings begins at 18 ft. and rises an additional 85 ft. up-slope, inland.

The reactor site encompasses approximately 239 acres in an industrial location approximately 43 miles (mi) north of the New York City metropolitan area, near the towns of Buchanan and Verplanck, in upper Westchester County. Figure 3.1-1 shows the location of the Indian Point site in relation to local geography and topography. Given the site's topography, the powerblock grading lends itself to the passive drainage of meteoric run-off into the Hudson River via gravity. The licensee also reported that a vehicle barrier system (VBS) is located along the perimeter of the reactor yard that serves to redirect run-off generated off-site and up-gradient away from and around the powerblock. See Figure 3.1-2. On-site flood water is managed by a combination of both permanent and temporary features.

Geographically, the physical setting for the reactor site is a fiord defined by the Hudson River. The river is generally recognized to be a remnant of the last continental ice age in North America having been formed by glacial scoring followed by a combination of melting glacier waters from inland locations to the north and a rising sea level of the Atlantic Ocean to the south (Tarr and Turner, 1902). As a result, the location of the lower portion of the river course has essentially been 'fixed' topographically for the last 13,000 years (Miller, 1914) and thus does not demonstrate the meandering behavior commonly associated with many river systems (e.g., Leopold, 1994). The main stem of the Hudson River below Troy is about 153 mi long and is generally considered to be an estuary (Geyer and Chant, 2006) since the construction of the Federal Dam (and lock) there in 1916; hence, the water surface elevation (WSE) of the river below the dam is influenced by tidal actions within the Atlantic Ocean rather than by the volume of runoff that might accumulate within the contiguous watershed (e.g., Schureman, 1934). The width of the Hudson River at a point opposite the reactor site varies from 4500 to 5000 ft. The licensee reported that river depth averages about 65 ft. at a distance of approximately 1000 ft. from shore; at some points, that depth can exceed 85 ft. (Entergy, 2014e). Groundwater intrusion is not reported to be a design issue at the site.

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[2] Indian Point Unit 1 was shutdown in 1974 and subsequently underwent decommissioning. All fuel was removed by January 1976. The NRC approved SAFSTOR status for Unit 1 in January 1996.

There are 20 sub-basin watersheds containing more than 65 tributaries that define the greater Hudson River watershed (Figure 3.1-3); collectively, this system encompasses about 13,390 square miles (mi^2). Within the greater watershed, the licensee reports there are about 1,000 dams of various sizes according to data collected by the United States Army Corps of Engineers (USACE). However, only 11 of the dams within the watershed were determined by the licensee to be of concern in any breached-based flooding scenario by virtue of their height (greater than 100 ft.) and/or storage capacity (200,000 ac-ft. or greater). Of those 11 dams, only 7[3] were considered by the licensee in its dam failure analysis owing to the following considerations: geographic proximity to the reactor site; peak estimated breach-flow discharge rate (being in excess of 1,000,000 cubic feet/second (cfs)); and their relative orientation/location (in series) on the same tributary of the Hudson River.

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

3.1.2 Design-Basis Flood Hazards

The CDB flood levels are summarized by flood hazard mechanism in Table 3.1-1. The licensee reported that the CDB flood hazard for the Indian Point site is due to multiple flood-causing mechanisms. Those mechanisms included a PMF due to a probable maximum precipitation (PMP) event, breaches or failures of specific dams, and storm surge originating within the Atlantic Ocean. The licensee noted that the reactor site was not previously evaluated to determine its susceptibility to floods resulting from LIP, seiche, tsunami, ice-induced flooding, channel migration, or a combined effects flood on the Hudson River (Entergy, 2014e); the NRC staff confirmed that these flood-causing mechanisms were not specifically addressed in the Updated Final Safety Analysis (Entergy, 2014d (for IP2); Entergy, 2017 (for IP3)).

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

3.1.3 Flood-Related Changes to the Licensing Basis

The licensee noted in its FHRR that there has been one flood-related change to the current design basis. It was reported that maintenance procedure 0-MET-402-GEN (AREVA, 2013) has been issued that protects the service water pumps and all areas vulnerable to external flooding up to an elevation of 17.9 ft. NGVD29 for both reactor units.

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

3.1.4 Changes to the Watershed and Local Area

Changes reported by the licensee to the watershed encompassing the Indian Point site included some limited development within the greater Hudson River watershed. Those changes include some (unspecified) commercial development outside of the reactor's controlled area as well as some additions within the controlled area itself. Changes consistent with most nuclear plant

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~~(CEII)~~ [3] [[redacted]]]

sites have been made at Indian Point since operations began, including the addition of the following permanent structures:

- Administration Buildings
- Security Buildings
- Warehouses
- FLEX Equipment Storage Building
- Security barriers such as a VBS

The licensee stated that there have been no changes to the watershed in the vicinity of the reactor site that impact flood hazard estimates. Other changes to the terrain would be implicitly accounted for in the hydrologic models used in the FHRR through the use of improved, higher-resolution topographic data for the region and site. The NRC staff reviewed the information provided in the FHRR and determined that sufficient information was provided to be responsive to Enclosure 2 of the 50.54(f) letter.

3.1.5 Current Licensing Basis Flood Protection and Pertinent Flood Mitigation Features

The licensee stated in its FHRR that there is no change to the licensing basis flood elevation for the Indian Point site. The site grade at the power block location for Unit 2 and Unit 3 (e.g., all personnel entrances to Category I structures) is at an elevation of 15 ft. above MSL per the NGVD29. Unless otherwise stated, all elevations in this staff assessment are given with respect to MSL based on the NGVD29 datum. Also, the NRC staff's earlier review of the licensee's Independent Plant Evaluation to External Initiating Events (IPEEE) (NRC, 1999 (for IP2) and NRC, 2001 (for IP3)) identified no vulnerabilities with respect to external flood hazards; however, not all of the flood-causing mechanisms evaluated for the purposes of the 50.54(f) request were reviewed for the purposes of the IPEEE.

The licensee stated that Indian Point has incorporated flood protection features that protect against the maximum flood level that include both incorporated/exterior and temporary features. The incorporated exterior features include permanent exterior barriers and require no operator manual actions. These barriers include exterior walls and floors of structures containing SSCs, backflow prevention valves, penetration seals, and conduit seals. For example, flood protection features at the Unit 2 location include both permanent and temporary features. The permanent features consist of door seals, dikes, exterior walls and floors of structures containing safety-related SSCs, backflow prevention valves, penetration seals, and conduit seals. The temporary protection features at Unit 2 are reported to include portable gas-powered pumps and submersible electric pumps. Temporary protection equipment is kept in the nearby decommissioned Unit 1 Turbine Building at an elevation of 33 ft. Relevant flood-protection doors are above the 15-ft. flood CDB elevation. Lastly, a 1-ft. dike exists around the Motor Control Center (MCC) 24A location in the Unit 2 Turbine Building to protect that feature during a flood event. The flood protection features for the Unit 3 location are identical to those of Unit 2, above, with one exception. There is no report of a flood-protection dike having been installed around the MCC feature within the Unit 3 Turbine Building.

The NRC staff reviewed the flood hazard information provided and determined that sufficient information on current licensing basis flood protection and pertinent flood mitigation features was provided to be responsive to Enclosure 2 of the 50.54(f) letter (NRC, 2012a).

3.1.6 Additional Site Details to Assess the Flood Hazard

During the week of May 27-30, 2014, the NRC staff audited the 2014 version of the revised FHRR (Entergy, 2014e). The purpose of the audit was for the staff to develop a better understanding of how the licensee conducted its FHRR analyses and how those analyses compared to standard methodologies. In connection with audit, the licensee provided electronic copies of staff-quested input/output (I/O) files used in the respective flood analysis calculations. The specific references and data sets reviewed are identified in the staff's audit reports.

3.1.7 Plant Walkdown Activities

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

By letter dated November 27, 2012, the licensee provided responses to Enclosure 4 of the 50.54(f) letter Required Response Item 2, for Indian Point Units 2 and 3 (Entergy, 2012a and 2012b). In addition, the licensee, by letter dated August 12, 2013 (Entergy, 2013a), submitted supplemental information regarding the Indian Point Unit 3 restricted access items walkdown results. The NRC staff issued a request for additional information (RAI) to the licensee regarding the available physical margin (APM) dated December 23, 2013 (NRC, 2013). The licensee responded by letter dated February 12, 2014 (Entergy, 2014a). On June 18, 2014 (NRC, 2014a), the NRC staff issued its assessment of the Walkdown Report which documented its review of that licensee action.

Overall, the staff concluded that the licensee's implementation of the flooding walkdown methodology met the intent of the 50.54(f) letter.

3.2 <u>Local Intense Precipitation and Associated Site Drainage</u>

This flood-causing mechanism was not described in the licensee's CDB. The licensee reported that the reevaluated flood hazard for LIP and associated site drainage is a stillwater-surface elevation that is estimated to not exceed 19.5 ft. NGVD29 in the Unit 2 transformer yard and 19.3 ft. NGVD29 in the Unit 3 transformer yard (Entergy, 2016c). The licensee stated that wind waves and run-up had no effect on the LIP-related flood elevations (Entergy, 2016c).

The licensee reevaluated the flood hazard from a LIP event using the *FLO-2D Pro Computer Code* (FLO-2D Software, Inc., 2014) to numerically-estimate discharges and water-surface elevations within a two-dimensional gridded domain that can include channels, hydraulic structures, and flow obstructions. The licensee stated that its LIP flood analysis was consistent with the Hierarchical Hazard Assessment (HHA) process described in NUREG/CR-7046 (NRC, 2011e). The staff considers the selection of FLO-2D for LIP flood modeling to be reasonable and consistent with current regulations and accepted engineering practice.

While the staff was reviewing the licensee's original (2013) FLO-2D analysis, the developer of the computer software identified some quality issues affecting the reliability of the calculations produced by that commercial computer code. The licensee subsequently repeated its LIP flood analysis using a corrected version of the FLO-2D computer code provided by the vender and in doing so, also addressed some of the earlier staff questions raised during the May 2014 audit (Entergy, 2013b). The licensee's revised FLO-2D analysis was submitted via letter dated August 18, 2014 (Entergy, 2014c) and the associated FLO-2D model I/O files. Following a review of that revised information, an updated set of information need requests were prepared by the staff and discussed with the licensee and its technical assistance contractor. The scope of those questions and their disposition is described in the NRC audit summary (NRC 2018).

Lastly, the licensee stated that the short duration of the precipitation event combined with the high precipitation rate allowed for negligible infiltration by ground surface materials. The licensee assigned specific Manning's *n* values (roughness coefficients) to land cover types within the LIP flooding model based primarily on coefficient ranges suggested in the *FLO-2D Reference Manual*. The staff reviewed the Manning's *n* values selected by the licensee and concluded that the values selected were reasonable. In connection with its review, the staff also reviewed aerial imagery of the Indian Point site to visually confirm the types of surface materials present within the FLO-2D computer model.

3.2.1 Site Drainage and Elevations

The licensee reevaluated the LIP flood hazard due to a postulated 6-hour PMP event over an immediate drainage area of 0.373 mi^2 [239 acres] that included the footprint of the Indian Point powerblock, the site's VBS, all contiguous natural drainage areas in the 0.019 mi^2 (12.2 acres) controlled area, and a portion of the Hudson River adjacent to the powerblock. In connection with this evaluation, the licensee relied on a digital terrain model (DTM) to approximate the topographic ground surface which included as-built features of the reactor site and environs. Data for the terrain model were acquired from multiple sources that included: photogrammetric analysis of available aerial photographs, conventional topographic ground-based survey information, and U.S. Geological Survey (USGS) digital elevation model data (Entergy, 2014a).

The licensee relied on a uniformly-sized, 10-ft. by 10-ft. grid system to serve as the computational domain for the FLO-2D LIP analysis; there are 52,840 grid cells in the computer model covering the Indian Point powerblock, the site's VBS, and adjacent contiguous natural drainage areas (Figure 3.2-1). The licensee assigned surface elevations to each grid cell consistent with the DTM data sources described in the previous paragraph. The licensee noted that the size of the grid cells was small enough to capture important site details within the powerblock and yet sufficient in size to ensure computational stability, such as reasonable computational output values and minimal errors.

One of the issues raised during the review of the FHRR was the effect of the local topography on the accumulation of rainfall in and around the powerblock. As mentioned earlier, the topography of the area surrounding the site is steep and does not favor the infiltration of rainwater, especially during a high-intensity precipitation event. The potential for rainwater infiltration is further limited as the site is underlain by relatively impervious limestone substrate that would transform most precipitation into sheet flow. In evaluating the LIP flooding event, the licensee's FLO-2D modeling results indicated that there is the potential for supercritical flow to occur at two locations within the powerblock (Entergy, 2014e). The specific staff concern was that there would be the potential for backwater effects in and around the Unit 2 transformer yard during an onsite PMP event owing to a transition from supercritical to subcritical flow at the base of the northern-most service road siting adjacent to the Unit 2 transformer yard (NRC, 2018).

Because the FLO-2D computer code does not explicitly model hydraulic jumps that would occur during such a flow transition, the licensee attempted to evaluate the potential for backwater effects by preparing a supplemental analysis that estimated the potential of a likely hydraulic jump taking place in this general area; this supplemental analysis was discussed during the June 2015 audit. (See information need #5 in the audit summary (NRC, 2018)). The staff reviewed the information provided and agreed with the licensee's conclusion that any hydraulic jump that might form at the location in question would result in a small increase in downstream subcritical flow depth and as a consequence, any backwater effects in or around the Unit 2 transformer yard would be minor.

The staff also had questions about the treatment of the southeast corner location of the Unit 3 Transformer Yard in the licensee's FLO-2D computer model. The grid cells at the location in question (specifically ID Nos. 15051, 15052, 15299, 15300, 15548, 15549, 15798, 15799, 16049, and 16050) appeared to be elevated relative to other cells in the computer model; the staff had no information available to it to suggest that the grid cells corresponded to anything other than some type of as-built structure. As was the case with the Unit 2 Transformer Yard, the concern again was that there was the potential at this location to block surface flow entering the Unit 3 Transformer Yard again resulting in backwater effects in adjoining areas of the powerblock. During the June 2015 audit, the licensee presented aerial photographs that revealed that the grid cell locations in question corresponded to an existing structure associated with the Unit 3 Transformer Yard and that the orientation of the computer mode grid relative to this structure created the false impression that there was an obstruction. The staff concluded that the information provided by the licensee was sufficient to address its questions.

Upon inspection and spot checks of the licensee-provided topographic maps, as well as the configuration and elevations obtained from recent Google imagery of the site, the staff confirmed that all major Indian Point structures and surface water flow features within the powerblock were represented in the licensee's FLO-2D computer model. The staff considers the licensee's use and implementation of the combined DTM elevation dataset and imagery reasonable for the purposes of the FHRR LIP flood analysis.

3.2.2 Magnitude of Local Intense Precipitation

For ESPs and COLs, current NRC guidance for LIP evaluation is to select the appropriate PMP event reported in the National Weather Service's (NWS's) *Hydrometeorological Reports* (HMRs) applicable to the site under review (NRC, 2011e). Using the HMR-51 (NOAA, 1982) and HMR-52 (NOAA, 1982) methodology applicable to the Indian Point site, the 1-hour (h), 1-mi^2 all-season precipitation depth estimated for the site would be 17.3 inches (in.). Consistent with guidance found in NUREG/CR-7046 (2011e), the licensee considered a storm with a duration extended to 6-h. For the 6-h, 10-mi^2 thunderstorm, the precipitation depth was determined to be 22.0 in. according to the HMR 51/52 methodology. However, the Indian Point site coincides with the so-called "stippled region" highlighted in the HMR-51 where the precipitation estimates reported by the National Oceanic and Atmospheric Administration (NOAA) might not be applicable because terrain effects associated with the Appalachian physiographic province were not evaluated when this particular HMR was under development.

In preparing its FHRR, the licensee alternatively relied on updated PMP estimates specific to the Indian Point site, as well as the greater Hudson River drainage basin. Those so-called site-specific PMP (ssPMP) estimates were prepared by Applied Weather Associates (AWA) – an

Entergy technical assistance contractor. The AWA site-specific approach to the development of a PMP estimate is described as utilizing the most recent meteorological observations and provides an alternative estimate of precipitation compared to the conventional HMR 51/52 methodology. In connection with understanding how those estimates were derived, the staff conducted two FHRR audits with the licensee. The first audit of the 2014 FHRR was on December 9, 2015. The resolution of the staff's audit questions in connection with the first version of the audit of the FHRR are summarized in NRC (2018). The second staff FHRR audit was an examination of the AWA process for generically deriving the ssPMP; that audit was conducted at NRC headquarters in May 2015. The resolution of those staff audit questions are summarized in NRC (2015a).

The contractor estimated the 6-h PMP as well as the 1-h and sub-1-h PMPs (Entergy, 2014e) for the Indian Point site. The licensee determined that the all-season precipitation event was the controlling rainfall scenario for the LIP flood-causing mechanism; only the all-season storm event analysis is discussed in this section. However, during its review of the AWA methodology, the staff noticed an inconsistency between the ssPMP value reported in the 2013 version of the FHRR – or 9.4 in. for a 1-h, 1-mi^2 thunderstorm (Entergy, 2013b) – and the final value reported in the FHRR – or 8.2 in. for a comparable event (Entergy, 2014e). During the December 2015 audit, the staff reviewed the explanation for this change, and concluded that the reduced 1-h, 1-mi^2 PMP value was justified and consistent with the AWA process (NRC, 2015). However, the licensee elected to employ the 9.4 in. ssPMP. The licensee's decision to use the higher 1-h rainfall depth estimate reflected a more-conservative modeling decision which the staff found to be reasonable.

The licensee also estimated the PMP value for a 6-h, 10-mi^2 rainfall event; in its FHRR, the licensee noted that this particular event was determined to be the controlling storm for the purposes of the LIP analysis as it produced the highest WSEs within the powerblock yard (Entergy, 2014). In examining how the LIP ssPMP estimate was applied to storm durations greater than 1-h, the licensee reported (in Section 3.1.2.1.2 of the 2014 FHRR) that the 6-h LIP rainfall depth was 15.3 in. Upon further investigation, the staff determined that this particular rainfall depth value was based on the all-season, watershed-scale event, rather than one limited to the immediate site and its associated drainage basin. Subsequent review of the LIP short list storms led the staff to conclude that the 6-h, 1-mi^2 rainfall depth should be 23.3 in., while the 6-h, 10-mi^2 rainfall depth should be 22.0 in. and not 15.3 in.

The staff performed a parametric sensitivity study to understand how the temporal distribution of the 6-h hyetograph affected the WSEs predicted by the licensee's LIP model. This issue had been discussed during a June 2015 audit with the licensee (NRC, 2018). The staff evaluated differences based on both front- and end-loaded rainfall distributions using both the HMR-51/52 references as well as the AWA methodology. The results of the staff's parametric sensitivity study involved examining different precipitation patterns in time[4]; that review indicated that the WSEs predicted by the FLO-2D computer code were essentially the same. Upon completion of its analysis, the NRC staff found that the predicted WSEs at selected locations within the Unit 2 transformer yard were reasonably close to those estimated by the licensee (Table 3.2-1). As a consequence, the staff concluded that the approach described by the licensee to derive an

[4] The alternative configurations examined by the staff included adopting an end-peak loading scheme, ignoring drainage effects, assuming a reduced flow cross-section at the transformer yard opening between the reactor and turbine buildings.

ssPMP value, as well as its temporal distribution patterns were reasonable to use in the LIP analysis.

3.2.3 Runoff Analysis

The physical features of the Indian Point powerblock (e.g., permanent buildings, roadways, the VBS) that were incorporated into the licensee's FLO-2D LIP model were described in either the 2014 FHRR or a complementary LIP flood calculation package (Entergy, 2014c). Collectively, these two documents summarize key details of the FLO-2D-based LIP model. Grid elements coinciding with building locations were treated in the computer model as obstructions that completely blocked the flow of surface water. In its DTM model, the licensee represented structures by raising the elevations of the grid cells corresponding to those buildings. The licensee represented the transformer yard moats for Units 2 and 3 in the FLO-2D computer model by adjusting (i.e., lowering) the elevations of the grid cells corresponding to the footprint of those features. These and additional features concerning the licensee's FLO-2D model were discussed during the June 2015 audit. The licensee ignored any storage effects provided by parapet walls during the LIP event. The staff reviewed the licensee's modeling approach for the treatment of these features and determined that it was reasonable.

As an additional conservatism, site drainage systems were assumed to be blocked and non-functional allowing for additional rainwater accumulation on the ground. The staff also determined that the location of the VBS and the Indian Point discharge canal/channel were appropriately represented in the model and that the licensee conservatively assumed the Indian Point discharge canal/channel opening was completely blocked (i.e., modeled as a levee). Based on the site topographic information provided by the licensee, the staff found the licensee's use of the outflow boundary conditions for the FLO-2D computer model were appropriate.

3.2.4 Water Level Determination

In its FHRR, the licensee reported that the reevaluated flood hazard for LIP was based on maximum WSEs estimated at multiple (11) external door locations (5 locations for Unit 2 and 6 locations for Unit 3); the maximum WSE attributed to LIP-related flooding at the door locations ranged from 18.3 to 19.2 ft. NGVD29, respectively (Entergy, 2014e). This flood-causing mechanism was not discussed in the licensee's CDB. The licensee's analysis determined that the reevaluated flood hazard for LIP and associated site drainage in the Unit 2 and Unit 3 transformed yards were not bounded by the CDB flood hazard (Entergy, 2014a).

In October 2016, the licensee submitted its MSA for Indian Point (Entergy, 2016c) and in doing so reported a revised WSE for the LIP flood hazard for the purposes of the 50.54(f) request. The FLO-2D modeling results indicated that the maximum WSEs varied across the powerblock. For the Unit 2 transformer yard, the licensee was reporting a maximum WSE of 19.5 ft. NAVD29; in the Unit 3 transformer yard, a maximum WSE of 19.3 ft. NGVD29 was reported in the FHRR (Entergy, 2016c). These WSE values were previously calculated by the licensee in connection with its revised 2014 LIP flood analysis (Entergy, 2014a), but they did not occur at locations adjacent to critical door openings and thus were not reported as the maximum flood elevation for the purposes of the 50.54(f) response (Entergy, 2014c). See Figure 3.3-2 for a map of the maximum WSE locations.

Wind wave/run-up effects were not included in the flood hazard evaluation as the licensee considered the LIP flood inundation depths too shallow and/or fetch lengths too short to produce significant wind/wave effects. For the purposes of this aspect of the LIP analysis, the site's drainage system was conservatively assumed to be nonfunctional. As a further conservatism, no infiltration by rainwater was assumed thereby increasing the mass flux on the ground surface. The staff concluded that the treatment of wind wave/run-up effects in the LIP model is reasonable.

After independently executing the licensee's FLO-2D computer model using the licensee-provided I/O files, the NRC staff confirmed the flood depths and locations of the maximum WSEs reported in the FHRR. The NRC staff found that: (a) mass balance errors were acceptably small; (b) flow pathways and areas of inundation appeared reasonable; (c) flow velocities were reasonable; and (d) no indication of numerical instabilities nor unexpected supercritical flow conditions were identified near potential flooding pathways.

The NRC staff further concluded that the maximum WSEs reported by the licensee were consistent with its confirmatory calculations. Therefore, the staff has determined that the methods described in the licensee's FHRR, the licensee's calculation package, and complementary submittals including responses to the staff's FHRR-audit questions are reasonable and consistent with present-day methods.

3.2.5 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. Therefore, the NRC staff expects that the licensee will submit a focused evaluation for LIP and associated site drainage for Indian Point Indian Point.

3.3 <u>Streams and Rivers</u>

The licensee reported that the reevaluated flood hazard for streams and rivers is based on a stillwater elevation of 16.5 ft. NGVD29 on the main stem of the Hudson River (Entergy, 2014e). The effects of wind-wave activity were analyzed for the PMF scenario that included consideration of the cool-season PMP in combination with a 100-year snowpack, a 25-year storm surge, and a 10-percent exceedance high tide induced as the downstream boundary condition for the analysis. The reevaluated maximum flood WSE with coincident wind-wave effects was 18.6 ft. NGVD29 (Entergy, 2014e). The CDB for the river-based PMF is a stillwater elevation 13.0 ft. NGVD29. When wind wave and runup effects were taken into account, the maximum WSE is 14.0 ft. NGVD29 at the Indian Point site.

The factors that influence the PMF within the Hudson River watershed that encompasses the Indian Point 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 Hudson River watershed that includes the reactor site; (b) estimation of the PMP event and 100-year snowpack associated with that watershed; (c) simulation of the PMF associated with the PMP event; and (d) evaluation of the effects of a combined flooding event. The PMF evaluation was limited to the portion of the Hudson River watershed upstream of the reactor site, which is slightly smaller compared to that of the entire watershed for the river (which is on the order of 12,750 mi^2). Runoff within the modeling domain following a simulated PMP event was estimated using hydrologic engineering center-hydrologic modeling center (HEC-HMS) computer software (USACE, 2010a). Using synthetic unit hydrographs to represent the runoff generation within sub-watersheds, runoff volumes and discharges were computed at upstream and tributary locations within the various sub-watersheds above the reactor site. The output from that computer-based analysis was subsequently used to route the river flow within the main stem of the Hudson River to estimate WSEs at the reactor site; this was achieved using the HEC river analysis system (RAS) computer software (USACE, 2010b). The two models used in the PMF calculation were calibrated by comparison to observed data from historical flood events.

The licensee estimated AEs (coincident wind-wave activity) using the USACE CEDAS-ACES computer software. The staff determined that all of the computer software used by the licensee in its FHRR reflects standard engineering practice.

To complete its review of the licensee's streams and rivers flooding analysis, the staff requested that the licensee provide the HEC-HMS and HEC-RAS I/O files used to obtain the PMF results described in the FHRR. In response, the licensee provided the requested files on May 19, 2014 (Entergy, 2014b).

3.3.1 Watershed and Sub-watershed Delineation

(CEII) The licensee partitioned the Hudson River watershed above the reactor site into 19 sub-watersheds based on the location of tributaries and topographically-defined catchment areas associated with those tributaries. These sub-watersheds correspond to the USGS' system of hydrologic unit code designations. Within the greater Hudson River watershed, the licensee also identified three hydraulically-significant dams based on both the vertical height of the dam and the volume of impounded water in the associated reservoir; they were the [[redacted])]]. Those features are depicted in Figure 3.3-1.

The staff reviewed the licensee's delineation of the Hudson River watershed boundary and determined that the licensee followed practices commonly used in hydrologic engineering. The staff concluded that the watershed delineation and the differentiation of the respective sub-watersheds is reasonable.

3.3.2 PMP Computation

The licensee relied on a basin-wide PMP estimate (hereafter BPMP) unique to the Hudson River watershed developed specifically for the purposes of the 50.54(f) PMF analysis; the basin-wide analysis methodology was similar to the one used by the NWS to prepare its HMRs, but with one key exception. The licensee's methodology, developed by AWA, relies on incorporating the most recent data available for extreme rainfall events occurring in the United States. As mentioned above, HMR-51 (NOAA, 1978) and HMR-52 (NOAA, 1982) would typically apply to the Indian Point site. However, because this particular location coincides with the so-called "stippled region" highlighted in HMR-51, the precipitation estimates reported by NOAA may be deficient because terrain effects were not evaluated when this particular HMR was under development.

Alternatively, the licensee's approach was to derive basin-specific depth-area-duration (DAD) curves necessary to estimate the total PMP depth over the Hudson River watershed. The licensee-estimated BPMP depths for all-season and cool-season weather events account for seasonal variations attributed to synoptic thunderstorms. The all-season event used by the licensee did not account for snowpack, whereas the cool-season event includes an antecedent snowpack and associated melting in combination with the cool-season PMP. The licensee used site-specific DAD curves for durations of 6, 12, 24, 48, and 72 h, and corresponding to areas of 10, 200, 1,000, 5,000, 10,000, and 20,000 mi^2.

Having derived the BPMP-based DAD curves, the licensee used the methods described in HMR-51, HMR-52, and the BOSS HMR52 software (BOSS International, 1988) to develop the BPMP distribution over the entire Hudson River watershed. The estimated areal average precipitation depth for the 72-h duration event was 10.8 in. for the all-season BPMP and 8.7 in. for the cool-season BPMP; the cool-season BPMP event included both the antecedent snowpack and its snow water equivalent. The licensee computed the 100-year snowpack from historical data. Because of the variation in topography from sea level to the highest elevation of the contiguous Adirondack Mountains (or approximately 5,000 ft.) – occurring within the so-called "stippled region" of the Appalachian Mountain system, the licensee evaluated the snowpack in elevation bands of 1,000-ft. increments at hourly time steps. The licensee estimated the snowpack melt rate using the energy budget methods described in EM1110-2-1406 (USACE, 1998). During the audit process, the licensee clarified that it relied on both the Federal Energy Regulatory Commission's (FERC's) "Engineering Guidelines for the Evaluation of Hydropower Projects" (FERC, 2002) and the ANSI/ANS-2.8-1992 guidance (ANS, 1992) to estimate the temporal distribution of snowmelt during the cool-season BPMP. The licensee temporally arranged the hourly snowmelt amounts in the same order as that of BPMP. Over the 72-hour period, the snowmelt produced an additional 4.6 in. of runoff. The licensee determined that the combined snowmelt and cool-season BPMP (total depth of 13.3 in.) was the controlling surface-water input event.

The staff reviewed the licensee's estimation process for snowmelt coinciding with a cool-season BPMP and determined that that licensee followed methods recommended in Federal agencies' guidance and those commonly used in standard engineering practice. The staff concluded that the licensee's development of BPMP scenarios was reasonable.

3.3.3 HEC-HMS Setup and Calibration

(~~CE~~II) The licensee's HEC-HMS computer-based model (USACE, 2010b) of the Hudson River watershed incorporated the [[redacted]] significant dams (and their impoundments) to account for the attenuation of floodwaters traveling through the Hudson River watershed model. As mentioned above, they were the [[redacted]]]. In the treatment of the BPMP estimate in the HEC-HMS computer code, the licensee relied on the Snyder (1938) unit hydrograph method to transform precipitation to runoff. The licensee then used the Muskingum method for routing the runoff flows through various reaches of the watershed. For the purposes of model calibration and verification, the licensee relied on USGS-reported streamflow measurements from each gaged sub-watershed. The licensee also used historic streamflow data corresponding to synoptic storms for further model calibration and verification. Given this data, the licensee subsequently calibrated certain input parameters in the watershed model[5] so that the computed flow matched the USGS stream flow measurements. The licensee confirmed the suitability of the parameter values selected by comparing computed results for the verification storms to USGS stream flow measurements. For those ungaged sub-watersheds within the Hudson River basin, the licensee estimated parameter values based on sub-watersheds (Table 3.3-1) with verified parameters.

Using the licensee-furnished computer model input files, the staff verified that the configuration of the HEC-HMS model used in the PMF analysis was consistent with the description in the FHRR. For example, the staff spot-checked sub-watershed curve number values and verified that they were consistent with antecedent moisture conditions. The staff also examined the licensee's HEC-HMS input parameters and settings and determined that they were reasonable. Lastly, the staff executed the HEC-HMS model using the licensee's input files and determined that there were no error messages nor significant warning messages. The staff determined that the licensee's analysis was reasonable and consistent with NUREG/CR-7046 (NRC, 2011e).

3.3.4 Computation of PMF Discharges

The licensee conservatively set the initial loss rates for all 19 Hudson River sub-watersheds situated above the reactor site to zero. During the audit of the FHRR (NRC, 2018), the licensee demonstrated that although significant portions of the Hudson River watershed are expected to be snow-covered at the time of a cool-season precipitation scenario, any frozen soils within the watershed are not likely to significantly affect the infiltration of precipitation and snowmelt. During the June 2015 FHRR audit, the licensee also demonstrated that the area-averaged continuing loss rate during validation of the watershed model was lower than the initially-calibrated estimate (NRC, 2018). The staff determined that the loss rates were appropriately determined following standard engineering practices.

Because of the non-linearity effects associated with PMP runoff behavior, the licensee increased the peak discharge of the Snyder unit hydrograph by 20 percent, reduced the time-to-peak discharge by 33 percent, and adjusted the falling limb of the hydrograph to conserve the total volume of the unit hydrograph. The staff determined that the licensee followed applicable guidance in estimating unit hydrographs for precipitation events larger than those that had been historically observed.

The licensee determined that the cool-season BPMP in combination with antecedent snowmelt produced more flood discharge than the warm-season BPMP that included an antecedent event equal to the 40 percent of the BPMP. The maximum discharge computed by the licensee for the Hudson River watershed using the calibrated HEC-HMS model (adjusted for non-linearity) was 1,213,800 cfs at the Indian Point site location.

3.3.5 HEC-RAS Setup and Calibration

~~(CEII)~~ The licensee used the HEC-RAS computer software (USACE, 2010a) to hydrodynamically model a 76 mi-section of the main stem of the Hudson River. The particular section of the river modeled extended over a distance 24 mi upstream and 52 mi downstream of the reactor site. Bathymetric and topographic data were obtained from certain on-line sources (e.g., Cornell

[5] Specifically the Snyder basin lag time, the Snyder peaking coefficient, initial loss, the constant loss rate, the Muskingum K parameter, the Muskingum X parameter, and the Muskingum number of sub-reaches.

University, 2016; and the Northeast Wind Resource Center, 2016). The licensee stated that multiple cross sections were constructed throughout the watershed using geographic information system (GIS), and that many of cross sections focused on the main stem of the Hudson River itself. Also, the licensee noted that the Manning's n value selected for the purposes of calibration (i.e., 0.022) was viewed to be consistent with the geologic/geomorphic character of the river below the [[redacted]]] location.

In connection with a 2015 audit of the FHRR, the licensee described how it configured the downstream boundary conditions for the HEC-RAS model. The licensee also noted that it had selected a 10 percent exceedance high tide for the downstream boundary condition at the Manhattan Battery location based on the example in Appendix H to NUREG/CR-7046. The licensee stated that the 10 percent exceedance high tide downstream boundary condition was specified as a constant WSE value and was not treated as a varying tide level. Upon review, those boundary condition values were judged by the staff to be reasonable as the Hudson River is generally recognized in the literature to be a tidally-influenced estuary.

The licensee calibrated its HEC-RAS computer model by comparing WSEs with two recorded river floods and two recorded tidal cycles. The licensee matched simulated WSE within 1 ft. of "peak observed historical data" at the Hudson River "South of Hastings-on-the-Hudson" USGS gage (No. 01376304), which is approximately 20 mi downstream of the reactor site. The licensee uniformly adjusted the Manning's roughness coefficient value for the main channel to achieve the necessary calibration. The licensee-derived Manning's roughness coefficient generated through this process was 0.022.

When describing the calibration of the HEC-RAS computer model during the audit process, the licensee noted that the model behavior was counterintuitive. For example, the licensee observed that predicted WSEs increased when the value of the Manning's roughness coefficient was lowered. The licensee reasoned that behavior reflected the tidal influence in this portion of the model reach taking place at the Manhattan Battery location (NRC, 2018).

Using the licensee's HEC-RAS computer model, the staff conducted a parametric sensitivity analysis to better understand what effect the Manning's roughness coefficient had on WSEs at the reactor site. According to Chow (1959), the recommended range of minimum Manning's roughness coefficients for major natural streams is 0.025 to 0.035. Both the licensee's and the staff's HEC-RAS computer simulations assumed the same PMF discharge hydrograph as the upstream boundary condition in the modeled reach. The licensee selected 'Alternative II' from Section 9.2.2.2 from ANSI/ANS-2.8-1992 (e.g., a streamside location for open and semi-enclosed bodies of water subject to tidal influence) for its controlling flooding event for the purposes of the FHRR tidally-influenced riverine analysis; the licensee-estimated WSE was 16.5 ft. NGVD29[6] exceeding the staff-estimated stillwater elevation of 16.2 ft. NGVD29.[7] Because tidal influences running upstream are likely to generate some flow resistance in a direction opposite of that to normal river flow, a higher stillwater elevation near the reactor site can be expected during the computer simulation when accompanied by a lower Manning's roughness coefficient. Consequently, the staff concluded that the licensee's selection of a

[6] Assuming a cool season PMF with snowpack coincident with 25-yr storm surge in combination with a 10 percent exceedance high tide.

[7] Based on a cool-season PMF and a 100-year snowpack with no tidal influence.

Manning's roughness coefficient value of 0.022 in the tidally-influenced alternative PMF scenarios was reasonable.

Later, during the February 2016 audit of its FHRR (Entergy 2014d), the licensee described a sensitivity analysis of the PMF HEC-RAS hydraulic model it had performed by increasing the Manning's roughness coefficient value over a range of 10 to 20 percent. The licensee reported that the resulting WSEs were 14 to 23 percent higher than that originally reported in the FHRR. The staff noted that the licensee's results were consistent the staff's sensitivity tests, and that both the staff's and licensee's sensitivity tests indicate that the WSE associated with a riverine-based PMF at the Indian Point site is sensitive to the value selected for the Manning's roughness coefficient (NRC, 2018).
Using input files provided by the licensee, the staff then determined that the configuration of the HEC-RAS model was consistent with the description in the FHRR (Entergy, 2014e). The staff determined that the primary assumptions in the licensee's models are associated with the HEC-HMS computer model and that those assumptions are reasonable.

3.3.6 PMF Elevation

The licensee considered three alternatives to estimate the maximum hazard posed for the riverine flood hazard (Entergy, 2014e and 2015). The event was based on a flooding scenario following the guidance in ANSI/ANS-2.8-1992 (ANS, 1992) for streamside locations of open and semi-enclosed bodies of water. The licensee used the HEC-RAS computer code to analyze the combined event PMF. After evaluating the three alternatives described in Section 6.2.2 of the ANS guidance, the licensee selected Alternative II – a cool-season PMF discharge as an upstream boundary condition (i.e., 14.6 ft. NGVD29) occurring with a 10 percent exceedance tide and a 25-year storm surge as the downstream boundary conditions. The licensee reported a maximum WSE of 16.5 ft. NGVD29 for Alternative II. When coincident wind-wave activity was taken into account, the resulting WSE reported was 18.6 ft. NGVD29 (Entergy, 2014e, and Entergy, 2015).

To independently confirm the licensee's WSEs, the staff executed the licensee's cool-season HEC-RAS computer model for the Hudson River with modification to the downstream boundary condition at the Manhattan Battery. Through this verification process, the NRC staff concluded that the licensee's combined events flood estimate was reasonable.

Lastly, the staff reviewed the licensee's wind-wave evaluation and determined that the methods used were consistent with NRC guidance and standard engineering practice. The NRC staff consulted currently-recognized hydrologic equations described in the most recent edition of the *Shore Protection Manual* prepared by the USACE and other sources for evaluating wind-wave and runup effects. The NRC staff's estimated wave run-up values indicate total water levels similar to, or slightly below, those reported by the licensee. The NRC staff concluded that the licensee's wind-wave estimates were reasonable.

3.3.7 Conclusion

The NRC staff confirmed the licensee's conclusion that the reevaluated hazard from flooding by streams and rivers is not bounded by the total CDB flood hazard elevation. Accordingly, the NRC staff expects that the licensee will analyze flooding from streams and rivers in either a focused evaluation or revised integrated assessment.

3.4 Failure of Dams and Onsite Water Control/Storage Structures

(CEII) The licensee reported that the reevaluated flood hazard for failure of dams and other onsite water control or storage structures is a stillwater elevation of [[redacted].]] NGVD29. The licensee estimated wind waves and runup effects increase the elevation of the free surface by an additional [[redacted].]], resulting in a WSE of [[redacted].]] NGVD29 at the reactor site. This flood-causing mechanism is discussed in the licensee's CDB. The CDB flood elevation for the failure of dams and onsite water control or storage structures is based on a stillwater elevation of [[redacted].]] NGVD29 reflecting what was described as the standard project flood occurring in combination with the failure of the [[redacted]]. The licensee did not consider wind waves and runup effects in connection with this flooding scenario but did account for local oscillatory wave runup effects of [[redacted].]], resulting in a total CDB elevation of [[redacted]t.]] NGVD29.

3.4.1 Initial Dam Screening

(CEII) Citing data prepared by the New York State Department of Environmental Conservation (State of New York, 2017), the licensee reported in excess of 1,000 dams within the Hudson River watershed. To determine which dams might be consequential for the purposes of the FHRR analysis, the licensee relied on the HHA approach described in NUREG/CR-7046 (NRC, 2011e). In screening those dams, the licensee reported that it only considered dams within the Hudson River drainage basin whose height was 100 ft. or greater, or possessed a storage capacity of 200,000 acres-ft. or greater. The licensee found that [[redacted]] dams met the aforementioned criteria. After applying a second set of screening criteria [i.e., proximity to the reactor site (200 mi) and estimated breach flow characteristics on the order of 1,000,000 cfs or greater], the licensee identified only [redacted]] of dams of interest for the purposes of the FHRR analysis – the [[redacted]] dams (Figure 3.4-1). The licensee also considered 4 other smaller dams located close to the reactor site ([[redacted]]) to understand what the potential consequences of a cascading or domino-like dam failure scenario and resulting WSEs might be. For the [[redacted]] dams considered in the analysis, the licensee assumed that not all dams would fail as a result of overtopping during a PMF event.

3.4.2 Computer Modeling

The licensee relied on three modeling scenarios to evaluate projected WSEs due to dam failure. Those scenarios included: (a) dam overtopping due to a PMF event; (b) forced failure of selected dams during a PMF event; and (c) a seismically-induced dam failure event combined with a ½ PMF. Breach outflows for each of the seven selected dams were estimated by the licensee using separate HEC-HMS computer models (USACE, 2010b). The licensee argued that the dam breach parameters selected for use in those HEC-HMS models were conservative. Results from the breach outflow simulations were then routed through a HEC-RAS computer model (USACE, 2010a) for the Hudson River watershed to estimate a WSE at the reactor site. During the June 2015 audit, the licensee described its approach to the calibration of the HEC-HMS computer simulations of dam failure. In calibrating the dam failure model, the licensee noted that it relied on the same calibration process that are discussed in Section 3.3.4 above. The licensee's audit response focused on selection of the Muskingham X and K parameters used in channel routing as well as the conservatism of the HEC-RAS watershed model. In regards to the former, the licensee-identified conservatisms included:

(CEII)
- the forced failure of the [[redacted]],
- the assumption that no flood control features are in place to moderate flood effects,
- the inclusion of snowmelt,
- the reliance on site-specific channel routing parameters for specific reaches of the Hudson River watershed, and
- the inclusion of a nonlinearity adjustment.

The licensee concluded that the WSE for the Hudson River watershed at the Indian Point site is essentially insensitive to dam breach.

When examining the HEC-HMS computer simulations themselves, the staff noted that the PMP storm for each of the seven modeling scenarios was located at the centroid of the greater Hudson River watershed. The effects of alternative centroid centering on predicted PMF dam breach outflow estimates (with the PMP storm limited to the respective sub-watersheds containing the seven dams under review), were not initially evaluated by the licensee. Later, in connection with the December 2015 audit of the FHRR, the licensee presented results from a flood-routing analysis that examined the sensitivity of alternative centering (locations) for the storm centroids on breach outflow estimates and made those available for review in the ERR (NRC, 2018). In describing its flood-routing analysis, the licensee also noted the following:

(CEII)
- Only [[redacted]] of the dams were found to have overtopped ([[redacted]]) during the simulated PMF event,
- The [[redacted])]] did not overtop during the simulated PMF event,
- The cascading failure scenario of the [[redacted]] smaller dams breaching in series ([[redacted]]) did not represent the bounding flooding scenario at reactor site, and
- The ½ PMF domino-type failure of the four smaller dams was not considered as it was judged that the peak outflow from a full PMF was a more conservative modeling assumption.

3.4.3 Revised Flood Water Elevation Estimates

(CEII) Upon review of the various dam breach scenarios involving the [[redacted]] of interest, the licensee determined that the controlling dam failure scenario was a riverine-based PMF in combination with the forced failure of the [[redacted]] (Figure 3.4-1); this failure scenario produced a maximum stillwater elevation of [[redacted].]] NGVD29 at the Indian Point site, which is [[redacted].]] below plant grade. When coincident wind-wave activity was taken into account, estimated as [[redacted].]], the resulting reevaluated flood WSE was [[redacted] NGVD29.

3.4.4 Independent Staff Analysis

(CEII) The staff confirmed that the [[redacted]] of interest identified by the licensee occur within the Hudson River watershed co-occupied by the Indian Point site. The staff also confirmed that the *National Inventory of Dams* (NID)-reported dimensions of those dams (heights and reservoir capacities) (USACE, 2014b) were the same as those described in the FHRR. The staff verified that the licensee followed the simplified approaches recommended in JLD-ISG-2013-01 (NRC, 2013b) to screen and evaluate the [[redacted]].

The staff did not independently replicate the computer simulations described by the licensee in its FHRR (Entergy, 2014e). Alternatively, the staff evaluated and verified certain assumptions and conclusions reported in the FHRR to determine their reasonableness. Some of these evaluations were discussed in the context of the FHRR audit of the 2014 version of the FHRR (NRC, 2018). Other key findings from the staff's independent FHRR review are discussed below:

Impact of Watershed Size/PMP Centering: The scenario considered by the licensee to estimate the PMF resulted from a postulated seismic dam failure rather than a PMF limited to the sub-watershed in which the dam was co-located, as called for in Sections 5.5 and 6.2 of ANSI/ANS-2.8-1992 (ANSI/ANS, 1992). Alternatively, the licensee relied on a 50 percent cool-season PMF discharge value for the entire watershed as the antecedent flood condition before the postulated seismic failure. Upon review, the staff concluded that the licensee's alternate approach was reasonable because the sub-watershed drainage areas corresponding to the dams of interest represent a relatively-small percentage of the greater Hudson River watershed (estimated to be only about 11 percent of the total surface area).

Consequently, it could be argued that a PMP storm centered over a sub-watershed containing a particular dam of interest would be limited to the dimensions of that lesser (smaller) drainage area and not the greater Hudson River drainage system. Thus, while a different PMF application (e.g., 50 percent of the PMF discharge limited to the sub-watershed containing a breached dam) might locally increase the peak flow within a tributary that includes a dam/reservoir of interest, any increased flow observed in the main stem of the Hudson River receiving discharge corresponding to that impoundment would likely be marginal owing to the early attenuation of breach flow within the tributary. Additionally, the antecedent flood discharge observed in the main stem of the river would also likely be significantly lower because a PMP/PMF event occurring within a sub-watershed occupied by one of the dams of interest is unlikely to occur contemporaneously with a PMP/PMF event that might take place basin-wide (NRC, 2018). Consequently, the staff concluded that the licensee's Hudson River watershed centroid centering case was reasonable because it maximized the amount of precipitation within the river basin and in doing so, maximized the antecedent flood discharge responsible for any higher-observed WSE at the reactor site (NRC, 2018).

Other Modeling Considerations: The staff determined that other associated effects caused by hydrodynamic loading, debris, sediment, groundwater ingress, or adverse weather conditions at the Indian Point site were not applicable or not considered to be significant to the dam failure flooding scenario. During the audit of the FHRR (Entergy, 2014e), the staff was advised that there is a bulkhead at the river's edge of the powerblock (NRC, 2018); this bulkhead was described as extending approximately 1 ft. above the finished site grade. While behaving like a weir during a flooding event, the licensee expected this feature to allow some river water to inundate the powerblock terrace whose elevation is 15 ft. NGVD29. However, the licensee explained that this feature would act as a barrier to any large flooding debris already entrained in the river from entering the powerblock yard at that elevation.

(CEII) *Re-evaluated WSEs:* The staff independently estimated WSEs at the Indian Point site using a bounding type of approach that relied on empirical hydraulic equations. Two different analytical methods were used. Both methods relied on the U.S. Bureau of Reclamation's (USBR) recommended dam breach flow equations (USBR, 1982 and 1983) to estimate peak river discharges at some location downstream from some dam of interest. In the first method, a mathematical expression was developed using the USBR river discharge estimate, the shallow water wave celerity approximation, and the dimension of the river channel in the vicinity of the reactor site. In the second method, a mathematical expression that relied on the USBR discharge formula was again used in conjunction with Manning's velocity equation. Lastly, two channel cross-sectional geometries were considered – rectangular and triangular. [[redacted]] and their respective reservoirs were evaluated: the [[redacted])]] (Figure 3.4-1). The results of the staff's analysis concluded that the estimated WSE due to dam failure was less than the licensee's WSE estimate and below the existing site grade.

3.4.5 Conclusion

(CEII) The NRC staff confirmed the licensee's conclusion that the reevaluated hazard from flooding by dam failure is not bounded by the total CDB flood hazard elevation. The controlling dam failure scenario at the Indian Point site is a watershed-scale PMF that occurs in combination with the failure of the [[redacted]]. The staff further determined that there are no on-site water control/storage structures located within the footprint of the powerblock that could flood at the Indian Point site. Accordingly, the NRC staff expects that the licensee will analyze flooding from upstream dam failure in either a focused evaluation or revised integrated assessment.

3.5 Storm Surge

The licensee reported that the reevaluated maximum elevation, including associated effects, for site flooding due to storm surge ranged from 21.0 to 23.6 ft. North American Vertical Datum of 1988 (NAVD88). This flood-causing mechanism is described in the licensee's CDB. The CDB elevation for site flooding due to storm surge is 15.0 ft. NAVD88, including associated effects.

The licensee's analysis of storm surge flooding consisted of five elements. Those elements included: (a) the collection of historical storm surge data for the Hudson River region; (b) the definition of probable maximum hurricanes (PMHs) likely to produce a probable maximum storm surge (PMSS) at the reactor site; (c) the estimation of probable maximum wind storms (PMWSs) likely to produce a PMSS at the reactor site; (d) definition of the antecedent water level to be used in any PMSS analysis; (e) definition of antecedent discharge values for the Hudson River; and (f) a description of the numerical model(s) and how they were executed to estimate a likely PMSS elevation at the reactor site.

3.5.1 Historical Storm Surge Data

In order to identify which storm event would generate the maximum surge at the Indian Point location, the license collected historic information on different types of tropical storms and hurricanes that could potentially impact the Eastern seaboard. The licensee began by identifying past storms and associated surges believed to be responsible for generating the highest historically-reported water levels near the mouth of the Hudson River. The locations for which those historic WSEs reports were obtained were from the Battery (Station 8518750) and

Sandy Hook (Station 8531680) CO-OP station locations operated by NOAA; both stations were located approximately 40 mi from the Indian Point site and provide, respectively, chronologic coverage for the years 1910−1917 and 1932−2014. From these two stations, the licensee identified 25 distinct events for which there were extreme WSEs. To supplement the historically-reported surge data, the licensee also executed NOAA's "SLOSH Display Program" (NOAA, 2012b) to provide predicted storm surge elevations for Category 1, 2, 3, and 4 hurricanes. The NRC staff determined that the methods described by the licensee to collect and evaluate historical storm surge data reflect current meteorological 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 range of hurricane parameters 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 this review was reported to conclude that some of the PMH parameter ranges presented in NWS-23 appear inconsistent with the current state-of-knowledge. Accordingly, 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 Indian Point 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* (NCEP), maintained by NOAA, to analyze distributions of the relevant hurricane parameters required for storm surge simulations.

The licensee's PMH model was used to develop the cohort of synthetic storms to be analyzed in order to update the hurricane parameter distributions in the storm surge model. This approach relied on numerical modeling results as well as evaluation of a hurricane data set whose duration relative to the return period of the PMH storm was limited. While the licensee's numerical model provides a reasonable analytical tool for estimating some of the needed parameters, that model does not account for all of the important processes that are expected to be associated with large-scale storm systems near the reactor site. The licensee's parametric modeling represents one component of the overall storm review and parameter analysis; the NRC staff found the overall approach was reasonable.

3.5.3 Definition of the Probable Maximum Wind Storm

The PMSS is defined in NUREG/CR-7046 (NRC, 2011e) as that storm surge that results from a combination of meteorological parameters of a PMH, a probable maximum wind storm (PMWS), or a moving squall line, and has virtually no probability of being exceeded in the region of interest. The licensee's evaluation of a PMWS relied on an evaluation of past PMH events. That review concluded that a major hurricane (or PMH-type event) is likely to be the controlling storm surge event at the Indian Point site. Post-Tropical Cyclone Sandy is an important historical storm surge event for the Indian Point site. The storm was generated in the Caribbean Sea and was classified as a hurricane along most of its track. Therefore, the storm would fall under PMH analyses as a tropical storm and not an extra-tropical storm.

The NRC staff determined that this modeling assumption was reasonable.

3.5.4 Definition of the Antecedent Water Level

The licensee calculated the antecedent water levels at both the Manhattan Battery location as well as the reactor site. At the Manhattan Battery location, the licensee calculated the 10 percent exceedance high tide of 2.75 ft.NAVD88 following ANSI/ANS (1992), the calculated sea level anomaly (or 0.18 ft.) and the expected 50-year sea level rise (or 0.46 ft.), thus providing a total antecedent water level of 3.4 ft.NAVD88. To estimate the antecedent water level at the Indian Point site, the licensee applied an attenuation factor of 0.64 (NOAA, 2013b) between the Manhattan Battery location and the Indian Point site; the value estimated by the licensee was 2.4 ft.NAVD88.

For the purposes of the SLOSH analysis, the licensee relied on the mathematical average of the antecedent water level between the Manhattan Battery and the Indian Point site locations; that average elevation value was 2.9 ft. However, for the purposes of the PMSS simulations themselves using the Advanced Circulation (ADCIRC) computer code (Westerink, et al., 1994), the licensee selected a tidal input value consistent with the 10 percent antecedent high tide derived from historically-reported tidal data at the Manhattan Battery location (i.e., the historical astronomical tide with amplitudes consistent with the calculated antecedent water level). Based on an evaluation of the effects of tidal variations typically on PMSS estimates, the licensee's ADCIRC simulations had the peak storm surge at the reactor site occurring coincident with the astronomical high tide. The antecedent water levels for the storm surge model simulations included tides as well as the potential for sea-level rise.

Based on the 10 percent exceedance high tide, calculated sea level anomaly, and the expected 50-year sea-level rise, the staff verified the licensee's calculation of antecedent water levels. The licensee selected an antecedent water level for its PMSS analysis that the staff considered to be reasonable.

3.5.5 Definition of the Antecedent Hudson River Discharge Value

The licensee made a White Paper (Entergy, 2016a) available as part of the audit process that described the refined evaluation of concurrent river flooding and storm surge, with particular emphasis on technical justification for use of a refined Hudson River discharge value or Q_{25}.[8] The licensee's White Paper focused on a flood event consisting of the combination of the 25-year flood on the Hudson River, the PMSS and seiche with wind-wave activity, and antecedent 10 percent exceedance high tide. The basis for selection of the Q_{25} discharge value was described in GZA International (2015). In that White Paper, the contractor recommended to use a river discharge of 53,000 cfs, citing Gunkel and others (2015), concurrent with a hurricane surge event for the combined events analysis. The recommended discharge value was considered to reflect normal river flow on the Hudson River during hurricane season. Again citing from its White Paper (Entergy, 2016a), the licensee concluded the following regarding the coincidence of river discharge and storm surge at the Indian Point site: (a) most major river floods occur during cool-season; (b) significant surge and river flood are not statistically correlated, but are (in rare cases) dependent; (c) there is a consistent time differential observed between peak storm and peak river flow (surge peak precedes river peak); and (d) there are differences in characteristics of storms that generate large surges versus large rainfall events.

Following a review of the 2014 FHRR material, the licensee and the staff conducted an audit on February 3-4, 2016, to discuss the licensee's approach to evaluating a combined effects flood at the Indian Point site. As part of those discussions (NRC, 2018), the respective approaches to defining average discharge rate (i.e., Q_{25}) on the Hudson River, and the WSEs associated with any discharge rate estimate at the Indian Point site were discussed. In considering the reasonableness of the licensee's preferred Q_{25} discharge estimate, the staff noted that the standard procedure for evaluating Q_{25} concerning Bulletin 17B (IACWG, 1981) was not appropriate for the main stem of the Hudson River as the broader basin is a regulated one by virtue of the many dams and associated impoundments that can be found there. Furthermore, the staff observed that a higher discharge estimate had been recently published for the Hudson River by the USGS (Lumia and others, 2006); the Survey estimated Q_{25} was 162,000 cfs (at the Green island gaging station location – Station 01358000). However, to support its review of the analysis described in the licensee's White Paper, including the Q_{25} discharge estimate (and in doing so preserve the overall intent of ANSI/ANS-2.8-1981[9]), the NRC staff performed an independent analysis of river discharge involving: (a) statistical analysis of river gauge data (filtered to remove the tidal component) at Green Island and Poughkeepsie (Station 01372058) in addition to a Log Pearson Type III; and (b) temporal and statistical analysis of tidal gauge data at the Manhattan Battery location as well as the aforementioned river gauge locations focusing primarily on the hurricane season; the data reviewed were compiled by the USGS staff and are publicly available upon request.

The NRC staff's independent statistical analysis of river gauge data involved both instantaneous and daily flow data in conjunction with conventional flood frequency analysis (e.g., Bulletin 17B) as well as maximum likelihood estimation considering a range of potential probability distribution functional forms. Several data filters were considered, including filtering gauge data to consider only river flows occurring during hurricane season, as well as filtering to remove observations

[8] "Q_{25}" refers to the daily stream flow that is equaled or exceeded 25 percent of the time.

[9] Which generally states that no single flood-causing event is adequate for determining a design-basis flood.

that occurred during hurricane events (which were addressed separately via a temporal analysis). The temporal analysis explored the relationship between the occurrences of the peak non-tidal residual (surge) at the Manhattan Battery and reactor locations, and the peak and coincident river discharges at the Green Island and Poughkeepsie gauge station locations. The analysis involved development of a suite of data series for each tropical cyclone identified in NOAA's HURDAT dataset as well as graphical assessments, basic statistical analysis, and regression analysis.

3.5.6 Historical Storm Surge Data

Based on its independent assessment, the staff arrived at different conclusions from the licensee regarding the seasonality of significant Hudson River discharges, the potential correlation and dependence of river discharge and storm surge events, the consistency of the time differential between the peak surge and peak river discharge, and the characteristics of events capable of producing both significant surge and significant discharge events. Staff noted that discharges of significance have been observed during hurricane season, both independent of and concurrent with hurricane events. However, like the licensee, the staff concluded that an alternate, more flexible interpretation of the guidance contained in ANSI/ANS-2/8 (American Nuclear Society, 1992) is reasonable. Therefore, the staff concluded that available information supports a lower-bound Q_{25} discharge range of 150,000 to 200,000 cfs for use in the combined events analysis. The results of the staff's independent assessment were communicated to the licensee as part of the audit process (NRC, 2018). Following those interactions, the licensee submitted the results of a final revised assessment of combined events that relied on a revised river discharge value of 150,000 cfs rather than the White Paper earlier-proposed value of 53,000 cfs (Entergy, 2016a).

Given the consistency of the value used in the licensee's final revised assessment with the results of the staff's independent analysis, the staff concluded the revised river discharge is reasonable.

3.5.7 Storm Surge Model

The licensee's storm surge model consisted of three components: (a) a surge propagation model; (b) a wave model; and (c) topography and bathymetry.

3.5.7.1 Surge Propagation Model

The licensee applied two-dimensional hydrodynamic computer programs to simulate wave effects on hydrodynamic flows near the project site. Those computer programs included: (a) the Sea, Lakes and Overland Surges from Hurricanes (SLOSH) model (NOAA, 2012a) Version 3.97, and (b) the ADCIRC model (version 50.99.10). The licensee used seven tidal potential constituents from the LeProvost tide database (LeProvost et al., 1994) to simulate the tides including the potential range of astronomical tides.

For the purposes of its review, the NRC staff applied the ADCIRC+SWAN model to evaluate the wave-induced water level changes near the Indian Point site. The staff concluded that the wave-induced water level changes near the project site computed by the licensee were reasonable.

3.5.7.2 Wave Model

The licensee used *Coastal Engineering Design Analysis System* CEDAS-ACES Version 4.03 (Veri-Tech, 2009) to calculate the wind-generated deep water significant wave height (H_{mo}) and period corresponding to the maximum sustained wind speed of select storm events at the Indian Point site. The licensee added the calculated wave height (using linear superposition) to the ADCIRC model-calculated water level to incorporate the wind-wave effects on water elevation. The licensee applied depth-limited wave breaking in surge inundated areas where wave heights were calculated following the USACE's *Coastal Engineering Manual* (USACE, 2002) guidance. The licensee used CEDAS-ACES (Version 4.03) to calculate wave runup from depth-limited waves on vertical building surfaces. The licensee's use of CEDAS-ACES (Version 4.03) to estimate the peak wave height by using wind duration and direction that generates the maximum fetch-limited deep-water wave growth at the Indian Point site is reasonable. The licensee's use of 0.78 as the ratio of breaking wave height to water depth and 0.7 times the wave height as the height of the wave crest above the stillwater elevation (calculated from ADCIRC) were also reasonable. The licensee's use of the CEDAS-ACES computer code to calculate wave run up on vertical surfaces of building is also reasonable.

3.5.7.3 Topography and Bathymetry

The SLOSH (version 3.97) model employed by the licensee uses curvilinear polar, elliptical, or hyperbolic grids divided into geographic basins across the U.S. East Coast, Gulf of Mexico, Hawaii, Guam, Puerto Rico, and the U.S. Virgin Islands. Elevation data used in the SLOSH 3.97 model mesh were obtained from the USGS National Elevation Dataset 1-arc second resolution topography data and the National Geographical Data Center (NGDC) 3-arc second resolution bathymetric data. NOAA defined bed roughness in the basins using a combination of land cover and depths. The licensee considered the SLOSH New York (NY3) mesh basin to provide sufficient geographic coverage and resolution near the project site. The element size of the mesh near New York City is approximately 0.8 nautical mi with a vertical datum referenced to NAVD88.

The ADCIRC (Version 50.99.10) model uses a non-structured, triangulated model grid with variable grid resolution and uses the bathymetry and topographic data from the current FEMA Region II flood coastal analysis and mapping.

The staff determined that the SLOSH model, which was applied as a screening tool by the licensee, does not have sufficient resolution to simulate WSEs near the reactor site. It can, however, provide reasonable screening-level results of boundary conditions near the Manhattan Battery, at the mouth of the Hudson River. The licensee applied the SLOSH computer code as a part of a modeling approach that included the ADCIRC computer code, which did contain sufficient resolution near the reactor site. The staff determined that the mesh setup and application to the storm surge model using ADCIRC is reasonable.

3.5.8 Estimated Water Surface Elevation

The licensee employed two approaches to assess the effects of a PMSS occurring simultaneously with a PMF: (a) a deterministic assessment; and a (b) hybrid-probabilistic-deterministic assessment. Both assessments were summarized in the 2014 FHRR (Entergy, 2014e). In that document, the licensee stated that its estimate of the reevaluated hazard was based on the results of the hybrid probabilistic-deterministic assessment. Following further study by the licensee (including development of assessments to support mitigating strategies), the licensee developed a revised combined events evaluation that utilized a deterministic assessment of storm surge hazard with a refined estimate of concurrent river discharge or Q_{25} (discussed above).

Following the February 2016 audit discussions of the licensee's White Paper (GZA International, 2015), the licensee resubmitted a revised assessment of combined flooding based on a river discharge value of 150,000 cfs (Entergy, 2016a); the revised WSEs also accounted for a PMSS, antecedent tidal conditions, and coincident wind-wave effects (Entergy,2016b). Aside from a revised Q_{25} value, no other changes were reported to the licensee's storm surge analysis. The licensee reported that a combined events flood at the project site produced a WSE of 18.9 ft. NAVD88 at multiple locations within the powerblock yard. When wind-wave effects were taken into account, the WSEs ranged from 21.0.1 to 23.6 ft. NAVD88 (Table 3.5-1) at the locations depicted in Figure 3.5-1.

In its review of the White Paper and its associated references, the staff focused on two key components: (a) the assessment of the 25-year river flood; and (b) the assessment of the probable maximum surge considering the concurrent river flood and tidal conditions associated with the stylized combined event. The staff performed independent assessments as part of its review of each of these components that included the following:

- Evaluation of tidal data for the Manhattan Battery location;

- Screening of antecedent rainfall events not applicable to the hurricane season window at the project site;

- Evaluation of instantaneous gage date for the Hudson River using multiple statistical methods in addition to the Log Pearson Type III distribution;

- Evaluation of Hudson River dynamics in response to PMP types of events;

- Evaluation of the Hudson River basin sensitivity to hurricane and antecedent rainfall events; and
- Evaluation of river discharge Q dependence/independence to hurricane events.

Based on the aforementioned, the staff concluded that the WSEs calculated by the licensee are reasonable. These revised WSEs values are those reported in the staff's Interim Staff Response (ISR) letter (NRC, 2016c).

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 Indian Point site. Therefore, the NRC staff expects the licensee will submit either a focused evaluation or an integrated assessment for flooding from storm surge.

3.6 Seiche

This flood-causing mechanism was not described in the licensee's CDB. In its FHRR, the licensee reported that the reevaluated hazard for seiche-related flooding effects are not applicable at this particular site. As discussed below, the licensee observed that the Indian Point site is not adjacent to a body of water (marine or non-marine) with a free surface area large enough to generate seiche-driven waves. Based on hydrological evidence, the licensee concluded that seiche-related flooding will not affect the reactor site as this flood-causing mechanism is not considered physically plausible at the reactor site location.

The licensee identified the main stem of the Hudson River and an adjacent discharge canal at the Indian Point site location as the two principal water bodies susceptible to seiche phenomena taking into account meteorological, astronomical, and seismic forcing as the potential causative mechanisms. The licensee first estimated the natural period of oscillation (primary seiche mode) of the surface water bodies identified above using *Merian's Formula* (Sheffner, 2008[10]). The licensee then analyzed the water level data for the Hudson River using spectral analysis to identify the river's natural periods, and compared those estimates to those developed using *Merian's Formula*. The licensee compared the natural period of the two surface water bodies to the periods of potential forcing mechanisms, including meteorological, astronomical and seismic conditions, to determine the potential for resonance. The licensee's estimated periods associated with these external forcing mechanisms were developed based on published ranges

[10] Merian's Formula is defined as the natural period $T = (1/n)(2L/\sqrt{(gd)})$ where n is the number of nodes, L is the horizontal dimension of the basin measured in the direction of wave motion, d is the depth of the basin, and g is the acceleration due to gravity.

typically found in the literature. Lastly, the licensee evaluated the flood levels where resonance could occur.

Based on the dimensions of the Hudson River estimated between the Federal Dam at Troy (to the North), and the Manhattan Battery location (to the South), the licensee stated that the natural period estimated using *Merian's Formula* for the primary mode, in the longitudinal direction, was approximately 24.6 h; in the transverse direction, the natural period was estimated to be on the order of 4 to 6 min. A service water intake canal also exists on-site, adjacent to the Unit 3 Turbine Building (Figure 3.1-2). Evaluation of the seiche potential for that 750-ft feature using *Merian's Formula* suggests that the primary mode for the canal is approximately 84 seconds (sec) in the longitudinal direction and 5 sec in the transverse direction.

Comparing the natural periods of oscillation obtained using *Merian's Formula*, the licensee's spectral analysis of the observed water level showed no direct evidence of seiche effects. The licensee stated that all of the spectral peak results were known tidal constituents observed in most coastal and estuarine environments. In addition, the power in the peaks for the principle components showed no sign of amplification toward the head of the river. When considering seismic forcing, the licensee stated that the period for natural earthquakes falls outside the ranges estimated for both the Hudson River and the service water intake canal compared to the ground motion periods for natural seismic events (typically not exceeding ten seconds). Similarly, the licensee stated that weather systems in the region have a temporal synoptic scale of approximately three to seven days (Wells, 1997) which is too long to force a seiche in the Hudson River. Therefore, based on the observation data, calculations of the natural period, and records of potential forcing mechanisms in the region, the licensee concluded that there are no evidence to suggest the potential for seiche dynamics within the main stem of the Hudson River system.

The staff performed independent calculations using *Merian's Formula* based on the licensee's input data and confirmed the licensee's results for natural periods within the main stem of the Hudson River. Upon comparing the licensee's astronomical observation tide data, seismic and meteorological forcing periods to the calculated natural periods of the Hudson River and the reactor site's discharge canal, the staff confirmed the licensee's conclusion that the reevaluated hazard for flooding from seiche alone could not inundate the Indian Point site.

In summary, the NRC staff confirmed the licensee's conclusion that seiche-induced floods could not inundate the site. The staff confirmed that the reevaluated hazard for seiche-induced flooding of the Indian Point site is bounded by the current design basis flood hazard.

3.7 Tsunami

This flood-causing mechanism was not described in the licensee's CDB. In its FHRR, the licensee reported that the reevaluated hazard for tsunami-related flooding effects is not applicable to the Indian Point site. The licensee further reported that the reevaluated tsunami hazard, including AEs, is not considered to be a significant flood hazard for the following reasons: (a) the inland location of the reactor site is well-away from recognized tsunami-generating sources; (b) the absence of a favorable river geometry/orientation conducive to tsunami wave propagation up the main stem of the Hudson River; and (c) the expectation that a tsunami wave entering the Hudson River would attenuate with distance as it travels up the main stem of the river.

The licensee obtained records of historical reports of tsunami runup events along the Atlantic Coast from the *National Geophysical Data Center* (NGDC) tsunami database (NOAA, 2012). The licensee noted that the tsunami runup heights, as measured by tidal gages in the vicinity of New York and New Jersey, ranged in height from 0.2 to 2.2 ft. and were attributed to the 1929 Grand Banks earthquake and tsunami previously described by Shepard (1933) and Gutenberg (1939). The staff's independent evaluation of historical tsunami records relied on NOAA records of tsunamis and tsunami-like waves compiled by Lockridge et al. (2002). The staff found that the information presented in the FHRR was consistent with published literature.

The licensee described a Pleistocene-age submarine landslide, located off the North Carolina Coast – the so-called Currituck submarine landslide, as the primary candidate for the generation of probable maximum tsunami (PMT) near the Hudson River and possibly the Indian Point site (Krause, 2011, and Grilli et al., 2009, 2010, 2011, and 2012). Deep-water submarine landslides or mass failures (SMFs), such as the Currituck SMF, have been found to be common along the Atlantic continental shelf (Twichell, et al., 2009).

The staff's independent analysis, based on published literature (ten Brink et al., 2008) and the NGDC database (NOAA, 2012) verified that the licensee reviewed all major tsunamigenic sources that could potentially affect the reactor site and confirmed the licensee's conclusion that the largest estimated SMF along the Atlantic seaboard is the Currituck SMF located off the coast of North Carolina.

The licensee simulated tsunami propagation using the results of a simplified, probabilistic first-order models (Grilli et al., 2009) of multiple SMFs along the Atlantic continental shelf; peak breaking wave heights were estimated in the range of 20 to 30 ft., at offshore breaking distances of about 800 to 1,000 ft. Based on these modeling results, the license concluded that inundation of the Indian Point site due to tsunami run-up along the Atlantic coastline would not occur as any tsunami wave/bolus entering the mouth of the Hudson River would likely attenuate before reaching the site. Two reasons for this position were given: (a) the moderate distance inland the reactor site is from the Atlantic coastline – about 60 mi; and (b) the availability of physical margin between the powerblock and the free surface of the Hudson River (at least 15 ft.).

The licensee used the HEC-RAS computer code (USACE, 2010a) to model propagation of a tsunami-like wave up the main stem of the Hudson River. The licensee's HEC-RAS analysis did not model tsunami bore propagation *per se* since the computer code does not have a dispersive model feature capable of capturing all the components of tsunami propagation and tidal interaction. Consequently, the licensee evaluated the ability of the main stem of the Hudson River to sustain the propagation of a tsunami-like bore upstream by applying a series of five, 12-minute gravity waves at the river's mouth (input as temporally-varying, elevated water levels). The FHRR provides a table of the HEC-RAS computer code output, with the licensee noting that any tsunami wave amplitudes produced will likely be significantly attenuated before reaching the reactor site, and thus will not impact any safety-related structures.

The staff performed (two-dimensional) numerical modeling of a likely PMT source based on a Currituck submarine landslide scenario using the Boussinesq-based hydrodynamic COULWAVE computer code (Lynett and Liu, 2002) to determine its potential impact on the

Indian Point site. The staff employed the bounding source parameters to obtain an upper limit on possible tsunami effects at the site. For example, for the purposes of the staff's independent tsunami analysis, the Currituck landslide was transposed to an offshore location along the continental shelf near the mouth of the Hudson River to evaluate the impact that type of event of that magnitude might have at the site.

Based on the staff's independent analysis, the estimated PMT water level at the Indian Point site is 4.9 ft. (1.5 m) due to tsunami with an additional 3.2 ft. (0.98 m) of antecedent water level, yielding a total WSE of 8.1 ft. NAVD88. As the maximum tsunami WSE associated with the PMT is below the CDB plant grade elevation, debris, water-borne projectiles, sediment erosion and deposition associated with the PMT were judged to not affect impact safety-related SSCs.

In summary, the NRC staff confirmed the licensee's conclusion that tsunami-induced flooding alone could not inundate the site. The staff confirmed that the reevaluated hazard for tsunami-induced flooding of the Indian Point site is bounded by the current design basis flood hazard.

3.8 Ice-Induced Flooding

This flood-causing mechanism was not described in the licensee's CDB. The licensee reported that ice-induced flooding had been reevaluated in the context of the PMF, and it had been determined that this flood-causing mechanism would not lead to the inundation of the Indian Point site.

The licensee noted that it began its review of historic ice jams on the main stem of the Hudson River waterway by interrogating a database maintained by the USACE. That GIS-based database is maintained by the *Cold Regions Research and Engineering Laboratory* (CRREL) and contains historic reports of ice jams on waterways found within the contiguous 48 states and Alaska (USACE, 2014a). The licensee reported that the largest ice-induced flooding event reported in the CRREL data base for the Hudson River was at Hadley, approximately 180 mi upstream from the Indian Point site.

Using the Hadley 1948 ice-jam elevation data, the licensee evaluated a comparable event at locations both upstream and downstream from the site. For the purposes of the upstream calculation, the licensee transposed the 11.35-ft. ice dam flood elevation reported for Hadley to the location of the Bear Mountain Bridge, the first bridge encountered above the Indian Point site; the 2255-ft. suspension bridge is located 3.8 mi to the north of the site. The peak wave height produced by the instantaneous release of water from a breach of the hypothetical ice dam at the Bear Mountain Bridge site was determined to be comparable to the mean tide elevation at the reactor site (defined by the licensee to be 1.13 ft.). As a modeling conservatism, the licensee noted that no allowance was given for the attenuation of the wave bolus travelling downstream. Hence, the flood elevation at the reactor site resulting from the breaching of a hypothetical ice dam scenario upstream was estimated to be 1.13 ft. plus an additional 11.35 ft. or 12.48 ft. for the bolus. The estimated flood level was 2.77 ft. below the 15.25 ft. flood level elevation that all reactor SSCs are protected to at the Indian Point site.

The second ice-induced flooding calculation performed by the licensee involved again transposing the 11.35-ft. flood elevation to the location of the first bridge encountered downstream from the Indian Point site; in this case, it was at the Tappan Zee Bridge. The Tappan Zee Bridge is a 1212-ft. span of a cantilever design located about 16 mi below the site.

The backwater flood elevation at the site resulting from a hypothetical ice dam forming at the bridge's location was also 12.48 ft., or 2.77 ft. below the finished site grade. Based on these analyses, as well as the absence of historic records to the contrary, the licensee concluded that ice-induced flooding at the site caused by ice jams in the Hudson River is unlikely and would not affect the safety of the two reactor units at this location.

The staff independently investigated the potential for flooding due to ice jams on the Hudson River. A review of the literature by the staff revealed the following. McCrone (1966) notes that the Hudson River north of Newburgh (about 18 mi upstream) is generally frozen-over from December to February. Grover (1937), at the time, notes that flood records for Hudson River basin are meager and did not extend back many years. That investigator did report (p. 96) the occurrence of an ice jam on the Hudson River near Hadley, sometime during the period 1921-36. Referencing stream gauge records, Tice (1968) later cites frequent reports of freezing of tributaries within the greater Hudson River basin but nothing on the main stem of the river *per se*. A query of the CRREL ice jam database by the NRC staff confirmed the same information reported by the licensee in the FHRR, as well as in Tice (1968). Based on the information reported in the CRREL database, the NRC staff concluded that ice jam formation or breaching of ice jam on the Hudson River was not likely to happen within 100 mi of the reactor site. The NRC staff also independently reviewed the hypothetical ice-induced flooding calculations developed by the licensee in its FHRR (Entergy, 2014e). Based on those reviews, the staff determined that this particular flooding scenario would not have an adverse flooding impact on the Indian Point site.

In summary, the staff confirmed the licensee's conclusion that ice-induced flooding alone could not inundate the site. The staff confirmed that the reevaluated hazard for ice-induced flooding of the site is bounded by the current design basis flood hazard.

3.9 Channel Migrations or Diversions

This flood-causing mechanism was not described in the licensee's CDB. The licensee reported that channel migration/diversion-induced flooding had been reevaluated in the context of the PMF, and the licensee had determined that this particular flood-causing mechanism would not lead to the inundation of the Indian Point site.

Citing NRC guidance (NRC, 2012), the licensee acknowledged that there are no well-established predictive models for estimating the potential for channel diversion in a riverine environment. Consequently, the licensee's review consisted of two elements intended to identify geologic/geomorphic evidence of channel migration or diversion in the past at the reactor site: a literature review and a temporal comparison of applicable USGS topographic maps. In its literature review, citing Sirkin and Bokuniewicz (2006), the licensee reported that the Lower Hudson River estuary exhibits geomorphic characteristics consistent with that of a fjord – i.e., a long, narrow tidal inlet generally recognized to have been formed by glaciers.

In its review of published USGS topographic maps, the licensee reported that it had examined the 1981 1:24,000-scale edition of the Peekskill Quadrangle sheet and compared it to GIS-based information maintained by the State of New York for physical evidence of geomorphic continuity of both the Hudson River, including the Indian Point site. Based on that comparison, the licensee concluded that there had been no topographic expression of river channel migration (or meandering) at the reactor site. Moreover, the licensee noted that there was an unspecified portion of the reactor site at the waterline near the reactor's intake structures that were protected by steel sheet pile walls, and that these engineering features were judged to be sufficient to protect the site from any shoreline erosion should it occur. The licensee concluded, therefore, that it was unlikely for river water to be diverted onto the plant site via channel diversion. The licensee reported in the FHRR that the reevaluated PMF, including associated effects, due to channel migrations or diversions would not inundate the Indian Point site.

In its independent review, the staff also examined topographic maps of the lower Hudson River basin for evidence of channel migration or river meandering. If there were evidence of channel migration or river meandering, there would be evidence to that effect present on topographic maps 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. See Salisbury and Atwood (1908). The staff's review of this topic initially involved interrogating the USGS' historic topographic map digital data base (USGS, 2017). The goal was initially 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 staff inspected those more recently-prepared maps of the reactor site to see if there had been changes in the topography in the intervening years.

The staff found that there were 11 topographic maps available that provide the earliest initial geographic coverage of the study area south of Troy – the northern-most extension of the Hudson River estuary to New York City; these maps were at a scale of 1:62,500 (or 1 in. = 1 mi). The Indian Point site was located on the West Point, NY, sheet. The staff did not identify any geomorphic/ topographic features along the lower Hudson River that could be interpreted as evidence of channel diversion or river migration. Upon further inspection, the topographic sheets studied by the staff confirmed that the geomorphic character Hudson River is like that of a fjord. See Holtedahl (1967) and Fairbridge (1968). This conclusion comported with the published literature that recognizes the lower Hudson River estuary as a glacially-formed fjord (e.g., Dunwell, 1991). As river meandering can be regarded as a temporal phenomenon, the second phase of the staff's review involved examining more recently-published topographic maps of the lower Hudson River basin for evidence of meandering or channel diversion subsequent to the initial publication of the USGS' 1:62,500 scale maps. Those maps were at a higher scale of resolution – or about 1:24,000. The staff's review of the 1981 Peekshill 1:24,000-scale topographic map did not reveal any evidence of meandering. This comparison leads the staff to conclude that there was no geomorphic evidence of river meandering and/or channel diversion for at least the last century.

In summary, the staff confirmed the licensee's conclusion that channel migrations or diversions could not inundate the Indian Point site. The staff confirmed that the reevaluated hazard for flooding from channel migrations or diversions is bounded by the current design basis flood hazard.

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

4.1 Reevaluated Flood Height for Hazards Not Bounded by the CDB

Section 3 of the staff assessment documents the NRC staff review of the licensee's flood hazard water height results. Table 4.1-1 contains the maximum flood height results, including wave effects, for flood mechanisms not bounded by the CDB. The NRC staff agrees with the licensee's conclusion that the following flood-causing mechanisms are not bounded by the CDB: LIP, streams and rivers, dam failure, and storm surge.

4.2 <u>Flood Event Duration for Hazards Not Bounded by the CDB</u>

The NRC staff reviewed information provided in the licensee's 50.54(f) response (Energy, 2015) 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.

4.2.1 Local Intense Precipitation

The licensee reported in its FHRR (Entergy, 2014e) that the warning time for LIP-related flooding is 24 hours[11]; the information related to LIP storm events will be obtained from the NWS approximately 24 hours ahead of the storm event and is based on the qualitative precipitation forecast. The staff notes the licensee also has the option to use Nuclear Energy Institute (NEI) 15-05 (NEI, 2015) to estimate warning time for LIP.

The maximum water surface elevations generated during the LIP event at multiple locations within the Indian Point powerblock are described in Table 2 of the ISR letter (NRC, 2016). Depending on the location, the duration of inundation ranges from about 0.25 hrs. to about 6 hrs. as reported in the MSA report (Entergy, 2014e and 2016a). Similarly, the licensee reports that depending on the location within the powerblock, the time necessary for the flood waters to recede from the site can range from 0.75 hrs. to 6 hrs. (Entergy, 2014e and 2016a).

The licensee used results from 2-dimentional numerical modeling to determine these FED parameters, as described in the MSA (Entergy, 2014e and 2016a), to determine the inundation and recession periods. Based on this review, the staff determined that the licensee's FED parameters for LIP were reasonable.

4.2.2 Streams and Rivers

The licensee has an abnormal operating procedure (AOP) to be implemented when impending Hudson River flood conditions are predicted (Entergy, 2014; Entergy, 2016c). The staff determined that the flood warning time in the MSA report was reasonable, as NOAA's hurricane forecasts reliably predict hurricanes more than 48 hours in advance.

To estimate the inundation and recession time due to the Hudson River PMF, the staff relied on the licensee's input and output files of HEC-RAS computer code (USACE, 2010a) used to prepare the ISR table (NRC, 2016c). Based on staff's use of those input and output files, the staff estimates that the duration of the PMF inundation period is approximately 14 hrs., whereas the recession time attributed to that flood is approximately 60 hrs. Based on this review, the staff determined that the licensee's FED parameters for the streams and rivers flood-causing mechanism are reasonable.

[11] For a LIP event in excess of 5 in.

4.2.3 Dam Failure

~~(CEII)~~ The licensee chose to evaluate the potential hydrologic failure of an upstream dam with the largest capacity in the watershed – namely the [[redacted]] – located about [[redacted]] upstream from the Indian Point site. The FHRR's dam failure scenario occurs in parallel with the PMF on the main stem of the Hudson River. As the warning time for the PMF event is 72 hrs. a like amount of time was assumed by the licensee for the purposes of the dam failure warning time. As the peak water elevation for this flood-causing mechanism is bounded by the streams and rivers flood-causing mechanism, the licensee chose to not provide separate periods of inundation and recession for the dam failure flood-causing mechanism (Entergy, 2016c). The staff agrees with the licensee's approach related to defining the FED parameters for dam failure by noting they are bounded by the streams and rivers flood-causing mechanism. This approach is consistent with guidance provided by Appendix G of NEI 12-06, Revision 2 (NEI, 2015).

4.2.4 Storm Surge

As mentioned above, the licensee identified an AOP regarding warning regarding impending flooding conditions at the reactor site, and credits the NWS for providing at least 48 hrs. prior to a hurricane making potential landfall (Entergy, 2016c). The staff found this to be reasonable since NOAA's hurricane forecasts reliably predict hurricanes more than 48 hours in advance.

The licensee reported that the duration of flooding due to storm surge was less than 4 hrs. (Entergy, 2014) and no recession time was reported. The staff is aware that the licensee relied on the ADCIRC computer code (Westerink, et al., 1994) to estimate the period of inundation due to storm surge. The staff independently reviewed the model-generated storm surge hydrograph provided by the licensee (Entergy, 2015), and found that the period of recession would be approximately 5 hrs. Therefore, and based on a review of the storm surge numerical model results, the staff conclude that the licensee's FED parameters were reasonable.

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

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

For the LIP event, the licensee stated (Entergy, 2016c) that the associated effects of LIP flooding are not considered credible (i.e., they are minimal) due to the relative-low water velocities and limited debris effects within the protected area. The staff confirmed this statement by reviewing the licensee-provided LIP model input and output files. The staff found that the estimated inundation depths and flow velocities were reasonable, and that the modeling is reasonable for use. The 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 riverine flooding, the licensee selected the PMF event combined with wind effects as a bounding event and only evaluated the AE parameters for this flood-causing mechanism (Entergy, 2016c). The licensee reported a hydrodynamic load of 1,825 pounds/foot (lb/ft) in its

FHRR (Entergy, 2014e). The licensee noted that its hydrodynamic load calculations relied on steady-state flow velocities consistent with the recommendations of FEMA (2011 and 2012). The hydrodynamic forces themselves were calculated consistent with the recommendations of FEMA (2012). In its FHRR, the licensee reported a debris load of 27,456 lbs., assuming a debris weight of 2,000 lbs. to represent the hydrodynamic impact of a typical floating tree log on the exterior portion of site's structures per the guideline by ASCE (2010). The licensee noted that it calculated the magnitude of the debris load impact consistent with the recommendations of FEMA (2012).

The staff reviewed the licensee's calculation of the debris load and maximum debris velocity. The staff noted that the licensee's assumption of a tree log debris meets the guidelines by the ACSE 7-10 (ASCE, 2010) with the following characteristics: 1,000 lb. in weight, 30 ft. in length, and 1 ft. in diameter. The staff found that the assumptions are reasonable and that the licensee-estimated debris load is reasonable.

For dam failure, the licensee stated that the AEs associated with dam failure are bounded by the riverine PMF event (Entergy, 2016c). The staff agrees with the licensee's conclusion that the AE parameters for this flood-causing mechanism are bounded by the respective riverine values. This approach also is consistent with the guidance provided by Appendix G of NEI 12-06, Revision 2 (NEI, 2015).

For storm surge, the licensee reported a hydrodynamic load of 1,825 lb./ft. and the debris load of 27,456 lbs., while the other AE parameters are not applicable because this hazard is also bounded by the streams and rivers flood-causing mechanism (Entergy 2014d). The staff agrees with the licensee's conclusion for the storm surge and also note the approach is consistent with guidance provided by Appendix G of NEI 12-06, Revision 2 (NEI, 2015). In summary, the staff determined the licensee's methods were appropriate and the provided AE parameters are reasonable.

4.4 Conclusion

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

5.0 CONCLUSION

The NRC staff reviewed the information provided for the reevaluated flood-causing mechanisms for the Indian Point site. Based on its review of the above available information provided in Energy's 50.54(f) response (Entergy, 2014e), as amended, the NRC staff concludes that the licensee conducted the hazard reevaluation using present-day methodologies and regulatory guidance used by the NRC staff in connection with ESP and COL reviews.

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

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

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

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

Table 3.0-1. Summary of Controlling Flood-Causing Mechanism Water Surface Elevations (WSEs) at the Indian Point Energy Center Site.

FLOOD-CAUSING MECHANISM	STILLWATER WSE (NGVD29)	ASSOCIATED EFFECTS	TOTAL WSE (NGVD29)	REFERENCE(S)
Local Intense Precipitation and Associated Drainage				
Unit 2 Transformer Yard	19.5	Minimal	19.5	Entergy (2016c)
Unit 3 Transformer Yard	19.3	Minimal	19.3	
Streams and Rivers*	16.5 ft.	2.1 ft.	18.6 ft.	FHRR Sections 3.4.2.5.1, 3.4.2.5.2, and 6.2.2
~~(CEII)~~ **Failure of Dams and Onsite Water Control/Storage Structures****	[[redacted]]]	[redacted]	[[redacted]]]	[[redacted]]]
Storm Surge				
Combined Event with 150,000 cfs Flow in Hudson River Coincident with the Probable Maximum Storm Surge (PMSS), Including Antecedent Water Level (AWL) and Coincident Wind-Generated Waves (CWGW) – Values Reported in Open Water in River Outboard of River Bulkhead and U2 Intake Structure	18.9 ft.	2.9 ft.	21.8 ft.	Entergy (2016b)
Combined Event with 150,000 cfs Flow in Hudson River Coincident with PMSS, Including AWL and CWGW – Values Reported in	18.9 ft.	2.1 ft.	21.0 ft.	

FLOOD-CAUSING MECHANISM	STILLWATER WSE (NGVD29)	ASSOCIATED EFFECTS	TOTAL WSE (NGVD29)	REFERENCE(S)
Open Areas of Powerblock Yard Between U2 Intake Structure and U2 Turbine Building				
Combined Event with 150,000 cfs Flow in Hudson River Coincident with PMSS, Including AWL and CWGW – Values Reported at River-facing Sides of Structures Between the River Bulkhead and the Turbine Buildings (Including West Sides of U2 and U3 Intake Structures) and River-facing (West) Side of U2 and U3 Turbine Buildings	18.9 ft.	4.7 ft.	23.6 ft.	
Combined Event with 150,000 cfs Flow in Hudson River Coincident with PMSS, Including AWL and CWGW – Values Reported at Location East of U2 and U3 Turbine Buildings	18.9 ft.	0.0 ft.	18.9 ft.	

* Based on cool season PMP event on the Hudson River (PMF with Snow Pack) coincident with 25-yr storm surge and 10% exceedance high tide.

~~(CEII)~~ ** [[redacted]]]

Table 3.1-1. Current Design Basis Flood Hazard Elevations at the Indian Point Energy Center Site.

FLOOD-CAUSING MECHANISM	STILLWATER ELEVATION (NGVD29)	ASSOCIATED EFFECTS	CDB FLOOD ELEVATION (NGVD29)	REFERENCE(S)
Local Intense Precipitation and Associated Drainage	Not Included in the CDB	Not Included in the CDB	Not Included in the CDB	FHRR Section 4.1.1
Streams and Rivers				FHRR Section 2.3.1 and Table 4.1-1
PMF on the Hudson River	12.7 ft.	1.0 ft.	13.7 ft.	
PMF on the Hudson River with Low Tide	13.0 ft.	1.0 ft.	14.0 ft.	
PMF on the Hudson River with High Tide	12.4 ft.	1.0 ft.	13.4 ft.	
~~(CEII)~~ **Failure of Dams and Onsite Water Control/ Storage Structures***	[[redacted].]]	[[redacted].]]	[redacted].]]	[[redacted]]]
Storm Surge				FHRR Section 2.3.1 and Table 4.1-1
Probable Maximum Hurricane with Spring High Tide on the Hudson River	13.5 ft.	1.0 ft.	14.5 ft.	
Standard Project Hurricane and Standard Project Flood on the Hudson River	14.0 ft.	1.0 ft.	15.0 ft.	
Standard Project Hurricane, Standard Project Flood, and Dam Failure on the Hudson River	14.0 ft.	1.0 ft.	15.0 ft.	
Seiche	Not Included in the CDB	Not Included in the CDB	Not Included in the CDB	FHRR Section 4.1.5
Tsunami	Not Included in the CDB	Not Included in the CDB	Not Included in the CDB	FHRR Section 4.1.6
Ice-Induced Flooding	Not Included in the CDB	Not Included in the CDB	Not Included in the CDB	FHRR Section 4.1.7
Channel Migrations or Diversions	Not Included in the CDB	Not Included in the CDB	Not Included in the CDB	FHRR Section 4.1.8

(~~CEII~~) * [[redacted]]]

Table 3.2-1. Results of Staff Analysis Evaluating Sensitivity of PMP Estimate on WSE within License's FLO-2D LIP Model at the Unit 2 Location.

UNIT 2 DOOR ID.	FLO-2D GRID CELL NO.	1-HR, 10 MI² (9.4 IN.)		6-HR, 10 MI² (15.3 IN.)		DIFFERENCE (IN.)
		FRONT-LOADING	***END-LOADING***	***FRONT-LOADING***	***END-LOADING***	
		[1]	*[2]*	*[3]*	*[4]*	*[2] - [1]* *[4] - [3]*
U2-PAB-1	29037	19.24	20.07	19.20	20.03	0.83
U2-ABFP-1	29617	18.89	20.05	19.00	21.16	1.16
U2-ABFP-2	28416	18.75	19.93	18.80	19.98	1.18
U2-ABFP-3	28116	18.81	19.95	18.80	19.94	1.14
U2-CB-1	25397	19.21	20.07	19.10	19.96	0.86

Table 3.3-1. Licensee-Verified Parameters for Gaged Sub-watersheds for Snyder's Unit Hydrograph Method and Loss Rates.

SUB-WATERSHED	STANDARD LAG (h)	PEAKING COEFFICIENT	CONSTANT LOSS RATE (in./h)	INITIAL LOSS RATE (in./h)
Hudson North Creek	21	0.40	0.040	0.00
Hudson Hadley	18	0.40	0.170	0.00
Upper Sacandaga	8	0.40	0.088	0.00
Upper Mohawk	20	0.40	0.068	0.00
Schoharie	19	0.49	0.060	0.00
Lower Mohawk	15	0.60	0.100	0.00
Hudson Green Island	18	0.55	0.035	0.00
Upper Ashokan	5	0.50	0.120	0.00
Lower Esopus	10	0.50	0.080	0.00
Lower Rondout	9	0.48	0.080	0.00
Wallkill	13	0.40	0.120	0.00
Wappinger	22	0.50	0.105	0.00
Lower *Sacandaga (Ungaged)*	10	0.40	0.130	0.00
Catskill *(Ungaged)*	10.1	0.48	0.050	0.00
Kinderhook *(Ungaged)*	11.2	0.48	0.100	0.00
Lower Ashokan East *(Ungaged)*	1.9	0.48	0.030	0.00
Lower Ashokan West *(Ungaged)*	3.6	0.48	0.030	0.00
Upper Rondout *(Ungaged)*	4.9	0.50	0.108	0.00
Lower Hudson *(Ungaged)*	27.9	0.55	0.034	0.00
Source: IPEC, 2014a (FHRR, Table 3.2-1)				

Table 3.5-1. Locations Selected by Licensee for Storm Surge Wave Calculation. Source: Entergy (2016a).

WAVE CALCULATION LOCATION		STILLWATER ELEVATION (NGVD29)	WAVE HEIGHT/ RUNUP	STILLWATER ELEVATION (NGVD29)
FEATURE	LOCATION (IN FIGURE 3.5-1)			
Riverward of Unit 2 Intake Structure	A	18.9 ft.	5.7 ft.	21.8 ft.
Landward of Unit 2 Intake Structure	Between A And B	18.9 ft.	3.9 ft.	21.0 ft.
Landward of Unit 2 Intake Structure	B	18.9 ft.	4.7 ft.	23.6 ft.
East of Unit 2 Turbine Building	C	18.9 ft.	Minimal	18.9 ft.
Riverward of Unit 3 Turbine Building	D	18.9 ft.	4.7 ft.	23.6 ft.
East of Unit 3 Turbine Building	E	18.9 ft.	Minimal	18.9 ft.

Table 4.1-1. Reevaluated Flood Hazard Elevations for Flood-Causing Mechanisms to be Used in the Focused Evaluation or Integrated Assessment.

FLOOD-CAUSING MECHANISM	STILLWATER ELEVATION (NGVD29)	ASSOCIATED EFFECTS	REEVALUATED FLOOD ELEVATION (NGVD29)	REFERENCE(S)
Local Intense Precipitation and Associated Drainage	< 19.5	Minimal	< 19.5	Entergy (2016c)
Streams and Rivers (1)	16.5 ft.	2.1 ft.	18.6 ft.	FHRR Sections 3.4.2.5.1, 3.4.2.5.2, and 6.2.2
(CEII) **Failure of Dams and Onsite Water Control/Storage Structures** (2)	[[redacted]	[[redacted]	[[redacted]	[[redacted]]]
Storm Surge	18.9 ft.	4.7 ft.	23.6 ft.	Entergy (2016b)

(1) Based on cool season PMP event on the Hudson River (PMF with Snow Pack) coincident with 25-yr storm surge and 10% exceedance high tide.
(CEII) (2) [[Based on forced failure of the Conklingville Dam in combination with Hudson River PMF.]]

Table 4.2-1. Flood Event Durations for Flood-Causing Mechanisms Not Bounded by the Current Design used in the Focused Evaluation or Integrated Assessment.

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)	< 6 h (2)	< 6 h (2)
Streams and Rivers (Cool Season PMF with Snow Pack Coincident with 25-year Storm Surge and 10% Exceedance High Tide)	48 h (3)	≈ 14 h (4)	≈ 60 h (4)
Failure of Dams and Onsite Water Control/Storage Structures [[[redacted])]]	48 h (3)	Bounded (5)	Bounded (5)
Storm Surge (Combined Event)	48 h (1)	≈ 4 h	≈ 5 h

(CEII)

(1) From FHRR (Entergy, 2013) and RAI response (Entergy, 2014).
(2) Estimated using FLO-2D hydrograph in FHRR (Figure 3.1-2)
(3) From MSA (Entergy, 2016).
(4) Estimate based on staff's review of the licensee's riverine cool-season PMF HEC-RAS model (NRC, 2010a).
(5) Inundation and recession periods are bounded by those for the streams and rivers flood-causing mechanism.

Table 4.3-1. Associated Effects Parameters not Directly Associated with Total Water Height for Flood-Causing Mechanisms not Bounded by the Indian Point Energy Center Current Design Basis.

	FLOODING MECHANISM			
ASSOCIATED EFFECTS PARAMETER	**LOCAL INTENSE PRECIPITATION**	**STREAMS AND RIVERS**	**DAM FAILURE (1)**	**STORM SURGE**
Hydrodynamic loading at plant grade	Minimal	1,825 lb./ft. (2)	Bounded	1,825 lb./ft.
Debris loading at plant grade	Minimal	27,456 lbs.	Bounded	27,456 lbs.
Sediment loading at plant grade	Minimal	Minimal	Bounded	Bounded (1)
Sediment deposition and erosion	Minimal	Minimal	Bounded	Bounded (1)
Concurrent conditions, including adverse weather	Minimal	Not Applicable	Bounded	Bounded (1)
Groundwater ingress	Minimal	Not Applicable	Bounded	Bounded (1)
Other pertinent factors (e.g., waterborne projectiles)	Minimal	Not Applicable	Bounded	Bounded (1)

Source: Entergy (2016c)

Notes:
(1) AE parameters are bounded by those of the streams and rivers flood-causing mechanism.
(2) lb./ft. refers to pounds per linear foot of structure in length.

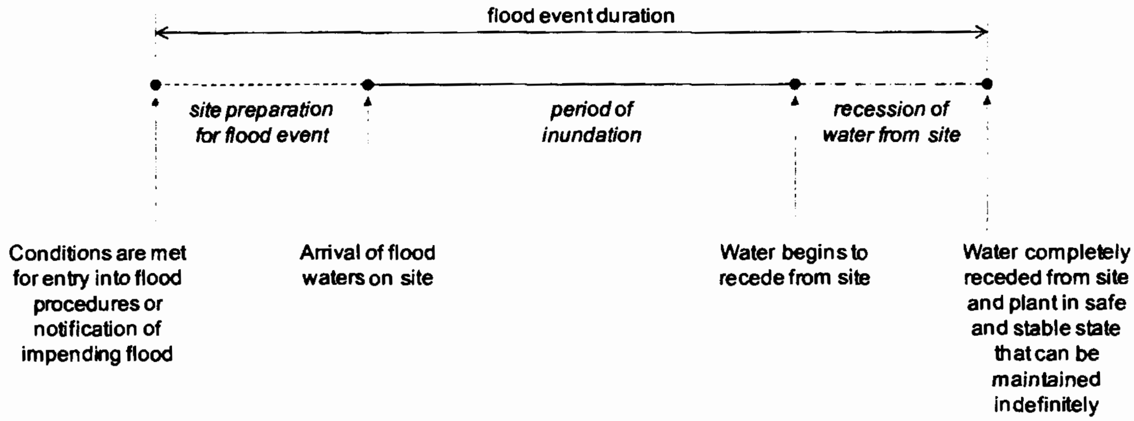

Figure 2.2-1. Flood Event Duration

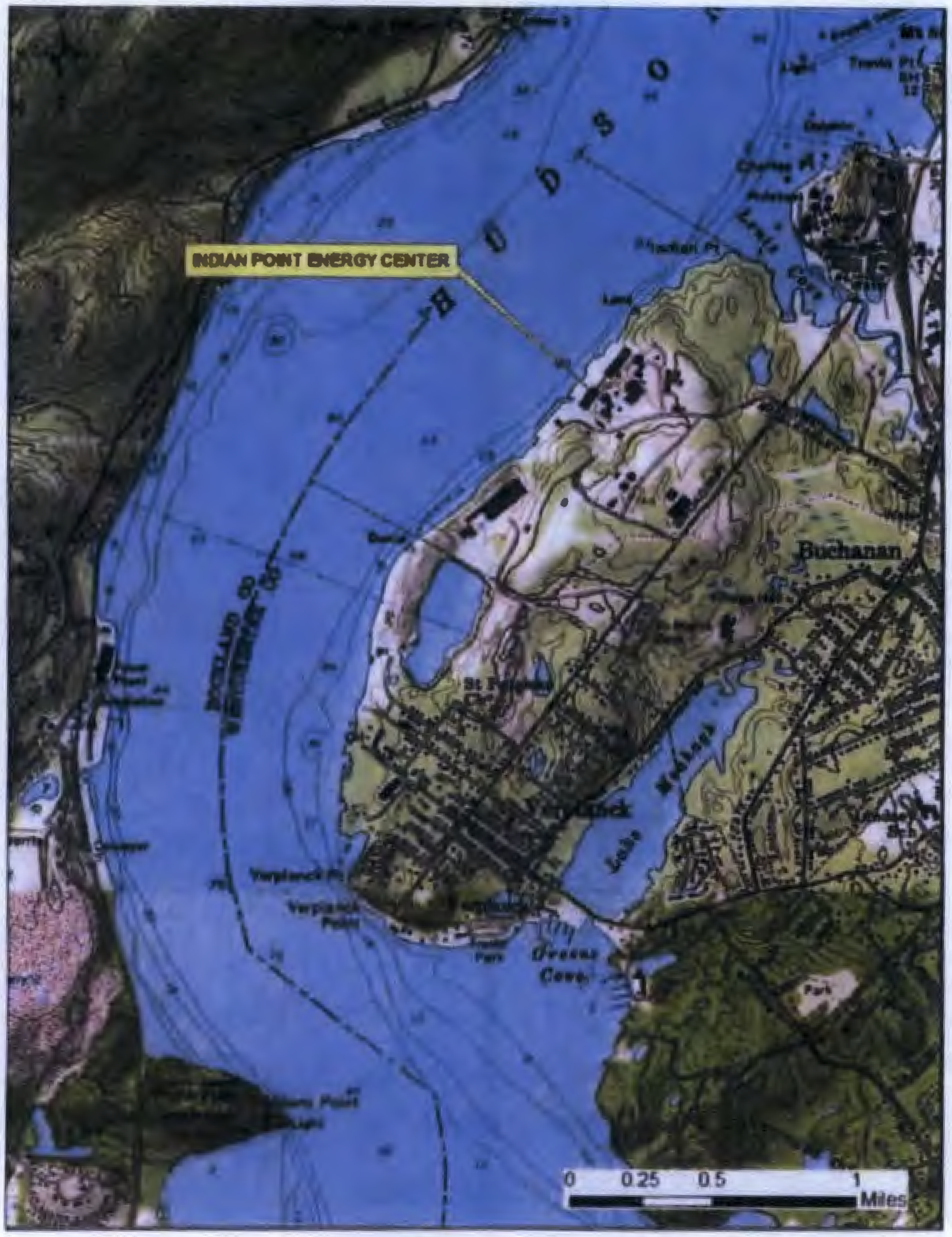

Figure 3.1-1. Map Showing Location of the Indian Point Energy Center Site in Relation to the Hudson River and other Points of Interest. Source: Entergy (2014)

Figure 3.1-2. Map Showing Features of the Indian Point Energy Center Powerblock in Relation to Local Topography. Source: Entergy (2014d)

Figure 3.1-3. Map Showing Location of the Indian Point Energy Center Site in Relation to the Hudson River Watershed and Its Respective Sub-Watersheds Located Above the Reactor Site. Source: Entergy (2014d)

Figure 3.2-1. Map Showing Boundary of FLO-2D Model Used to Calculate Local Intense Precipitation Flood at the Indian Point Energy Center Site. Source: Entergy (2014c)

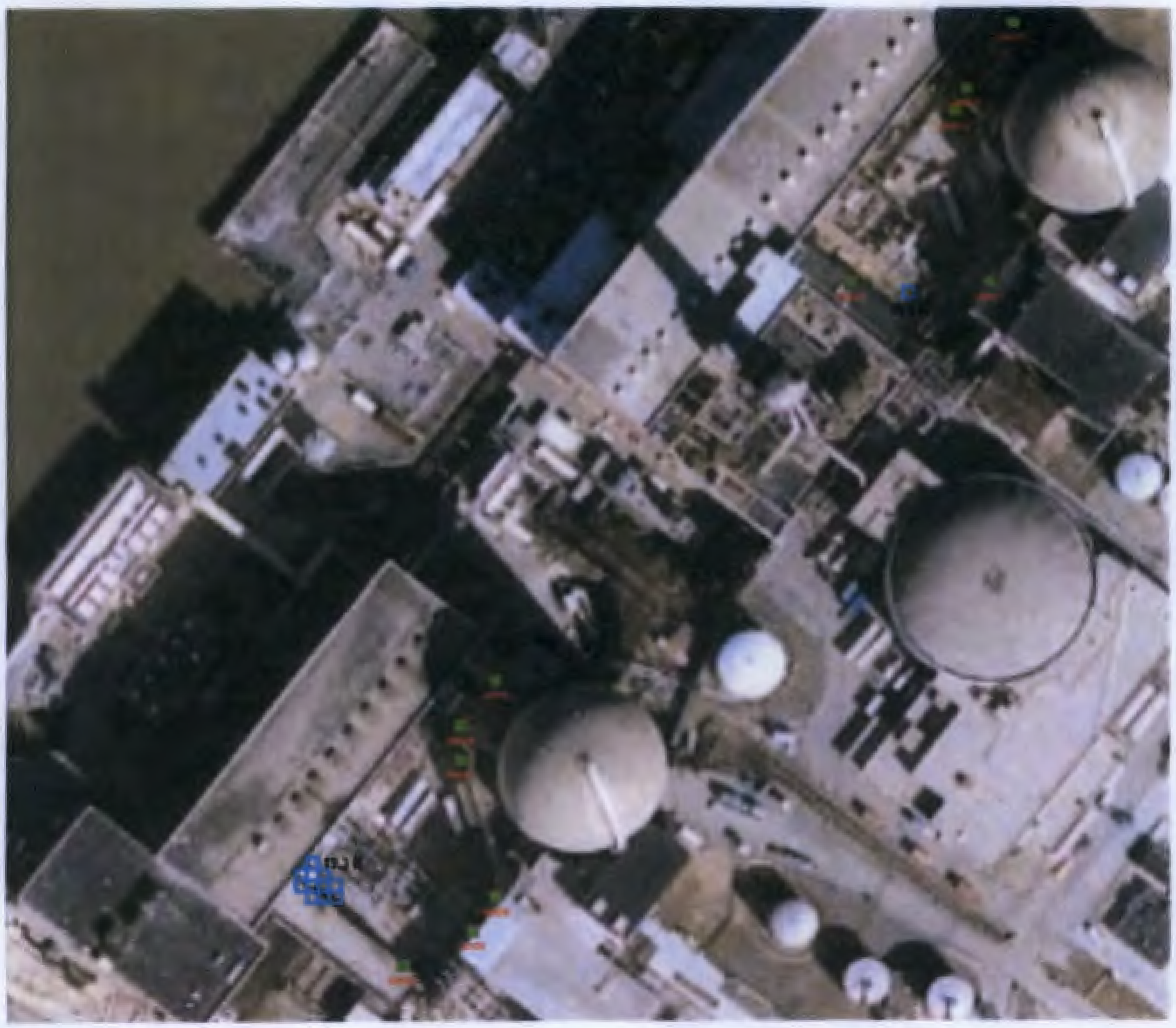

Figure 3.2-2. Image Showing FLO-2D Modelling Results Depicting Locations of Maximum WSEs due to Local Intense Precipitation at the Indian Point Energy Center Site. Image shows Unit 2 and Unit 3 Transformer Yards doors, and other locations in the transformer yards where higher WSEs were predicted by the computer code.

(CEII) [[

[redacted]

]]

(CEII) **Figure 3.4-1. Map Showing Boundary of Hudson River Watershed and Significant Dams Upstream of the Indian Point Energy Center Site. [[redacted])]]**

Figure 3.5-1. Figure Showing Locations of Reported WSEs for the Storm Surge Flood Reevaluation at the Indian Point Energy Center Site. Locations are Indexed to Table 3.5-1. Source: Entergy (2016a)

SUBJECT: INDIAN POINT NUCLEAR GENERATING UNIT NOS. 2 AND 3 – STAFF ASSESSMENT OF RESPONSE TO 10 CFR 50.54(f) INFORMATION REQUEST – FLOOD-CAUSING MECHANISM REEVALUATION (CAC NOS. MF3313 AND MF3314 EPID L-2013-JLD-0031) DATED MAY 31, 2018

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