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

November 15, 2017

Mr. William R. Gideon
Site Vice President
Brunswick Steam Electric Plant
8470 River Rd. SE (M/C BNP001)
Southport, NC 28461

SUBJECT: NUCLEAR REGULATORY COMMISSION REPORT FOR THE AUDIT OF DUKE ENERGY PROGRESS FLOOD HAZARD REEVALUATION REPORT SUBMITTAL RELATED TO THE NEAR-TERM TASK FORCE RECOMMENDATION 2.1-FLOODING FOR BRUNSWICK STEAM ELECTRIC PLANT, UNITS 1 AND 2 (CAC NOS. MF6104 AND MF6105; EPID L-2015-JLD-007 AND EPID L-2015-JLD-008)

Dear Mr. Gideon:

By letter dated June 11, 2015 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML15148A762), the U.S Nuclear Regulatory Commission (NRC) informed you of the staff's plan to conduct a regulatory audit of Duke Energy Progress LLC's (Duke, the licensee) Flood Hazard Reevaluation Report (FHRR) submittals related to the Near-Term Task Force Recommendation 2.1-Flooding for Brunswick Steam Electric Plant, Units 1 and 2 (Brunswick). The Brunswick FHRR was submitted March 11, 2015 (ADAMS Accession No. ML15079A385). The audit was intended to support the staff review of the FHRR and the subsequent issuance of a staff assessment.

The audit(s) were conducted over multiple sessions from October 2015 to February 2017 and were performed consistent with NRC Office of Nuclear Reactor Regulation, Office Instruction LIC-111, "Regulatory Audits," dated December 29, 2008, (ADAMS Accession No. ML082900195). Therefore, the purpose of this letter is to provide you with the final audit report, which summarizes and documents the NRC's regulatory audit of Duke's FHRR submittal. The details of this audit report have been discussed with Mr. Paul Guill of your staff.

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

If you have any questions, please contact me at (301) 415-1132 or by 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. 50-325 and 50-324

Enclosures:
1. Audit Report (Non-Public
2. Audit Report (Public)

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NUCLEAR REGULATORY COMMISSION REPORT FOR THE AUDIT OF DUKE ENERGY PROGRESS, LLC's FLOOD HAZARD REEVALUATION REPORT SUBMITTAL RELATED TO THE NEAR-TERM TASK FORCE RECOMMENDATION 2.1-FLOODING FOR BRUNSWICK STEAM ELECTRIC PLANT, UNITS 1 AND 2 (CAC NOS. MF6104 AND MF6105)

BACKGROUND AND AUDIT BASIS

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

By letter dated March 11, 2015 (Agencywide Document Access and Management System (ADAMS) Accession No. ML15079A385, non-public), Duke Energy Progress, LLC (Duke, the licensee), submitted its Flood Hazard Reevaluation Report (FHRR) for Brunswick Steam Electric Plant, Units 1 and 2 (Brunswick). By letter dated June 11, 2015 (ADAMS Accession No. ML15148A762), the NRC informed the licensee of the staff's plan to conduct a regulatory audit of the Brunswick FHRR.

The audits performed provided the NRC staff with a better understanding of the analyses (and supporting documentation) of the flooding hazards presented in the Brunswick FHRR, and supported the completion of the staff's review of the FHRR, the issuance of the interim hazard letter (issued by letter dated March 16, 2017, ADAMS Accession No. ML17072A364), and will support the subsequent issuance of a staff assessment. The purpose of this report is to provide the results of the audit that was completed in accordance with the guidance set forth in NRC Office of Nuclear Reactor Regulation Office Instruction LIC-111, "Regulatory Audits," dated December 29, 2008 (ADAMS Accession No. ML082900195).

AUDIT LOCATION AND DATES

The audit was completed by document review via electronic reading room (ERR), remote webinar sessions, and ultimately a site visit. The details are as follow:

Webinar Sessions	10/28/2015; 11/16/2015; 1/26/2016; 3/10/2016; 4/28/2016; 6/23/2016; and 9/29/2016.
Site Visit	2/23/2017.

A closeout phone call was held on November 13, 2017.

Enclosure 2

AUDIT TEAM

Title	Team Member	Organization
Team Leader, NRR/JLD	Juan Uribe	NRC
Branch Chief, NRR/JLD	Gregory Bowman	NRC
Branch Chief, NRO/DSEA	Christopher Cook	NRC
Project Manager, NRO/DSEA	Richie Rivera Lugo	NRC
Lead Hydrologist	Warren Sharp	NRC
Hydrologist	Lyle Hibler	NRC
Technical Support	Various contractors	Department of Energy National Laboratory, Taylor Engineering.

DOCUMENTS AUDITED

Attachment 1 of this report contains a list that details the documents reviewed by the NRC staff, in part or in whole, as part of this audit.

AUDIT ACTIVITIES

In general, the audit activities consisted of the following actions:

- Review background information on site topography and geographical characteristics of the watershed.
- Review site physical features and plant layout.
- Understand the selection of important assumptions and parameters that would be the basis for evaluating the individual flood-causing mechanisms described in the 50.54(f) letter.
- Review model input/output computer files, such as Hydrologic Engineering Center (HEC)-River Analysis System (RAS), FLO-2D, and HEC- Hydrologic Modeling System (HMS), to gain an understanding of how modeling assumptions were programmed and executed.

The Oak Ridge National Laboratory (ORNL) staff assisted the NRC staff with the review and evaluation of information provided by the licensee for the following hazards: (1) local intense precipitation (LIP) and associated site drainage, (2) flooding in streams and rivers, and (3) failure of dams and onsite water control/storage structures.

For the LIP analysis, the licensee used the FLO-2D model, a two-dimensional hydrodynamic model that uses the dynamic wave momentum equation to route flood hydrographs and rainfall-runoff over unconfined flow surfaces and in channels (Duke, 2015).

Calculation inputs consist of site topography and existing conditions data, a 1-hour (hr), 1-mi^2 probable maximum precipitation (PMP) hyetograph, high resolution orthoimagery, surface roughness coefficients, and site security features (height and location).
The ORNL staff reviewed the licensee's LIP analysis as presented in the FHRR and supplemental information presented within the audit. The ORNL staff's examination of the calculation packages revealed the following important information:

- The FLO-2D model used a grid element size of 10 feet (ft.) by 10 ft. with 87,158 grid elements (see Section 3.1 in (AMEC), 2015a).
- The LiDAR [Light Detection and Ranging] data was corrected and filtered by the licensee to generate bare earth topography. The door elevations to safety-related structures and buildings were surveyed and verified with as-built drawings, with differences found to be minimal and acceptable (see Section 3.1 in AMEC, 2015a).
- A 1-hr hyetograph was constructed using 5-minute increments (see Section 4.2 in AMEC, 2015a) following a front-loaded rainfall distribution (i.e., the highest intensity precipitation occurs at the beginning of the event).
- Buildings were elevated in the grid, allowing FLO-2D to recognize buildings as obstructions with a height equivalent to the approximate top or roof elevation. These building elevations were determined based on LiDAR data (see Section 4.2 in AMEC, 2015a). Water on rooftops was routed from the buildings to an adjacent site grade (see Section 4.2 in AMEC, 2015a).
- High resolution orthoimagery was used to determine the types of land cover at the Brunswick site and to estimate Manning's roughness coefficient. The licensee used the following Manning's coefficient values: 0.02 for water surface, 0.05 for gravel, 0.03 for buildings and other structures, 0.035 for asphalt and concrete, 0.40 for trees and shrubs, and 0.32 for Bermuda and dense grass or dense vegetation (see Section 4.2 in AMEC, 2015a).

The ORNL staff reviewed the licensee's probable maximum flood (PMF) analysis as presented in the FHRR and supplemental information presented within the audit. The ORNL staff's examination of this information from the calculation packages specifically involved:

- Review of Table 5-2 (AMEC, 2015b) to evaluate the calibrated model and its performance as validated by the licensee.
- Estimation of baseflow (USGS [United States Geological Survey] mean monthly discharges divided by drainage areas) and treatment of reservoirs (initial water levels, etc.) (AMEC, 2015b).
- Review of sensitivity of flow to various watershed centroids (AMEC, 2015b).
- Calculation for datum conversions (AMEC, 2015d).
- Review of the Manning's roughness coefficient (n-value) description and treatment and determination of downstream boundary condition for HEC-RAS for the Cape Fear watershed (AMEC, 2015d).
- Review of Figure 5-1 (AMEC, 2015d) for cross section placement relative to the site and clarification of general starting location for HEC-RAS model.
- Review of the licensee's explanation of use of stage-discharge curve utilized in the HEC-RAS model for assessing water surface elevations based on flowrates (AMEC, 2015d).
- Review of plots of results for flowrates and elevations (AMEC, 2015d).
- Review of the Manning's n-value description (Nancy's Creek), Figure 4-1 for cross-section and site location, bridge modeling, and assumptions made for boundary conditions (AMEC, 2015e).
- Review of flow results and Figure 4-2 for resulting water surface elevation (AMEC, 2015e).

The ORNL staff reviewed the licensee's dam failure analysis as presented in the FHRR and supplemental information presented within the audit. The ORNL staff's examination of this information from the calculation packages specifically involved:

- Review of the PMP values to assess the maximum effect of the rainfall event (AMEC, 2015b).

- Estimation of the breach parameters used to assess dam failure at the Brunswick site using the Froehlich and the Xu & Zhang methodologies (AMEC, 2015c).
- Review of wind/wave effects for combined events (AMEC, 2015f).

Attachment 2 of this report provides more details and summarizes specific technical topics (and resolution) of important items that were discussed and clarified during the audit. The items discussed in Attachment 2 may be referenced/mentioned in the staff assessment in more detail. Attachment 3 of this report contains Figures, Tables and/or graphs reviewed during the audit that are useful in understanding the review performed. Attachment 4 of this report contains a summary of the Brunswick FHRR white paper compiled for the audit on February 2017. The White Paper was developed by Duke in order to compile information and various papers by Duke, Amec Foster Wheeler, and the independent evaluations by Dr. Peter Vickery with Applied Research Associates (ARA) and Dr. Brian Blanton acting as a sub consultant to ARA into a single document, and as a result facilitate a path forward regarding NTTF 2.1 - Flood and Flood Mitigation Strategies Assessment (MSA) for Brunswick. The white paper summarizes Duke's understanding of the current FHRR storm surge modeling. Attachment 5 contains a summary of the revised 10 percent High Tide exceedance review performed by Duke as a result of the audit performed. Additional details related to this effort are included in Attachment 2.

CONCLUSION

During the audit exit meeting held on November 13, 2017, the NRC communicated that no findings or open/unresolved items were found during the audit.

Attachments:

1) Brunswick Steam Electric Plant, Units 1 and 2 Audited Document List
2) Brunswick Steam Electric Plant, Units 1 and 2 Information Needs and Response Summary
3) Brunswick Steam Electric Plant, Units 1 and 2 Information Need Figures
4) White Paper Summary of Brunswick's Flooding Audit Review and Licensee's Revised 10% Exceedance High Tide Statement

ATTACHMENT 1
Brunswick Steam Electric Plant, Units 1 and 2 Audited Document List

AMEC, 2014, "Brunswick Nuclear Plant Channel Migration or Diversion Evaluation," BRUNSWICK Calculation No. BNP-MECH-FHR-008 (AMEC Calculation No. BNP-14-008), Revision 0, December 29, 2014, Available to staff on electronic hard drive for the audit, received June 2015.

AMEC, 2015a, "Evaluation of Brunswick Plant Local Intense Precipitation – Severe Accident Management (SAM) for Fukushima Near-Term Task Force (NTTF) Recommendation 2.1 Flood Re-evaluation," BRUNSWICK Calculation No. BNP-MECH-FHR-001 (AMEC Calculation No. BNP-14-001), Revision 0, February 26, 2015, Available to staff on electronic hard drive for the audit, received June 2015.

AMEC, 2015b, "Hydrologic Evaluation of the Cape Fear River Watershed for Brunswick Nuclear Plant," BRUNSWICK Calculation No. BNP-MECH-FHR-002 (AMEC Calculation No. BNP-14-002), Revision 0, February 18, 2015, Available to staff on electronic hard drive for the audit, received June 2015.

AMEC, 2015c, "Evaluation of Dam Breaches and Failures for Cape Fear River Watershed," BRUNSWICK Calculation No. BNP-MECH-FHR-003 (AMEC Calculation No. BNP-14-003), Revision 0, February 26, 2015, Available to staff on electronic hard drive for the audit, received June 2015.

AMEC, 2015d, "Flood Hydraulics for the Cape Fear River," BRUNSWICK Calculation No. BNP-MECH-FHR-004 (AMEC Calculation No. BNP-14-004), Revision 0, February 26, 2015, Available to staff on electronic hard drive for the audit, received June 2015.

AMEC, 2015e, "Nancy's Creek Flood Hazard Reevaluation for Brunswick Nuclear Plant," BRUNSWICK Calculation No. BNP-MECH-FHR-005 (AMEC Calculation No.NP-14-005), Revision 0, February 26, 2015, Available to staff on electronic hard drive for the audit, received June 2015.

AMEC, 2015f, "Combined Effects Flood Evaluation," BRUNSWICK Calculation No. BNP-MECH-FHR-009 (AMEC Calculation No. BNP-14-009), Revision 0, February 27, 2015, Available to staff on electronic hard drive for the audit, received June 2015.

AMEC, 2015g, "Data for MMC Precip Tool," Microsoft EXCEL spreadsheet prepared as part of calculations packages for the Brunswick Nuclear Plant, February 2015.

AMEC, 2015h, "Storm Surge and Seiche Evaluation," BRUNSWICK Calculation No. BNP-MECH-FHR-006 (AMEC Calculation No. BNP-14-006), Revision 0, March 4, 2015, Available to staff on electronic hard drive for the audit, received June 2015.

AMEC, 2015i, "Tsunami Evaluation for Brunswick Nuclear Plant," BRUNSWICK Calculation No. BNP-MECH-FHR-007 (AMEC Calculation No. BNP-14-007), Revision 0, March 4, 2015, Available to staff on electronic hard drive for the audit, received June 2015.

Codiga. D.L., 2011, Unified Tidal Analysis and Prediction Using the UTide Matlab Functions, Technical Report 2011-01, Graduate School of Oceanography, University of Rhode Island, Narragansett, RI, 59pp.

Duke Energy (Duke Energy Progress, Inc.), 2012, Brunswick Steam Electric Plant, Units 1 and 2, Updated Final Safety Analysis Report (UFSAR) Revision 23, August 14, 2012.

Duke Energy, 2015a, Letter dated March 11, 2015. Subject: Brunswick Steam Electric Plant, Units Nos. 1 and 2, Renewed Facility Operating License Nos. DPR-71 and DPR-62 Docket Numbers 50-325 and 50-324, Enclosure: BRUNSWICK Flooding Hazard Reevaluation Report, ADAMS Accession No. ML15079A385, NON-PUBLIC.

Duke Energy, 2015b, "Data for MMC Precip Tool," spreadsheet located in the folder "2-HydrologicEvaluation\02_Spreadsheets\12-PMP precipitation," Available to staff on electronic hard drive for the audit, received June 2015.

Duke Energy, 2015c, FLO-2D model files; this content includes all of the files located in the folder named "1-LIP\Model," Available to staff on electronic hard drive for the audit, received June 2015.

Duke Energy, 2015d, HEC-HMS model files; this content includes all of the files located in the folder named "3-DamBreach\05_Models\BNP-14-003 HEC-HMS model Rev B\CFHMS," Available to staff on electronic hard drive for the audit, received June 2015.

Duke Energy, 2015e, "BNP Dam Breach Parameters_Overtopping" spreadsheet located in the folder named
"3-DamBreach\02_Spreadsheets\2 - Dam Breach Parameters," Available to staff on electronic hard drive for the audit, received June 2015.

Duke Energy, 2015f, PMF model files; this content includes all of the files located in the folder named "4-PMFHydraulicsSteady\05_Models\Rev B" on the hard drive, received June 2015.

Duke Energy, 2015g, Electronic files for Nancy's Creek; this content includes all of the files located in the folder named "5-NancysCreek\Model\NancysCreekRASmodel," Available to staff on electronic hard drive for the audit, received June 2015.

Duke Energy, 2016a, Fukushima NTTF 2.1 BRUNSWICK Storm Surge Audit ERR Database Entry #1, "Brunswick Storm Surge Info Needs –Final Response 21 Jan 2016", Certrec Inspective Management System, Added March 3, 2016.

Duke Energy, 2016b, Fukushima NTTF 2.1 BRUNSWICK Storm Surge Audit ERR Database Entry #2, Certrec Inspective Management System, Added March 3, 2016.

Duke Energy, 2016c, Fukushima NTTF 2.1 BRUNSWICK Storm Surge Audit ERR Database Entry #3, Certrec Inspective Management System, Added March 3, 2016.

Duke Energy, 2016d, Fukushima NTTF 2.1 BRUNSWICK Storm Surge Audit ERR Database Entry #4, Certrec Inspective Management System, Added Month 9, 2016.

Duke Energy, 2016e, Fukushima NTTF 2.1 BRUNSWICK Storm Surge Audit ERR Database Entry #5, Certrec Inspective Management System, Added Month 9, 2016.

Duke Energy, 2016f, Fukushima NTTF 2.1 BRUNSWICK Storm Surge Audit ERR Database Entry #6, Certrec Inspective Management System, Added March 9, 2016.

Duke Energy, 2016g, Fukushima NTTF 2.1 BRUNSWICK Storm Surge Audit ERR Database Entry #7, "Complete Response to NRC Information Need 2, 4, 13, and General Clarification", Certrec Inspective Management System, Document date January 28, 2016. Added March 9, 2016.

Duke Energy, 2016h, Fukushima NTTF 2.1 BRUNSWICK Storm Surge Audit ERR Database Entry #8, Certrec Inspective Management System, 32 items, Added March 29, 2016.

Duke Energy, 2016i, Fukushima NTTF 2.1 BRUNSWICK Storm Surge Audit ERR Database, Entry #9, "Evaluation of Brunswick Nuclear Plant Probable Maximum PMH Parameters, Revision 1", Certrec Inspective Management System, Added September 26, 2016.

Duke Energy, 2016j, Fukushima NTTF 2.1 BRUNSWICK Storm Surge Audit ERR Database, Entry #10, "Evaluation of Brunswick Storm Surge Parameters and Path Forward", Certrec Inspective Management System, Presented on September 29, 2016, Added September 26, 2016.

Duke Energy, 2016k, Fukushima NTTF 2.1 BRUNSWICK Storm Surge Audit ERR Database, Entry #11, "Summary Table PMH Results", Certrec Inspective Management System, Document dated October 7, 2016. Added October 20, 2016.

Duke Energy, 2016l, Fukushima NTTF 2.1 BRUNSWICK Storm Surge Audit ERR Database Entry #12, "Brunswick Responses to NRC FHRR Info Needs – Presentation – 11-16-2015", Certrec Inspective Management System, Added November 3, 2016.

Duke Energy, 2016m, Fukushima NTTF 2.1 BRUNSWICK Storm Surge Audit ERR Database Entry #13, "Brunswick Nuclear Plant Flooding FHRR Item Tracker Revision 3", Certrec Inspective Management System, Added November 7, 2016.

Duke Energy, 2016n, Fukushima NTTF 2.1 BRUNSWICK Storm Surge Audit ERR Database Entry #14, "BNP FHRR White Paper Summary of Delft3d Model and Storm Input Parameters with Concentration of Hydraulic Gradients Across Frying Pan Shoals", Certrec Inspective Management System, Added November 29, 2016.

Duke Energy, 2017, "Brunswick FHRR White Paper: Storm Surge Reevaluated Hazard", Compiled on February 6, 2017. Seven Enclosures: 1) " Evaluation of Brunswick Nuclear Plant Probable Maximum Hurricane (PMH Parameters)" Revision 1; 2) "Evaluation of FHRR Hydraulic Gradients Across Frying Pan Shoals"; 3) "Independent Evaluation of FHRR Hydraulic Gradients Across Frying Pan Shoals Evaluation"; 4) "Independent Assessment of Reports by Bell, Andreas, and NUREG CR-7134 on Application of Wind Drag Coefficients"; 5) "Validation of FHRR Wind Drag Coefficients with Hurricane Fran"; 6) "Conservatisms in Storm Surge Model"; and 7) "10% Exceedance High Tide Adjustment", Certrec Inspective Management System, emailed to NRC on February 7, 2017 as part of the audit

Holthuijsen, L. H., M. D. Powell, and J. D. Pietrzak, 2012, Wind and waves in extreme hurricanes, *J. Geophys., Res.*, 117, C09003.

NOAA (National Oceanic and Atmospheric Administration), 1979, NOAA Technical Report NWS 23 (1979), "Meteorological Criteria for Standard Project Hurricane and Probable Maximum Hurricane Windfields, Gulf and East Coasts of the United States".

NOAA, 2016, Tidal Datums website accessed at https://tidesandcurrents.noaa.gov/datum_options.html, NOAA, 2000, Tidal Datums And Their Applications, NOAA Special Publication NOS CO-OPS 1, for the U.S. Department of Commerce, National Ocean Service, Center for Operational Oceanographic Products and Services.

Powell, M. D., P. J. Vickery, and T. A. Reinhold, 2003, "Reduced drag coefficients for high winds speeds in tropical cyclones," Nature, Volume 422, March 2003.

Powell, M. D., 2007, Drag Coefficient Distribution and Wind Speed Dependence in Tropical Cyclones, Final report to the JHT, April 2007, 26 pp.

U. S. Army Corps of Engineers, 1994, "Engineering and Design - Hydraulic Design of Flood Control Channels," Engineer Manual (EM) 1110-2-1601.

Zervas, C. 2004, North Carolina Bathymetry/Topography Sea Level Rise Project: Determination of Sea Level Trends, NOAA Technical Report NOS CO-OPS 041, May 2004, Available at https://tidesandcurrents.noaa.gov/publications/techrpt41.pdf.

ATTACHMENT 2
Brunswick Steam Electric Plant, Units 1 and 2 Information Needs and Response Summary

Information Need No.	Reference Number/ Transmittal Date[1]	Information Need Description	Response
1	1 10/20/15	**<u>Comparison of Reevaluated Flood Hazard with CLB</u>** <u>Background</u>: Recommendation 2.1 of the 50.54(f) letter (NRC, 2012) provides instructions for the development of the FHRR. Specifically, licensees are requested to perform a comparison of current and reevaluated flood-causing mechanisms at the site. <u>Request</u>: Based on lessons learned, please clarify if (and wherever necessary correct the description and/or comparison of the reevaluated flood hazard to the current design basis (CDB)) for any flood hazard mechanism throughout the report that may have been incorrectly compared with the current licensing basis (CLB). Please confirm that this has been verified throughout the FHRR (Duke Energy, 2015).	The licensee's response (Duke Energy, 2016) stated that FHRR Table 5-1 correctly compares the reevaluated flooding hazards to the design basis for the Brunswick, Units 1 & 2. The licensee further noted that the term "current design basis" is used in the FHRR without the need to use the term "current licensing basis." The licensee therefore states that these two terms can be used interchangeably. The staff concluded that the licensee provided an adequate response to the staff's request.
2	2 10/20/15	**<u>Local Intense Precipitation</u>** <u>Background</u>: The files supporting the local intense precipitation (LIP) calculations with FLO-2D, as well as Figure 4-2 in calculation package BNP-MECH-FHR-001 (AMEC, 2015a) (Local Intense Precipitation), show the Vehicle Barrier System (VBS) or other barrier blocks surrounding several circular on-site structures (such as those in the southeastern portion of the site). Section 4.2 of calculation package BNP-MECH-FHR-001 (AMEC, 2105a) states that: "The concrete blocks were used in building security barriers on the site."	The licensee provided the responses to the information needs (Duke Energy, 2016): a. The licensee's response confirmed that all VBS structures and other barriers were modeled in FLO-2D as levees and provided layout plans (including schematic drawings and associated aerial photos) for the missile barrier around both the Unit 1 CST and the Unit 2 CST. The licensee also noted that the noticeable gaps that are visible in aerial photography around the CSTs are actually parking curbs, as evidenced in ground-level photos provided by the licensee during the audit.

[1] The reference number was the info need number assigned when originally transmitted to the licensee.

Information Need No.	Reference Number/ Transmittal Date[1]	Information Need Description	Response
		The licensee's modeling has attempted to capture these barriers as levees. However, it is not clear how accurately levees represent the areas around the Condensate Storage Tank (CST) Missile Barrier and northwest of the Auxiliary Building as shown in Figure 4-2 of the calculation package. For instance, publicly-available aerial imagery of the above mentioned buildings appear to show concrete blocks arranged such that there are visible gaps between the blocks. It is not clear how these barrier blocks were included in the FLO-2D model, or how the gaps between these blocks were modeled. <u>Request</u>: The staff requests the following: a. Provide clarification on how the VBS structures and other barriers were modeled in the LIP analysis, especially in areas surrounding the CST Missile Barrier and northwest of the Auxiliary Building. b. Describe how any gaps between the concrete blocks and other VBS structures were included in the model. c. Provide a legible copy of Figure 4-2 from the calculation package BNP-MECH-FHR-001 (Local Intense Precipitation) (AMEC, 2015a).	b. The licensee's response stated that gaps between individual elements of VBS structures and other concrete barriers were not included in the FLO-2D model because such gaps are smaller than the 10-ft. grid spacing used in the model and because the difference in water elevation across such elements is not significant. The licensee further stated that it is a conservative assumption not to include these small gaps because the barriers are represented as obstructions that prevent flow from draining away from the site. c. The licensee committed to providing the original file of calculation package BNP-MECH-FHR-001 (AMEC, 2015a) in PDF format for the docket. The NRC staff reviewed the information provided in the response and concluded that the licensee provided an adequate response to the staff's request.
3	3 10/20/15	**<u>Probable Maximum Precipitation (PMP) and Probable Maximum Flooding (PMF) - Storm Configurations</u>** <u>Background</u>: Section 4 of the FHRR (Duke Energy, 2015) states that "HMR52 software was used to evaluate storm configurations producing the highest	The licensee provided the following responses (Duke Energy, 2016): Related to (a)(i), the licensee investigated sensitivity to the location of the storm center by considering three possible locations, corresponding with the centroid of the Cape Fear

Information Need No.	Reference Number/ Transmittal Date[1]	Information Need Description	Response
		basin-averaged rainfall over the watershed," but this approach appears to have only placed the storms at the centroids of each of the sub-basins and obtained only the resulting maximum rainfall on the basin upstream of the site. Request: Provide additional information related to the following: a. Provide discussion of sensitivity analyses, if any, which were considered or performed for (i) orienting the storm centers at locations other than the centroid of the basin, or (ii) conducting a moving storm analysis to obtain maximum flows. b. Provide rationale for determining only the maximum basin precipitation upstream of the site associated with the various storm locations rather than determining storm locations and orientations that produce maximum flows and resultant maximum elevations at the site.	River (CFR) watershed upstream of Brunswick and the centroids of two sub watersheds (i.e., the upper portion of the CFR watershed upstream of the Brunswick site and the lower portion of the CFR watershed upstream of the Brunswick site). For the storm orientation, the licensee used the HMR 52 program to select the orientation that provided the maximum precipitation on the drainage area for the particular storm center considered. Related to (a)(ii) the licensee noted that the use of HMR 52 is accepted by NUREG/CR-7046 (NRC, 2011b). The licensee further stated that HMR 51 and HMR 52 (NOAA, 1978; NOAA, 1982) do not consider the scenario involving a moving storm. The licensee's response for (b) referenced Table 5-8 in calculation package BNP-MECH-FHR-002 (AMEC, 2015b) to compare the watershed-averaged PMF 72-hour precipitation depth for the different storm centers considered, and also pointed to Table 5-9 in that same calculation package in regard to the selection of the storm center as the analysis that was most critical in terms of peak discharge at the site. Table 5-9 indicated that the centroid of the CFR watershed upstream of the Brunswick site is the most critical. The NRC staff reviewed the information provided in the response and concluded that the licensee provided an adequate response to the staff's request.
4	4 10/20/15	**PMF - Peak Flow magnitude and Timing** Background: Review of calculation package BNP-MECH-FHR-002 (AMEC, 2015b) (Hydrologic Evaluation of the Cape Fear Watershed) indicates that the upper and lower portions of the Cape Fear watershed are calibrated to 1998 and 1999 rainfall	The licensee's response (Duke Energy, 2016) confirmed that the March 1998 storm event and the September 1999 storm event were used to develop a calibrated and "combined" HEC-HMS (USACE, 2010b) model. Furthermore, the parameters calibrated for the March 1998 storm were used in the combined model for that portion of the Cape Fear River

Information Need No.	Reference Number/ Transmittal Date[1]	Information Need Description	Response
		events, respectively. Using this calibration, a combined calibrated model is used to test validation against the 1998 and 1999 events, in addition to an independent rainfall event from 2013. Validation results for the three events are presented in Tables 5-4, 5-5, and 5-6 in calculation package BNP- MECH-FHR-002 (AMEC, 2015b) for comparison of peak flood arrival timing and magnitude between the simulated and observed at various stream gages located throughout the total watershed. In most cases, the model over predicts the peak flow and misses the timing of the peak flow arrival by 10 to 15 hours in some cases. Of interest are the results at the three stream gages 02105769, 02106500, and 02108000 (listed in Figure 3-1 of calculation package BNP-MECH-FHR-002) (AMEC, 2015b) on the Cape Fear, Black, and Northeast Cape Fear Rivers, respectively. The validated model predicts peak flow occurring 1.5 to 3 days early on the Black and Northeast Cape Fear Rivers and 6 hours late on the Cape Fear River. These 3 stream gages represent locations in the model just upstream of the confluence of these rivers forming the Cape Fear River just 20 miles (mi) upstream of the Brunswick site. As such, the model's ability to correctly predict flow timing at these locations is critical to estimating the resulting flow at the Brunswick site. This validated model is used to assess peak flows at the site for various rainfall distributions which are subsequently used as input to the HEC-RAS (U.S. Army Corps of Engineers (USACE), 2010a) model for predicting the maximum flood elevation at the Brunswick site.	watershed upstream of the USGS gage on the Cape Fear River at Lock #1 near Kelly, NC. The parameters calibrated for the September 1999 storm were used for the remainder of the watershed. In its response, the licensee also provided narrative on the conservatism of the combined model with respect to (1) modeled flows in the Cape Fear River watershed for the 1998, 1999 and 2003 storm events, (2) early prediction of peak flow for the Black and Northeast Cape Fear Rivers that under-predicts the time between precipitation and peak flow, and (3) over-prediction by 38 hours for the 1999 storm for the USGS gage at Lock #1; however, the licensee noted that the difference in the time-to-peak is compensated by the over-prediction (i.e., 144%) in peak flow. The NRC staff reviewed the information provided in the responses and concluded that the licensee provided an adequate response to the staff's request.

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		Request: The licensee is requested to provide discussion regarding the effect(s) that over- or under-prediction of both time-to-peak and validated peak flow at the Black and Northeast Cape Fear Rivers, located just upstream of the confluence with the Cape Fear River, have on conservatism relative to peak flow magnitude and timing at the Brunswick site.	
5	5 10/20/15	**PMF - Modeling Assumptions** Background: Review of calculation packages BNP-MECH-FHR-002 (AMEC, 2015b) (Hydrologic Evaluation of the Cape Fear Watershed) and BNP-MECH-FHR-004 (AMEC, 2015d) (Flood Hydraulics for the Cape Fear River) indicates that the HEC-HMS (USACE, 2010b) model is used to route flooding along the main rivers (Haw, Deep, Black, and the Cape Fear Rivers) throughout the watershed. The HEC-RAS (USACE, 2010a) model is then used to route the flood waters from a location approximately 13 mi upstream of the Brunswick site for approximately 20 mi downstream to the Atlantic Ocean. Request: Provide clarification on the following items: a. Discuss the rationale for using HEC-HMS (USACE, 2010b) (with the Muskingum routing method) to route the flooding down the main rivers (Haw, Deep, Black, and the Cape Fear Rivers) in lieu of using HEC-RAS (USACE, 2010a) (with Manning's *n* roughness coefficient). b. Discuss the rationale for utilizing a steady flow analysis versus an unsteady analysis in the HEC-RAS (USACE, 2010a) model.	In its response to 5a, the licensee stated (Duke Energy, 2016) that the Muskingum routing method is appropriate for flood wave routing based on guidance in [Japan Lessons-Learned Division (JLD) Interim Staff Guidance (ISG)] JLD-ISG-2013-01 (NRC, 2013b), and the licensee calibrated the method based on observed flows at USGS gages. In response to 5b, the licensee stated that the steady flow analysis using the peak flow value is conservative (as confirmed by NUREG/CR-7046 [NRC, 2011b], page B-23) since it results in higher water surface elevations than the corresponding unsteady flow analysis. As it relates to 5c, the licensee stated that the use of a cross-section located upstream of the intake channel as a reference for the evaluation of the maximum water surface elevation at the site is conservative. The licensee also noted that the water surface elevation in the intake channel results from backwater in the Cape Fear River, as shown by the FEMA Flood Insurance Study for Brunswick County, NC, dated October 16, 2008. Nancy's Creek was also modeled (see calculation package BNP-14-005/BNP-MECH-FHR-005) (AMEC, 2015e), and the licensee obtained the topography for this study from GIS data. The licensee's calculated PMF peak water surface elevation for Nancy's Creek is 15.46 ft. National Geodetic Vertical Datum of 1929 (NGVD 29), which is 4.54 ft.

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		c. Discuss the rationale for not including the geometry and topography of the Brunswick site and the intake channel in the HEC-RAS (USACE, 2010a) model sections. d. Discuss any sensitivity studies performed to analyze the effect of Manning's *n* roughness coefficient as applied in the HEC-RAS (USACE, 2010a) model, since the model's extent did not include upstream river sections with flow gages that could be used for validation. e. With regards to the dam failure flooding mechanism analysis provided in the FHRR, please discuss any operational guidelines for Jordan Lake and Shearon Harris dams that were implemented in HMS, relative to conservatism of the flooding scenario being considered.	below site grade. The licensee concluded that the reason for not including surveyed geometry and topography for the Brunswick site is that the water surface elevations from flooding on either the Cape Fear River or Nancy's Creek, do not inundate the Brunswick site. In the licensee's response to 5d, the licensee justified the absence of sensitivity studies by observing that conservative values of Manning's roughness coefficient (*n*=0.05 for the deep portions of the river which is maintained by dredging, and 0.02 elsewhere, based on engineering judgement and aerial imagery) were used in the model. The licensee also noted that any sensitivity studies incorporating less conservative Manning's *n*-values would result in lower (i.e., less conservative) estimates of the maximum water surface elevation at the site. In response to 5e, the licensee stated that the preliminary HEC-HMS (USACE, 2010b) simulations showed the assumption of closed gates at Jordan Lake dam provided the most conservative estimate of peak flow (see calculation package BNP-MECH-FHR-003), (AMEC, 2015c) because the resulting maximum water surface elevation and volume in the reservoir, which affect the computation of dam breach parameters, are greater than the situation in which the gates are open. The auxiliary reservoir spillway for the Shearon Harris dam discharges into the main reservoir, and the main reservoir spillway discharges downstream of the dam. The licensee stated that these two reservoirs were conservatively modeled in HEC-HMS (USACE, 2010b) as a single reservoir, and storage of both main and auxiliary reservoirs were taken into account.

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			The NRC staff reviewed the responses and concluded that the licensee provided an adequate response to the staff's request.
6	6 10/20/15	**<u>Dam Failure - Lake Surface Elevations</u>** <u>Background</u>: In the analysis of dam failures, the initial water surface elevation in Jordan Lake was set equal to the conservation pool level of 216 ft. For Shearon Harris reservoirs, the initial water surface elevation was set equal to the maximum controlled elevation in the main reservoir (i.e., 220 ft.). In the composite data, the initial surface elevation is assumed equal to the top of the dam. It is not clear why the initial water surface elevation for the Jordan Lake reservoir was not set equal to the top of the dam, particularly for overtopping dam breach. <u>Request</u>: Staff requests discussion pertaining to: a) Any sensitivity studies that were performed for evaluating peak discharge associated with selecting "top of flood control pool" as opposed to "conservation pool" in the overtopping dam breach analysis. b. Rationale for not setting the Jordan Lake reservoir initial surface elevation to the top of the dam for the overtopping dam breach scenario.	In its response to 6a (Duke Energy, 2016), the licensee referred to calculation package BNP-MECH-FHR-003 and cited data on the actual operation of the dams in lieu of the performance of sensitivity studies. The licensee noted that Jordan Lake is operated by the Corps of Engineers as a flood-control structure, and there is reasonable justification that the conservation pool level of 216 ft. NVGD29 would be maintained in anticipation of a large rainfall event, such as the PMP. The licensee's review of actual lake levels prior to the March 1998 and September 1999 storm events showed the reservoirs were maintained at 216.19 ft. and 216.57 ft., respectively, which is very close to the conservation pool elevation. The licensee's response to 6b stated that setting the initial water surface elevation to the top of the dam would be overly conservative and would not be representative of actual operations in anticipation of a large rainfall event, during which the water surface elevation does not reach the top of the dam. The licensee stated that the use of the conservation pool elevation as the initial water surface elevation (see calculation package BNP-MECH-FHR-001 [AMEC, 2015a]) is acceptable according to guidance in JLD-ISG-2013-01 (NRC, 2013b). The NRC staff reviewed the information provided in the responses and concluded that the licensee provided an adequate response to the staff's request.

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7	7 10/20/15	**Dam Failure- Determination of Maximum Volume** Background: For the dam breach calculations, the time evolution of water surface elevation and water volume in the reservoirs of the individual dams (i.e., Jordan Lake and Shearon Harris Dams) is evaluated using two scenarios: (a) in Scenario A, the surface elevation for overtopping dam breach was set equal to the elevation of the top of the composite dams, while individual dams were not breached, (b) in the second scenario, individual dams were set to breach at a point corresponding to maximum volume in the reservoir, which was determined in Scenario A. Request: The licensee is requested to provide rationale for determining the maximum volume in the individual reservoirs using Scenario A, rather than using the maximum volume of individual reservoirs.	The licensee's response (Duke Energy, 2016) noted that Scenario A was intended to allow for the computation of the actual maximum volume reached in the individual reservoirs during the governing PMP event, based on which breach parameters were calculated and time of failure was set. The licensee stated that the use of the maximum volume of the individual reservoirs would be overly conservative, and would not reflect the actual maximum volume conditions in the reservoirs, corresponding to water surface elevations below the top of the dam as in the simulations for Scenario A. The licensee also observed that analyses in the previously approved Shearon Harris FHRR confirmed that the water surface never reaches the 260 ft. NVGD29 elevation, which is at the top of the dam. The NRC staff reviewed the information provided in the response and concluded that the licensee provided an adequate response to the staff's request.
8	8 10/20/15	**Dam Failure-Dam Breach Analysis** Background: Dam breach parameters corresponding to failure were estimated following Froehlich (2008) and Xu & Zhang (2009) methodologies. The method providing the shortest time of failure was considered for each dam and, conservatively, variables corresponding to high erodibility were used in the calculations. However, there were no discussions if there are any alternative methods to consider other than Froehlich (2008) and Xu & Zhang (2009).	The licensee's response (Duke Energy, 2016) confirmed that the two methodologies cited in this Information Need were identified according to the guidance in JLD-ISG-2013-01 (NRC, 2013b). The licensee also noted the ISG guidance does not specify how many methodologies should be used. The licensee selected the Froehlich method because it is widely used in nuclear studies, and the Xu & Zhang method was selected as a recently developed alternative. The license stated that the parameters corresponding to the dam breach methodology with the shortest breach formation time was used, and the licensee indicated that this was the most conservative selection.

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		Request: Provide justification for assessing only the Froehlich (2008) and Xu & Zhang (2009) methodologies in the dam breach analysis.	The NRC staff reviewed the information provided in the responses and concluded that the licensee provided an adequate response to the staff's request.
9	9 10/20/15	**Storm Surge Analysis – Contribution of Seiche Flood Hazard Reevaluated** Background: The seiche flood mechanism was included in the storm surge section titles for both CDB and for the reevaluated hazard. However, the FHRR (Duke Energy, 2015) did not provide any details specific for this mechanism. Request: The licensee is requested to provide a comparison of the CDB flood elevation and the reevaluated flood elevation for the seiche flood-causing mechanism at the site.	In response to this information need the licensee stated that (Duke Energy, 2016): "The evaluation of "surge and seiche" is recommended in Section H.4 of Appendix H of NUREG/CR-7046 (NRC, 2011b) for combined-effect floods along the shores of enclosed bodies of water. Due to the location of the Brunswick site on a semi-enclosed body of water, in the present re-evaluation study, the seiche flood mechanism is considered to be induced by the same storm event that would cause the surge flood, and its potential occurrence is evaluated during the simulation of the storm surge events. In essence, any seiching is expected to occur alongside with the surge, either preceding it, occurring in the wake of the surge, or coinciding with the surge directly driven by the incident storm. Therefore, the results presented for the storm surge events are also inclusive of the seiching mechanism. For this reason, surge and seiche were presented together in Table 5-1 of the FHRR. The contribution of the seiche in the simulated scenarios is relatively minor, on the order of 10% or less compared to the main surge levels and does not inundate the site. A comparison of the current design basis flood elevation and the reevaluated flood elevation for Storm Surge & Seiche is presented in Table 5-1 of the FHRR.

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			The NRC staff reviewed the information provided in the response and concluded that the licensee provided an adequate response to the staff's request.
10	10 10/20/15	**<u>All Flood Causing Mechanisms – Input to Additional Assessment(s) - Mechanisms Considered</u>** <u>Background:</u> SECY-15-0019 "Closure Plan for the Reevaluation of Flooding Hazards for Operating Nuclear Power Plants" (NRC, 2015) requests the licensee to perform the additional assessment(s) of the plant's response to the reevaluated hazard if the reevaluated flood hazard(s) is (are) not bounded by the CDB. The NRC staff noted from Section 5 and Table 5-1 of the FHRR (Duke Energy, 2015) that some of the reevaluated site flood levels exceed the corresponding design-basis flood levels, which trigger the additional assessment. <u>Request:</u> Based on the information provided in FHRR (Duke, 2015), it is not clear to the staff the flood-causing mechanisms that were not bounded by the CDB that Duke subsequently plans to evaluate as part of the additional assessment(s), as described in the 50.54(f) letter (NRC, 2012a) and the COMSECY-15-0019 (NRC, 2015). Specifically, FHRR Table 5-1 lists six (6) reevaluated flood causing mechanisms as not bounded by the CDB (LIP; Streams and Rivers; Dam Breach-overtopping; dam breach-seismic; tsunami and combined effect floods). Provide a Table that confirms all mechanisms not bounded by the CDB that will be further assessed.	In response to this information need the licensee stated that (Duke Energy, 2016): In Table 5-1 in the FHRR (Duke Energy, 2015), Duke expects the following beyond-design-basis events will be input to the MSA: 1. LIP – Seismic Class I safety-related structures, which include the Control Building, Diesel Generator Building, Reactor Buildings 1 and 2, and Service Water Intake Building, are protected against the LIP maximum flooding elevation up to 22 ft. NGVD29. 2. Combined-Effects Flood: The Controlling Scenario that is applicable from Appendix H of NUREG/CR-7046 (NRC, 2011b) is Alternative 3 from "Section H.3.2 Streamside Location": • Probable maximum surge and seiche with wind-wave activity. • 25-year flood. • Antecedent 10% exceedance high tide. The results from FHRR (Duke Energy, 2015) Table 5-1 on Combined-Effects Flood refer to this scenario. The NRC staff reviewed the information provided in the response and concluded that the licensee provided an adequate response to the staff's request.

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11	11 10/20/15	**<u>Input to Additional Assessment(s) - Flood Height and Associated Effects</u>** <u>Background</u>: COMSECY-15-0019 (NRC, 2015) requests the licensee to perform the additional assessment(s) of the plant's response to the reevaluated hazard if the reevaluated flood hazard is not bounded by the CDB. Flood scenario parameters from the flood hazard reevaluation serve as the input to the additional assessment(s). To support efficient and effective evaluations for the additional assessment(s), the NRC staff will review flood scenario parameters as part of the flood hazard reevaluation and document results of the review as part of the staff assessment of the flood hazard reevaluation. <u>Request</u>: The licensee is requested to provide the flood height and associated effects (as defined in Section 9 of JLD-ISG-2012-05 [NRC, 2012b]) that are not described in the FHHR (Duke Energy, 2015) for mechanisms that trigger the additional assessment. This includes the following quantified information for each mechanism (as applicable): • Hydrodynamic loading, including debris • Effects caused by sediment deposition and erosion (e.g., flow velocities, scour) • Concurrent site conditions, including adverse weather • Groundwater ingress • Other pertinent factors	In response to this information need the licensee stated that (Duke Energy, 2016): For hydrodynamic loading, including debris, Tables 4-20 and 4-21 in the BNP FHRR present the Maximum Predicted Hydrostatic and Hydrodynamic Forces and Debris Impact Loads. Effects caused by sediment deposition and erosion (e.g., flow velocities, scour) are found in FHRR Sheet 62 of 68 which states: "No erosion is expected for asphalt/concrete because the maximum values of flow velocity that can be sustained without significant erosion are at least an order of magnitude higher than those expected during the governing combined effect flood scenario. Furthermore, the recommended maximum permissible mean channel velocity for fine gravel per EM 1110-2-1601 (Reference 51) [USACE, 1994] is 6 feet/second. Gravel mobilization could potentially occur in shallow gravel areas further away from the safety-related structures; however, no entrainment and transport in suspension is expected." Concurrent site conditions were analyzed in the combined effects calculation package following NUREG/CR-7046 (NRC, 2011b). For groundwater ingress, the licensee stated that all critical structures essential to a safe shutdown of the reactor are flood protected to EL [elevation] 22 ft.-NGVD29. Therefore, Brunswick is not subject to effects associated with groundwater ingress.

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			The licensee stated that there are no other pertinent factors for the site. The NRC staff reviewed the information provided in the response and concluded that the licensee provided an adequate response to the staff's request. However, the staff notes that the combined effect flood hazard elevation under the storm surge analysis was changed as a result of the NRC staff's review and therefore, the staff expects the licensee to provide revised associated effects values for this hazard in a future submittal for the staff to review.
12	12 10/20/15	**<u>Hazard input to the Additional Assessment(s) - Flood Event Duration Parameters</u>** <u>Background</u>: COMSECY-15-0019 (NRC, 2015) requests the licensee perform an additional assessment(s) of the plant's response to the reevaluated hazard if the reevaluated flood hazard is not bounded by the CDB. Flood scenario parameters from the flood hazard reevaluation serve as the input to the additional assessment(s). To support efficient and effective evaluations for the additional assessment(s), the NRC staff will review flood scenario parameters as part of the flood hazard reevaluation and document the results of the review as part of the staff assessment of the flood hazard reevaluation. <u>Request</u>: The licensee is requested to provide the applicable flood event duration parameters (see definition and Figure 6 of the Guidance for Performing an Integrated Assessment, JLD-ISG-2012-05 [NRC, 2012b]) associated with mechanisms that trigger an additional assessment using the results of the flood	The licensee responded with the following information (Duke Energy, 2016): <u>Warning Time</u> The warning time will be further evaluated as part of the Mitigating Strategies Assessment. <u>Period of Inundation</u> The site begins to flood above door sill until the flood level recedes below door sill. The period of inundation is based on the hydrograph adjacent to door D-24 located on the northwest side of the Turbine building. Door D-24 was estimated in Calculation BNP-MECH-FHR-001 (AMEC, 2015a) to experience the longest period of inundation where the water surface elevation exceeded the plant grade, and therefore all of the other doors are anticipated to experience shorter periods during the LIP event. <u>Recession Period</u>

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		hazard reevaluation. This includes (as applicable) the warning time the site will have to prepare for the event (e.g., the time between notification of an impending flood event and arrival of floodwaters on site) and the period of time the site is inundated for the mechanisms that are not bounded by the CDB. The licensee is also requested to provide the basis or source of information for the flood event duration, which may include a description of relevant forecasting methods (e.g., products from local, regional, or national weather forecasting centers) and/or timing information derived from the hazard analysis.	Due to insignificant difference between ground elevation at door and adjacent ground, recession is assumed to end at the same time as the period of inundation. The NRC staff reviewed the information provided in the response and concluded that the licensee provided an adequate response to the staff's request. However, the staff notes that the flood hazard elevation for the combined event under the storm surge analysis was changed as a result of the NRC staff's review.
13	SSA #1 12/22/15	**Storm Surge Analysis** Background: The FHRR (Duke Energy, 2015) does not include any information related to sea level rise (SLR) at the Brunswick site. Request: Please provide additional information to clarify whether any SLR analyses were completed as part of the surge hazard reanalysis. Also, if these analyses were performed, clarify if and how the SLR was accounted for in the estimation of the storm surge hazard at Brunswick.	The licensee responded that (Duke Energy, 2016): "Projected values for SLR were considered in the analysis, and summarized in the last paragraph on sheet 40 of 43 in the more detailed BNP-MECH-FHR-006 Storm Surge Analysis Calculation [AMEC, 2015f] package. The NUREG CR-7046 Section 5.7 (5-10) [NRC, 2011b] states that in the interest of accounting for the potential effects of climate variability on design-basis flood estimation, a sensitivity analysis may be performed including the effect of projected SLR during the operational life of the plant to determine whether the site has adequate margins available to accommodate anticipated changes in the design-basis flood. In this context, SLR projections can be made based on the assumption that the operational life of Brunswick would last through 2036 (approximately 22 years). The SLR projections derived by Zervas (2004) at the nearest stations with historical water level data to the Brunswick location, at Wilmington and Southport (0.08 in/yr), yield potential increases in mean sea level of 0.15 ft. over the operational life of the plant. Even assuming the highest projected rate based on historical data in North

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			Carolina of 0.168 in/yr (Duck, NC), the projected mean sea level rise would be 0.31 ft. over the next 22 years. These represent very small increases in mean sea level relative to the magnitude of the storm surges and normal tidal range, and are considered to be comparable to the error bounds of the present modeling and analytical methods. Therefore, the projected SLR during the operational life of the plant is not considered to have an impact on the conclusions of the present assessment of flood hazards due to a PMH [Probable Maximum Hurricane] event." The NRC staff reviewed the information provided in the response and concluded that the licensee provided an adequate response to the staff's request.
14	SSA 2 12/12/15	**Storm Surge Analysis** Background: The Brunswick FHRR (Duke Energy, 2015) Combined-Effects Floods section (Section 4h) includes the antecedent 10% exceedance high tide as part of the Alternative 3 analysis. Alternative 3 is stated as representing the governing combined-effect scenario. The FHRR only mentions the magnitude of the 10% exceedance high tide in one location (Section 4b; page 32). The FHRR states that "The HEC-RAS model downstream boundary condition was set to a known water surface elevation of 2.63 ft. NGVD29 corresponding to 10% exceedance high tide in accordance Section H.3.2 of NUREG CR/7046 (Reference 3) [NRC, 2011b]." The FHRR statement references the HEC-RAS modeling and not the Delft3d (storm surge) modeling (Duke Energy, 2015). Request: Please provide additional information to clarify the following:	In response to this information need the licensee stated that (Duke Energy, 2016): a) Yes, the 10% exceedance (90% non-exceedance) high tide value was calculated at 2.63 ft. relative to the NGVD29 datum (2.03 ft. above present-day mean seal level [MSL]), and this level was applied as the initial stillwater level in the Alternative 3 analysis. However note that the base case Probable Maximum Storm Surge (PMSS) event was set to occur at an initial stillwater level equivalent to the present-day MSL. Therefore, the difference in initial stillwater levels between the PMSS and Alternative 3 scenarios is 2.03 ft. The vertical datum applicable to the storm surge calculations were derived from historical data at Southport, and presented in Table 3-3, on sheet 11 of 43, in the detailed BNP-[MECH-FHR]-006 Storm Surge Analysis Calculation (AMEC, 2015f) package. Potential confusion may arise from the fact that all results were ultimately converted and presented relative to the

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		a. Whether the 2.63 ft. NGVD29 value was applied as the 10% exceedance high tide in the Delft3d modeling. b. What data and methodology were applied to develop the 10% exceedance high tide value within the storm surge modeling?	NGVD29 datum, for direct comparison to the UFSAR (Duke, 2012). b) The tidal water level measurements were obtained at Southport, NC (station 8659084). The Southport tide gauge dataset was selected as the nearest location to the BESP site with long-term water level records. Based on a harmonic tidal analysis of a recent full year of data (the year 2007 was selected), a 19-year (2014-2032 inclusive) tidal water level prediction was generated using the Matlab implementation of the UTide toolbox by Codiga (2011). The 10% exceedance (90% non-exceedance) high tide value was derived from the cumulative frequency distribution of the 19-year tidal water level prediction. The NRC staff reviewed the response and concluded that the licensee provided their response/method for the info need. However, a supplemental Information Need was issued (see Information Need #18) to get additional clarification on this response.
15	SSA 3 12/22/15	**<u>Storm Surge Analysis</u>** <u>Background</u>: The FHRR (Duke Energy, 2015) Combined Effects Floods section (Section 4h) includes the 25-year flood as part of the Alternative 3, which is stated as the governing combined-effect scenario. Review of the maximum water surface elevation results in FHRR Tables 4-15 and 4-16 (Storm Surge/Seiche) and Tables 4-18 and 4-19 (Combined Effect Analysis) indicated that Combined Effect Analysis Alternative 3 (which includes 25-year river flow and 10% exceedance high tide) produced maximum water levels at Brunswick that were approximately 2.5 ft. higher than the Storm Surge/Seiche levels. The FHRR did not	In response to this information need the licensee stated that for parts a and b (Duke Energy, 2016): The Alternative 3 scenario included the 25-year flood in the stream, combined with the probable maximum surge and seiche with wind-wave activity occurring at an initial stillwater level equivalent to the 10% exceedance high tide (2.03 ft. above present-day MSL). Therefore, as noted in Info Need Response 14a, the difference in initial stillwater levels between the PMSS and Alternative 3 scenarios is 2.03 ft. Furthermore, the Alternative 3 simulation was initialized by simulating the riverine discharge alone for several days,

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		provide details of how the river flow or 10% exceedance high tide affected the storm surge near Brunswick (Duke Energy, 2015). Request: Please provide additional information to clarify the following: a. Describe how the river flow and 10% exceedance high tide affected the storm surge near Brunswick. b. Given that the only value for the 10% exceedance high tide magnitude indicates a magnitude of 2.63 ft. NGVD (See Information Need 14), explain how the Combined Effect Analysis Alternative 3 values show less than a 2.6 ft. change in maximum water level near Brunswick (Combined Effect Analysis results vs Storm Surge/Seiche results).	allowing the model to spin up the resulting estuarine circulation in a realistic fashion. The timing of events was arranged in a way that the peak water levels near the Brunswick site induced by the riverine flood event were set to approximately coincide with the arrival of the peak storm surge in the Cape Fear estuary in the vicinity of the site. While the different processes are expected to interact with and contribute to the modeled surge levels at the site in a complex and non-linear manner, it is noted that the 2.5 ft. of difference in modeled peak water levels at Brunswick is not fully accounted for by the 2.03 ft difference in initial stillwater levels, and the remaining difference of approximately 0.5 ft can be attributed to the influence of the riverine discharge. The NRC staff reviewed the information provided in the response and concluded that the licensee provided an adequate response to the staff's request.
16	SSA 4 12/22/15	**Storm Surge Analysis** Background: The FHRR (Duke Energy, 2015) (Section 4d, page 46) states that the worst case PMH scenario was developed from 79 different PMH scenarios. The FHRR stated the worst case PMH featured a "a maximum wind speed of 145 knots, radius of 30 mi, forward speed of 30 miles/hour (mi/h), bearing of 310 degrees, landfall point 18.6 mi west of Cape Fear River mouth, and minimum central pressure of 12.96 pounds per square inch, (psi)." The 310 degree bearing equates to a storm heading 50 degrees west of north (FHRR Figure 4-18). The FHRR does not contain details of the results for the 79 screening runs or if other storms produced maximum storm surge near Brunswick that nearly equaled the worst case storm (Duke Energy, 2015).	In response to this information need the licensee stated that (Duke Energy, 2016): The ranges for the different values associated with storm characteristics included in the screening analysis were selected based on the guidance in the NOAA Technical Report 23 (TR23) (NOAA, 1979), as described on sheet 21 of 43 in the BNP-MECH-FHR-006 Storm Surge Analysis Calculation (AMEC, 2015f) package. In particular, limits of storm track directions for the PMH event are presented as a function of coastal distance and storm category in Figure 3-9 (sheet 22 of 43 of the same calculation package, equivalent to Figure 2.9 in the NOAA TR23). The PMH Screening Process is further described in Section 4.2 (sheet 32 of 43) in the BNP-MECH-FHR-006 Storm Surge Analysis Calculation (AMEC, 2015f) package. The stillwater level equivalent to present-day MSL was used in all screening simulations. Based on the

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		As part of the audit material reviewed for Brunswick (FHRR calculations and reports), the staff looked at additional details on the 79 screening storms. Review of the results for the 79 screening runs at licensee-selected locations near the site (PMHscreeningRuns11.xls in the folder: BNP-14-006_Storm_Surge & BNP-14 009_Combined_Effects\01 Data Package\PMH_Screening_Results) indicated that storms with more northerly tracks (bearings 350 or 10) produced significantly higher surge at Southport (less than 4 mi south of the site) than the maximum surge values listed in the tables for the PMH worst case scenario storm. The storms with more northerly tracks that produce high water levels near Southport, feature reduced water levels (more than 2 ft.) at the site. Independent ADCIRC simulations conducted by NRC staff found that that some storms with northerly tracks can feature higher surge levels at Brunswick than at Southport. From the NRC independent ADCIRC simulations, the top surges at Brunswick resulted from storms that featured tracks with storms heading north or east of north. <u>Request</u>: Please provide additional discussion on the physical explanation for how the more northerly storms that feature high water levels at Southport do not result in worst case water levels at Brunswick (see Figures 1 and 2 in Attachment 3; Figure 1: Screen capture from PMHscreeningRuns11.xls with runs sorted by water level at the site; and Figure 2: Screen capture from PMHscreeningRuns11.xls with runs sorted by water level at Southport)	NOAA TR23 (NOAA, 1979) guidance, the plausible limits of storm track directions at landfall were considered within the range of 270 degrees to 10 degrees to true north, and screening runs were subsequently focused on discrete direction bins from 290 degrees to 10 degrees. Therefore, the direction of 30 degrees was not considered as a plausible storm track direction for candidate PMH events as per TR23 (NOAA, 1979). The results from the screening runs indicated a sensitivity to direction at landfall. However, it is noted that the results are simultaneously sensitive to the values of the forward speed and landfall location as well. The simulated surge levels induced by PMH candidate storms near the site are the result of several forcing factors that interact with each other in a complex coastal environment. It is not unexpected that peak water levels would vary spatially and temporally, particularly when comparing water levels at Southport and those in the inflow channel or Nancy's Creek near the site. The licensee provided their response/method for this specific information need. However, the response did not close the Item as the response did not adequately explain the Delft3D model features. Therefore, the NRC staff issued a follow-up information need (Information Need #19).

<table>
<tr><th>Information Need No.</th><th>Reference Number/ Transmittal Date[1]</th><th>Information Need Description</th><th>Response</th></tr>
<tr>
<td>17</td>
<td>SSA 5
12/22/15</td>
<td><u>Storm Surge Analysis</u>
<u>Background</u>: Page 10 of FHRR Section 3 (Duke Energy, 2015), Site Information, contains a footnote related to the conversion between MSL and NGVD29 that states the following: “The UFSAR references most elevations in the Mean Sea Level (MSL) datum. However, Duke Energy verified that the MSL datum referenced in the UFSAR is equal to the NGVD29 datum. Therefore, all elevations in this report will be reported in the NGVD29 datum unless otherwise noted.” The FHRR Calculation Package Document BNP-14-009_Combined_Effects_Calculation_rev0 (contained on hard drive; AMEC2015g)) lists conversions for North American Vertical Datum of 1988 (NAVD88) to NGVD29 and NAVD88 to MSL (Equations 3-1 and 3-2 below). These conversions do not indicate that MSL at Brunswick is equal to NGVD29.
<u>Request</u>: Please provide clarification on how the conversion between MSL and NGVD29 was performed at Brunswick. Please provide clarification on how the conversion between MSL and NGVD29 was performed at Brunswick.</td>
<td>In response to this information need the licensee stated that (Duke Energy, 2016):

“The question arises due to the difference in historical MSL (used in the UFSAR [Duke Energy, 2012] report, and considered equivalent to the NGVD29 datum), and present-day MSL (used in Equations 3-1 and 3-2 in the BNP-[MECH-FHR]-009 Combined Effects Calculation” package) [AMEC, 2015g]. The 10% exceedance tide applicable to the storm surge calculations was derived from historical data at Southport, and presented in Table 3-3, on sheet 11 of 43, in the detailed BNP-MECH-FHR-006 Storm Surge Analysis Calculation (AMEC, 2015f) package, and an excerpt is shown below. The present-day MSL is labeled as MSL (2014).
<table>
<tr><th>Tide</th><th>Water Level (ft MSL)</th><th>Water Level (m MSL)</th><th>Description</th></tr>
<tr><td>90% non-exceedance</td><td>2.03</td><td>0.62</td><td>90% non-exceedance water level</td></tr>
<tr><td>NAVD88</td><td>0.46</td><td>0.14</td><td>North American Vertical Datum, 1988</td></tr>
<tr><td>MSL (2014)</td><td>0.00</td><td>0.00</td><td>Mean Sea Level</td></tr>
<tr><td>NGVD29</td><td>-0.60</td><td>-0.18</td><td>National Geodetic Vertical Datum of 1929</td></tr>
</table>
The NRC staff reviewed the information provided in the response and concluded that the licensee provided an adequate response to the staff’s request.</td>
</tr>
</table>

Information Need No.	Reference Number/ Transmittal Date[1]	Information Need Description	Response
18	SSA 2a 1/28/16	**<u>Supplemental Request for Storm Surge Analysis</u>** <u>Background</u>: The Brunswick FHRR (Duke Energy, 2015) Combined-Effects Floods section (Section 4h) includes the antecedent 10% exceedance high tide as part of the Alternative 3 analysis. Alternative 3 is stated as representing the governing combined-effect scenario. The FHRR only mentions the magnitude of the 10% exceedance high tide in one location (Section 4b; page 32). The FHRR states that "The HEC-RAS model downstream boundary condition was set to a known water surface elevation of 2.63 ft. NGVD29 corresponding to 10% exceedance high tide in accordance Section H.3.2 of NUREG/CR-7046 (Reference 3) [NRC, 2011b]." The FHRR statement references the HEC-RAS modeling and not the Delft3d (storm surge) modeling (Duke Energy, 2015). In Section 3.4.2.1 "Tides", of Interim Staff Guidance number JLD-ISG-2012-06 (NRC, 2013a) the NRC recommends the following: "In computing the surge level, the 10 percent exceedance high tide should be considered to occur coincidentally with the storm surge. The 10% exceedance high tide is the high-tide level that is equaled or exceeded by 10 percent of the maximum monthly tides over the tidal epoch (a continuous 21-yr period in most locations). This tide can be determined from the recorded tide or from the predicted astronomical tide. If astronomical tides are used, sea level anomaly should be added. Sea level anomalies (also referred to as initial rise) are departures of the water surface elevation from astronomical tides due to various meteorological and	In response to this information need the licensee stated that (Duke Energy, 2016): The JLD-ISG-2012-06 (NRC, 2013a) document (Section 3.3.2.1.) states that the 10% exceedance high tide can be derived either from the recorded tide, or from the predicted astronomical tides over the tidal epoch (defined as "a continuous 21-yr period in most locations"). The Southport tide gauge station was selected because it was the nearest station to the Brunswick site, and furthermore the data available were of sufficient quality and length (in excess of 1 continuous year) to provide the basis for a robust harmonic tidal analysis and prediction of astronomical tidal water levels over the tidal epoch (Section 4.0 in BNP-MECH-FHR-004; AMEC, 2015d). Therefore the Southport station was considered by Duke Energy to be the most representative of conditions expected at the Brunswick site. By comparison, the Wilmington station was considered by Duke Energy to be relatively far away from the site (Figure 3-2 in BNP-MECH-FHR-006; AMEC, 2015f), and due to the coastal configuration, subject to localized factors affecting water levels that are not applicable to the Brunswick site (e.g. stronger effect of riverine discharge, and potential local effects of dredging operations in the area). Furthermore, JLD-ISG-2012-06 (NRC, 2013a) states that if astronomical tides are used, sea level anomaly should be added. Sea level anomalies are defined as departures of the water surface elevation from astronomical tides due to various meteorological and oceanographic forcings. The addition of the sea level anomaly as required by JLD-ISG-2012-06 was accomplished through modelling the sea level response to the PMH and Standard Project Hurricane (SPH) events in the Alternative 1 and 3 scenarios in the Combined Effects

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		oceanographic forcings. Historical and current tide observations, information on tidal datum, as well as predicted tide levels can be found on the NOAA Tides and Currents Web site (NOAA, 2012a). NOAA maintains a network of tide gage stations along the U.S. shoreline, including the Great Lakes." <u>Original Request</u>: Please provide additional information to supplement the response provided to information need 14b, which originally requested the following: b. What data and methodologies were applied to develop the 10% exceedance high tide value within the storm surge modeling? <u>Supplemental Request</u>: The NRC reviewers request the following supplemental information: • Discuss the process for selecting data from the Southport station (station 8659084), which provides less than the continuous 21-year period recommended in JLD-ISG-2012-06. • Discuss why a "harmonic tidal analysis of a recent full year of data" (2007) was selected, instead of "the maximum monthly tide over the tidal epoch (a continuous 21-year period in most locations)", as recommended in JLD-ISG-2012-06 (NRC, 2013a). Please explain how this method provides a similar, realistic estimation of the 10-percent exceedance tide as the recommended methodology in JLD-ISG-2012-06 (NRC, 2013a) for calculation of the 10% exceedance high tide.	calculation, and by addition of a 25-year surge level in the Alternative 2 case. In all Combined effects scenarios the initial high tide level was derived purely from the astronomical tides. This approach captures all contributions to the water levels as required by JLD-ISG-2012-06 (NRC, 2013a) and NUREG CR-7046 (NRC, 2011b), while ensuring that storm surge contributions are not counted twice (once in the derivation of the antecedent high tide, and again in the modelling of the surge events). Finally, the JLD-ISG-2012-06 (NRC, 2013a) guidance document defines the tidal epoch as "a continuous 21-yr period in most locations". However in the present calculation the period of 19 years of predicted astronomical tides was selected as appropriate for this location, based on the NOAA definition of the National Tidal Datum Epoch as a 19-year tidal cycle, applicable to all locations except Alaska and the Gulf of Mexico (NOAA, 2000; NOAA, 2016). The 19 year period is used because it is the closest full year to the 18.6-year node cycle, the period required for the regression of the moon's nodes to complete a circuit of 360 degrees of longitude. Therefore, Duke Energy concluded that using 19 years of tidal water levels is not expected to yield meaningfully different values for the 10% exceedance high tide statistic compared to using 21 years of tidal levels. As directed by the 50.54(f) letter (NRC, 2012a), the NUREG CR-7046 (NRC, 2011b) guidance was used as the primary guidance in development of the Combined effects scenarios. It is noted that the NUREG CR-7046 (NRC, 2011b) does not specify that the calculation should only include the monthly maximum values as a basis for the 10% exceedance high tide. The calculation in the FHRR for the antecedent 10 percent exceedance high tide was based on the entire 19-year time

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			series of predicted hourly tidal levels, and not a limited subset of the monthly tidal maxima. The response provides additional information on the licensee's methods and approach for site selection, combined effects, and tidal epoch. However, the response includes reference to guidance that does not represent the most up-to-date guidance on the calculation of the 10% annual exceedance high tide (only use monthly maximum data, not entire data set). Based on discussions with licensee, the licensee then moved forward with calculating the 10% exceedance high tide using only the monthly maximum data. On October 27, 2016, Duke Energy provided final results with revised 10% tide level included. The results table did not contain a separate value for 10% exceedance high tide, just the storm water levels based on models that applied a revised tide. Based on results and comparison to original FHRR tables, the new tide level is about 2 ft. higher than original FHRR value (2.63 ft. NGVD). The licensee provided an explicit statement in the enclosure "10% Exceedance High Tide Adjustment" (Duke Energy, 2017) which stated that: "Tidal water level measurements were obtained at Southport, NC (station 8659084). The Southport tide gauge dataset was selected as the nearest location to the Brunswick site with long-term water level records. The calculation proceeded in the following stages: i. A harmonic tidal analysis of a recent full year of data (the year 2007 was selected) was conducted in order to extract the astronomical tidal constituents in a robust manner.

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			ii. The tidal constituents were then used to generate a 21-year (2014-2034 inclusive) tidal water level prediction using the Matlab implementation of the UTide toolbox by Codiga (2011). iii. Monthly maxima were extracted over the 21-year period, amounting to 252 monthly maximum values. iv. The 10% exceedance value (3.56 ft. above MSL) was taken as the 26th highest value among the monthly maximum values, equaled or exceeded by 10% of the monthly maxima (25 months). The NRC staff reviewed the information provided in the response and concluded that the licensee provided an adequate response to the staff's request.
19	SSA 4a 2/2/16	**<u>Supplemental Request for Storm Surge Analysis</u>** <u>Background</u>: The FHRR (Section 4d, page 46) (Duke Energy, 2015) states that the worst case PMH scenario was developed from 79 different PMH scenarios. The FHRR states the worst case PMH featured "a maximum wind speed of 145 knots, radius of 30 mi, forward speed of 30 mi/h, bearing of 310 degrees, landfall point 18.6 mi west of Cape Fear River mouth, and minimum central pressure of 12.96 psi." The 310 degree bearing equates to a storm heading 50 degrees west of north (FHRR Figure 4-18). The FHRR does not contain details of the results for the 79 screening runs or if other storms produced maximum storm surge near Brunswick that nearly equaled the worst case storm (Duke Energy, 2015).	In response to this information need the licensee provided (Duke Energy, 2016): Figures depicting snapshots of water level elevations at 10-minute (min) intervals for the selected 6 storm events (nominally ordered 1 to 6 as presented in the request) from the screening runs. Figures were provided for Areas 1 and 2, as well as over a wider area over the continental shelf (labeled as Area 0). The series of figures have been used to produce animations at 6 frames per second (1 hour model time per second). The folder names, figure titles and animation file names were labeled using the format "PMH_u145_r45_s45_b310_lf30", to provide the basic parameters of the storm events, as follows: u (max wind speed, knots); r (radius of max winds, km); s (forward speed, km/h); b (storm track bearing, degrees to); lf (landfall distance west of Cape Fear River mouth, km). The figures and animations depict the spatial and temporal variability of the

Information Need No.	Reference Number/ Transmittal Date[1]	Information Need Description	Response
		As part of the audit material reviewed for Brunswick (FHRR calculations and reports), the NRC staff reviewed the results for the 79 screening runs at licensee-selected locations near the site (PMHscreeningRuns11.xls in the folder: BNP-14-006_Storm_Surge & BNP-14 09_Combined_Effects\01 Data Package\PMH_Screening_Results). The review indicated that storms with more northerly tracks (bearings 350 or 10) produced significantly higher surge at Southport (less than 4 mi south of the site) than the maximum surge values listed in the tables for the PMH worst case scenario storm. The storms with more northerly tracks that produce high water levels near Southport, feature much reduced water levels (more than 2 ft.) at the site. Independent ADCIRC simulations conducted by NRC staff found that some storms with northerly tracks can feature higher surge levels at Brunswick than at Southport. From the NRC independent ADCIRC simulations, the top surges at Brunswick resulted from storms that featured tracks with storms heading north or east of north. <u>Original Request</u>: Please provide additional discussion on the physical explanation for how the more northerly storms - that feature high water levels at Southport - do not result in worst case water levels at Brunswick (See Figures 1 and 2 in Attachment 3; Figure 1: Screen capture from PMHscreeningRuns11.xls with runs sorted by water level at the site and Figure 2: Screen capture from PMHscreeningRuns11.xls with runs sorted by water level at Southport) <u>Supplemental Request</u>: The NRC reviewers request the following supplemental information:	surge response in the Cape Fear Estuary, and illustrate the differences in water at Southport and the Brunswick site. Figures of bathymetry and topography of Areas 1 and 2 were attached, along with the bathymetry for the wider Area 0, consistent with the results figures presented above. Figure 1, Figure 2, and Figure 3 present the bathymetry for Areas 0, 1, and 2, respectively. Uniform roughness coefficient values were applied throughout the Delft3D grids, therefore separate maps are not provided. The Delft3D model incorporates a characterization of sea bottom and land roughness based on the Manning roughness coefficient, where the value of 0.020 $s/m^{1/3}$ (0.013 $s/ft^{1/3}$) has been used as the most appropriate value for the overall model domain. The staff found the licensee response and products (figures/tables) provide the materials requested. However, NRC staff had unresolved questions concerning the model results within the products provided. The products do not remove the concerns of the NRC staff over the Delft3D model features, therefore the NRC staff requested supplemental information (see Information Need #22).

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		• For each of the two approximate areas shown in Figures 3 and 4 (Area 1, Area 2) shown in Attachment 3 please provide a series of figures or an animation of water levels for the storms listed in Table 1. The products provided (series of figures or animations) should include temporal resolution to show how the storm surge propagates northward from the ocean past Southport and to the site. • Provide figures that show the Delft3d model bathymetry and topography for Area 1 and Area 2 with a contour interval for Area 2 that allows examination of features that will alter storm surge between Southport and the site. • Provide figures that show the Delft3d model land use and/or bottom friction coefficient for Area 2 with a contour interval that allows examination of features that will alter storm surge between Southport and the site.	
20	13 2/2/16	**Calculation of wind wave effects** Background: Section 3(b)(7) of the FHRR (Duke Energy, 2015) discusses combined effects, including wave runup, but it does not appear in Section 3(b)(7) that any of the wind-wave analysis applies to streams and rivers flooding. In addition, FHRR Section 4(h) describes the analysis of combined effects as applicable to "combined sea-related and riverine flooding," but no combined effects calculations appear to be provided for riverine (a.k.a. streams and rivers) flooding by itself.' Guidance in NUREG/CR-7046 (NRC, 2011b) describes a hierarchical hazard assessment approach in Section	In response to this information need the licensee stated that (Duke Energy, 2016): From Calculation BNP-MECH-FHR-004 (AMEC, 2015d), the governing precipitation-driven peak discharge (512,000 cubic feet per second (cfs), the overtopping dam failure peak discharge (674,505 cfs), and the seismic dam failure peak discharge (360,491 cfs) produce a peak water surface elevation of [[redacted]] ft. NAVD88 ([[redacted]] ft. NGVD29), [[redacted]] ft. NAVD88 ([[redacted]] ft. NGVD29), and [[redacted]] ft. NAVD88 ([[redacted]] ft. NGVD29), respectively, at the Brunswick intake. This is [[redacted]] ft., [[redacted]] ft. and [[redacted]] ft.,

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		2. That approach specifies what is needed for the analysis of wind-wave combined effects in regard to the PMF: "Therefore, the PMF is estimated using a conservative and a relatively simple approach. Coincident wind waves should now be estimated at the site based on the longest fetch length and a 2-year wind and added to the PMF stillwater elevation at the site." Without the inclusion of wind and wave effects for streams and rivers flooding, the margin to site grade is not clearly defined. Furthermore, there is no design basis for the streams and rivers flooding mechanism to compare the reevaluated flooding results. <u>Request</u>: The staff requests that wind and wave calculations be provided relative to the streams & rivers flooding mechanism. These calculations should be provided independent from other flooding mechanisms. The calculations should indicate the amount of margin to site grade at the Brunswick site from the PMF when wind and wave effects are included.	respectively, below the nominal plant grade elevation ([[redacted]] ft. NAVD88/[[redacted]] ft. NGVD29). Calculation BNP-MECH-FHR-009 (AMEC, 2015g) recognizes in Section 3.1 that Appendix H.1 of NUREG/CR-7046 (NRC, 2011b) requires that floods caused by precipitation events are evaluated using combined wind-wave activity derived from the 2-year wind speed applied along the critical direction, on top of stillwater levels from the governing precipitation-driven PMF and dam failure scenario. However, it is noted in Section 6.1 of Calculation BNP-MECH-FHR-009 (AMEC, 2015g) that a stillwater level of [[redacted]] ft. NGVD29 is calculated (in Calculation BNP-MECH-FHR-004; AMEC, 2015d) from the resulting combination of the governing PMF and postulated dam failure; the site is not flooded, and thus waves will not affect the Brunswick site under this scenario. With regard to Nancy's Creek, from Calculation BNP-MECH-FHR-005 (AMEC, 2015e), the governing PMF discharge produces a peak water surface elevation in Nancy's Creek of [[redacted]] ft. NAVD88 ([[redacted]] ft. NGVD29) which is approximately [[redacted]] ft. below the plant grade ([[redacted]] ft. NAVD88 / [[redacted]] ft. NGVD29). Analogously to the case of flooding from the Cape Fear River, the site is not flooded, and waves will not affect the Brunswick site under this scenario. As a conservative assessment, the impact of waves on the maximum water surface elevation can be evaluated by using the maximum value of wave runup on vertical structures of [[redacted]] ft, computed in Calculation BNP-MECH-FHR-009 (AMEC, 2015g) for the Surge and Seiche scenario for Probable Maximum Hurricane (PMH) and also reported in Table 5-1 of the FHRR (Duke Energy, 2015). Being this value is associated with the PMH, it represents a very conservative

Information Need No.	Reference Number/ Transmittal Date[1]	Information Need Description	Response
			estimate for the streams and rivers flooding scenario. Adding the [[redacted]] ft. wave runup to the peak stillwater surface elevation of [[redacted]] ft. NAVD88 ([[redacted]] ft. NGVD29) for the Cape Fear River and [[redacted]] ft. NAVD88 ([[redacted]] ft. NGVD29) for Nancy's Creek provides a maximum water surface elevation of [[redacted]] ft. NAVD88 ([[redacted]] ft. NGVD29) and [[redacted]] ft. NAVD88 ([[redacted]] ft. NGVD29), respectively. In both cases, the maximum water surface elevation is still below plant grade (freeboard of [[redacted]] ft. for the Cape Fear River and [redacted] ft. for Nancy's Creek), therefore not challenging the site. Even using the maximum value of wave runup on vertical structures for buildings not containing [structures, systems and components] SSCs of [[redacted]] ft. ([[redacted]] ft. greater than the [redacted]] ft. value for buildings containing SSCs) leads to the same conclusion. The NRC staff reviewed the information provided in the response and concluded that the licensee provided an adequate response to the staff's request.
21	14 2/2/16	**<u>General Clarification:</u>** <u>Background</u>: It appears that there may be a typographical error in the FHRR relative to overtopping dam breach at the top of page 42 of 68; ([[redacted]] ft. and [[redacted]] ft.) (Duke Energy, 2015). These numbers are not consistent with the values presented in Table 5-1 on page 63 of 68; ([[redacted]]). The numbers in the text of the FHRR are the same as streams and rivers values for Nancy's Creek. <u>Request:</u> Please clarify the apparent discrepancy.	The licensee's response referred to calculation package BNP-MECH-FHR-004 (BNP-14-004) (AMEC, 2015d) and agreed that the values at the top of page 42 of the FHRR are a typographical error, and that the values for Nancy's Creek were reported by mistake. The licensee stated that the values in FHRR Table 5-1 are correct for the Cape Fear River (i.e., [[redacted]] ft. NGVD29 peak water surface elevation, which is [[redacted]] ft. below nominal plant grade). The NRC staff reviewed the information provided in the response and concluded that the licensee provided an adequate response to the staff's request.

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22	SSA 4b 3/16/16	**<u>Supplemental Request for Storm Surge Analysis</u>** <u>Background</u>: After analyzing the licensee's responses to the information needs on the storm surge analysis and the discussion held during the March 10, 2016, audit, the NRC staff determined the need for additional supplemental information. This additional information will support the evaluation of the licensee's methodology and results of the reevaluated storm surge flooding mechanism at Brunswick. <u>Request</u>: 1. The license should provide plots that show the maximum water level (over the entire storm) for the 6 storms included in our original Information need request. Figure extents that match the licensee's Area 0, 1, and 2 (licensee ground elevation plots) would allow comparison between storms and locations. 2. To understand the features water level gradients inside/outside the barrier islands observed (and discussed) during the audit, the licensee is requested to provide ground elevation and water levels along the transects shown in the figure below [see Attachment 3). The water level data should occur at times before, during, and after peak water levels inside and outside of the barrier islands.	In response to this information need the licensee uploaded documentation (Duke Energy, 2016) that listed for each of the six storm events the time of maximum water level and a tabular reference for page numbers corresponding to the profile set for each of the four transects. The licensee also uploaded plots of water level and ground elevation at 10-minute time steps along each of the four identified transects and for each of the six storm events. The licensee's response and products (figures/transects) provide most of the materials requested in this revised information need request. However, the maximum water level plots for the 6 storms were not provided. After review of the transect plots, NRC staff had unresolved questions concerning the model results within the products provided and therefore, issued a supplemental information need request (See Information Need # 23).
23	SSA 4c 4/13/16	**<u>Supplemental Request for Storm Surge Analysis</u>** <u>Background</u>: After analyzing the licensee's responses to the information needs on the storm surge analysis	In response to this information need the licensee provided maximum water level plots for six storm events

Information Need No.	Reference Number/ Transmittal Date[1]	Information Need Description	Response
		and the discussion held during the March 10, 2016, Flooding Hazard Audit, the NRC staff determined the need for additional supplemental information. The intention of Information Need 22 Part 1, was to receive, for each of the six storm events, a contour plot of Area 0, 1, and 2 that showed the maximum water level that occurred over the entire storm event. These "maximum plots" plots would show the maximum water level that occurred during the storm for each location in the area (Area 0, 1, and 2). In response to Information Need 22 Part 1, the information uploaded to the Certrec site on 3/29/16 includes a document that lists, for each of the six storm events, the time of maximum water level and page number in profile set for each of the four transects. <u>Supplemental Request</u>: Provide for each of the six storm events, a contour plot of Area 0, 1, and 2 that shows the maximum water level that occurred over the entire storm event in that specific area. The contour plots should contain contour ranges specific to the plot area such that gradients in water level are discernable.	The licensee stated in response to the information request (Duke Energy, 2016) that the water level gradients modeled over the barrier islands south of the Brunswick site develop mainly due to a combination of two factors: i. the difference in water levels inside the estuary and offshore from the barrier islands, maintained over a period of time due to the characteristic response of the estuary to the storm forcing, which is different from the response on the offshore side of the barrier islands; ii. The effectiveness of the barrier islands in restricting water transfer into the estuary through overtopping, due to the relatively small difference between the maximum modelled surge levels and barrier island elevation during the screening runs. During the pre-peak stage of the PMH_u145_r45_s55_b10_lf30 storm, the surge levels rise faster on the offshore side of Transect 4, south of the barrier islands, than they do inside the estuary. This is due to a combination of the gradual approach of the large pressure-induced surge feature to the west of the mouth of the estuary, which increases surge levels offshore, while there is a limited influx of water into the estuary before overtopping of the barrier islands; as well as due to the predominantly easterly winds that push the water inside the estuary to the west behind Oak Island, maintaining lower levels on the estuary side of Transect 4. As soon as the water levels on the offshore side rise to the level where the barrier islands are overtopped, the levels on the estuary side rise faster until the gradient disappears. During the adjustment period (before Day 00 19:00:00), a water level gradient exists over the barrier islands with an estimated slope of up to roughly 4%. Estimates of the Froude number during this period indicate that the flow would indeed be expected to become critical or

Information Need No.	Reference Number/ Transmittal Date[1]	Information Need Description	Response
			supercritical over the peaks of the barrier islands, particularly in the earlier stages of overtopping when the water depth is very shallow. Our review of the Delft3D model results, and tests conducted using an alternate numerical scheme for handling more extreme supercritical flows, indicate that the model exhibits stable and reasonable behavior during and after the periods when supercritical flow occurs, with either numerical scheme. Therefore we do not find evidence that the occurrence of water level gradients over the barrier islands in the screening runs is unphysical or contributes to unreasonable surge response near the Brunswick site. More discussion on the handling of supercritical flow by Delft3D is provided in response b. Based on the limited information available on the NRC independent SWAN+ADCIRC model setup, it is plausible that the differences in behavior between those runs and the Delft3D screening scenarios arise due to differences in the physical processes included in the models. Namely, it is Duke Energy's understanding that the SWAN+ADCIRC model mentioned in the information need request includes wave forcing (through radiation stresses) on the flow. The Delft3D screening-level runs did not include a coupled wave model, as the screening process aimed to quantify the relative impact and ranking of the storm candidates based on the main wind- and pressure-driven surge component. The full set of physical processes, including the coupled wave model (2-way coupling), were added to the flow model in the main model runs presented in the FHRR. The results presented for the base case PMH scenario indicate that the additional forcing by the coupled wave model contributes more than 5 ft to the surge levels observed for the selected PMH event PMH_u145_r45_s45_b310_lf30), compared to the equivalent

Information Need No.	Reference Number/ Transmittal Date[1]	Information Need Description	Response
			screening-level run. Therefore, NRC notes that the maximum surge levels of the Delft3D screening-level runs are not directly comparable to a model run that includes wave coupling. Furthermore, it is plausible that if the NRC independent runs included wave forcing as postulated above, and assuming the storms and antecedent water levels are comparable, the additional surge contribution due to the wave forcing could result in overtopping of the barrier islands at a significantly faster rate and with a larger height of the water column above the barrier island (allowing larger fluxes), than would occur without wave forcing (as seen in the Delft3D screening-level runs). In that case it is plausible that the modeled water level gradients would be weaker, or would persist for significantly shorter periods of time. The occurrence and persistence of water level gradients across the barrier islands could be further diminished if the antecedent water level for the SWAN+ADCIRC model is higher than MSL, as this would further decrease the time to full inundation and water fluxes over the barrier islands. The Delft3D screening scenarios, and PMH base case scenario, were run with an initial level of MSL. There was no discussion of supercritical flow in response b; however, the licensee stated in their white paper (Duke Energy, 2017) that "[t]he Delft3D screening level run exhibited stable behavior during the entire duration of the simulation and over all areas, with relatively smooth variability in water levels and currents. The Delft3d screening runs were conducted with the default Delft3d method for spatial discretization of the horizontal advection terns, called the Cyclic scheme." The staff found the licensee's response and products (figures) provide the materials requested. However, NRC staff had unresolved questions concerning the model results within the

Information Need No.	Reference Number/ Transmittal Date[1]	Information Need Description	Response
			products provided. The products do not remove the concerns of the NRC staff over the Delft3D model features, therefore the NRC staff requested supplemental information (see Information Need #24).
24	SSA 4d 5/17/16	**<u>Supplemental Request for Storm Surge Analysis</u>** <u>Background</u>: In order to determine the degree to which the wind field differences between the licensee's and NRC's independent surge analysis contribute to surge stillwater level determinations, the staff is considering a more direct comparison of the simulations. The information below should provide the needed data pertinent to the wind fields used in the licensee's storm surge analysis in order to perform a simulation in ADCIRC. <u>Request</u>: The NRC staff request the licensee provide the wind field data used for the analysis of the following candidate storms: • PM45_r45_s55_b10_lf45; storm similar to NRC storm that produced high water levels at site (storm moving 10 degrees east of north; similar to NRC independent simulations with high surge) • PMH_u145_r45_s45_b310_lf30; FHRR storm that produced highest water levels at site (storm moving to northwest; 310 degrees angle) • PMH_u145_r45_s45_b10_lf45; very similar to NRC storm that produced highest water levels at site (slower forward speed, more similar to NRC independent simulations). Please provide the requested data in one of the following format options:	In response to this information need the licensee stated that (Duke Energy, 2016): Duke Energy provided FHRR storm files in ADCIRC model format to the NRC for independent study in the ADCIRC model as requested. On June 26, 2016, the NRC provided feedback from the NRC independent analysis of the differences in surge still water elevations. The NRC independent Delft3D model storm results show stillwater elevations that are ~3-7 ft higher than FHRR values (with higher wind drag coefficient value (Cd) for maximum wind speeds). The NRC contends that higher wind coefficients are supported by recent data and studies (Powell, 2007). FHRR model runs applied Cd value that are non-conservative (too low). The NRC simulations testing Delft3D model time step and other parameter settings did not produce significant changes in maximum water levels. The NRC simulations with ADCIRC applying Brunswick Delft3D model storm forcing water levels ~10 ft higher near site that FHRR Delft3D model. Dr. Peter Vickery was engaged by Duke Energy to perform an independent evaluation of the AMEC selection of PMH parameters and specifically, the sea surface drag coefficient used in the resulting storm surge calculations/models. Dr. Vickery's review was presented to the NRC staff during the webinar on 9/29/16. Dr. Vickery's independent conclusion was that the PMH parameters were reasonable and followed

Information Need No.	Reference Number/ Transmittal Date[1]	Information Need Description	Response
		Option 1: The attached Excel file[2] contains the detailed information related to the nested wind and pressure grids applied in the ADCIRC model from the Oceanweather (OWI) data. If the licensee can provide their winds in a similar format for receiving the FHRR storm winds would help ensure the best comparison to the NRC independent simulations. Option 2: Provide a gridded dataset of X_wind, Y_wind, and pressure over time, but the grid must cover the entire ADCIRC domain for some of the input formats, which is quite a large area. Option 3: The link below provides the documentation for the various wind forcing formats accepted by ADCIRC. Provide wind files in some of the accepted formats (i.e. Hwind or ATCF Best Track), http://adcirc.org/home/documentation/users-manual-v51/input-filedescriptions/single-file-meteorological-forcing-input-fort-22/.	the guidance prescribed in NOAA Technical Report NWS 23. Dr. Vickery also concluded that the wind drag coefficient selected in the AMEC FHRR model was consistent with latest technical studies (Powell et al 2003; Holthuijsen et al. 2012). A webinar with the NRC staff, Duke Energy, and ARA consultants was held on 9/29/16 to discuss PMH storm size, model variation (wind drag coefficients), and 10% exceedance high tide determination. A site visit at Brunswick was held on February 23, 2017. The NRC staff and the licensee discussed the remaining issues with the FHRR storm surge analysis and the uncertainty associated with the storm surge stillwater and total water surface elevation flood hazards. The licensee agreed that an upward adjustment of the FHRR flood hazard elevations was appropriate to provide additional margin as a measure of conservatism. These adjustments were included in the Brunswick FHRR Mitigating Strategies Flood Hazard Information Table 2 (NRC, 2017). In addition, the NRC staff expects the licensee will provide any revised flood event durations and associated effects for this hazard as part of the Mitigating Strategy Assessment.

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[2] The referenced excel sheet is not provided in this summary report, since it was provided to the licensee to clarify the format of information to be submitted in the electronic reading room.

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Duke Energy, 2016, Fukushima NTTF 2.1 BRUNSWICK Storm Surge Audit ERR Database Entry #13, "Brunswick Nuclear Plant Flooding FHRR Item Tracker Revision 3", Added November 7, 2016.

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ATTACHMENT 3
Brunswick Steam Electric Plant, Units 1 and 2 Information Need Figures

Wind Speed (Knots)	Radius (km)	Forward Speed (km/h)	Bearing (deg to)	Landfall (km west of Cape Fear River Mouth)	C1	C03	NC3	Southport	B13
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13.48	[illegible]	14.60	13.19	[illegible]
145	45	35	290	45	12.93	13.78	[illegible]	12.24	13.88
145	45	35	290	60	12.66	13.68	14.63	12.17	13.81
145	45	35	350	45	13.45	13.75	14.57	14.27	13.81
145	45	45	330	30	13.65	13.75	14.57	13.85	13.78
145	45	45	330	45	13.55	13.71	14.44	14.44	13.75
145	45	35	310	30	13.02	13.62	14.53	12.63	13.68
145	45	35	310	45	13.09	13.55	14.30	12.89	13.65
145	45	35	330	45	13.22	13.58	14.44	13.81	13.65
145	45	55	310	45	13.22	13.55	14.30	13.22	13.65
145	45	35	330	60	12.89	13.39	14.21	13.68	13.48
145	45	35	310	60	12.73	13.35	14.17	13.22	13.45
145	45	45	290	60	12.40	13.25	14.21	12.04	13.45
145	45	35	350	30	13.45	13.39	13.98	14.04	13.42
145	45	45	310	60	12.86	13.32	14.11	13.16	13.39
145	45	55	310	60	12.93	13.32	14.01	13.35	13.39
145	45	55	350	45	13.78	13.39	13.55	15.72	13.39
145	45	35	290	30	12.50	13.22	14.24	11.81	13.32

C1: Mouth of inflow channel
C03: Inflow channel near plant
NC3: Nancy's Creek near plant
B13: Water building
SouthportIHO

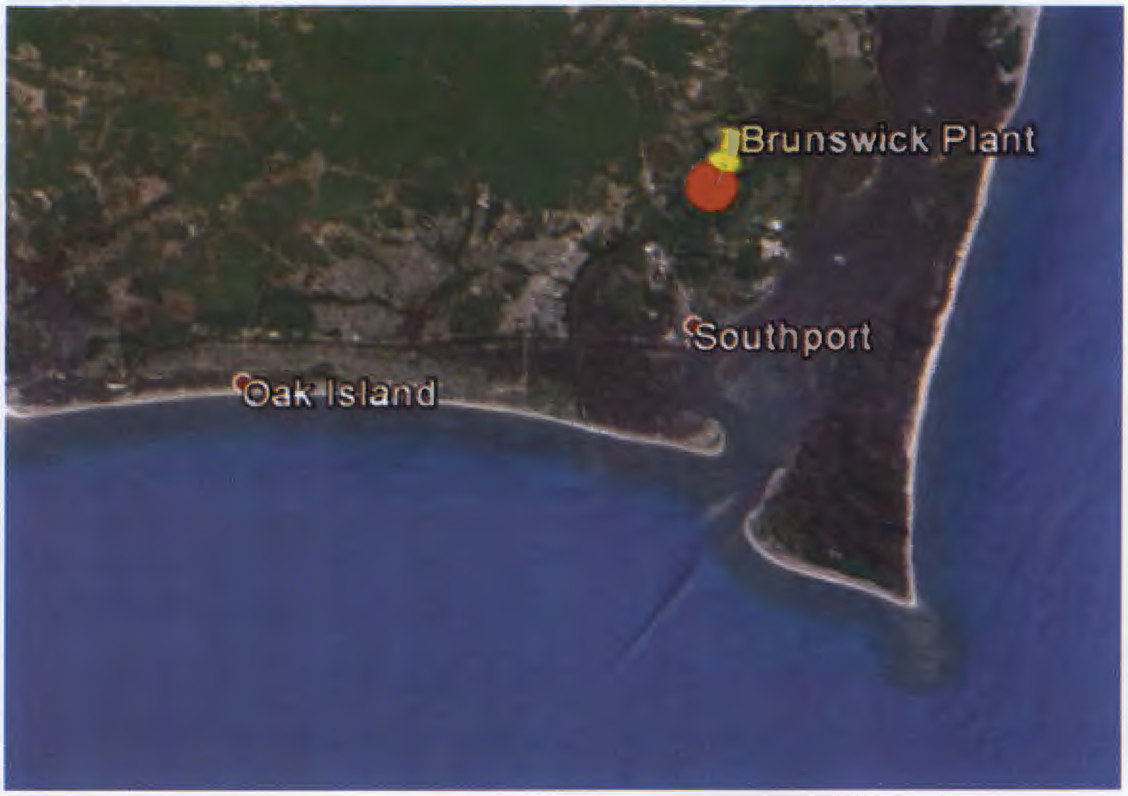
Information Needs 16 and 19 – Figure 1: Screen capture from PMHscreeningRuns11.xls with runs sorted by water level at the site

Wind Speed (Knots)	Radius (km)	Forward Speed (km/h)	Bearing (deg to)	Landfall (km west of Cape Fear River Mouth)	C1: Mouth of inflow channel	C03: Inflow channel near plant	NC3: Nancy's Creek near plant	Southport IHO	B13: Water building
145	45	55	350	45	13.78	13.39	13.55	15.72	13.39
145	45	55	10	30	13.88	13.09	12.57	15.52	13.02
145	45	55	10	45	13.35	12.86	12.96	15.35	12.76
145	45	45	10	30	13.75	13.32	13.35	14.76	13.25
145	45	45	350	45	13.39	13.25	13.75	14.70	13.32
145	45	55	350	30	13.65	12.96	12.53	14.67	12.96
145	45	45	330	45	13.55	13.71	14.44	14.44	13.75
145	45	55	350	60	12.83	12.76	13.12	14.44	12.76
145	45	45	10	15	13.65	12.80	11.91	14.40	12.70
145	45	55	330	45	13.22	12.96	13.55	14.30	13.02
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13.45	13.75	[illegible]	14.27	[illegible]
145	45	45	350	30	13.42	12.96	12.93	14.27	12.96
145	45	55	10	15	13.16	12.27	10.27	14.21	12.14
145	45	45	10	45	12.96	12.57	12.80	14.21	12.50
145	45	45	350	60	12.98	13.06	13.52	14.14	13.09
145	45	45	350	15	13.52	12.89	12.37	14.11	12.86
145	45	35	350	30	13.45	13.39	13.98	14.04	13.42
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13.65	13.75	14.57	13.85	[illegible]
145	45	35	330	45	13.22	13.58	14.44	13.81	13.65
145	45	45	330	60	12.83	13.09	13.71	13.81	13.16
145	45	55	330	60	12.73	12.83	13.52	13.81	12.89
145	45	55	330	30	13.39	13.12	13.85	13.68	13.16
145	45	35	330	60	12.89	13.39	14.21	13.68	13.48
145	45	55	330	15	13.48	12.83	13.29	13.65	12.86
145	45	55	350	15	12.96	11.94	10.33	13.58	11.42
145	45	35	10	45	12.86	12.99	13.68	13.48	13.09
145	45	35	10	30	13.09	13.22	13.85	13.39	13.25
145	45	55	310	60	12.93	13.32	14.01	13.35	13.39
145	45	35	350	60	12.60	12.86	13.65	13.25	12.93
145	45	55	310	45	13.22	13.55	14.30	13.22	13.65
145	45	35	310	60	12.73	13.35	14.17	13.22	13.45
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13.48	[illegible]	[illegible]	13.19	[illegible]

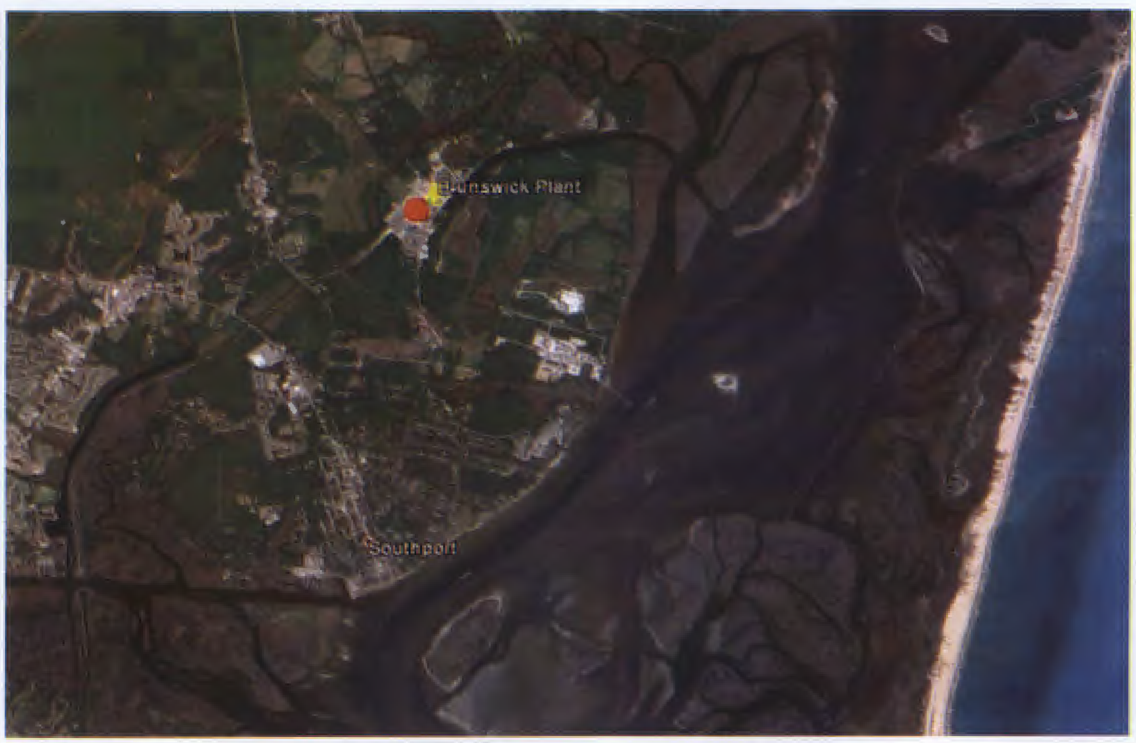
[illegible]
FHRR 2rd highest at Plant
FHRR 3rd highest at Plant
FHRR 4th highest at Plant
FHRR 5th highest at Plant

C1: Mouth of inflow channel
C03: Inflow channel near plant
NC3: Nancy's Creek near plant
B13: Water building
SouthportIHO

Information Need Nos. 16 and 19 – Figure 2: Screen capture from PMHscreeningRuns11.xls with runs sorted by water level at Southport



Information Need No. 19 – Figure 3: Area 1 approximate boundary



Information Need No. 19 – Figure 4: Area 2 approximate boundary

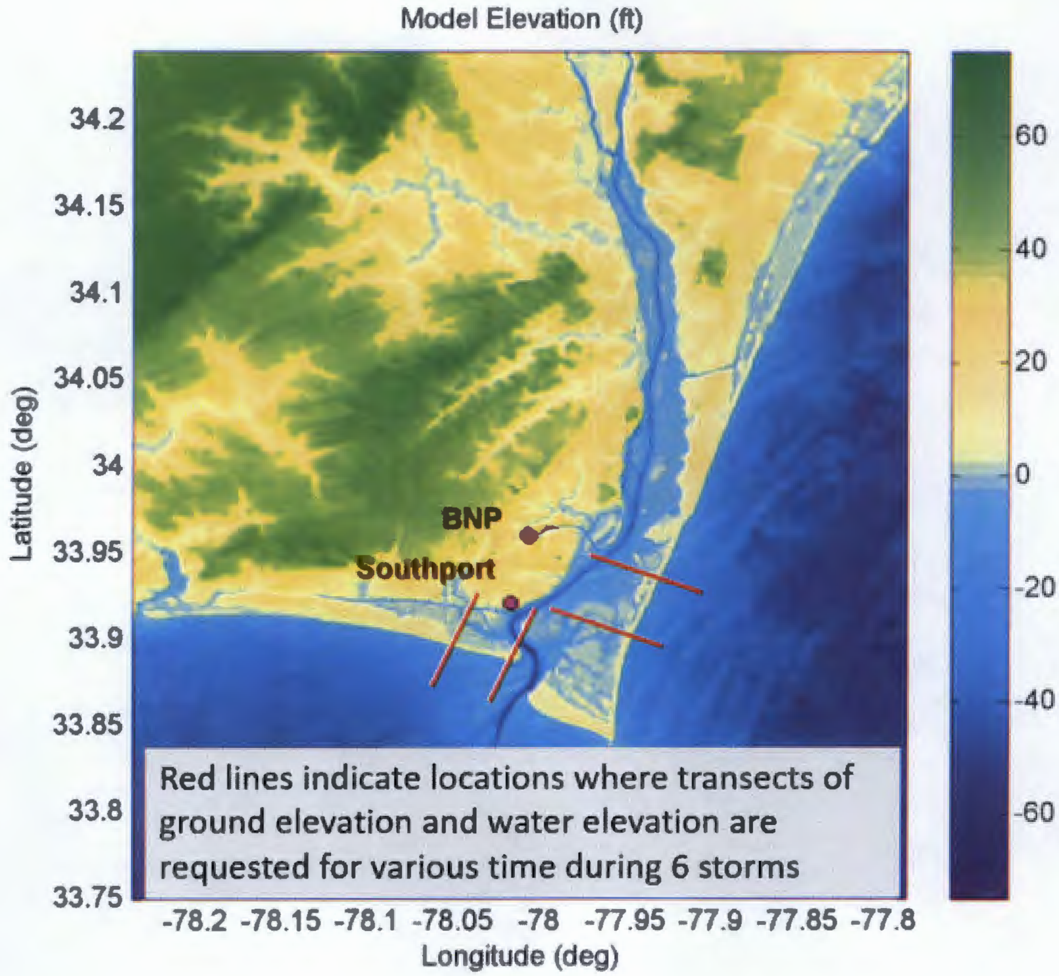


Figure 2: Area 1

Information Needs No. 22 – Figure of Transects

ATTACHMENT 4
WHITE PAPER SUMMARY OF BRUNSWICK'S FLOODING AUDIT REVIEW AND LICENSEE'S REVISED 10% EXCEEDANCE HIGH TIDE STATEMENT

Duke prepared a white paper (WP) that compiled information from various sources to facilitate a path forward with regard to the NRC staff's review of FHRR. The WP contained a summary of its seven enclosures that were relevant to the FHRR storms surge modeling. With regards to storm surge, the licensee stated in the WP that "[r]esolution is not as simple as evaluating strictly the wind drag coefficient but evaluating the storm selection that impacts the selection of the wind drag coefficient, which involves calibration and validation of the other model parameters." In the information needs summary table, the staff drew from the WP enclosures to document the status of specific information needs. Summary information is presented below from the WP and its enclosures:

<u>Enclosure 1: Independent Evaluation of Brunswick Nuclear Plant Probable Maximum Hurricane (PMH) Parameters</u>

"This paper evaluates the hurricane parameters used in the storm surge analysis provided in the FHRR to define the probable maximum hurricane (PMH). The paper employed the use of a peer reviewed hurricane simulation model and a review of the PMH parameters given in the NWS-23 publication. This paper indicates that the PMH parameters in the FHRR are reasonable, and clearly meet the requirement of NWS-23 in that the parameters are a rare combination, likely having a probability of 10^{-7} or less."

<u>Enclosure 2: Evaluation of FHRR Hydraulic Gradients Across Frying Pan Shoals</u>

"The paper discusses the behavior of the hydraulics in the Brunswick FHRR Delft-3D model results on storm surge with concentration on the area located near Frying Pan Shoals. In order to provide clarity, a description of the driving forces behind the hydraulics is provided as well as an overview of important storm input parameters. The barrier islands present a significant obstacle for the surge to overcome, particularly in the screening-model runs that do not include the wave contribution to coastal surge. Ultimately the results from the Delft3D screening runs, as well as those from the comprehensive model runs presented in the FHRR, are consistent with and explained by the atmospheric forcing and the coastal configuration near the site."

<u>Enclosure 3: Independent Evaluation of FHRR Hydraulic Gradients Across Frying Pan Shoals Evaluation</u>

"The document reviews the evaluation of the FHRR hydraulic gradients across the Frying Pan Shoals discussion provided in Enclosure 2. This discussion provides details on a numerical study of the storm surge threat at Brunswick. This paper relates to the FHRR in that is assesses the storm surge hazard threat at Brunswick under extreme tropical cyclone conditions. In the FHRR, flooding from coastal storm surge at the site was evaluated by simulating the coastal ocean response to probable maximum hurricanes (PMH), using the Delft3D modeling system. This paper states the Delft3D is an accepted model for this type of analysis. The regional response to a wind field with large onshore/offshore differences results in water level differences and gradients, the sizes of which are functions of the wind speed, the detailed orientation of the winds to the irregular coastline, and the complexity of the real coastline. The primary mechanisms that generate the large water level gradients of the storm surge analysis in the FHRR are correct."

Enclosure 4: Independent Assessment of Reports by Bell, Andreas, and NUREG CR-7134 on Application of Wind Drag Coefficients

"This paper concludes that the drag coefficient data given in Andreas et al. (2012) and Bell et al. (2012) do not provide any evidence to reject the hypotheses that the sea surface drag coefficient in hurricanes decreases with increasing wind speed beyond mean wind speeds of about 40 m/sec. NUREG CR-7134 also recognizes that the wind drag coefficient likely decreases with increasing wind speed greater than 40 m/sec. These studies show that the use of the Garratt (1977) model for Cd with a cap of 0.0035 is extremely conservative."

Enclosure 5: Validation of FHRR Wind Drag Coefficient with Hurricane Fran

"This paper presents an additional validation for the Delft-3D model based on a comparison to observations for hurricane Fran in 1996. The results of this validation study indicate that the hurricane wind and pressure field produce a good overall representation of the forcing mechanism for hurricane Fran, and the modeled coastal storm surge response in the Delft3D model is consistent with the observed elevations of the high water marks along the coastline of North Carolina, with maximum combined tide-surge levels of up to 16 feet (NGVD29). The results suggest that the wind drag coefficient formulation used in the FHRR Delft3D model is appropriate within this range of wind speeds."

Enclosure 6: Conservatisms in Storm Surge Model

"This paper summarizes the conservative assumptions and inputs into the storm surge model used to evaluate the flood levels at Brunswick. Given the conservatism implicit in each of the model components and inputs, the model results overall can be considered to provide a conservative estimate of the flood levels that can be expected due to a probable maximum storm event."

Enclosure 7: 10-percent Exceedance High Tide Adjustment

"This paper discusses the adjustments to the FHRR storm surge model to account for monthly maximum high-tide data in accordance with JLD-ISG-2012-06 that maintains all remaining parameters as the original FHRR including WDC graph with 0.0015 established for wind speeds greater than approximately 70 m/s. The results are tabulated, and the summary of these results indicate the highest still water level (containing safety related SSC's) at elev. 24.48 ft NGVD29 and maximum wave run-up (containing safety related SSC's) at elev. 31.78 ft NGVD29."

ATTACHMENT 5

Summary of Revised 10-Percent Exceedance High Tide Adjustment (As developed by Duke in the Brunswick White Paper (See Attachment 6))

As part of the audit material reviewed for Brunswick (FHRR calculations and reports), and based on the staff's review of responses to Information Needs #2 (December 12, 2015; and supplemented in January 28, 2016), #3 (December 22, 2015), and licensee communications on June 2, 2016 ("10 Percent Monthly Max Tide Update – Preliminary Results"), the NRC determined that additional information was needed to close the 10-Percent Exceedance High Tide Adjustment analysis.

Request 1: Provide the finalized 10-percent exceedance high tide for the Brunswick site

Response:

Results of the 10-percent exceedance high tide (based on the monthly maximum per JLD-ISG-2012-06) for the Brunswick site are provided in Table 1, Enclosure 7 of the white paper discussed in Attachment 4 of this report. Below is a high level summary of Table 1 results:

- Highest still water level (containing SSC's) = 24.48 ft (NGVD29)
- Highest max wave run-up (containing SSC's) = 31.78 ft (NGVD29)

Requests 2, 3, 4:

Provide the methodology applied to develop the finalized 10-percent exceedance high tide. Discuss whether the value was determined using the ISG recommend method (JLD-ISG-2012-06: Guidance for Performing a Tsunami, Surge, or Seiche Hazard Assessment), or any other method. Provide the source and record length for the data applied to develop the finalized 10-percent exceedance high tide.

Response:

The updated 10-percent exceedance monthly maximum tide value was calculated by implementing the guidance from the JLD-ISG-2012-06 guidance document by the U.S. NRC (2013), which states that "*The 10% exceedance high tide is the high-tide level that is equaled or exceeded by 10 percent of the maximum monthly tides over the tidal epoch (a continuous 21-yr period in most locations). This tide can be determined from the recorded tide or from the predicted astronomical tide.*" Tidal water level measurements were obtained at Southport, NC (station 8659084). The Southport tide gauge dataset was selected as the nearest location to the BNP site with long-term water level records. The calculation proceeded in the following stages:

a) A harmonic tidal analysis of a recent full year of data (the year 2007 was selected) was conducted in order to extract the astronomical tidal constituents in a robust manner.

b) The tidal constituents were then used to generate a 21-year (2014-2034 inclusive) tidal water level prediction using the Matlab implementation of the UTide toolbox by Codiga (2011).

c) Monthly maxima were extracted over the 21-year period, amounting to 252 monthly maximum values.

d) The 10% exceedance value (3.56 ft above MSL) was taken as the 26th highest value among the monthly maximum values, equaled or exceeded by 10% of the monthly maxima (25 months).

The 10-percent exceedance monthly maximum tide value was used as the initial stillwater level throughout the Delft3D hydrodynamic and wave models in the combined effects scenario. Therefore the conservative assumption was applied that the maximum storm surge would coincide with the maximum tide level, consistent with the guidance provided in JLD-ISG-2012-06.

References

Codiga, D.L., 2011. Unified Tidal Analysis and Prediction Using the UTide Matlab Functions. Technical Report 2011-01. Graduate School of Oceanography, University of Rhode Island, Narragansett, RI. 59pp.

NOAA, 2016. Station ID 8659084, https://tidesandcurrents.noaa.gov/harcon.html?id=8659084. [accessed May 2016].

U.S. Nuclear Regulatory Commission, 2013. JLD-ISG-2012-06 Guidance for Performing a Tsunami, Surge, or Seiche Hazard Assessment, Interim Staff Guidance, Revision 0 (January 4, 2013).

Brunswick White Paper, Enclosure 7, Table 1:

"10-percent Exceedance High Tide Adjustment; Summary of PMH Results at buildings containing SSCs (Revision of Table 6-1 in BNP-14-009)"

Door ID	Building	Adjacent Ground Level	Finish Flood Level	Still water Level	Depth Above Ground	Max Wave Height	Max Wave Run Up	Flood Duration Above Adjacent Ground	Max Wave Height Instantaneous Water Surface Elevation	Max Wave Run Up Instantaneous Water Surface Elevation
		ft (NGVD29)			ft			hr	ft (NGVD29)	
D-2	Reactor Building	20.00	20	24.45	4.45	2.84	7.09	2.27	25.87	31.54
D-3		19.94	20	24.47	4.53	2.44	6.1	2.16	25.69	30.57
D-4	Diesel Generator Building	19.63	23	24.48	4.85	2.84	7.09	3.13	25.9	31.58
D-5		21.41	23	24.43	3.02	2.88	7.21	1.44	25.87	31.63
D-6		20.02	23	24.44	4.42	2.44	6.1	3.14	25.66	30.54
D-7		19.44	23	24.44	5	2.44	6.1	3.25	25.66	30.54
D-8		22.36	23	24.41	2.05	2.44	6.1	1.09	25.63	30.52
D-13	Service Water Intake Building	20.47	23	24.35	3.88	2.44	6.1	1.69	25.57	30.45
D-14		18.89	23	24.38	5.49	2.44	6.1	3.25	25.6	30.48

Brunswick White Paper, Enclosure 7, Table 2:

"10-percent Exceedance High Tide Adjustment; Summary of PMH Results at buildings not containing SSCs (Revision of Table 6-2 in BNP-14-009)"

Door ID	Building	Adjacent Ground Level	Finish Flood Level	Still water Level	Depth Above Ground	Max Wave Height	Max Wave Run Up	Flood Duration Above Adjacent Ground	Max Wave Height Instantaneous Water Surface Elevation	Max Wave Run Up Instantaneous Water Surface Elevation
		ft (NGVD29)			ft			hr	ft (NGVD29)	
D-1	Radwaste Building	19.01	23	24.5	5.49	2.88	7.21	3.15	25.94	31.7
D-9	AOG Building	19.54	22.33	24.41	4.87	2.88	7.21	3.12	25.85	31.62
D-10		19.81	22.33	24.36	4.55	2.88	7.21	3.12	25.8	31.57
D-11		19.81	22.33	24.38	4.57	2.44	6.1	3.12	25.6	30.49
D-12		19.67	22.33	24.42	4.75	2.88	7.21	3.13	25.86	31.62
D-15	Flex Storage Building	28.39	30.17	-	-.	-	-	-	-	-
D-16		28.54	30.17	-	-	-	-	-	-	-
D-17	Turbine Building	19.88	20	24.57	4.69	2.88	7.21	3.11	26.01	31.78
D-18		19.91	20	24.57	4.66	2.88	7.21	2.43	26.01	31.78
D-19		19.87	20	24.56	4.69	2.88	7.21	2.48	26	31.77
D-20		19.85	20	24.57	4.72	2.88	7.21	3.11	26.01	31.78
D-21		19.63	20	24.66	5.03	2.84	7.09	3.14	26.08	31.75
D-22		19.94	20	24.57	4.63	2.51	6.27	3.08	25.83	30.84
D-23		19.94	20	24.57	4.63	2.51	6.27	3.08	25.83	30.84
D-24		19.87	20	24.67	4.8	2.52	6.31	3.1	25.93	30.98
D-25		19.89	20	24.67	4.78	2.51	6.27	3.1	25.92	30.94
D-26		20.00	20	24.66	4.66	2.77	6.93	3.25	26.04	31.59

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