UNITED STATES
NUCLEAR REGULATORY COMMISSION
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December 20, 2017

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

SUBJECT: CALVERT CLIFFS NUCLEAR POWER PLANT UNITS 1 AND 2 – FLOOD HAZARD MITIGATION STRATEGIES ASSESSMENT (CAC NOS. MF7908 AND MF7909)

Dear Mr. Hanson:

By letter dated March 12, 2012 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML12053A340), the U.S. Nuclear Regulatory Commission (NRC) issued a request for information 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 (NTTF) report (ADAMS Accession No. ML111861807).

Enclosure 2 to the 50.54(f) letter requested that licensees reevaluate flood hazards for their sites using present-day methods and regulatory guidance used by the NRC staff when reviewing applications for early site permits and combined licenses (ADAMS Accession No. ML12056A046). Concurrent with the reevaluation of flood hazards, licensees were required to develop and implement mitigating strategies in accordance with NRC Order EA-12-049, "Order Modifying Licenses with Regard to Requirements for Mitigation Strategies for Beyond Design Basis External Events" (ADAMS Accession No. ML12054A735). In order to proceed with implementation of Order EA-12-049, licensees used the current licensing basis flood hazard or the most recent flood hazard information, which may not be based on present-day methodologies and guidance, in the development of their mitigating strategies.

By letter dated November 9, 2016 (ADAMS Accession No. ML16314A017), Exelon Generation Company, LLC (the licensee) submitted the mitigation strategies assessment (MSA) for Calvert Cliffs Nuclear Power Plant Units 1 and 2 (Calvert Cliffs). The MSAs are intended to confirm that licensees have adequately addressed the reevaluated flooding hazards within their mitigating strategies for beyond-design-basis external events. The purpose of this letter is to provide the NRC's assessment of the Calvert Cliffs MSA.

The NRC staff has concluded that the Calvert Cliffs MSA was performed consistent with the guidance described in Appendix G of Nuclear Energy Institute 12-06, Revision 2, as endorsed by Japan Lessons-Learned Division (JLD) interim staff guidance (ISG) JLD-ISG-2012-01, Revision 1, and that the licensee has demonstrated that the mitigation strategies are reasonably protected from reevaluated flood hazards conditions for beyond-design-basis external events. This closes out the NRC's efforts associated with CAC Nos. MF7908 and MF7909.

If you have any questions, please contact me at 301-415-1056 or via electronic mail at Lauren.Gibson@nrc.gov.

Sincerely,

Lauren Kate Gibson

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

Enclosure:
Staff Assessment Related to the
Mitigating Strategies for Calvert Cliffs

Docket Nos. 50-317 and 50-318

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STAFF ASSESSMENT BY THE OFFICE OF NUCLEAR REACTOR REGULATION RELATED TO MITIGATION STRATEGIES FOR CALVERT CLIFFS NUCLEAR POWER PLANT UNITS 1 AND 2 AS A RESULT OF THE REEVALUATED FLOODING HAZARD NEAR-TERM TASK FORCE RECOMMENDATION 2.1- FLOODING CAC NOS. MF7908 AND MF7909

1.0 INTRODUCTION

By letter dated March 12, 2012 (NRC, 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 (NTTF) report (NRC, 2011). Enclosure 2 to the 50.54(f) letter requested that licensees reevaluate flood hazards for their sites using present-day methods and regulatory guidance used by the NRC staff when reviewing applications for early site permits and combined licenses. Concurrent with the reevaluation of flood hazards, licensees were required to develop and implement mitigating strategies in accordance with NRC Order EA-12-049, "Order Modifying Licenses with Regard to Requirements for Mitigation Strategies for Beyond-Design-Basis External Events" (NRC, 2012a). That order requires holders of operating reactor licenses and construction permits issued under 10 CFR Part 50 to modify the plants to provide additional capabilities and defense-in-depth for responding to beyond-design-basis external events, and to submit to the NRC for review a final integrated plan that describes how compliance with the requirements of Attachment 2 of the order was achieved. In order to proceed with implementation of Order EA-12-049, licensees used the current licensing basis flood hazard or the most recent flood hazard information, which may not be based on present-day methodologies and guidance, in the development of their mitigating strategies. Calvert Cliffs Nuclear Power Plant Units 1 and 2 (Calvert Cliffs) submitted its flood hazard reevaluation report by letter dated March 12, 2013 (Exelon, 2013), as supplemented by letters dated February 10, 2014, March 7, 2014, and September 23, 2015 (Exelon 2014a, 2014b, and 2015, respectively).

The NRC staff and industry recognized the difficulty in developing and implementing mitigating strategies before completing the reevaluation of flood hazards. The NRC staff described this issue and provided recommendations to the Commission on integrating these related activities in COMSECY-14-0037, "Integration of Mitigating Strategies for Beyond-Design-Basis External Events and the Reevaluation of Flood Hazards," dated November 21, 2014 (NRC, 2014b). The Commission issued a staff requirements memorandum on March 30, 2015 (NRC 2015a), affirming that the Commission expects licensees for operating nuclear power plants to address the reevaluated flood hazards, which are considered beyond-design-basis external events, within their mitigating strategies.

Nuclear Energy Institute (NEI) 12-06, Revision 2, "Diverse and Flexible Coping Strategies (FLEX) Implementation Guide" (NEI, 2015b), has been endorsed by the NRC as an appropriate methodology for licensees to perform assessments of the mitigating strategies against the reevaluated flood hazards developed in response to the March 12, 2012, 50.54(f) letter. The guidance in NEI 12-06, Revision 2, and Appendix G in particular, supports the proposed Mitigation of Beyond-Design-Basis Events rulemaking. The NRC's endorsement of NEI 12-06, including exceptions, clarifications, and additions, is described in NRC Japan Lessons-Learned Division (JLD) interim staff guidance (ISG) JLD-ISG-2012-01, Revision 1, "Compliance with Order EA-12-049, Order Modifying Licenses with Regard to Requirements for Mitigation Strategies for Beyond-Design-Basis External Events" (NRC, 2016a). Therefore, Appendix G of NEI 12-06, Revision 2, describes acceptable methods for demonstrating that the reevaluated flooding hazard is addressed within the Calvert Cliffs mitigating strategies for beyond-design-basis external events.

2.0 BACKGROUND

By letter dated April 16, 2015 (NRC, 2015b), the NRC issued a staff assessment of the licensee's flood hazard reevaluation report for Calvert Cliffs. The NRC issued a supplement to that staff assessment by letter dated October 21, 2015 (NRC, 2015c). The letter provided the reevaluated flood hazards that exceeded the current design-basis for Calvert Cliffs and were suitable inputs for the mitigating strategies assessment (MSA) (i.e., defines the mitigating strategies flood hazard information described in Nuclear Energy Institute (NEI) guidance document NEI 12-06). For Calvert Cliffs, the mechanisms listed as not bounded by the current design basis (CDB) in the letter are local intense precipitation (LIP) and storm surge hazard mechanisms.

By letter dated September 23, 2015 (Exelon, 2015), the licensee submitted an amendment to its 2013 FHRR for Calvert Cliffs. The licensee revised their reevaluations for LIP and storm surge, such that storm surge was now bounded by the CDB. The NRC reviewed this revision as part of this assessment, as discussed in Section 3.1 and agrees with the licensee that the only remaining flood hazard mechanism not fully bounded by the CDB is LIP.

The letter also stated that NRC staff would evaluate, as applicable, the flood event duration parameters (including warning time and period of inundation) and flood-related associated effects developed by the licensee during the NRC staff's review of the MSA. This is consistent with the guidance provided in Revision 2 of NEI 12-06. The licensee submitted the flood event duration parameters by letter dated October 2016 (Exelon, 2016a), and the MSA by letter dated November 9, 2016, (Exelon, 2016b).

3.0 TECHNICAL EVALUATION

3.1 Confirmation of the Flood Hazard Elevations in the MSA

NRC staff reviewed the flood hazard elevations presented in the original 2013 Flood Hazard Reevaluation Report (FHRR) provided by the licensee. The staff concluded in its supplemental staff assessment letter (NRC, 2015) that the flood hazard elevations for both LIP and storm surge flood-causing mechanisms are not bounded by the respective design-basis values. The licensee submitted the site's MSA letter (Exelon, 2016) with updated flood elevations for these two unbounded flood-causing mechanisms as described in the amended FHRR (Exelon, 2015).

The licensee reported in its MSA letter that the updated maximum LIP flood elevation of 44.4 feet (ft.) National Geodetic Vertical Datum (NGVD29) at the power block area is 1.5 ft. lower than the value reported in the original FHRR (2013), even though it is bounded by the design-basis. The licensee also reported in its MSA that the updated peak storm surge (including wave runup) elevation of 26.8 ft. NGVD29 is 4.5 ft. lower than the value reported in the original FHRR and supplemental staff assessment and is bounded by the design-basis (28.1 ft. NGVD29). Therefore, the staff reviewed the updated flood hazard reevaluation for LIP and storm surge reported in the amended FHRR as part of the MSA review.

Flood elevations mentioned in the amended FHRR are based on a mixed vertical datum of mean sea level (MSL) and NGVD29, which is 0.64 ft. higher than the MSL value; however, this report uses the NGVD29 datum consistently as it was used in the supplemental staff assessment (NRC, 2015).

3.1.1 Review of the Updated LIP Flood Analysis

As described in its original FHRR, the licensee applied a combination of U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) hydrologic model (USACE, 2010) and HEC-RAS (river analysis system) hydraulic model (USACE, 2014) to evaluate LIP flood hazard. The staff performed a review of the LIP modeling described in the original FHRR and determined that the modeling is acceptable (NRC, 2015). For the updated LIP flood analysis in the amended FHRR, the licensee used the same models, but changed the LIP scenario from the National Oceanic and Atmospheric Administration (NOAA's) Hydrometeorological reports (HMRs) 51 and 52 based PMP to site-specific probable maximum precipitation (ssPMP) (Exelon, 2017a). The LIP rainfall scenario mentioned in both original and amended FHRRs is a 6-hour duration, 1 square mile (mi^2) point rainfall as the area covered by the LIP basin for Calvert Cliffs is less than one mi^2.

Before reviewing the licensee's ssPMP estimation, the staff performed a sensitivity analysis to investigate the change of the maximum LIP flood level at the plant site due to switching the rainfall scenario from the HMR-based to ssPMP-based value. As a result, the staff identified the maximum flood level change due to the change of the LIP scenario is significant (e.g., more than 0.5 ft. difference in flood level). Therefore, the staff performed a review of the license's estimation of the ssPMP values as described below.

A. Site-specific Probable Maximum Precipitation

The NRC staff conducted a technical review of the point-based LIP ssPMP estimation provided by the licensee (Exelon, 2017a; 2017b). The following is a summary of the staff's review:

- Short List Storm: The licensee evaluated all storms used in previous ssPMP studies at other sites in the region considered transpositionable to the Calvert Cliffs site to develop a list of the storms needed for proper LIP ssPMP evaluation. This resulted in 12 short-list events being evaluated for use in LIP calculations. These storms are located in the east coastal zone covering from St. George, GA to Westfield, MA. The staff reviewed the licensee-provided short and long lists of historical storms used in estimating the ssPMP and confirmed no unreasonable exclusions for the site compared to other nearby nuclear plant sites for which ssPMP estimations were already reviewed by the staff.

- USACE Black Book Storm: The staff also checked observed storm precipitation data from the USACE 'Black Book' and identified the storm events at Ewan, NJ in 1940, St George, GA in 1911, and Jewell, MD in 1897 as the largest historic storms (pre-1970) that could control the SSPMP at the site. The staff confirmed all three of these large historic storms are included in the licensee's short storm list.

- Depth-Area-Duration (DAD) for Recorded Storms: For the selected storms, the licensee prepared DAD tables for storm durations up to 72 hours and areas up to 20,000 mi^2. The staff compared the original (USACE) and revised (i.e., SPAS) DAD data for any non-conservative deviations. The only non-conservative deviations identified is associated with the Ewan, NJ storm in 1940. The USACE 6-hour, maximum station observed DAD value is 21.0 inches (in) compared to the corresponding DAD value of 20.5 in. The decrease of 2.4 percent of the ssPMP value is a potential source of non-conservatism.

- Storm Elevation Data: The licensee's ssPMP calculation explicitly addresses elevation for updated maximization factors and explicitly defined transposition limits for each storm considered. The licensee's calculation provides adjustments for storm elevation to the nearest 100 ft. of elevation. Further, the elevation of the site was determined in this analysis, providing more accurate calculations to account for differences in available atmospheric moisture due to elevation differences between the original storm location and each site. Using digital elevation data with 4-km resolution U.S. Geological Survey (USGS) National Elevation Dataset, the staff independently looked up elevations at the storm center location, storm representative dew point location, transpositioned dew point location for each storm, and the site location. While there are some moderate differences between the licensee's and staff's elevations, the staff found the differences would not largely impact the ssPMP calculation.

- Dew Point Temperature: The licensee adjusted the storms analyzed by the National Weather Service (NWS) and USACE, which occurred prior to 1948 and used 12-hour persisting dew points in the storm maximization process so that the updated dew point climatology could be utilized consistently with the updated maximum average dew point climatologies. For thunderstorms and mesoscale convective complex (MCC) storm events, 7 degrees Fahrenheit (°F) was added to the NWS/USACE storm representative dew point. This was done to adjust for using average dew point values for varying durations versus 12-hour persisting dew point values. Using land-based dew point data and sea surface temperature data collected during previous ssPMP reviews at other sites, the staff conducted an independent evaluation of dew point values for all Short List storms. Using these data and various licensee-provided storm data (e.g., Latitude/Longitude, gauge identification, storm date, etc.), the staff independently computed adjustment factors for each storm on the Short List and compared the results with the licensee's results.

- Adjustment Factors: The in-place maximization factor and transposition adjustment factor were combined to observed DAD data to obtain adjusted DAD data for ssPMP. The staff estimated these factors independently as discussed above and compared them with licensee's values. The staff found the factors for most storms are not significantly different from the licensee's value, ranging from 7 percent lower to 10 percent higher.

- Comparison of Controlling Storms: For the Jewell, MD storm in 1897, which turned out to be the controlling storm for the plant site, the staff-estimated 1-hour-1-mi^2 PMP value is 6.8 percent higher than the licensee's value. The staff's 6-hour-1-mi^2 PMP is 4.0 percent higher than the licensee's value. These are mainly due to an increase in the dew point climatology values. The staff relied upon station data to inform dew point climatology selection whereas the licensee used smoothed maps.

- Interpolate PMPs for Different Durations: For use in the LIP modeling, the 1-hour ssPMP value is required to be split into increments of 5-minute and 15-minute. The licensee applied the incremental ratios derived in HMR 52. Using the ssPMP values estimated for 5-minute, 15-minute, 30-minute, 1-hour, and 6-hour durations, the licensee performed a linear fit of the PMP data to the logarithm of the duration to obtain the interpolated 2-hour and 3-hour ssPMP values for use in the HEC-HMS LIP modeling (see Table 3.1.1-1).

In summary, the staff noted that there are a few technical concerns with the licensee's evaluation of the LIP ssPMP estimation. These includes selecting dew point climatology values and reducing the observed depth-area-duration value for the Ewan, NJ event from 21 inches (in) to 20.5 in. Instead of requesting that the licensee update the estimation of the ssPMP values, the staff performed another sensitivity analysis of the estimated LIP flood levels with the staff-estimated ssPMP values with the corrections mentioned above. The staff used the licensee-provided HEC-HMS and HEC-RAS models for this sensitivity analysis. As a result, the staff found the maximum flood level would increase by 0.2 ft. by the staff-estimated 6-hour ssPMP value, which is approximately 4 percent higher than the licensee's value. As the flood level change is insignificant, the staff concludes that the licensee's LIP ssPMP values are acceptable for use in the MSA.

B. LIP Flood Modeling

The licensee applied USACE-developed HEC-HMS and HEC-RAS models sequentially to evaluate the LIP flood hazard caused by a LIP flood-causing mechanism. They postulated a 6-hour ssPMP scenario as input to the Calvert Cliffs HEC-HMS model. That is, they distributed the 6-hour ssPMP value into 5-minute, 15-minute, 1-hour, 2-hour, 3-hour, and 6-hour intervals for input to the model (see Table 3.2.0-1). They used a front-peaking distribution in time. To set up the Calvert Cliffs HEC-HMS model, the licensee divided the onsite LIP basin into 6 subbasins and then linked the subbasins by channels as shown in Figure 3.1.1-1.

As described in its original FHRR, the licensee used the HEC-RAS model to route flood elevations at the Calvert Cliffs Units 1 and 2 power block area. The main features of the HEC-RAS are onsite drainage channels and cross-sections (see Figure 3.1.1-2). The licensee used the simulated outflow flow hydrographs from the HEC-HMS at locations, "J-2", "Outlet-I", and "Outlet-2" as upstream inflows to channels in HEC-RAS.

For its amended FHRR (Exelon, 2015), the licensee adopted the same setup of the HEC-HMS and HEC-RAS used in the original FHRR, but changed a couple of modeling options for HEC-RAS, including new inflow hydrographs for the ssPMP scenario, downstream boundary conditions, lateral weir coefficients, and computational routing method. The licensee used a steady-state simulation of HEC-RAS for its original FHRR (Exelon, 2013); however, for the amended FHRR, they relied on an unsteady state flow simulation with a mixed flow regime option in order to improve the accuracy of flood routing. The unsteady flow simulation is in general based on a finite difference approximation of the St. Venant equation.

For its original FHRR (Exelon, 2013), the licensee identified eight monitoring locations near the entrance doors for critical structures related to safe operation of the plant. The licensee used the same locations for use in the amended FHRR (Exelon, 2015) as listed in Table 3.1.1-2. The elevations for the entrances of safety-related structures are 45.6 ft. NGVD29, except that of the Diesel Generator Building which is 46.1 ft. NGVD29. Table 3.1.1-2 summarizes the entrance elevations as well as peak water levels, maximum water depths, channel velocities, and freeboards. The staff noted the maximum flood elevation in the vicinity of the power block area due to the LIP flood-causing mechanism is 45.5 ft. NGVD29, which is below the respective entrance elevation of 45.6 ft. NGVD29. The staff also noted the LIP flood with high velocity occurs only along the steep slopes within the Downstream-1 channel but not in the power block area.

In summary, the staff reviewed the licensee's ssPMP estimation described in the amended FHRR and determined that the licensee-provided ssPMP values in the amended FHRR are adequate for use in the LIP modeling. The staff also reviewed the LIP modeling presented in the amended FHRR and determined that the maximum LIP flood elevations are acceptable for use in the MSA, as discussed above. The staff confirmed that the updated LIP flood elevations reported in the amended FHRR (Exelon, 2015) are not bounded by the current design basis.

3.1.2 Review of the Updated Storm Surge Analysis

For the updated storm surge analysis in its amended FHRR (Exelon, 2015), the licensee applied three-dimensional Delft 3D model (Deltares, 2011) with site-specific hurricane parameters. They performed an updated storm surge modeling designed to more accurately characterize the storm surge hazard compared to the surge analysis in the original FHRR, which relied on the SLOSH model developed by the National Hurricane Center (Jelesnianski et al., 1992). They used a deterministic approach to determine a probable maximum storm surge (PMSS) at the plant site. The licensee stated that the Calvert Cliffs Delft 3D model improves the previous SLOSH approach in the original FHRR by using more robust wind model, improved grid resolution, wind-wave interaction, wave setup, and fine resolution for the topographic and bathymetric data (Exelon, 2015).

The licensee concluded in the amended FHRR (Exelon, 2015) that the peak surge elevation including wave runup at the Units 1 and 2 Intake Structure would be 26.8 ft NGVD29. This updated maximum surge elevation is lower than that reported in the original FHRR and is bounded by the CDB value of 28.1 ft NGVD29. The staff performed a review of the storm surge analysis presented in the amended FHRR as described below. In particular, the staff's review was focused on the four specific technical issues identified through the review: screening probable maximum storm scenarios, treating initial water level in surge modeling, determining wind drag coefficient, and estimating wave runup.

A. Probable Maximum Hurricane Parameters

The licensee used a postulated probable maximum hurricane (PMH) as input to the storm surge analysis. The key PMH parameters in general include pressure deficits, radii of maximum wind (RMWs), forward speeds, landing location, and tract directions. The licensee obtained the range of the site-specific PMH parameters (except landing location) from NWS 23 (NOAA, 1979) as recommended by NUREG/CR-7046 (NRC, 2011). The NWS 23 provides the range of each PMH parameter applicable for a given site anywhere along the Atlantic and Gulf of Mexico coasts. The selected ranges of PMH parameters used in the licensee's storm surge analysis are summarized in Table 3.1.2-1. The licensee considered different landfall locations parameterized by the distance from the plant site to the center of hurricane as an independent variable for the sensitivity analysis.

The licensee postulated multiple PMH scenarios to simulate the surge model, where each scenario consists with PMH parameter values sampled within the respective ranges determined by NWS 23. That is, they divided the range of each parameter equally (up to 10 intervals) and then sampled from each intervals as deemed applicable for the site. They applied a sensitivity analysis to select an optimal (critical) scenario that produces a maximum peak storm surge levels at the plant site. For this sensitivity analysis, they used the Calvert Cliffs Delft 3D model, a version that was not fully calibrated yet.

The licensee used a sequential screening approach to identify the critical PMH scenario among multiple plausible scenarios. The approach starts with assuming an initial PMH parameter set that could generate a high surge based on a professional judgement. For a selected PMH parameter (preferably more sensitive one first), the surge model is used to simulate surges with varying values for a selected parameter but fixing other parameter values (subset scenarios for a parameter). The parameter value that produces the maximum surge elevation is taken as an optimal for the subset scenarios. The sensitivity runs move on to other parameters sequentially until a complete set of optimal parameters for the PMH is obtained. The following summarizes the step-by-step procedure used by the licensee for the screening:

i. Hold the pressure deficit of 123 milibar (mb) which is the maximum, and synchronize the timing of the storm surge with incoming high tide.

ii. Simulate the Calvert Cliffs Delft 3D model with 10 track directions (152, 157, 162, 167, 172, 177, 182, 187, 192, and 197 degrees clockwise from the north) with an initial RMW of 26 nm, forward speed of 17 m/s, and center distance of zero from the plant site. From these sensitivity runs, the licensee identified the track direction of 192 degrees as it produces the maximum surge level (see Figures 3.1.2-3a and 3.1.2-4a).

iii. Simulate the model with 8 RMWs (10, 15, 20, 25, 26, 30, 35, 38 nautical miles (nm)) with the storm direction of 192 degree, forward speed of 17 m/s, and center distance of zero. The radius of maximum wind sensitivity was extended beyond the range presented in NWS 23 to determine if hurricanes with larger RMWs increase the surge level at the plant site. From these runs, the licensee determined an optimal RMW of 20 nm (see Figure 3.1.2-4b).

iv. Simulate the model with 6 storm forward speeds (17, 22, 27, 32, 37, and variable speed of 8 and 17 knots (kt)) with the storm direction of 192 degree, RMW of 20 nm, and center distance of zero. The licensee-identified combined forward speeds of 8 kt before landing and 17 kt after landing turned out to be optimal (see Figure 3.1.2-4c).

v. Simulate 8 center distances (1.25, 1.0, 0.65, 0.25, 0, -0.15, -0.5, -0.25 times RMW (see Figure 3.1.2-3b)), where positive value means storm center is shifted to the left from the site, while negative is to the right. The licensee selected -0.25 times RMW (0.25 times radii to the left) as an optimal (see Figures 3.1.2-3b and 3.1.2-4d).

Table 3.1.2-1 lists the licensee-provided optimal PMH parameter values from the resulting of the screening. Figure 3.1.2-4 displays the results of the sensitivity analysis, where each plot forms clear surge level peaking for most of the parameters. As the rates of changes at the peak are insignificant (e.g., mostly less than a foot), the staff determined the discrete parameter intervals used in the licensee's screening is acceptable without further refining the parameter values at finer discrete intervals. In particular, the staff noted onsite surge level is less sensitive to the change of RMW values compared to those at open coastal sites. The staff believes this is due to the breaking and attenuation of offshore surge and wave, as the plant site is located approximately 80 miles inside from the mouth of the Chesapeake Bay.

The staff also noted the licensee's selection of 20 nm RMW storm is based on a single "base" track that goes over site, even though it is within the range provided by NWS 23. That is, the sensitivity to RMW parameter was not checked for multiple storm tracks, angles, and landing locations. For example, the licensee settled on the 20 nm RMW value with a simple track (landfall and angle) that may not produce the maximum water level at the plant site. The staff also recognized the screening could be improved further by refining the PMH parameter values, such as using RMW values at the 1nm resolution or tract positions at the finer (e.g., 0.1 times RMW) resolution. These refinements would end up a higher surge level estimates than the ones presented by the licensee in the amended FHRR. To resolve this issue, the staff found from Figure 3.1.2-4 that the change of surge level at or near optimal RMW (e.g., 20 nm) is small for those initial "base" runs (e.g., much less than one foot per discrete interval tried), and that the same is true for other PMH parameters. Therefore, the staff determined the result of the licensee's screening is acceptable without further refining the parameter intervals. In all, the staff concludes the screening process to obtain site-specific PMH parameters is reasonable and the resulting PMH parameters are acceptable for use in the MSA as the licensee followed a hierarchical approach recommended by the guideline provided in NUREG/CR-7046 Appendix E (NRC, 2011).

B. Pressure and Wind Fields

The licensee generated atmospheric forcing pressure and wind fields, which are used as input to the Calvert Cliffs Delft 3D model (Exelon, 2015). The space-time pressure and wind fields are in general expressed as a function of steady-state PMH parameters. The licensee used a spreadsheet calculator based on the method described in NWS 23 (NOAA, 1979) to calculate the pressure and wind fields (Exelon, 2017). In the calculator, storm is assumed to be 600 nm in diameter and is idealized as nearly symmetrical along its path. Values in the pressure and wind field are calculated in 8-degree intervals around the storm. These rough-scale pressure and wind fields are used as input to Delft 3D which interpolates internally the detailed pressure and wind fields at computational grid nodes.

For calibration and verification of the Calvert Cliffs Delft 3D model, the licensee also obtained atmospheric forcing for Hurricanes Isabel and Irene from the parametric wind and pressure field model calculator (Exelon, 2017). The model can approximately reproduce the wind field and pressure field of historical hurricanes with meteorological parameters including hurricane path, atmospheric pressure, and radius of maximum wind. These parameters were assembled from the NOAA National Hurricane Center. The generated pressure and wind fields was used as inputs for both the Delft3D-FLOW and Delft 3D-WAVE modules during calibration.

The radius of maximum winds for Hurricane Isabel was further investigated as input in this calculation and was approximated based on empirical relations. The calculator computes the maximum wind speeds based on the NWS 23 equations for the distribution of the hurricane wind field. The licensee stated, in many cases, the maximum wind speed computed by the calculator did not match the recorded maximum wind speed at each particular track position. This is due to the NWS 23 distribution differing from the actual hurricane wind field distribution. Therefore, to correct for the difference between the computed and observed maximum wind speed for historical hurricanes, the licensee hardwired the observed maximum wind speed in the calculator and idealized the remainder of the wind field distribution to fit the NWS 23 empirical distribution.

For simulation and parameter sensitivity runs, the licensee generated synthetic pressure and wind fields given the steady-state PMH parameters without correction as described above. The licensee used the following NWS 23 pressure field equation to generate a synthetic storm:

$$p = p_c + \Delta p \exp\left(-\frac{RMW}{r}\right) \qquad (1)$$

where, p and p_c in mbar are pressure at distance r (m) and center, respectively, and Δp is the pressure differential (mb), and RMW is radius of maximum winds. The generated pressure field was used in the Calvert Cliffs Delft3D model to compute the storm surge associated with the lowering of the air pressure within the hurricane (i.e., the pressure setup).

The gradient winds in a hurricane blow with circular motion, parallel to the pressure isobars, in which the centripetal and Coriolis accelerations together balance the horizontal pressure gradient force per unit mass. The NWS 23 overwater wind field equation is also used for synthetic storms as:

$$V_{gx} = K\sqrt{\Delta p} - \frac{(RMW*f)}{2} \qquad (2)$$

where, V_{gx} is the maximum gradient wind speed (knots), and K is the coefficient depending on air density. The overwater, stationary hurricane maximum 10-m, 10-minute wind speed is about 95 % of V_{gx}.

The calculator tabulates wind speeds (V_s) against the distance (r) from the center of the hurricane. For this calculation, wind speeds (V_s) are tabulated in 1 nautical miles (nm). An asymmetry factor to account for forward speed and directionality is added to the wind speeds (V_s) for a stationary hurricane to account for the forward speed of the hurricane. Wind speed at other degree angle positions at set locations around the hurricane center were computed using the NWS 23 methodology. The wind field was further modified such that the wind field takes the track direction into consideration at each track location to correctly apply the translational speed to the final wind speed to determine the location of maximum velocity (Exelon, 2017f).

The staff reviewed the licensee's procedure to generate the pressure and wind fields as well as Delft3D input files related to these fields. Correspondingly, the staff determined the generation of the pressure and wind fields is acceptable for use in the surge modeling as they followed the guidelines provided in NWS-23, which are also recommended by NUREG/CR-7046 (NRC, 2011).

C. Antecedent Water Level

The licensee estimated the antecedent water level (AWL) at the plant site and used its value in estimating the total surge elevation (Exelon, 2015). They conservatively assumed the AWL condition occurs coincidently with the peak storm surge caused by the postulated PMH event. To match the two events, the licensee used a two-step approach: They first ran the Calvert Cliffs Delft 3D model without wind forcing to determine the timing of the tide at the site, and then re-ran the model in a synchronized mode of surge and wave so that the peak of the storm surge would arrive at high tide.

The licensee estimated an AWL value of 4.34 ft. NGVD29 which includes the following three components:

- 10 percent exceedance high tide of 2.17 ft. NGVD29
- Initial rise of 1.10 ft. from RG 1.59 (NRC, 1977), and
- Long-term sea level rise of 1.07 ft.

By definition, initial rise (or so called forerunner or sea level anomaly) is an anomalous departure of the tide level from the predicted astronomical tide. Initial rise value is estimated in general from long term recorded and/or predicted tides. Recorded tide data include the effects of regional meteorological parameters such as barometric pressure and wind acting on water at the surface level. American National Standards Institute/American Nuclear Society (ANSI/ANS) 2.8 (ANSI/ANS, 1992) provides the following guideline in connection to applying the initial rise in estimating storm surge levels "For the determination of the probable maximum surge, the sea level anomaly need not be included when 10% exceedance high tide is based on recorded tides. If the 10 percent exceedance high tide is based on predicted tide levels, sea level anomaly shall be added. Whichever is lower may be used."

The staff noted the licensee's estimation of tide and sea level rise values is based on the historical tide and sea level data. The staff made an independent confirmatory estimation of AWL without the initial rise using up-to-date tide and sea level rise data available near the plant site. The staff projected sea level rise for the remaining plant operating life of 50 years. The resulting AWL value by the staff is 3.69 ft. NGVD29, which is lower than the licensee's value. Therefore, the staff determined that the licensee-estimated AWL of 4.34 ft. NGVD29 is conservative and acceptable for use in the MSA.

The licensee stated in the note of FHRR Table 2.4.7 (Exelon, 2015) that the AWL is not included in the surge model but added to the final simulated surge elevation afterwards. That is, the licensee used a simple superposition of a high tide and storm surge without considering their interaction. This approach could lead to errors in both magnitude and timing of the model-simulated peak surge due to ignoring the nonlinear terms in the hydrodynamic equations. In particular, it could result in underestimating the total surge level especially at shallow-depth water. To be a realistic and conservative surge estimation, the AWL condition must be specified as an initial condition in the surge model. The staff checked the licensee-provided input files for the Calvert Cliffs Delft 3D model and found that the parameter 'Zeta0' is set to zero for all the nested grids. That is, the AWL (especially the long term sea level component) is not included as a starting water level, resulting in underestimating the total surge level.

To investigate the degree of the underestimation, the staff performed a sensitivity analysis using the licensee-provided Calvert Cliffs Delft 3D model with simple pre-adding of the licensee's AWL value (4.34 ft. NGVD29) as an initial condition of the model. As a result, the staff found the maximum surge level at the site is about a foot higher than the licensee's estimate, but it would be reduced if the staff-estimated AWL (i.e., 3.68 ft. NGVD29) was used rather than the licensee's AWL. Therefore, the staff concludes that the licensee's surge modeling approach with post-adding of the AWL value as well as the resulting total surge level is acceptable for use in the MSA.

D. Calibration and Verification of the Surge Model

The licensee obtained the topography and bathymetry data used to build the Calvert Cliffs Delft3D model from the following sources (Exelon, 2015):

- One-kilometer resolution gridded bathymetric data from the Atlantic Ocean, the General Bathymetric Chart of the Ocean (GEBCO).
- The shallow-water bathymetry at Chesapeake Bay and near shore of the Atlantic Ocean obtained from NOAA's National Ocean Service (NOS).
- The local topography data based on Light Detection and Ranging (LiDAR) discrete-return point cloud data obtained from the USGS.
- Additional site features such as the Intake Channel and Intake Deck.

The licensee converted the above raw topography and bathymetry data at different datums to model grid values at the MSL to use as input to the surge model. The staff reviewed the gridded elevation data files provided by the licensee and compared with the raw data. As a result, the staff determined that the resolutions and accuracy of the gridded elevation data are appropriate, especially at the plant site area.

The licensee used the Delft 3D modeling software (Deltares, 2011) to solve two-dimensional surge and wave equations using a finite-difference scheme on the square grid system. They applied Delft 3D-FLOW for storm surge and Delft 3D-WAVE (SWAN) for wave dynamics. The Calvert Cliffs Delft 3D model consists of a nested grid system of multiple layers with varying resolutions of course and fine grids. Coarse grid in general is large enough to cover the sufficient long path of the PMH, whereas fine grid is detail enough to accurately model the surge dynamics at the plant intake. The staff found the boundaries of the licensee's coarse grid are located on the deep water of the Atlantic Ocean, sufficiently far enough from the site to prevent reflection at boundaries from impacting the result of surge at the site.

Due to the size of the model area under study, the licensee considered five Delft 3D FLOW grid domains: one large domain with coarse resolution of 3.1 mi (5 km) square grids, and four refined grids of increasingly finer grid resolutions created by the domain decomposition tool within Delft 3D-FLOW. The licensee's grid domain decomposition was set to convey the information from the coarse grid to provide boundary conditions for the next fine grid. The finer resolution grid was created only for areas close to the site in Chesapeake Bay. The finest square grid in the vicinity of the site has a resolution of 26 ft. (8 m). The licensee also generated four nested grids for the Delft 3D-WAVE (SWAN) model. The nested modeling approach in the Delft3D-WAVE program was used to insert the refined wave grids into the coarse grid domain ranging from 3.1 mi to 118 ft. square grids. The staff determined the resolution of the model grid is acceptable as the licensee's simulated surge values for calibration and validation cases match, by and large, the recorded values.

The licensee performed calibration and validation of the Calvert Cliffs Delft 3D model by comparing simulated and observed surge and tide values for selected historical hurricane (Exelon, 2015). They calibrated key model parameters manually based on sensitivity runs with varying parameter values, where the parameter value that produces least peak error with stable surge solution is selected as an optimal. The licensee performed the calibration and verification for the following historical events:

- Delft3D calibration for tides (September 2013)
- Delft3D calibration for Hurricane Isabel (September 2003)
- Delft3D verification for 2011 Hurricane Irene (August 2011)

The licensee stated in its amended FHRR (Exelon, 2015) that the tidal calibration was done for a month long, and that Hurricanes Irene and Isabel were selected because of the strength of the storms, availability of recorded data (e.g., surge level and wave height), and the track and landing location relative to the plant site. Figure 3.1.2-6 shows the tracks of these hurricanes. Calibrating Manning's n-Value

The licensee first calibrated the Calvert Cliffs Delft 3D model with respect to the bottom friction coefficient (Manning's n-values) (Exelon, 2015). During the tidal calibration, they turned off Delft 3D-WAVE, as well as atmospheric pressure and wind forcing in Delft3D-FLOW. For this tidal calibration, tidal constituents (without wind or wave forcing) used at the open ocean boundary provide the only forcing within the model. The licensee's tidal calibration features a one-month period (September 15-October 15, 2013) in order to span a complete spring neap tidal cycle. The licensee used a simulation time step of 1-minute to capture the peak tide accurately. The river inflow to the model domain is derived predominantly from Susquehanna, Potomac, Rappahannock, and James Rivers. The licensee used historical discharge time series from these rivers as input to the model for the calibration.

The licensee relied on a manual calibration where they changed the Manning's n-values (ranging from 0.008 to 0.025) across the model domain to match the simulated and recorded tidal values (Exelon, 2015). They used 20 tidal gage stations to cover the Chesapeake Bay area and the Atlantic coast. As a result, they were able to demonstrate an excellent agreement between observed and simulated tide values, with an average root mean square error of less than 0.2 ft. Figure 3.1.2-5 shows the calibrated Manning's n-values in the model domain. The staff determined based on the review of the calibration process and the results that the tidal calibration is acceptable for use in the MSA as the calibration errors at most stations are acceptably small.

Calibrating Wind Drag Coefficient

The licensee also calibrated the Delft3D-FLOW model with the recorded surge levels for Hurricane Isabel. They focused on calibrating the wind drag coefficient for the Delft3D-FLOW model. Wind drag coefficient, which is one of the key parameters in surge modeling, is expressed in general as a function of wind speed. Delft 3D-FLOW provides an option to specify the relation between wind drag coefficient and wind speed with the use of a piece-wise linear function with three break points, namely A, B, and C.

Several recent journal articles related to the wind drag formulation in ocean conclude that the wind drag coefficient (C_d) value in ocean reaches its upper limit at wind speed of 25 to 33 m/s. The licensee referenced the C_d relations proposed by Makin (2005), Vatvani et al. (2012), and Vickery et al. (2009). They then postulated six C_d scenarios as listed in Table 3.1.2-3, where the C_d values at high wind speed (e.g., Point C) range from 0.0015 to 0.004. The licensee simulated Hurricane Isabel using Delft 3D-FLOW with each C_d scenario. As a result, they selected Scenario 2 (C_d value of 0.0018 at Point C) which produces the least mean square errors of surge levels at selected monitoring locations (see Table 3.1.2-3). The staff determined the Scenario 2 is adequate as this scenario results in reasonable matching between the simulated and recorded surge hydrographs at five nearby gaging stations around the plant site as presented in Figures 2.4-21 through 2.4-24 in the amended FHRR (Exelon, 2015).

The staff also performed a review of recent journal articles related to the wind drag coefficient relation to determine the adequacy of the calibrated C_d values. Specifically, Bryant and Akbar (2016) concluded based on a comprehensive review of up-to-date articles that C_d value increases linearly up to wind speed values ranging from 22 m/s to 33 m/s, and that it is leveled off or reduced gradually thereafter due to foams, bubbles, and streaks created on the water surface during high wind events. They also concluded C_d values near shore vary far more than offshore values due to shoaling, local bathymetry, water depth, and the state of the ocean relative to storm center. The staff noticed that the licensee-calibrated C_d values incorporates the effects of such near-shore conditions adequately by adopting a fine grid regulation modeling.

The NRC staff noted that the maximum wind speeds for Hurricane Isabel (about 30 m/s) do not approach the level of PMH wind speeds (about 90 m/s). That is, this historical hurricane event may not provide much insight into wind drag cap values for extremely high wind speeds that would occur during PMH conditions. Also, the staff recognized from the error statistics summarized in Table 3.1.2-3 that the high wind C_d value of 0.0018 could be further refined (increased) as the next high value tested for Scenarios 1 and 5 is 0.004. Therefore, the NRC staff performed two additional sensitivity run of the model with refined high wind C_d values. The staff obtained the following surge result:

- 0.3 ft. for high wind C_d of 0.002
- 0.8~1.0 ft. for high wind C_d 0.0025.

The result of the staff's additional Delft3D runs indicates that the model-simulated surge levels increase with increasing high wind C_d value from Scenario 2 but the rate of change near the plant site is not as significant as those determined at open ocean sites. The staff believes this insignificant change may be due to the unique location of the site which is far enough inside the shallow bay that incoming surge waves are attenuated. The staff concludes that the calibration process is adequate and the resulting licensee's C_d values are acceptable for use in the surge modeling.

E. Wave Runup

The licensee estimated storm surge-induced wave runup at the Units 1 and 2 Intake Structure (Exelon, 2015). The licensee assumed that runup occurs when wind-generated wave moves over the top of the intake deck and hits the front wall of the Intake (see Figure 3.1.2-7). They determined the controlling depth of water on the deck is 4.85 ft. The controlling depth limits the wave height over the deck as the break of large waves may occur in front of the deck. The licensee determined a maximum wave height after break is equal to 3.78 ft. using a depth limiting constant of 0.78 (Exelon, 2015). The licensee estimated runup values using the following two methods described in Army Corps of Engineering (USACE) Coastal Engineering Manual (CEM) (USACE, 2011):

- Method 1: Empirical formulation for runup on a smooth impermeable slope described in the USACE CEM, EM 1110-2-1100 (USACE, 2011), which results in a runup of 11.32 ft.
- Method 2: Empirical formulation for runup on a vertical slope described in the USACE Shore Protection Manual, Volumes 1 and 2 (USACE, 1984), which results in a runup of 8.68 ft.

The licensee then selected the runup value of 11.32 ft. conservatively (Exelon, 2015). This runup estimate is for the 2 percent exceedance maximum wave runup as indicated by CEM Equation VI-5-7 (USACE, 2011). The NRC staff examined the licensee's methods and conditions for the wave runup on the step-like intake structure. The staff confirmed the methods and conditions used by the licensee to estimate runup is reasonable and the runup estimates are reproducible. In addition, the staff performed independent runup calculations using the following alternative methods as:

- CEM irregular, breaking wave runup methods using different tools result in wave runup values ranging from 9.2 ft to 12.11 ft. at 0.1 percent exceedance probability level.
- USACE CEM, EM 1110-2-1100 (USACE, 2011), VI-5-2, the equivalent slope method results in a runup height of 6.0 ft.

For the equivalent slope method, the staff assumed the step-like intake deck cross section from the toe of the deck to intake wall is idealized as an impermeable slope. With the deck height of 10 ft. and length to the wave direction of 50 ft., the staff estimated an equivalent slope of 17.2 degree using the guideline provided by the CEM (USACE, 2011). The staff's independent calculations demonstrates that the licensee-estimated wave runup values are within the range of the staff's values even though the licensee used different runup conditions and exceedance probability level. Therefore, the staff concludes the licensee's runup estimate is acceptable for use in the MSA as they followed the guidelines provided by USACE (2011).

F. Total Storm Surge Elevation

The licensee added the Delft3D-simulated probable maximum surge with wind-wave activity, and AWL to get a total surge elevation (Exelon, 2015). This is equivalent to the H.3 combined surge event recommended by NUREG/CR-7046 (NRC, 2011). The licensee's AWL estimate includes antecedent 10 percent annual exceedance high tide, initial rise, and long-term sea level rise. The resulting total surge elevation is equal to 26.8 ft. NGVD29. Table 3.1.2-2 compares storm surge estimates for the Calvert Cliffs site from different reports. Noticeably, the total surge level reported in the amended FHRR and used in the MSA is lower than the previous estimates. The staff noted that the lower surge estimate is partly due to the use of more accurate and realistic modeling and assumptions. It should be noted that the stillwater surge level estimated using SLOSH in the original FHRR (Exelon, 2013) includes an additional 20 percent added to the estimated surge depth conservatively based on the stated generic prediction error within the SLOSH model results (Jelesnianski, et al., 1991).

With the updated surge analysis, the licensee concluded in the MSA that the probable maximum storm surge including wave runup would not overtop the roof top of the Intake Pump House (29.14 ft. NGVD29). The amended surge value is bounded by the design-basis (28.14 ft. NGVD29). The staff found that the licensee's evaluation of the PMSS is based on a mixture of conservatisms and non-conservatisms. For instance, the licensee's PHM and wind drag coefficient parameter values could be refined further to get a higher surge elevation. The staff estimated the surge level would be increased by about a foot by refining these parameters. Also, based on a sensitivity analysis, the staff identified that pre-adding AWL as an initial condition to the surge model would raise surge elevation by 0.3 ft. On the other hand, the staff identified the following conservatisms applied to the licensee's storm surge modeling:

- Ignoring the effects of the Baffle Walls in front of the Intake Bay on surge, as the wall may break the approaching surge wave.
- Adding an initial rise value of 1.1 ft. to the antecedent water level estimation.
- Using a conservative runup estimation.
- Having a safety margin of 2.33 ft. to the CDB.
- Use of the Calvert Cliffs Delft 3D model which tends to overestimate the maximum surge level as was shown by the model validation with Hurricane Irene.

The staff determined that these conservatisms would be more than enough to make up the effects of aforementioned non-conservatisms. Therefore, the staff concludes that the storm surge analysis in the amended FHRR is acceptable for use in the MSA.

3.1.3 Summary of the Updated LIP and Storm Surge Analyses

The staff reviewed the updated LIP and storm surge modeling presented in the amended FHRR (Exelon, 2015) as part of the MSA review. The staff noted the amended LIP maximum flood elevation used in the MSA is decreased by 1.5 ft. compared to the original FHRR value, mainly due to using a site-specific PMP. The staff also found that the updated total storm surge elevation was decreased by 4.5 ft. from the original FHRR value due to using a site-specific PMH scenario and detailed, realistic storm surge modeling. Table 3.1.3-1 compares the flood hazard elevations presented in both original and amended FHRRs. Table 3.1.3-2 summarized the maximum flood reevaluation values for the flood-causing mechanisms not bounded by respective CDB. The staff concludes these peak flood elevations are adequate for use in evaluating flood event durations and associated effect parameters.

3.1.4 Change of Interim Flood Protection Measures

The licensee concluded in its original FHRR (Exelon, 2013) that the reevaluated flooding hazards for LIP and storm surge flood-causing mechanisms are not bounded by the respective CDB or plant protection and, therefore, interim actions needed to be provided.

For the LIP flood-causing mechanism, the original FHRR stated that the reevaluated LIP event may affect the safety-related auxiliary building, and the non-safety-related turbine building which houses safety-related equipment and provides control room access. The doors of the auxiliary building will be exposed to a maximum flooding depth of about 2.0 ft. during the LIP event, which will persist for a short period of time. The doors of the Auxiliary Building are not watertight, and water may enter. However, based on consideration of the internal flooding elevation, the licensee indicated that flooding from a LIP event will not affect safety-related equipment housed in the turbine building because (1) external flood waters are guided to the basement without affecting equipment along the flow path, and (2) the flood depth in the basement would be below the critical flood elevation of 18 ft. NGVD29.

The original FHRR (Exelon, 2013) also stated that the site severe weather procedure would be modified to mitigate intrusion of LIP flood water through use of sandbags or alternate commercial flood barriers at access paths, or through implementation of measures to guide water to the lowest elevations of the turbine building without affecting safe functioning of the plant. The NRC staff (i.e., Resident Inspector) confirmed that the site's severe weather procedure has provisions to minimize water intrusion on the 45 ft. elevation of the turbine building deck through portable containment berms and that the licensee can implement the provisions in the associated time (NRC, 2014).

For the storm surge flood-causing mechanism, the original FHRR states that the elevation associated with the reevaluated probable maximum storm surge (31.3 ft. NGVD29) exceeds the roof elevation of the intake structure (29.14 ft. NGVD29 or 28.5 ft. MSL), and thus the floodwater could potentially enter the structure via the ventilation louvers in the intake structure roof and impact the safety related saltwater system pumps. The licensee concluded in the original FHRR that the structure (other than the louvers) will not be impacted because there is no parapet (or other installation) to prevent floodwaters from flowing over the sides of the structure to the deck and into the Chesapeake Bay. The licensee proposed to revise the station procedures to direct the installation of covers over the intake structure ventilation louvers to prevent water ingress into the intake structure, which houses safety-related Systems, structures and components. The original FHRR indicates that these covers would only be put in place prior to the arrival of the hurricane at the Calvert Cliffs site (NRC, 2014).

However, the licensee concluded in its amended FHRR (Exelon, 2015) that the above interim actions are no longer applicable since the updated flood level estimates for the LIP and storm surge flood-causing mechanisms are bounded by the respective current licensing (design) basis. The staff agrees with the licensee's statement that the interim actions are no longer applicable.

3.2 Mitigating Strategies under Order EA-12-049

The NRC staff evaluated the Calvert Cliffs strategies as developed and implemented under Order EA-12-049. This evaluation is documented in a safety evaluation issued by letter dated September 29, 2016 (NRC, 2016b).

The safety evaluation concluded that Calvert Cliffs has developed guidance and proposed designs, which if implemented appropriately will adequately address the requirements of Orders EA-12-049 and EA-12-051.

3.3 Evaluation of Current FLEX strategies

In the MSA, Section 5 explains that the FLEX design criteria, Final Integrated Plan, and FLEX Validation Integrated Review for Calvert Cliffs incorporated the flood parameters for LIP and PMSS from its March 2013 FHRR as design inputs into the FLEX strategies. Furthermore, the licensee stated that the flood levels from its March 2013 FHRR are higher than the amended 2015 FHRR flood levels for LIP and PMSS. However, since the amended LIP flood may have location-specific impacts that were not fully included in the plant design-basis and was not considered by the NRC staff in its supplemental staff assessment, the licensee performed an assessment to verify that the FLEX strategy, as designed, is not adversely impacted by the amended LIP flood. The staff finds it appropriate that the licensee assessed its site based on the amended FHRR flood levels, which incorporates new information from a site-specific meteorological study, to confirm whether its FLEX strategy can be impacted by local ponding from a LIP event.

3.3.1 Probable Maximum Storm Surge

As discussed above, the licensee incorporated the PMSS flood parameters from its March 2013 FHRR into its FLEX Design Criteria, Final Integrated Plan, and FLEX Validation Integrated Review. The licensee also confirmed that the PMSS flood levels from its March 2013 FHRR are higher than the amended, 2015 FHRR flood levels for the PMSS hazard; thus, all aspects of FLEX (including storage and deployment of FLEX equipment, validation of FLEX actions, and viability of FLEX connection points) use the more limiting flood hazard information, and the FLEX design-basis bounds the amended PMSS flood hazard. The staff confirmed that the PMSS flood levels identified in the licensee's March 2013 FHRR are consistent with the information provided in the staff's supplemental staff assessment dated October 21, 2015. The staff finds it reasonable that FLEX can still be implemented when considering the Mitigating Strategies Flood Hazard Information (MSFHI) for the PMSS flood hazard because the licensee has already incorporated and considered the impacts of the reevaluated PMSS flood hazard into its FLEX design-basis.

3.3.2 Local Intense Precipitation

In the MSA, Section 6 explains that the assessment of the FLEX strategies with the amended FHRR LIP flood levels used two methods to demonstrate that the FLEX strategies are not impacted. First, safety-related structures (Auxiliary Building, 45.0 ft. MSL) are physically higher than the amended LIP peak level of 44.9 ft. MSL, and therefore, there is no impact on permanently installed FLEX equipment connections. Furthermore, the licensee's FLEX design-basis LIP levels (i.e., LIP flood levels from March 2013 FHRR and supplemental staff assessment letter) are higher than the amended 2015 FHRR levels.

Since the LIP flood hazard is not bounded by the design-basis, Section G.4.1 of NEI 12-06 indicates an assessment should be performed by the licensee to address the impacts of the MSFHI on (1) the sequence of events, (2) the design and implementation of the FLEX strategies, (3) the FLEX equipment storage, (4) the robustness of plant equipment, (5) the location of FLEX connection points, and (6) the flood protection features credited in the FLEX strategies.

The licensee performed an assessment consistent with the guidance in Section G.4.1 of NEI 12-06 and determined, in part, the following:

- The FLEX storage buildings are located at elevations greater than the LIP flood hazard from the March 2013 FHRR. In addition, the immediate grounds of both FLEX storage buildings contain drywells, drainage channels, and positive grade to ensure drainage away from the structures to prevent flooding in the buildings.
- The topography of the site is comprised of three tiers, which grade downhill from the switchyard, to the power block and then the waterfront (Switchyard at 70 ft. NGVD29, Power Block at 45 ft. NGVD29, and Waterfront at 10 ft. NGVD29), and promotes water flow away from the power block area and towards the Chesapeake Bay.
- The FLEX strategies and associated FLEX guidelines were developed using the reevaluated LIP flood hazard from the March 2013 FHRR; thus, upon completion of the amended LIP flood reevaluation, the FLEX guidelines remained unchanged as the March 2013 FHRR LIP flood bounds the amended FHRR LIP flood.
- Site access routes are at higher elevations than the site and low-lying areas, and small streams or other obstructions will not impede access to the plant by offsite resources.
- The March 2013 FHRR LIP flood was considered in the FLEX design-basis flood, and it was determined there was no impact on existing plant equipment.

Furthermore, the licensee used the amended LIP flood in this assessment to determine whether it could have location-specific impacts on implementing the site's FLEX strategy. Based on the results of this assessment with the amended LIP flood, the licensee determined that (1) temporary flood protection features are not required, (2) FLEX equipment deployment locations, cable and hose deployment paths are above flood levels for the duration of the event, and (3) areas required for FLEX implementation (e.g., refueling of FLEX generators and diesel driven pumps) are above flood levels and remain fully accessible during the event. Thus, the licensee confirmed that there are no location-specific impacts from a LIP event on implementing the site's FLEX strategies.

The staff finds it reasonable that the licensee's FLEX strategy will not be impacted by the LIP flood hazard and can be implemented as designed because the bounding LIP flood hazard was considered during the development of the FLEX strategies and the licensee has evaluated the potential for location-specific ponding issues from the amended LIP flood hazard.

3.4 Evaluation of Associated Effects

The staff reviewed information provided by Exelon (Exelon; 2015, 2016) regarding reevaluated associated effects (AE) parameters for flood hazards not bounded by the CDB. The AE parameters related to water surface elevation (i.e., stillwater elevation with wind waves and runup effects) were reviewed by staff as discussed in the previous section as part of the MSA review. The AE parameters not directly associated with water surface elevation are discussed below and are summarized in Table 3.4-1.

The licensee stated in its MSA report, that the amended FHRR LIP water surface elevations in the powerblock area are below finish floor elevation of safety-related structures. They also stated that the amended FHRR peak water surface elevations for the storm surge, including wind-wave runup, is below the design-basis of 28.1 ft. NGVD29. Therefore, they concluded that the AE parameters for both LIP and storm surge flood-causing mechanisms are not applicable. The staff reviewed the LIP flood and storm surge modeling, as described in Section 3.2.0 of this report, and concluded the amended peak flood elevations used in the MSA analyses are below the respective protection levels. Therefore, the staff confirms the licensee's position that the AE parameters for LIP and storm surge flood-causing mechanisms are not applicable.

In summary, the staff concludes the licensee's methods were appropriate and that the AE parameter results for LIP and storm surge flood-causing mechanisms are reasonable for use in the MSA.

3.5 Evaluation of Flood Event Duration

The staff reviewed information provided by Exelon (Exelon, 2015; 2016) regarding the flood event duration (FED) parameters needed to perform the MSA for flood hazards not bounded by the CDB. The FED parameters for the flood-causing mechanisms not bounded by the CDB are summarized in Table 3.5-1.

The licensee stated in the MSA report (Exelon, 2016) that the amended FHRR (Exelon, 2015) LIP water surface elevations in the powerblock area are below finish floor elevation of safety-related structures. The licensee also stated that the amended FHRR peak water surface elevations for the storm surge, including wind-wave runup, is below the design-basis of 28.1 ft. NGVD29. Therefore, they concluded that the FED parameters for both LIP and storm surge flood-causing mechanisms are not applicable. The staff reviewed the LIP flood and storm surge modeling, as described in the Section 3.2.0 of this report and concluded that the amended peak flood elevations used in the MSA analyses are below the respective protection levels. Therefore, the staff confirms the licensee's position that the FED parameters for LIP and storm surge flood-causing mechanisms are not applicable.

In summary, the staff agrees with the licensee's conclusion related to determining the FED parameters as the approach is consistent with the guideline provided by Appendix G of NEI 12-06, Revision 2 (NEI, 2015). Based on this review, the staff determined that the licensee's FED parameters for all flood-causing mechanisms are reasonable and acceptable for use in the MSA.

4.0 CONCLUSION

The NRC staff has reviewed the information provided in the Calvert Cliffs MSA related to the original FLEX strategies, as evaluated against the reevaluated hazard(s) described in Section 3 of this staff assessment, and found that:

- the sequence of events for the FLEX strategies are not affected by the impacts of the interim staff response (ISR) flood levels (including impacts due to the environmental conditions created by the ISR flood levels) in such a way that the FLEX strategies cannot be implemented as currently developed, and

- the deployment of the FLEX strategies is not affected by the impacts of the ISR flood levels.

Therefore, the NRC staff concludes that the licensee has followed the guidance in NEI 12-06, Revision, 2, and demonstrated the capability to deploy the original FLEX strategies, as designed, against local intense precipitation.

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Table 3.1.1-1. Incremental ssPMP values estimated by the licensee for the Calvert Cliffs LIP modeling (from Amended FHRR (Exelon, 2015).

Duration	PMP Value (inches)
5-minute	3.9
15-minute	6.1
1-hour	11.7
2-hour	17.3
3-hour	19.3
6-hour	24.8

Table 3.1.1-2. Reevaluated LIP Flood Elevations at Critical Structures, taken from the Amended FHRR Table 2.1-5 (Exelon, 2015).

Critical Structures	**Entrance Floor Elevation (ft. NGVD29)**	**Reevaluated Flood Elevation (ft. NGVD29)**	**Max Water Depth (ft.)**	**Flow Velocity (ft./s)**	**Free Board [to][3] Entrance (ft.)**	**Duration of Flood at Entrance (hour) (1)**
South Service Building	45.6	45.5	1.16	1.36	0.14	N.A.
Turbine Building	45.6	45.5	1.11	-0.9 (2)	0.19	N.A.
Auxiliary Building-1	45.6	45.5	1.51	0.61	0.14	N.A.
Auxiliary Building-2	45.6	45.5	1.31	1.18	0.19	N.A.
Auxiliary Building-3	45.6	45.4	1.64	0.71	0.21	N.A.
Auxiliary Building-4	45.6	45.4	1.26	1.32	0.24	N.A.
Turbine Building-5	45.6	44.3	0.64	5.4	[0.36][3]	N.A.
Diesel Generator Building	46.1	44.3	0.64	5.4	1.86	N.A.

Notes:

1. Duration of flooding at entrances were not reported as the area surrounding the power block will remain dry during the LIP event.
2. Negative velocity indicates the discharge in HEC-RAS model goes opposite to downstream.
3. Changed as the result of audit discussions related to the focused evaluation. See the staff assessment of the focused evaluation (ADAMS Accession No. ML17338A356).

Table 3.1.2-1. PMH Parameters Calvert Cliffs Units 1 and 2 Deterministic Storm Surge Simulations (from the amended FHRR Table 2.4-6).

Parameter	NWS 23 Range	Selected PMH Parameters for the Calvert Cliffs Site
Pressure Deficit (mb)	123	123
Radius of Maximum Winds (nm)	10~26	20
Forward Speed (kt)	17~37	8 before landfall 17 after landfall
Track Direction (clockwise from the north) (degree)	68~152	192

Table 3.1.2-2. Comparison of Parameters and Results for Storm Surge and Wave Runup (from amended FHRR, Table 2.4-3).

Parameter	UFSAR for Units 1 & 2	UFSAR for Unit 3	Original FHRR	Amended FHRR
PMH Parameter				
Central Pressure deficit (mb)	135	123	55-124	123
Radius of Maximum Wind (nm)	26	10~26	28~40	10~26
Storm Surge and Wave Runup				
Antecedent Water Level (ft. NGVD29)	2.82	4.4	4.4	4.34
Surge Level (ft. NGVD29)	16.24	17.6	17.5	15.49
Significant Wave Height (ft.)	11.4	10.8	10.9	10.14
Breaking Wave Height (ft.)	N/A	7.6	5.84	3.78
Wave Runup (ft.)	11.9	15.6	13.8	11.32
Surge + Runup (ft. NGVD29)	28.14	33.2	31.3	26.81

Notes:

1) Ft. NGVD29 = ft. MSL + 0.64
2) Wave runup is calculated for the Makeup Water Intake Structure.

Table 3.1.2-5. Wind drag coefficient sensitivity scenarios (from the amended FHRR Table 2.4-5), where Scenario 2 was selected as the final set of calibration parameters.

Scenario	Wind Speed for Break Point (m/s)			Wind Drag Coefficient, C_d			RMSE for Estimated Surge Levels at 5 Locations (ft.)[(1)]
	A	B	C	A	B	C	
1	0	33	90	0.00063	0.0025	0.0040	0.93
2	**0**	**27**	**90**	**0.00063**	**0.0030**	**0.0018**	**0.74**
3	0	33	90	0.00063	0.0024	0.0015	0.98
4	0	25	90	0.00063	0.0024	0.0015	0.88
5	0	25	90	0.00063	0.0030	0.0040	0.74
6	0	25	90	0.00063	0.0030	0.0015	0.75

(1) From Exelon (2017). RMSE stands for root mean square error.

Table 3.1.3-1. Comparison of Original and Amended FHRR Flood Hazards for Flood Causing Mechanisms Not Bounded by CDB.

Flood-Causing Mechanism	Maximum Flood Elevation with Runup (ft. NGVD29)			Difference (Original-Amended FHRR)
	Design-Basis	Original FHRR (Exelon, 2013)	Amended FHRR (Exelon, 2015)	
LIP	44.8	45.1~47.0	44.3~45.5	0.8~1.5 ft.
Storm Surge	28.1[(1)]	31.3	26.8	4.5 ft.

1. From the MSA Table 3.0-4 (Exelon, 2016).

Table 3.1.3-2. Reevaluated Flood Hazards for Flood Causing Mechanisms Not Bounded by CDB for Use in the MSA.

Flood-Causing Mechanism	Stillwater Elevation (ft. NGVD29)	Waves/Runup	Reevaluated Flood Level (ft. NGVD29)	Reference
Local Intense Precipitation and Associated Drainage	44.3 ~ 45.5	Minimal	44.3 ~ 45.5	Amended FHRR Table 3.0-3, MSA
Storm Surge	15.5	11.3 ft.	26.8	Amended FHRR Table 3.0-4, MSA

Table 3.5-1. Flood Event Durations for Flood-Causing Mechanisms Not Bounded by the CDB

Flood-Causing Mechanism	Time Available for Preparation for Flood Event	Duration of Inundation of Site	Time for Water to Recede from Site
Local Intense Precipitation and Associated Drainage (1)	Not Applicable	Not Applicable	Not Applicable
Storm Surge (2)	Not Applicable	Not Applicable	Not Applicable

Source: Exelon (2015; 2016)

Notes:
1. MSA (Exelon, 2016) states the amended FHRR (Exelon, 2015) LIP water surface elevations in the powerblock area are below finish floor elevation of safety-related structures. Therefore, they concluded that the FED parameters for the LIP flood-causing mechanism are not applicable.
2. MSA (Exelon, 2016) states the amended FHRR (Exelon, 2015) peak water surface elevations for the PMSS, including wind-wave runup, is below the design-basis of 28.1 ft. NGVD29. Therefore, they concluded that the FED parameters for the LIP flood-causing mechanism are not applicable.

Table 3.4-1 Associated Effects Parameters not Directly Associated with Total Water Height for Flood-Causing Mechanisms not Bounded by the CDB.

Associated Effects Parameter	Local Intense Precipitation and Associated Drainage (1)	Storm Surge (2)
Hydrodynamic loading at plant grade	Not Applicable	Not Applicable
Debris loading at plant grade	Not Applicable	Not Applicable
Sediment loading at plant grade	Not Applicable	Not Applicable
Sediment deposition and erosion	Not Applicable	Not Applicable
Concurrent conditions, including adverse weather - Winds	Not Applicable	Not Applicable
Groundwater ingress	Not Applicable	Not Applicable
Other pertinent factors (e.g., waterborne projectiles)	Not Applicable	Not Applicable

Source: Exelon (2015, 2016)

Notes:

1. MSA (Exelon, 2016) states the amended FHRR (Exelon, 2015) LIP water surface elevations in the powerblock area are below finish floor elevation of safety-related structures. Therefore, they concluded that the AE parameters for the LIP flood-causing mechanism are not applicable.
2. MSA (Exelon, 2016) states the amended FHRR (Exelon, 2015) peak water surface elevations for the PMSS, including wind-wave runup, is below the design-basis of 28.1 ft. NGVD29. Therefore, they concluded that the AE parameters for the LIP flood-causing mechanism are not applicable.

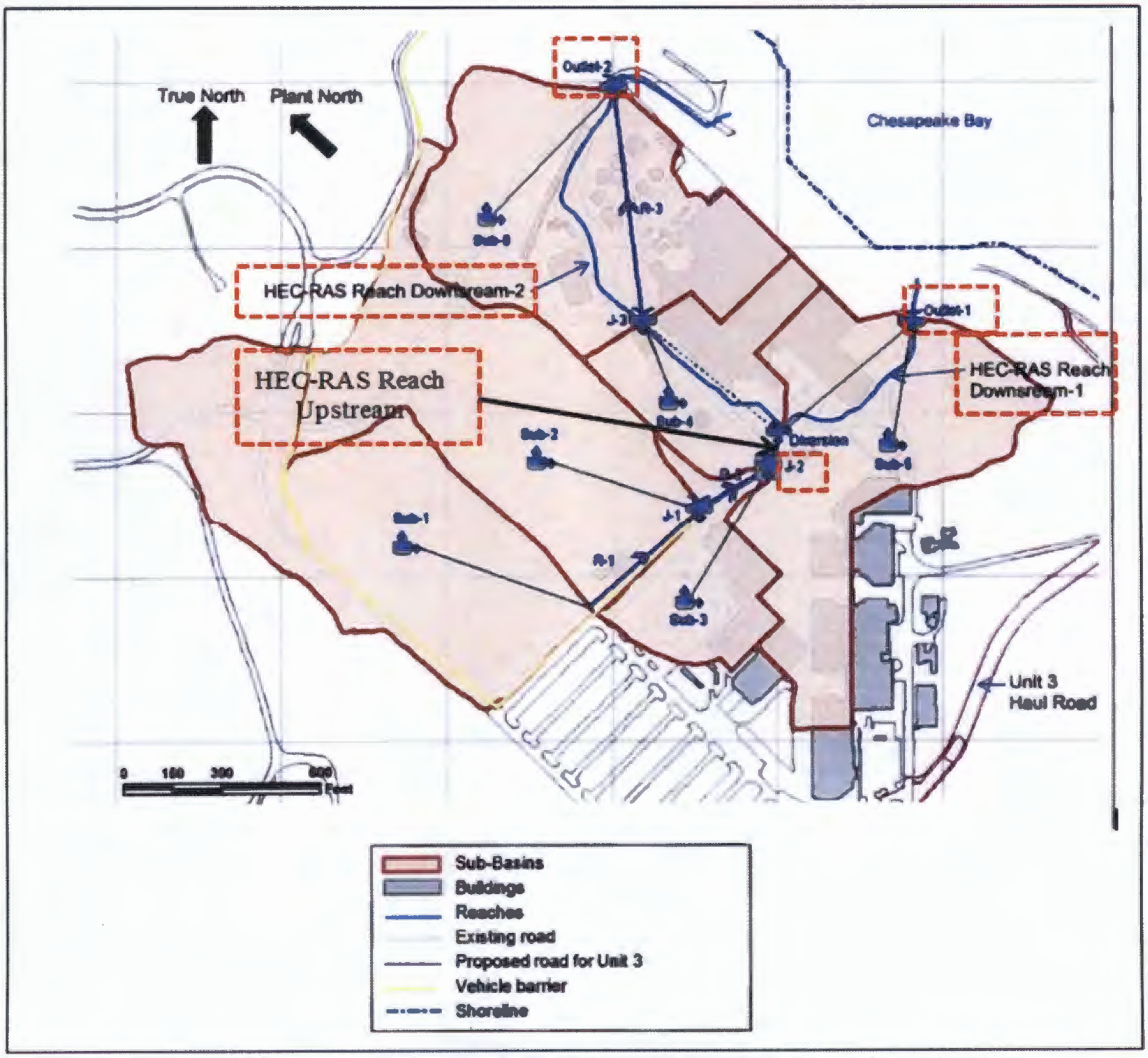

Figure 3.1.1-1. Schematic of HEC-HMS model, taken from the Amended FHRR (Exelon, 2015).

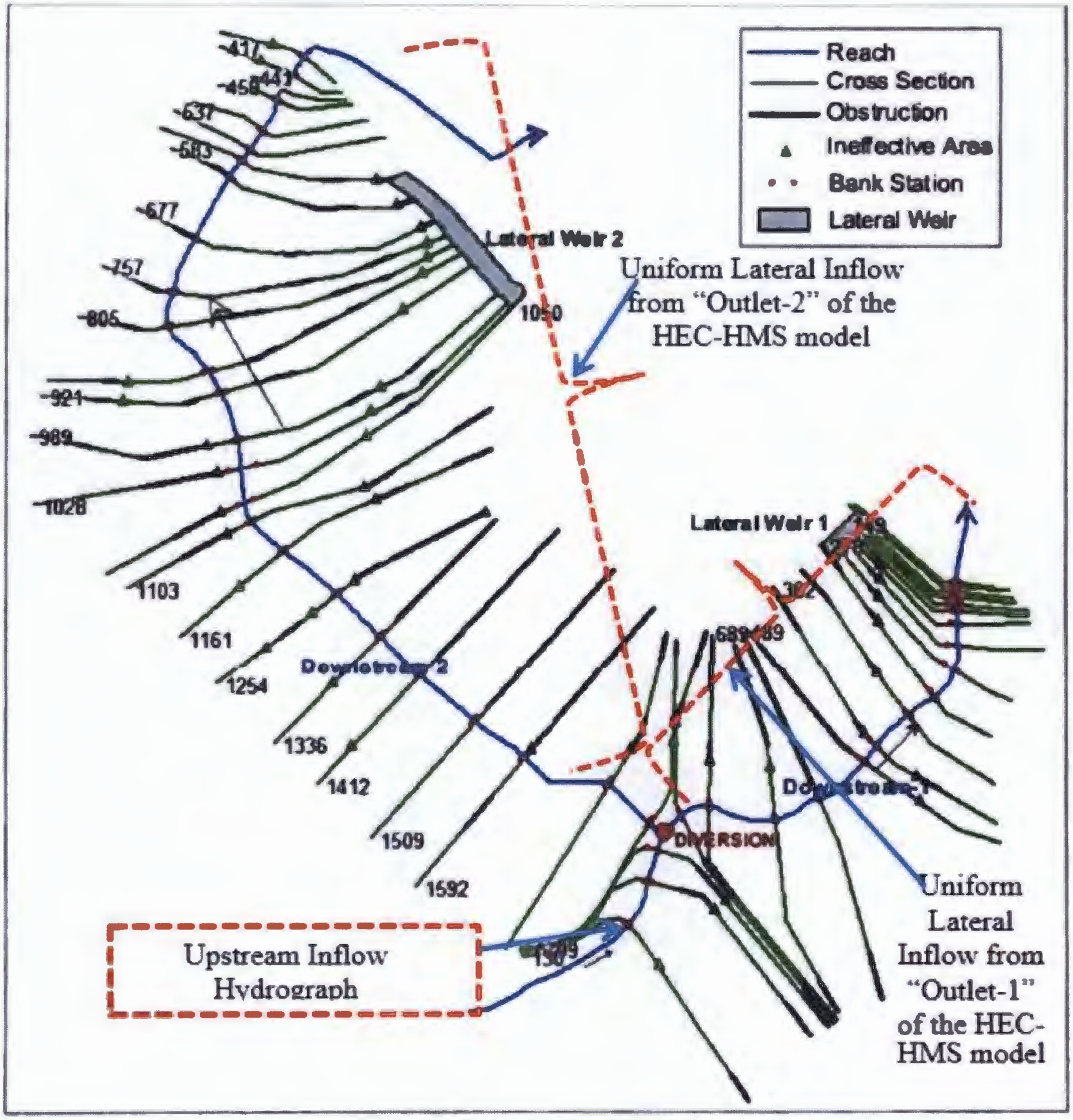

Figure 3.1.1-2. Schematic of the HEC-RAS hydraulic model for simulating the LIP flood-causing mechanism.

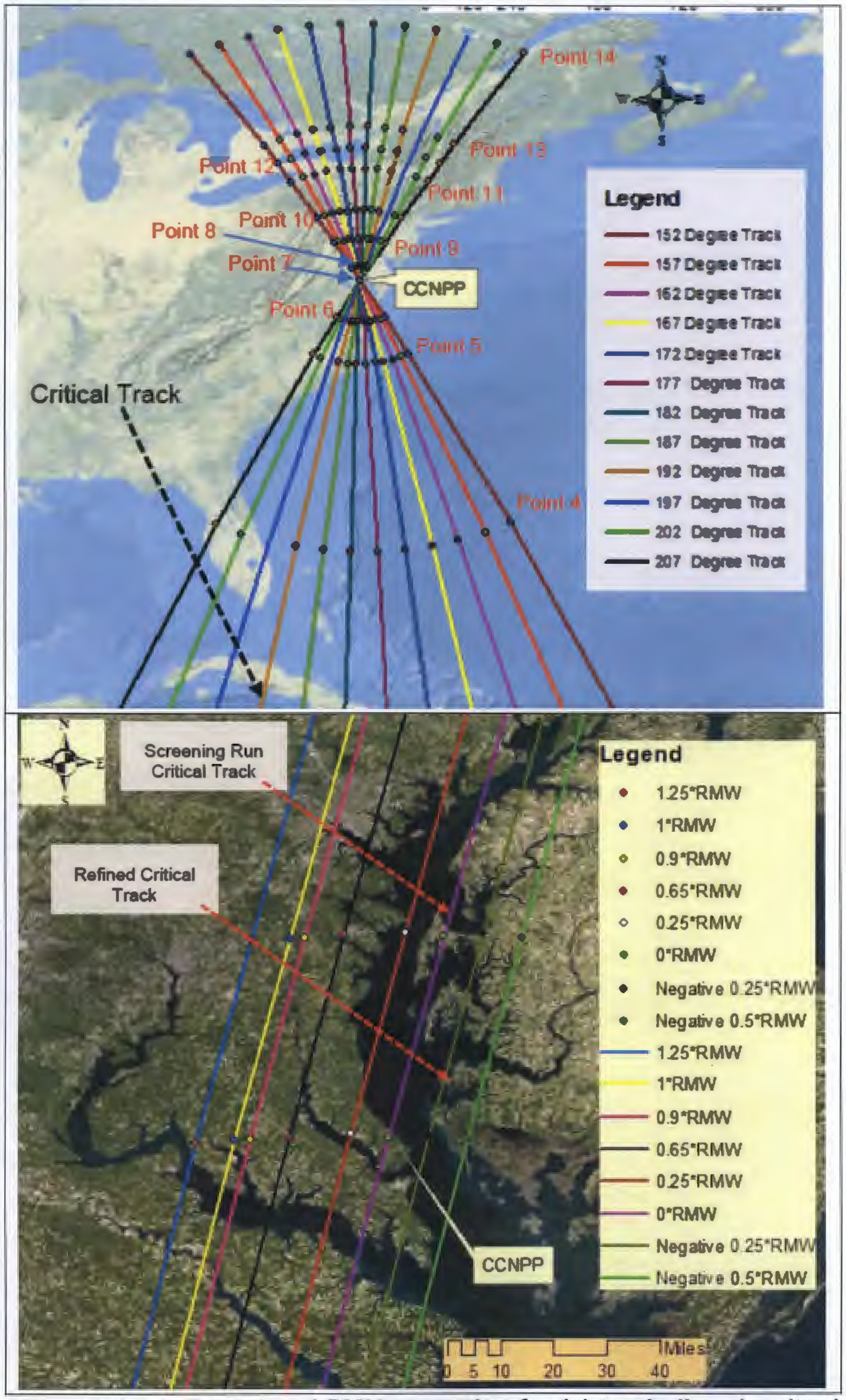

Figure 3.1.2-3. Postulated PMH scenarios for (a) track direction (top) and (b) distance from the plant site to storm center (bottom) (from Exelon (2017).

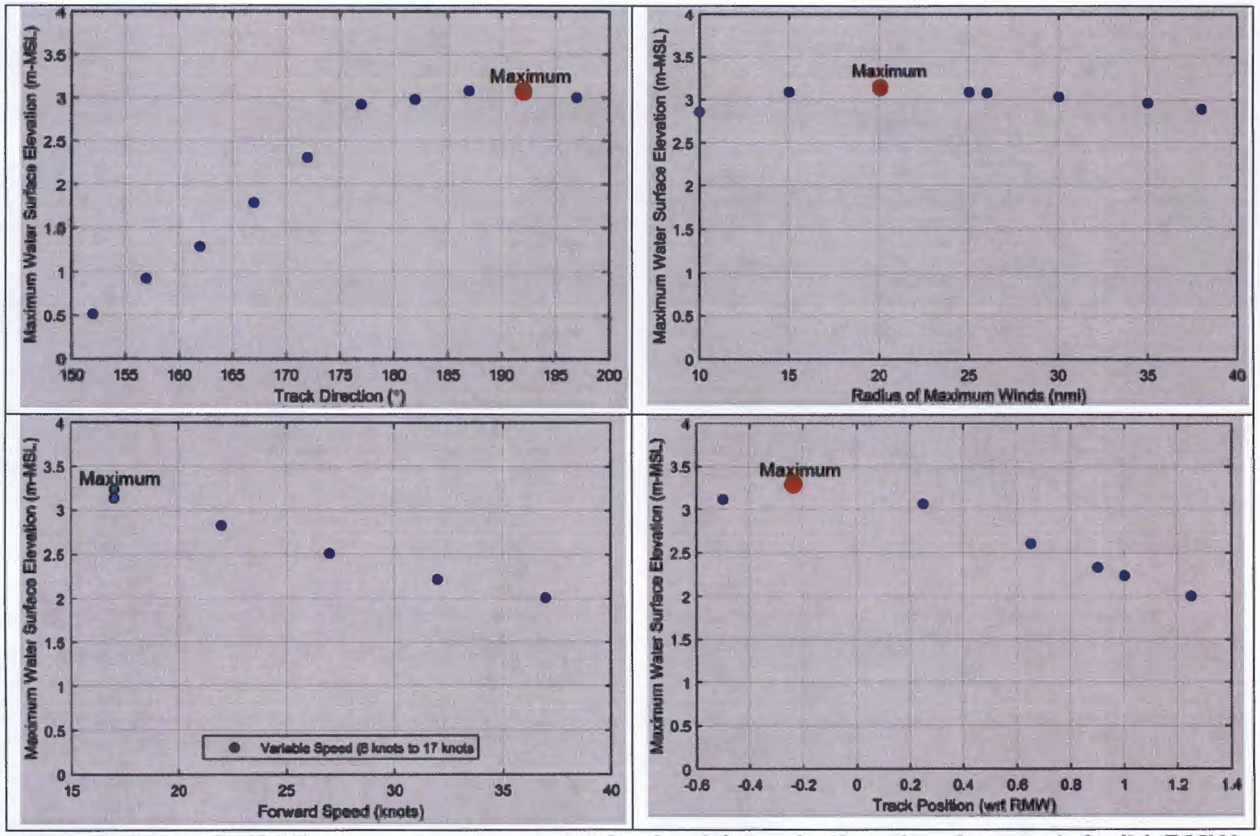

Figure 3.1.2-4. Delft3D storm surge sensitivity for (a) track direction for top-left, (b) RMW for top-right (c) forward speed for bottom-left, and (d) storm track for bottom right (from Exelon(2017)).

Figure 3.1.2-5. Calibrated Manning's roughness coefficients, or n-values (from the amended FHRR Figure 2.4-16).

Figure 3.1.2-6. Tracks for Hurricane Irene in 2011 and Hurricane Isabel in 2003 (from Exelon (2017)).

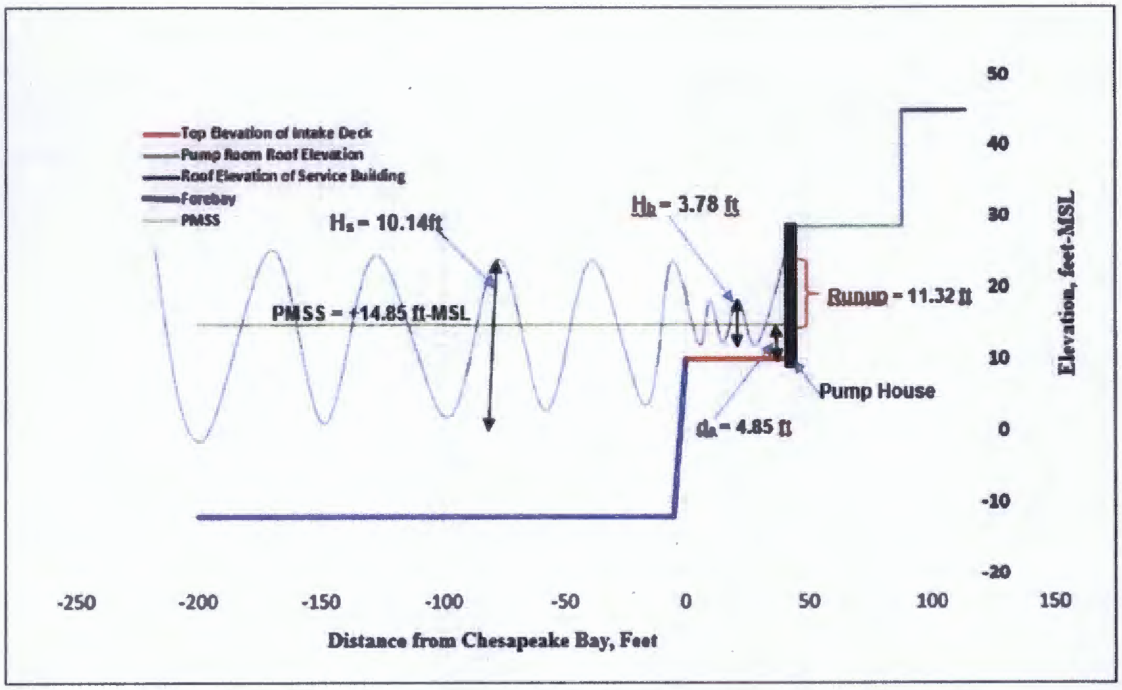

Figure 3.1.2-7. Cross Section Schematic of Wave Activity on Pump House at Calvert Cliffs Units I and 2 House (from the amended FHRR, Figure 2.4-32).

SUBJECT: CALVERT CLIFFS NUCLEAR POWER PLANT, UNITS 1 AND 2 – FLOOD HAZARD MITIGATION STRATEGIES ASSESSMENT (CAC NOS. MF7908 AND MF7909) DATED December 20, 2017

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