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

August 29, 2019

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: QUAD CITIES NUCLEAR POWER STATION, UNITS 1 AND 2 – STAFF ASSESSMENT OF FLOOD HAZARD INTEGRATED ASSESSMENT (EPID NO. L-2018-JLD-0008)

Dear Mr. Hanson:

The purpose of this letter is to document the staff's evaluation of the Quad Cities Nuclear Power Station, Units 1 and 2 (Quad Cities), flooding integrated assessment (IA) that was submitted in response to Near-Term Task Force (NTTF) Recommendation 2.1 "Flooding." The U.S. Nuclear Regulatory Commission (NRC) has concluded that the results and risk insights described in the Quad Cities flooding IA and the staff's independent assessment support the NRC's determination that no further response or regulatory actions are required.

By letter dated March 12, 2012 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML12053A340), the NRC issued a request for information to all power reactor licensees and holders of construction permits in active or deferred status, under Title 10 of the *Code of Federal Regulations* (10 CFR), Section 50.54(f), hereafter referred to as the "50.54(f) letter." The request was issued in connection with implementing lessons learned from the 2011 accident at the Fukushima Dai-ichi nuclear power plant, as documented in the NRC's 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). By letter dated March 12, 2013 (ADAMS Accession No. ML130810038), Exelon Generation Company, LLC (Exelon, the licensee), submitted its flood hazard reevaluation report (FHRR) for Quad Cities.

After reviewing the licensee's FHRR, the NRC staff issued, by letter dated September 4, 2015 (ADAMS Accession No. ML15238B672), a summary of its review of Quad Cities' reevaluated flood-causing mechanisms. The NRC staff also issued a staff assessment by letter dated November 18, 2016 (ADAMS Accession No. ML16323A343), which provided the documentation supporting the NRC staff's conclusions summarized in the letter. These letters affirmed that the local intense precipitation (LIP) and combined event (consisting of a combined event of riverine flooding, dam failure, and wind and wave runup) flood-causing mechanisms at Quad Cities are not bounded by the plant's current design basis, and, therefore, additional assessments of the flood hazard mechanisms were necessary.

By letter dated June 29, 2018 (ADAMS Accession No. ML18180A033), the licensee submitted its IA for Quad Cities. The IAs are intended for the NRC to assess the site's capability to cope with the reevaluated hazard and to determine if additional regulatory actions are necessary under the backfit regulation. The purpose of this staff assessment is to provide the results of the NRC's evaluation of the Quad Cities IA.

As set forth in the attached staff assessment, the NRC staff has concluded that the Quad Cities IA was performed consistent with the guidance described in Nuclear Energy Institute (NEI) 16-05, Revision 1, "External Flooding Assessment Guidelines" (ADAMS Accession No. ML16165A178), and consistent with the NRC staff endorsement of that guidance. Guidance document NEI 16-05, Revision 1, has been endorsed by Japan Lessons-Learned Division (JLD) interim staff guidance (ISG) JLD-ISG-2016-01, "Guidance for Activities Related to Near-Term Task Force Recommendation 2.1, Flood Hazard Reevaluation" (ADAMS Accession No. ML16162A301).

The NRC staff has concluded that the licensee has demonstrated that effective flood protection, if appropriately implemented, exists for the LIP flooding mechanism and that the site is reasonably protected against this flood hazard.

In addition, the NRC staff has further concluded that, for the combined event flood-causing mechanism, the licensee has adequately evaluated the flood hazard using the guidance in NEI 16-05, Revision 1 as endorsed. This determination is primarily based on the following considerations:

1. For the combined event flood-causing mechanism, the site has adequately characterized the "high" and "low" likelihood flooding scenario threshold as equivalent to the site grade elevation of 595 ft. mean sea level.

2. For "high" likelihood (more frequent) flooding scenarios, the licensee has an effective flood protection strategy that does not rely on manual or time-sensitive actions, and will reasonably protect the plant in any mode of operation.

3. For "low" likelihood (less frequent) flooding scenarios, the licensee has a feasible flood mitigation strategy. This strategy relies on anticipatory actions taken well in advance of the flood waters reaching the site, such as performing the normal (current design basis) shutdown and cooldown procedures, opening of doors to equalize water pressures, and the availability of additional offsite equipment, if needed.

4. The staff has inspected, audited, and reviewed, as appropriate, pertinent provisions of the licensee's strategy and found it acceptable.

Based on the above, the NRC staff concludes that no additional regulatory actions are necessary.

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

Sincerely,

Mary Jane Ross-Lee, Acting Director
Division of Licensing Projects
Office of Nuclear Reactor Regulation

Docket Nos: 50-254 and 50-265

Enclosure:
Staff Assessment Related to the
Flooding Integrated Assessment for Quad Cities

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STAFF ASSESSMENT BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO THE INTEGRATED ASSESSMENT

FOR QUAD CITIES NUCLEAR POWER STATION, UNITS 1 AND 2

AS A RESULT OF THE REEVALUATED FLOODING HAZARD

NEAR-TERM TASK FORCE RECOMMENDATION 2.1 - FLOODING

EPID NO. L-2018-JLD-0008

1.0 INTRODUCTION

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, under Title 10 of the *Code of Federal Regulations* (10 CFR), Section 50.54(f), hereafter referred to as the "50.54(f) letter." The request was issued in connection with implementing lessons learned from the 2011 accident at the Fukushima Dai-ichi nuclear power plant, as documented in the NRC's Near-Term Task Force (NTTF) report (ADAMS Accession No. ML111861807).

Enclosure 2 of the 50.54(f) letter requested that licensees reevaluate flood hazards for their respective sites using present-day methods and regulatory guidance used by the NRC staff when reviewing applications for early site permits and combined licenses (ADAMS Accession No. ML12056A046). If the reevaluated hazard for any flood-causing mechanism is not bounded by the plant's current design basis (CDB) flood hazard, an additional assessment of plant response would be necessary. Specifically, the 50.54(f) letter states that an integrated assessment (IA) should be submitted, and described the information that the IA should contain. By letter dated November 30, 2012 (ADAMS Accession No. ML12311A214), the NRC staff issued Japan Lessons-Learned Project Directorate (JLD) interim staff guidance (ISG) JLD-ISG-2012-05, "Guidance for Performing the Integrated Assessment for External Flooding."

On June 30, 2015 (ADAMS Accession No. ML15153A104), the NRC staff issued COMSECY-15-0019, "Closure Plan for the Reevaluation of Flooding Hazards for Operating Nuclear Power Plants," describing the closure plan for the reevaluation of flooding hazards for operating nuclear power plants. The Commission approved the closure plan on July 28, 2015 (ADAMS Accession No. ML15209A682). Language in COMSECY-15-0019 outlines a revised process for addressing cases in which the reevaluated flood hazard is not bounded by the plant's CDB. The revised process describes a graded approach in which licensees with hazards exceeding their CDB flood may not be required to complete an IA, but instead may perform a focused evaluation (FE). By letter dated September 1, 2015 (ADAMS Accession No. ML15174A257), the NRC informed all affected licensees of the plan to use a graded approach in addressing the reevaluated flood hazard.

Nuclear Energy Institute (NEI) 16-05, Revision 1, "External Flooding Assessment Guidelines" (ADAMS Accession No. ML16165A178), was issued by NEI to describe a method of applying a graded approach to address the reevaluated flood hazards. It has been endorsed by the NRC as an appropriate methodology for licensees to use in response to the 50.54(f) letter. The NRC's endorsement of NEI 16-05, including exceptions, clarifications, and additions, is described in NRC JLD-ISG-2016-01, "Guidance for Activities Related to Near-Term Task Force Recommendation 2.1, Flood Hazard Reevaluation" (ADAMS Accession No. ML16162A301). Therefore, NEI 16-05, Revision 1, as endorsed, describes acceptable methods for Quad Cities Nuclear Power Station, Units 1 and 2 (Quad Cities) to address their response to the reevaluated flood hazard mechanisms.

The NRC staff described how the licensee's assessment of the reevaluated hazard would be reviewed to determine if further regulatory action should be taken, such as backfitting additional safety enhancements, in an internal memorandum dated September 21, 2016 (ADAMS Accession No. ML16237A103). This memorandum describes the formation of a Senior Management Review Panel (SMRP) consisting of three division directors from the Office of Nuclear Reactor Regulation that are expected to reach a decision for each plant submitting an integrated assessment. The SMRP is supported by NRC technical staff who are responsible for consolidating relevant information and developing recommendations for the consideration of the panel. In presenting recommendations to the SMRP, the supporting technical staff is expected to recommend placement of each flooding IA plant into one of three groups:

1) **Group 1** will include plants for which available information indicates that further regulatory action is not warranted. For flooding hazards, Group 1 will include plants that have demonstrated (1) effective protection for severe flood hazards, and (2) that consequential flooding is expected to occur only for hazards with a sufficiently small mean annual frequency of exceedance.

2) **Group 2** will include plants for which further regulatory action should be considered under the NRC's backfit provisions. This group may include plants that are unable to protect against relatively frequent flood hazards such that the event frequency in combination with other factors result in a risk to public health and safety for which a regulatory action is expected to provide a substantial safety enhancement.

3) **Group 3** will include plants for which further regulatory action may be needed, but for which more thorough consideration of both qualitative and quantitative risk insights is needed before determining whether a formal backfit analysis is warranted.

The evaluation process that was performed to provide the basis for the staff's grouping recommendation to the SMRP for Quad Cities is described below. Based on its evaluation, the staff recommended to the SMRP that Quad Cities be classified as a Group 1 plant and therefore, no further regulatory action was warranted.

2.0 BACKGROUND

This document provides the final NRC staff assessment associated with the information that the licensee provided in response to the reevaluated flooding hazard portion of the 50.54(f) letter. Therefore, this background section includes a summary description of the reevaluated flood information provided by the licensee and the associated assessments performed by the NRC staff. The reevaluated flood information includes: 1) the flood hazard reevaluation report (FHRR); 2) the mitigation strategies assessment (MSA); and 3) the IA. Also, because the current design basis for the site is important background information for the staff's assessment of the combined events flood mechanism, a summary of the work done to complete the NTTF 2.3 flooding walkdown is provided.

Flood Hazard Reevaluation Report

By letter dated March 12, 2013 (ADAMS Accession No. ML130810038), Exelon Generation Company, LLC (Exelon, the licensee) submitted its FHRR for Quad Cities. After reviewing the licensee's FHRR, the NRC staff issued an Interim Staff Response (ISR) by letter dated September 4, 2015 (ADAMS Accession No. ML15238B672), that provided a summary of the staff's review of Quad Cities' reevaluated flood-causing mechanisms. The NRC staff also issued a staff assessment by letter dated November 18, 2016 (ADAMS Accession No. ML16323A343), that provided the documentation supporting the NRC staff's conclusions summarized in the letter. These letters affirmed that the local intense precipitation (LIP), and a combined event (consisting of a combined event of riverine flooding, dam failure, and wind and wave runup) flood causing mechanisms at Quad Cities are not bounded by the plant's current design basis, and, therefore, additional assessments of the flood hazard mechanisms were necessary.

Mitigation Strategies Assessment

By letter dated December 1, 2016 (ADAMS Accession No. ML16336A805), the licensee submitted the flooding MSA for Quad Cities for review by the NRC staff. The MSAs were intended to confirm that licensees had adequately addressed the reevaluated flooding hazards within their mitigating strategies for beyond-design-basis external events that were put in place to meet NRC Order EA-12-049, "Order Modifying Licenses with Regard to Requirements for Mitigation Strategies for Beyond-Design-Basis External Events." The NRC staff's safety evaluation for the licensee's compliance plans for Order EA-12-049 was issued on December 13, 2018 (ADAMS Accession No. ML18333A016). By letter dated October 4, 2017 (ADAMS Accession No. ML17269A049), the NRC staff issued its assessment of the Quad Cities MSA.

In SECY-16-0142, "Draft Final Rule – Mitigation of Beyond-Design-Basis Events [MBDBE] (RIN 3150-AJ49)," (ADAMS Accession No. ML16291A186) provisions were proposed that would have required mitigation strategies to address the reevaluated flood hazard information on a generic basis. As reflected in the Affirmation Notice and Staff Requirements Memorandum (SRM) dated January 24, 2019 (ADAMS Accession No. ML19023A038), associated with SECY-16-0142, the Commission determined that sites addressing the reevaluated hazards on a generic basis was not needed for adequate protection of public health and safety but should instead be assessed on a plant-specific, case-by-case basis under the requirements of 10 CFR § 50.109, "Backfitting," and § 52.98, "Finality of combined licenses; information requests."

The January 24, 2019, Affirmation Notice and SRM directed the staff to use the 50.54(f) process to ensure that the NRC and its licensees will take the needed actions, if any, to ensure there is no undue risk to public health and safety due to the potential effects of the reevaluated flood hazards. The SRM further directed that the staff should continue these efforts, utilizing existing agency processes to determine whether an operating power reactor license should be modified, suspended, or revoked in light of the reevaluated hazard.

The licensee stated in its December 1, 2016, MSA that the FLEX design basis for the LIP and Mississippi River flood event combination flood-causing mechanism bound the reevaluated flood hazard parameters. The reevaluated LIP and river flood hazards found in the ISR letter were used as input for developing the FLEX strategy, including aspects related to the storage and deployment of FLEX equipment, validation of FLEX actions, and viability of FLEX connection points. The NRC staff concludes that for the combined event that the December 13, 2018, safety evaluation for the licensee's compliance plans for Order EA-12-049 is not affected by the January 24, 2019, Commission SRM and that the Quad Cities mitigation strategies will address the combined event reevaluated flood hazard at the site.

As discussed below, in its IA the licensee provided a revised LIP analysis to support its assessment of structures, systems, and components (SSCs) to provide key safety functions (KSFs) of core cooling, containment integrity, and spent fuel pool cooling. The revised LIP resulted in an increase in flood levels reported at some doors on the order of 0.4 ft. The staff did not reperform an assessment of the ability to implement mitigation strategies under such conditions. The staff does not believe that such an analysis is necessary because:

1) as documented in the staff's assessment below, the staff has determined that the licensee has effective flood protection against the reevaluated LIP such that SSCs and KSFs will be able to address the flood without having to rely on FLEX strategies,

2) the conservatisms associated with the LIP analysis are such that, should a LIP event of the magnitude reported in the IA occur, in all likelihood the mitigation strategies should be able to be employed and serve a defense-in-depth function should the SSCs associated with the KSFs fail, and

3) the frequency of a LIP event is low, such that identifying a cost-justified substantial safety improvement in accordance with 10 CFR 50.109 to ensure that FLEX strategies will provide a defense-in-depth function, given KSFs are maintained using installed plant equipment, is unlikely.

Integrated Assessment

By letter dated June 29, 2018 (ADAMS Accession No. ML18180A033), the licensee submitted its integrated assessment for Quad Cities. The IAs are intended for the NRC to assess the site's capability to cope with the reevaluated flood hazard and to determine if additional regulatory actions are necessary. These regulatory actions would be taken in accordance with 10 CFR 50.109, "Backfitting." To facilitate its review, the NRC staff issued an audit plan by letter dated July 18, 2017 (ADAMS Accession No. ML17192A452), stating its intention to review additional relevant information and supporting documentation, as needed.

Flooding Walkdowns

In addition to the assessments described above associated with the reevaluated hazards, the licensee also performed flooding walkdowns at the plant in response to Enclosure 4, "Recommendation 2.3: Flooding," to the 50.54(f) letter. In the Enclosure, licensees were requested to identify and address degraded, nonconforming, or unanalyzed conditions using the corrective action process, verify the adequacy of monitoring and maintenance procedures, and report the results to the NRC with regard to the design basis flood hazard level(s) for all flood-causing mechanisms, including groundwater ingress.

By letter dated November 27, 2012 (ADAMS Accession No. ML12332A307), Exelon submitted a flooding walkdown report for Quad Cities. By letter dated June 25, 2014 (ADAMS Accession No. ML14106A648), the NRC staff issued a staff assessment documenting the results of its evaluation of the walkdown report. In the staff assessment, the NRC concluded that Exelon responded appropriately to the requested information, and that no immediate safety concerns were identified. In addition, NRC inspectors independently verified that licensees were implementing the flooding walkdowns in accordance with NRC-endorsed walkdown methodology by accompanying licensee personnel on a sample of the walkdowns. An inspection report dated January 31, 2013 (ADAMS Accession No. ML13031A617), documents the results of this inspection and notes that no findings of significance were identified. The results of the flooding walkdown of the Quad Cities current design basis are considered in the staff assessment found in Section 3.3.1 of this document.

3.0 TECHNICAL EVALUATION

Quad Cities, Units 1 and 2, are General Electric boiling-water reactors (BWRs), Model 3, with Mark I containments. The Quad Cities site is located on the east bank of the Mississippi River, approximately 506.6 miles upstream of the confluence of the Ohio River with the Mississippi River and midway between Lock and Dam No. 14 and Dam No. 13. The licensee noted in the IA that unless specified otherwise, all elevations are given relative to the Mean Sea Level (MSL) datum of 1912. Other elevations may be relative to the North American Vertical Datum of 1988 (NAVD88). The conversion between datums is MSL minus 0.70 feet (ft.) equals NAVD88.

As stated in the IA and Updated Final Safety Analysis Report (UFSAR), the mean station elevation as well as the ground floor level for the Reactor Building (RB) is 595.0 feet (ft) MSL. The ground surface at the site drops off abruptly at the bank of the river, forming a bluff about 30 ft. high. Topographic relief at the site is low and relatively flat.

The current licensing basis for flooding at Quad Cities was exceeded for two mechanisms, as described in the September 4, 2015, letter and summarized in Table 3.1-1. Guidance document NEI 16-05, Revision 1, as endorsed, describes the different flood impact assessments paths.

For LIP, the licensee is pursuing Path 2 in order to adequately demonstrate that effective flood protection is provided for this mechanism. For the combined event, the licensee is pursuing Path 5, a scenario-based approach. Because the assessment for the combined event was evaluated under this approach, an IA was necessary instead of a focused evaluation (consistent with NEI 16-05). Since the site response to each of these mechanisms is different, the NRC evaluated them separately below.

3.1 Characterization of Flood Parameters

In the IA, the licensee stated that the LIP flood hazard mechanism was revised/updated since the issuance of the NRC's September 4, 2015, ISR letter. The revisions were performed to incorporate the effects of modifications performed at the plant. As a result, the adequacy of these changes, as well as the corresponding associated effects (AE) and flood event duration (FED) parameters were evaluated by the NRC staff and are documented in this assessment.

With respect to the combined event, the licensee stated in the IA that no changes have been made to the flooding analysis previously reviewed by the NRC staff. However, in the FHRR staff assessment the NRC reviewed and documented its partial evaluation of the AE and FED information that was provided, but stated that additional information was needed in subsequent flooding assessments to complete the review (See Tables 4.2-1 and 4.3-1 of the FHRR staff assessment). Exelon used the AE and FED parameters for both flooding mechanisms as input to the Quad Cities IA.

3.2 Local Intense Precipitation

For LIP, the NRC staff evaluated the impact of the unbounded mechanism, the available physical margin (APM), and the reliability of the site protection features to confirm that key SSCs are protected.

3.2.1 Description of Revisions to Local Intense Precipitation Flood Mechanism

The LIP flood parameters were revised to incorporate the effects of modifications performed at the plant. Specifically, the changes included the effects of rooftop parapets, a Trackway 2 expansion, footprints of both mitigation strategies storage buildings (also referred to as FLEX storage building and FLEX +1 storage building), and site grading changes around the Independent Spent Fuel Storage Installation (ISFSI) expansion, among others.

These changes were subsequently incorporated into the licensee's FLO-2D model. Although these changes produced flood elevations that differ from those described in the site's ISR letter, the changes were found by the NRC staff to be minimal. The revised LIP flooding analysis is summarized in the IA and fully described in site calculation LIP-QDC-001, "Quad Cities Local Intense Precipitation Evaluation," Revision 5, updated August 2017, which was reviewed by the NRC staff in accordance with the audit plan described in letter dated July 18, 2017 (ADAMS Accession No. ML17192A452).

The NRC staff reviewed the changes made to the licenses FLO-2D model by comparing the previous and current versions of the Digital Elevation Model (DEM) used in the licensee's FLO-2D model (Figure 3.2-1). The NRC staff found that changes made by the licensee to the DEM are consistent with the description provided by the licensee in their IA. Additionally, the NRC staff verified that the rooftop parapets on the RB and Turbine Building (TB) were properly incorporated into the licensee's FLO-2D model.

The NRC staff also reviewed the licensee's precipitation inputs used to estimate the flood hazard elevations in the IA and confirmed the precipitation inputs match those used in the licensee's FHRR and MSA. Based on the licensee's use of the same precipitation input previously approved by the NRC staff, the NRC staff determined that there was no significant change in the AEs and FEDs previously reviewed by the NRC, and therefore the revised LIP analysis is suitable input for the IA (ADAMS Accession No. ML18347B217, non-publicly available).

3.2.2 Description of Impact(s) of Reevaluated Local Intense Precipitation Flood Mechanism

The expected water surface elevations for the revised LIP analysis were evaluated by the licensee at 23 points of interest and documented in calculation LIP-QDC-001, Revision 5. Points of interest generally correspond to SSCs that provide the KSFs of core cooling, spent-fuel cooling, and containment integrity. The maximum stillwater level results identified in the IA were 598.8 ft. MSL and found to occur at the RB doors 1 and 5 which is a 0.4 ft increase from the initial issuance of this analysis. Other key locations were also found to be impacted such as the TB and the 1/2 Emergency Diesel Generator (EDG) building. (The 1/2 EDG building houses a swing EDG that can provide power to either unit.)

As a result of these hazard exceedances, the licensee stated that a flooding protection strategy using a combination of temporary and permanently installed flood barriers will be made available at 18 locations. The new temporary flood barriers consist of fastlogs (a modular stackable temporary flood barrier), adjustable door panels, hinged panels, and quick dams. The permanent passive flood features are installed features at the site that have been evaluated and credited with protection of key SSCs that provide KSFs. The flood protection features to be installed and their corresponding locations are fully described in Section 6.1.1 of the IA.

3.2.3 Evaluation of Site Response, Available Physical Margin and Reliability of Flood Protection Features

As a result of the potential impacts of LIP at the site, the licensee calculated the structural loading (hydrostatic and hydrodynamic forces generated by the LIP flood event) against the capacity of proposed flood protection features to verify their adequacy and the APM. The licensee documented its evaluation and results in calculation QDC-000-S-2089, Revision 2, "Quad Cities Nuclear Power Station, Evaluation of Flood Boundary Structures for Local Intense Precipitation."

As part of its review, in accordance with the July 18, 2017, audit plan, the NRC staff reviewed calculation QDC-000-S-2089, Revision 2 (and supporting documentation as part of the IA audit). Specifically, the NRC staff was able to access drawing SK-LIP-00 of calculation QDC-0000-S-2089. In this drawing, the licensee identified a perimeter around the RB and TB, including portions of the service building (SB), radwaste building, and 1/2 EDG building. This perimeter represents the LIP flooding boundary, and it includes building walls, rolling steel doors, and access doors that will serve as flood barriers. For the same reason, each portion was evaluated by the licensee to assess the boundary's capacity to withstand the LIP flooding loads. Where needed, the licensee identified compensatory measures to ensure that LIP waters remain outside the boundary. Compensatory measures include temporary flood barriers and construction of masonry block walls to provide additional structural stability to existing block walls that may not have the structural capacity needed to withstand the LIP flooding loads. Details of the licensee's analysis were audited by the NRC staff, as explained in the following paragraphs.

The licensee stated in its IA, that Section 7.2 of calculation QDC-0000-S-2089 assessed the structural capacity of the existing steel doors and the portion of the TB North Siding that form a portion of the LIP flood boundary. The NRC staff audited this portion of the calculation and notes that the licensee compared tornado generated loads (300-mile per hour (mph) winds) to the LIP flooding loads at each steel door and at the TB North Siding. The calculation confirmed that the tornado generated loads, originally used for the design of the walls and doors, are greater than the LIP flooding loads. The NRC staff was able to confirm that calculations used the correct input information and that acceptable engineering practices were followed, as stated in the NEI 16-05, Revision 1, Appendix B guidance, as endorsed. The licensee stated in its calculation that walls and doors were inspected as part of a walkdown to identify leak pathways, and that actions were taken to seal the identified leak pathways. Doors found susceptible to failure under LIP flooding loads are to be protected by temporary flood barriers. The licensee identified a variety of flood barriers, some of which will be anchored to structures that form the LIP flood boundary.

The licensee stated that Section 7.3 of calculation QDC-0000-S-2089 provides the design of new anchorage for temporary flood barriers (fastlogs, swing gates, and other adjustable barriers) to be installed as part of the LIP flood boundary. To confirm these statements, the NRC staff audited Section 7.3 of the calculation. In doing so, the NRC staff confirmed that the licensee used acceptable engineering practices to design and evaluate the anchorage connections to walls. The calculations described the different anchorage systems and assessed different failure mechanisms associated with the LIP flooding loads at each location where flood barriers will be installed. Material properties of both anchors and walls were demonstrated to be sufficient to withstand the LIP flooding loads. Given the information provided by the licensee, the barrier anchorage should have sufficient capacity to withstand the LIP flooding loads.

The licensee stated that Section 7.4 of calculation QDC-0000-S-2089 assessed the capacity of seismic category II masonry block walls in the SB, the TB, and in the Laundry, Tool, and Dry Active Waste Building against the LIP flooding loads. To confirm these statements, the NRC audited Section 7.4 of the referenced calculation. In this portion of the calculation, the licensee identified masonry block walls in the SB that might not be strong enough to withstand the LIP flooding loads. To resolve this, the licensee proposed to design and construct new block walls in accordance with acceptable design standards to reinforce existing walls part of the LIP flood boundary. The NRC staff audited the analysis methods used to assess these masonry block walls and determined that the license followed acceptable engineering practices. Section 7.5 of calculation QDC-0000-S-2089 described the design of new masonry block walls for the SB. The NRC staff confirmed, during the audit of calculation QDC-0000-S-2089, that these new walls are designed in accordance with acceptable design standards and that they should have sufficient capacity to maintain the LIP flood boundary. The licensee updated the information regarding LIP and stated that the SB south wall mentioned in QDC-0000-S-2089, Section 7.4.1 was found to be not acceptable for the LIP event as constructed. A new wall was designed in section 7.5 of QDC-0000-S-2089. This new wall was installed per Engineering Change (EC) package 396297 "Above Grade Flood Barriers for the Local Intense Precipitation (LIP) Event – Fukushima." All installation activities (including the new block walls) were complete by March 19, 2015. Based on the information provided by the licensee, the NRC staff agrees that the portion of the LIP flood boundary addressed by this installed modification should withstand the LIP flooding loads.

The licensee also stated that Section 7.6 of calculation QSD-0000-S-2089 assessed the capacity of existing reinforced concrete walls in the RB and TB that are part of the LIP flood boundary. In its assessment, the licensee made a qualitative comparison between the material properties of the reinforced concrete walls and the masonry block walls. The argument was based on the inherently stronger capacity of reinforced concrete when compared to the masonry block walls. In previous sections of the calculation, masonry walls were demonstrated to have sufficient capacity (some after modifications) to withstand the LIP flooding loads. The NRC staff evaluated this assessment and concluded that, if the masonry block walls that are part of the LIP flood boundary can withstand the LIP generated loads, the reinforced concrete walls also should be expected to withstand the LIP flooding loads.

During the audit of calculation QSD-0000-S-2089, the NRC staff noted that the document referred to multiple EC packages with information associated with walkdowns and work done to assess the integrity of the LIP flood boundary. For example, in EC 393258, Revision 1, "Evaluate the Effects of the Local Intense Precipitation (LIP) and the River Flood Event – Fukushima," the licensee identified the LIP flood boundary, documented walkdowns completed to identify penetrations and potential leak paths, determined the amount of leakage that might enter the LIP flood boundary, and provided recommendations to prevent leakage and to prioritize actions. In EC 393258, the licensee stated it considered the effect of LIP water from the roofs draining to the ground level. In EC 396297, the licensee documented processes to seal several leak paths and to install flood barriers needed for the LIP flood boundary. The same EC also provides instructions and supporting references (drawings, calculations, and plant procedures) to complete all protective actions identified in the EC. The work documented in these ECs provides assurance regarding the information used in calculation QSD-0000-S-2089 and the effectiveness of the licensee's preventive actions.

In addition, the licensee provided IA Tables 4 and 5, where different representations of APM are provided. The licensee also explained the reasoning behind each APM representation and stated that the different representations were meant to provide at least one APM value for each barrier. The first APM consideration is the difference between flood depth and the barrier height, which is very straight forward and simple to understand. The second APM consideration is related to the flood depth needed to reach the loading capacity of the flood barriers versus the actual depth for the LIP flood. In the IA, the licensee referred to Tables 7.1.3.A and 7.1.3.B of calculation QSC-0000-S-2089 for a detailed explanation of this APM. As part of the audit, the NRC staff reviewed the tables and noted that the licensee used the allowable loads (considering both hydrostatic and hydrodynamic components) for each barrier to estimate the height of water needed to exceed the allowable. In other words, this second APM representation is essentially the difference between the LIP flood depth needed to fail the barrier and the actual LIP flood depth. After understanding the licensee's APM representation, the NRC staff concluded that the licensee's overall approach is conservative.

The licensee explained, in its IA, that the third way APM is presented is as the maximum structural interaction coefficient (IC). The IC, as explained by the licensee in its IA, is determined by dividing the calculated design load (i.e, the LIP flooding load) by the allowable load (i.e, the barrier's structural properties). An IC less than 1.0 indicates that the LIP flooding load is less than the barrier's allowable load and is acceptable. The maximum IC for each barrier was determined by the structural property having the most limiting (greater) ratio. The licensee also explained that a smaller IC means a greater APM. As part of the audit process, the NRC staff reviewed the structural calculations in calculation QSC-0000-S-2089 to confirm that the IC did consider the most limiting design scenarios for the barriers. In its analysis, the licensee assessed different loading conditions for each barrier and selected the dominant loads for design. The NRC staff audited a sample of these calculations where the barrier design loads (tornado wind load) was divided over the allowable load to confirm that the IC ratio is accurate. Based on the information provided by the licensee, the NRC staff concludes that the three different representations of APM provide sufficient information to conclude that there is APM for each of the barriers.

In Section 7.1.2 of the IA, the licensee provided information regarding adequate APM justification and reliability of flood protection. The licensee stated that the APM, relative to the LIP, is adequate due to conservative approaches taken in the analysis process. Among these conservative approaches, the licensee stated that runoff losses due to infiltration and surface retention were ignored, that conveyance of drainage systems was ignored, and that the model used to quantify the expected volume of LIP water allowed more water accumulation than would actually occur. In addition, the licensee stated that the evaluation of barriers considered conservative approaches as demonstrated with APM. After assessing the information in the IA and in supporting calculations, the NRC staff concludes that the licensee has adequate reliable flood protection features, and that there is APM, relative to the LIP flood hazard.

In its IA, the licensee also described the time-sensitive actions (TSAs) required at the site for the timely installation of the temporary flood protection barriers. In its discussion, the licensee stated that the analysis was included as part of Validation Plan #12 of EC 404409, "Integrated Review of FLEX Action IAW NEI Validation Process Fukushima." As part of its review, the NRC staff evaluated the TSAs developed by the licensee against the guidance described in NEI 16-05, Appendix C, "Evaluation of Site Response." The NRC staff was able to confirm that the licensee developed TSAs at the site that are feasible and have clear and unambiguous trigger conditions. Furthermore, the staff concludes that the licensee should be able to effectively respond to the LIP flood hazard and perform the TSAs given the expected environmental conditions, competing tasks, and outside support needs, as applicable.

3.2.4 Conclusion

The NRC staff concludes that APM and reliable flood protection features exist for the LIP flooding mechanism. In addition, all TSAs relied upon for the overall response strategy have been evaluated and confirmed following the guidance of NEI 16-05, as endorsed, and determined to be feasible.

3.3 Combined Event (Combined Effects of Riverine Flooding, Dam Failure, and Wind Wave Runup)

For the combined effects flood mechanism, the licensee is pursuing Path 5 of guidance document NEI 16-05, Revision 1. The purpose of Path 5 is to demonstrate an effective response to consequential flooding that has a relatively high likelihood of occurrence and a feasible response to mitigate the effects of an extreme flood with a low likelihood of occurrence. The licensee stated that no changes to the flood mechanism evaluation have occurred since the submittal of the FHRR, which the NRC staff has reviewed.

Guidance document NEI 16-05, Revision 1, as endorsed, states that floods with an annual exceedance probability (AEP) of 1E-4 (or 1E-3 with margin) should be considered for the more frequent floods. In the IA, the licensee calculated a consequential flooding elevation corresponding to an AEP of 1E-4 of 591.5 ft. MSL at the 95 percent confidence limit and 589.2 ft. MSL median value. The licensee's AEP of 1E-4 also included a 1.4-foot increase above the computed value to account for uncertainties. Furthermore, the licensee stated in the IA that the threshold between "low" and "high" likelihood events would be set at an elevation equal to site grade in order to account for additional margin at Quad Cities. As previously described, the site grade is located at elevation 595 ft. MSL.

The NRC staff reviewed the licensee's determination of the consequential flooding elevation corresponding to an AEP of 1E-4, and also reviewed the proposed site response to scenarios both above and below that elevation to determine if additional regulatory actions are necessary.

3.3.1 Current Licensing Basis Flooding Response

Sections 2.4.and 3.4 of the Quad Cities UFSAR fully describe the current licensing basis floods and the associated flood protection features for Class I structures and components at the site, respectively. Highlights from these UFSAR sections are found below.

<u>Licensing Basis Flood Hazard Characterization</u>

With regard to the probable maximum flood (PMF), Exelon stated in the Quad Cities UFSAR that the 100-year and 200-year floods would reach elevations of 588 ft. MSL and 589 ft. MSL at the site, respectively. The 200-year flood was initially considered to be the PMF and is 6 ft. below station elevation of 595 ft. MSL.

The NRC modified the PMF criteria subsequent to the issuance of the construction permit of Quad Cities in 1967 and, in the 1975 Standard Review Plan, adopted the U.S. Army Corps of Engineers (USACE) PMF as criteria for plant design purposes. This updated PMF was evaluated in both the licensing basis Safety Evaluation Report and in the UFSAR. The licensee further explained in the flooding walkdown report that during construction permit reviews, the PMF (as defined by USACE) was analyzed and resulted in floods reaching elevation of 603 ft. MSL at the site (see ADAMS Accession No. ML14238A384). Therefore, 603 ft. MSL is the relevant elevation to which the plant can safely mitigate flooding effects and is described as the licensing basis PMF by Exelon.

As part of the IA evaluation, the NRC staff reviewed the "Technical Evaluation Report [TER] on the Review of the Individual Plant Examination of External Events [IPEEE] at Quad Cities

Nuclear Power Station, Units 1 and 2," dated January 2001 (ADAMS Accession No. ML011410547), and confirmed that the licensing basis information presented in the IA is consistent with previous NRC evaluations, and notes that the IPEEE TER concluded that the licensee screened out all high winds, flooding, and other initiators (HFO) events, and has deemed them to be insignificant contributors to the risk of severe accidents at Quad Cities. Correspondingly, no vulnerabilities or safety enhancements were identified, and no commitments for plant improvements related to HFO initiators were made by the licensee. Furthermore, by letter dated April 26, 2001 (ADAMS Accession No. ML011410427), the NRC staff concluded that the IPEEE results at Quad Cities were reasonable given the design, operation, and history of the plant.

As noted in Section 2.0 of this document the licensee performed a flooding walkdown of the site in response to the 50.54(f) letter associated with NTTF Recommendation 2.3. As documented in the staff's January 24, 2014 assessment (ADAMS Accession No. ML14106A648), the NRC staff concluded that the licensee verified the plant configuration with the current flooding licensing basis of 603 ft. MSL; addressed degraded, nonconforming, or unanalyzed seismic conditions; and verified the adequacy of monitoring and maintenance programs for protective features.

<u>Licensing Basis External Flood Protection Measures</u>

The Quad Cities UFSAR states that, at the time of design, the external flood control efforts were directed towards the prevention of damage associated with the Mississippi River PMF, which resulted in a flood elevation of 589 ft. MSL at the site. Based on a 33 percent increase in normal allowable stresses from the expected PMF elevation, the initial structural design of SSCs was based on a water level corresponding to elevation 590 ft. MSL. Subsequent evaluations for higher flood levels show that elevation 603 ft. MSL is the maximum flood elevation which can assure that the plant can be shut down and maintained in a safe condition.

For floods occurring to the level of the plant grade elevation of 595 ft. MSL, no additional protective measures are needed to maintain structural integrity of SSCs. For floods of any elevation from 595 ft. MSL up to the surrounding ground elevation of 603 ft. MSL, the plant can and will be maintained in a safe condition by flooding the plant buildings to match the river elevation. A flood of this magnitude would provide sufficient time to enable shutdown procedures to be enacted and flooding of the structures to be initiated as described below.

The generalized steps for securing the station in the unlikely event of a flood above the level of the historic flood of record will be initiated a minimum of 3 days prior to the predicted arrival of a flood of elevation 594.5 ft. MSL or greater and are described in UFSAR Section 3.4.1.1, "External Flood Protection Measures." Steps include:

1. Shut down both units (normal procedures)
2. Remove decay heat (normal procedures)
3. Install residual heat removal (RHR) system six-inch firehoses crosstie to fire water supply system (FWSS)
4. Fill both tori with water through six-inch firehoses to RHR system
5. Remove shield plugs, drywell heads and reactor vessel head
6. Set up the portable pumping equipment
7. Fill radwaste tanks with fire system water
8. Place portable makeup demineralizers in service to fill condensate storage tanks
9. Fill reactor cavities and separator-dryer pools using core spray system and RHR system

10. Remove gates between storage pools
11. Rack out all main breakers for equipment below elevation 608 ft. MSL
12. Open plant doors

The licensee stated in its IA that flood stage levels on the Mississippi River are predicted several weeks in advance by the USACE. In the unlikely event of having a flood predicted that is similar to the licensing basis PMF, steps to shutdown and cool the plant will be initiated a minimum of 3 days prior to the predicted time at which the water will exceed the plant grade elevation of 595 ft. MSL. These actions will reduce the decay heat from the reactor to a level which can be removed by natural circulation cooling between the reactor and the reactor cavities and storage pools. Once the reactor is shutdown and cooled down, the drywell and reactor vessel heads will be removed. The reactor cavities and dryer-separator pools will be filled to the level of the spent fuel pool. Finally, the spent fuel pool gates will be removed permitting free circulation of water through the storage pools, reactor cavities and dryer-separator pools.

In the event of a flood exceeding site grade, the torus for each unit will be completely filled with water once the reactor is shutdown and cooled down to address buoyancy concerns associated with the torus. The drywells for both units will be filled to the level attained when the torus is full using a six-inch fire hose connecting the FWSS to the RHR system. This connection will use the existing disconnect between the drywell spray isolation valves 1(2)-1001-23A and 1(2)-1001-26A. The river water from the FWSS will be routed into the RHR system and into the torus. It will take less than 12 hours to add the 1,000,000-gallons of water required to fill the torus completely. With the torus filled, the water level in the drywell will be just below the recirculation pump motors. After the torus is filled, the two 4,700 gallon per minute core spray pumps will be started, and the contents of the two 350,000-gallon storage tanks and the 100,000-gallon clean demineralized water storage tanks will be pumped into the reactors, thereby filling the reactor cavities and dryer separator pools to approximately 25 percent full.

River water from the FWSS, through the RHR system or core spray system, will then be used to complete filling the pools to normal level. This operation will take approximately 3 hours. The gates between the fuel storage pools and the reactor cavities will then be opened allowing free circulation of water through the storage pools, reactor cavities, and dryer-separator pools. Independently-powered portable pumping equipment available onsite will be set up above the projected flood elevation to supply the 200-gallon per minute makeup water required in the storage pools due to the evaporative cooling loss. A 250-gallon fuel supply is available on the site to supply this equipment. Prior to flooding the drywell, all electrical equipment will be de-energized. Electrical equipment below elevation 608 ft. MSL will be racked out of service after the pumping operations are completed and prior to flood stage exceeding grade level. Plant doors will be opened to allow water levels to equalize on building walls.

3.3.2 Reevaluated Hazard Flooding Response

3.3.2.1 Characterization and Determination of Annual Exceedance Probability

As described in Section 3 of this document, NEI 16-05, Revision 1 (as endorsed by NRC under JLD-ISG-16-01), provides guidance which states that flood scenarios with an AEP equal to 1E-4 or less may be characterized as low frequency or low likelihood events and those with an AEP greater than 1E-4 may be characterized as being more likely or occurring at a higher frequency. Under the IA review process, which follows Path 5 of NEI 16-05, "effective" flood protection should be demonstrated for those flood scenarios considered to be higher likelihood, and a "feasible" flood response should be demonstrated for lower likelihood flood scenarios. Guidance document NEI 12-06, Revision 2 (Appendix G) presents a process to determine a feasible response to flooding mechanisms.

In COMSECY-15-0019, the staff clarified that, "...if a flooding hazard associated with a frequency of [1E-4] per year cannot be defined in a timely and/or a technically defensible manner for a site...a surrogate (e.g., [1E-3] plus a factor [(margin)]) consistent with the current state of practice may be developed to provide quantitative risk insights to augment the available qualitative risk insights". In the resulting staff requirements memorandum (SRM), the Commission directed staff to, "...continue to look for additional opportunities to address any conservatism in the flood hazard evaluations and streamline the process..." (SRM-COMSECY-15-0019). As a result, the characterization between a low likelihood flood scenario and a higher likelihood scenario can be made at an AEP of 1E-3 plus a factor (margin). This was the basis for NRC's review of the licensee's IA submittal.

The licensee's IA submittal details its evaluation of the flood frequency and related flood elevations for a combined event riverine flood scenario. The licensee's IA proposed the nominal site grade elevation of 595 ft. MSL as the boundary elevation between the low and higher likelihood flood scenarios (i.e. flood elevations above nominal site grade are assessed as having low likelihood). In its IA, the licensee describes data selection and usage, modeling assumptions, methods, and software tools, as well as uncertainty analysis used to support this conclusion. Each of these are briefly described in the following paragraphs.

Data Sources and Assumptions

The licensee used streamflow data from three Mississippi River stream gages near Quad Cities to perform a flood frequency analysis. The resulting flood frequency relationships were converted to stage frequency relationships using the stage-discharge curve developed in the Quad Cities FHRR. Streamflow data during the period from 1940-2016 was obtained from the current USGS Gage 0542050 located at Clinton, IA, just upstream from the Quad Cities site. Data from the period of 1873-1934 was obtained from a historic gage located at Le Claire, IA, approximately 10 miles downstream of Quad Cities. Data during the periods from 1861-1873 and 1935-1939 were obtained from a historic gage located at Davenport, IA, approximately 15 miles downstream from Le Claire (approximately 25 miles downstream from Quad Cities).

Considering the proximity of the Davenport and Le Claire gages and that flows at the two locations were reported to be comparable, the licensee appended the Davenport flow data to the record at Le Claire without adjustment[1]. The streamflow data from the Clinton gage was transpositioned to Le Claire using the ratio of the contributing drainage areas for the two gages[2]. The final result of appending the Davenport data and transposing the Clinton data is a nominal systematic flow record at Le Claire for the period of 1861-2016 (with the exception of a few years with missing data, as described below). Since the historic Le Claire gage location is downstream of Quad Cities, the IA concludes that the constructed systematic record is therefore a conservative representation of the flows at Quad Cities.

The licensee developed and utilized perception thresholds to account for missing data in the systematic record and extend the systematic record. Perception thresholds are floods that are

[1] Streamflow at Davenport (15 miles downstream from Le Claire) will be greater than that at Le Claire, so appending Davenport flow data to the record at Le Claire is conservative.

[2] Flows at Clinton are multiplied by the ratio of Le Claire drainage area to Clinton drainage area.

considered as perceivable and would have been observed or measured if they had occurred. Perception thresholds were used to address missing systematic data for the time period of 1863-1865, and for the years 1868, 1869, and 1872. The licensee set low perception thresholds[3] for these time periods and years as the lowest recorded annual maximum flow from the prior time period or year. Perception thresholds were also developed for the time period before the systematic record using regional historic information from the time period of 1828-1860. The licensee set the low perception threshold for the period of 1828-1860 as the maximum discharge observed during the flood of record (1965). Additionally, in a sensitivity study that supplemented the systematic and historical record with paleoflood information, the licensee used regional paleoflood information[4] to develop perception thresholds for the time period of 600 to 1835. The perception threshold values used by the licensee are presented in Table 3.3-1.

Some additional assumptions made by the licensee in the IA supporting analysis are:

1. Systematic flow data acquired for the time period between 1861 and 2016 were considered to be reliable,
2. The inclusion of a regional or weighted skew coefficient[5] was not considered necessary,
3. The effect of climate change on flows during the period of record was considered insignificant, and
4. The impacts of flow regulation, channelization, or watershed regulation and watershed land use changes over the period of record were considered negligible.

Methods and Models

The licensee performed the flood frequency analysis using the USACE Hydrologic Engineering Center Statistical Software Package (HEC-SSP), Version 2.1. This software package implements the flood frequency analysis approach described in the United States Geological Survey's "Guidelines for Determining Flood Flow Frequency — Bulletin 17C (England, et al., 2018). The Bulletin 17C approach uses the available flood information to parametrize a log-Pearson Type III distribution (LP-III) to describe the flood frequency curve. This approach utilizes the Expected Moments Algorithm (EMA) to estimate the LP-III parameters using multiple datasets such as the systematic, historical and paleoflood records used by the licensee in this analysis. This approach also uses perception thresholds to extend the period of record using historic or paleoflood information or to account for missing data in the systematic record.

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[3] A perception threshold is defined in the United States Geological Survey's "Guidelines for Determining Flood Flow Frequency – Bulletin 17C" (England, et al., 2018) as the stage or flow above which it is estimated a source would provide information on the flood peak in any given year. Perception thresholds reflect the range of flows that would have been measured or recorded had they occurred. A perception threshold is allocated to each information source for each year of the flood record. Perception thresholds may involve a significant amount of judgment on the part of the scientist and (or) historian regarding, for any given year, what is the smallest event that would have been recorded (in a physical or textural manner) such that we would actually know about it today.

[4] No paleoflood studies have been performed in the Mississippi River adjacent to the Quad Cities site or the Clinton and Le Claire stream gage locations. In lieu of site-specific paleoflood data, the licensee leveraged regional paleoflood information obtained from peer-reviewed geomorphology and archeology studies to deduce periods of relatively low and high flood occurrences during the time period of 600 to 1835.

[5] Weighted skew coefficients are discussed in Bulletin 17C and use regional skew information to augment limited site-specific data.

The licensee performed a flood frequency analysis for the period of 1828-2016. As described above, the licensee set the low perception threshold for the period of 1828-1860 as the maximum discharge observed during the 1965 flood of record (318,000 cubic feet per second (cfs)) and set low perception thresholds for the missing years and time periods as the lowest recorded annual maximum flow from the prior time period or year.

The licensee also performed a flood frequency analysis for the period of 600-2016. In this sensitivity analysis, the low perception threshold was set as the maximum discharge observed during the 1965 flood of record (318,000 cfs) for the period of 600-1199 and as the cool season PMF at Quad Cities (745,000 cfs) for the period of 1200-1835. Other perception thresholds were the same as the previous analysis.

Treatment of Uncertainties

In the licensee's flood frequency analysis, aleatory variability and epistemic uncertainty were addressed in the following ways:

> *Aleatory Variability*: As described above in the set of assumptions, the licensee accounted for aleatory variability with the flood frequency curve. Other aspects described in the assumptions above were assumed to be negligible.
>
> *Epistemic Uncertainty*: The licensee examined uncertainty that resulted from distribution choice and estimation method by fitting several alternative distributions to the systematic data using the method of L-Moments to estimate distribution parameters. Flood frequency curves developed using Log-Normal, GEV, Pearson Type 3, Log-Pearson Type 3, and Kappa distributions fitted with L-Moments, were very similar to the flood frequency curve developed using LP-III and EMA. These results are reported in Table 3.3-2.

The licensee recognized that uncertainties also existed in the stage-discharge relationship at the Quad Cities site, the impact of a potential upstream dam failure and wind wave action. To account for these uncertainties, the licensee increased the stage-discharge curve which had been developed by a total of 1.4 ft. The licensee attributed approximately 0.7 ft of this increase to the potential impact of seismically-induced failure of multiple dams under ½ PMF conditions and attributed 0.7 ft. to uncertainties in the stage discharge relationship. Additional details are provided below:

- *Dam Failure*: In its FHRR, the licensee evaluated the increase in water surface elevations due to dam failure relative to selected base flow conditions. In one scenario (seismically-induced failure of multiple dams under ½ PMF conditions) the resulting water surface elevation would increase by 0.7ft. In another scenario (hydrologically-induced failure of multiple dams occurring under full PMF conditions) the licensee determined that the resulting water surface elevation would increase 0.4 ft. Based upon the FHRR results, the licensee used 0.7 ft. to account for uncertainty related to dam failure.

- *Stage Discharge Relationship*: In its FHRR, the licensee determined the uncertainty related to stage discharge by comparing the observed stages and modeled results for the five largest floods that impacted the Quad Cities site. The licensee found that the largest difference between the observed and modeled water surface elevations was 0.7 ft. Based upon the FHRR results, the licensee used 0.7 ft. to account for uncertainty related to stage discharge.

The results of the licensee's flood frequency analysis and conversion to stage frequency values are presented in Table 3.3-3. Based on the results, the licensee determined that flood elevation values expected at an AEP of 1E-3 and 1E-4 for both the median and the 90 percent Confidence Interval (CI) Upper Limit are expected to be below the site grade of 595 ft. MSL. This includes the additional 1.4 ft. that was added to account for the uncertainties described above.

3.3.2.2 NRC Staff Review

To verify the licensee's selection of the site grade as the boundary, or threshold, between low and higher likelihood events, the NRC staff performed an evaluation of the licensee's data, assumptions, models, and methods, as presented in the IA submittal and supporting documentation, as described in the audit plan issued by letter July 18, 2017 (ADAMS Accession No. ML17192A452).

The NRC staff's review consisted of four general steps as follows:

1. Verification of the data sources, and assumptions used by Exelon in the IA supporting analysis,

2. Confirmatory analyses used to verify the model execution and results presented in the licensee's analysis (Analyses 1 and 2 below),

3. Sensitivity analyses performed by the NRC staff to evaluate the results on varying the data set, assumptions and distributions used by the licensee (Analyses 3 and 4 below), and

4. The NRC staff independent evaluation of uncertainty that resulted due to distribution choice (Analysis 5 below).

Verification of Data and Assumptions

The NRC staff reviewed the systematic record (annual peak streamflow values at three gage locations) presented by the licensee and concluded that these data values were consistent with published data.

As mentioned above, the licensee used the Davenport data to extend the systematic record for the Le Claire gage and transposed data from the Clinton gage to the former Le Claire station. The NRC staff reviewed this approach and found the flows measured at the Davenport gage to be consistently higher than those at Le Claire during the time period where these two systematic records overlap. As a result, the NRC staff determined that use of Davenport gage data to extend the Le Claire record was conservative. Transpositioning the Clinton data to Le Claire using drainage area ratio was also judged to be appropriate given the minor differences in the drainage area and channel morphology between the two locations.

When considered together, the licensee's assumptions 3 and 4 listed in Section 3.3.2.1 of this assessment constitute an assumption that the systematic record is statistically stationary (i.e., free of trends or shifts in statistical properties). As a result, the NRC staff performed a trend analysis and a change point analysis to assess the stationarity assumption.

With regard to the trend analysis, NRC staff performed a Kendall's Tau test to assess and determine if a definable trend existed in the data used by the licensee in the evaluation. The NRC staff found that no significant linear trend was present. This result agreed with the licensee's trend analysis results obtained using the same method. With regard to the change point analysis, the NRC staff performed a confirmatory analysis using a number of independent change point detection algorithms. These included the At Most One Change method, Mann-Whitney method, Pettitt test, Buishand range test, Buishand U test, and Standard Normal Heterogeneity test (Kundzewicz and Robson, 2004). Each test identified the same change point location (1964) and magnitude shift in the mean streamflow in the period after 1964 (approximately 21%). This result demonstrated that the change point was robust since multiple methods identified the same change point location and magnitude shift. However, NRC staff did not attempt to attribute this change point to a specific cause (e.g, shift in climate or change in the watershed). Instead, the potential impact of a change in the mean of annual maximum streamflow the data, as indicated by this change point analysis, was assessed by the staff in the sensitivity analysis, which is presented as part of Analysis 4, below.

The NRC staff did not perform a detailed review of the paleoflood information provided by the licensee to support the use of perception thresholds for the period of 600-1828. Instead, the NRC staff performed a sensitivity analysis to evaluate the impact of omitting this information (Analysis 1, below).

The NRC staff reviewed the assumption made by the licensee that 1.4 ft. was a conservative addition to the stage-discharge curve to account for uncertainties. As previously discussed, the licensee attributed approximately 0.7 ft. of this increase to the potential impact of seismically-induced failure of multiple dams under ½ PMF conditions, and attributed 0.7 ft. to uncertainties in the stage discharge relationship. The NRC staff reviewed both justifications and determined that the use of 0.7 ft. to account for uncertainty due to dam failure is conservative because it is the maximum value resulting from the evaluated dam failure scenarios. Additionally, the NRC staff determined that 0.7 ft. was also adequate for representing uncertainty for the stage-discharge curve based upon calibration results reported in the FHRR and reviewed by staff.

To better understand how the additional 1.4 ft. compares to the uncertainty inherent in the flood frequency analysis, the NRC staff calculated the standard deviation around the median at the 10^{-3} AEP. The NRC staff found that the increase due to +1 standard deviation ranges from 1.22 ft. to 1.4 ft. for the licensee's scenario. This was confirmed by the NRC staff in confirmatory Analysis 1, described below. Also, this indicates that adding 1.4 ft. to the stage discharge relationship to account for uncertainty amounts to a conservatism that is approximately equal to +1 standard deviation.

In conclusion, the NRC staff determined that the licensee's increase of 1.4 ft. to account for the described uncertainties is reasonable. As a result, the NRC staff also increased the estimated results in the staff's independent analysis by 1.4 ft., as discussed below and shown in Table 3.3-3.

Confirmatory and Sensitivity Analyses

The NRC staff used HEC-SSP, Version 2.1 to perform two confirmatory analyses (of scenarios modeled by the licensee) to verify results presented in the IA. These analyses are described as follows:

- Analysis 1
  The NRC staff used the set of systematic data starting in 1861 and perceptions thresholds presented by the licensee for the year 1828 forward. This included perception thresholds based on historical data and reasonable assumptions.

- Analysis 2
  For this case the NRC staff used the data discussed in Analysis 1, and also included the licensee's basin paleoflood information from the year 600 to 1828.

The NRC staff also evaluated two scenarios not analyzed by the licensee in the IA in order to serve as sensitivity analyses. The NRC staff developed input for these modeling scenarios by parsing the records available from different data sources and time periods. The purpose of these analyses was to assess the effect of uncertainty in data and assumptions on the resulting flood elevations. These sensitivity analyses are described as follows:

- Analysis 3
  In this case, the NRC staff elected not to use the licensee's perception thresholds and simply used the licensee's data from the year 1861 forward in order to determine the sensitivity of the results to the licensee's perception thresholds.

- Analysis 4
  As discussed above, the statistical change point tests performed as part of the NRC review of gage data indicated the possibility that two populations with different means exist within the gage data record, with a change point occurring around the year 1964. The NRC staff used data from the year 1964 forward to assess the impact of assuming a separate population with a higher mean on the resulting 10^{-3} AEP flood elevations.

In addition to the confirmatory and sensitivity studies based on alternative parsing of the record mentioned above, the NRC staff independently evaluated the epistemic uncertainty due to distribution choice. This evaluation is described below:

- Analysis 5
  The NRC staff used Matlab to fit alternative distributions to the systematic data using the Maximum Likelihood Method (MLM). The NRC staff used the following five distributions: Log-Normal, GEV, Pearson Type III, Gamma, and Weibull.

In each of these analyses, the NRC staff converted the flow rates into flood elevations for each of the analyses discussed above using the licensee's rating curve for Quad Cities. The NRC staff also increased estimated stages by 1.4 ft. to account for uncertainty as described by the licensee and verified by the NRC staff.

Results of Confirmatory and Sensitivity Studies

For confirmatory analyses 1 and 2 performed by the NRC staff, the estimates of the 10^{-3} AEP stage and associated confidence intervals were comparable to the licensee's results obtained via the Bulletin 17C Method.

For sensitivity analyses 3 and 4 performed by the NRC staff, the estimates of the 10^{-3} AEP stage and associated confidence intervals were comparable to the licensee's results obtained via the Bulletin 17C Method, except for Analysis 4 (1964 Forward) in which the Upper Limit of the 90% confidence interval exceeded the nominal plant grade of 595 ft. MSL. However, it is likely that the large confidence interval is mainly due to use of the shorter record (50 years rather than 142 years). As a result, the NRC staff did not give the results obtained using the shorter record the same weight as the elevations reported for confidence intervals developed using the full record. For Analysis 4 (1964 Forward), the NRC staff determined that the site grade falls just above the Upper Limit of the 85% Confidence Interval, so the sensitivity is small. Based on the results of these sensitivity analyses (3 and 4), the NRC staff concludes that the sensitivity of the system to the licensee's perception thresholds and to the change point do not require further analysis and their impact does not need to be considered in the NRC staff's confirmatory analyses 1 and 2.

The NRC staff results for Analysis 5 (using alternative probability distributions fit to the systematic data) show a somewhat larger range in the estimated median stage at 1E-3 AEP than the licensee's analysis. However, NRC staff results indicate that median flood stages at 1E-3 AEP do not exceed the nominal plant grade (595 ft. MSL) for any of the distributions examined.

Given the results of the confirmatory analysis and insensitivity to the uncertainties explored in the sensitivity and epistemic analyses (Analyses 3 through 5), the NRC staff considers the 1.4 ft increase in flood stage along with the consideration of the stage corresponding to the Upper Limit of the 90% confidence interval at 1E-3 AEP in confirmatory analyses 1 and 2 to be a reasonable estimation of the 1E-3 AEP stage plus a factor (or margin), consistent with the current state of practice, and the guidance described in NEI 16-05, as endorsed by the NRC.

3.3.2.3 Conclusion of Annual Exceedance Characterization

Based on the guidance discussed in Section 1 of this document, the NRC staff performed a review of the licensee's flood frequency analysis and the resulting stage frequency relationships presented in their IA submittal for Quad Cities, including supporting information reviewed in accordance with the audit plan. The NRC staff also conducted its own confirmatory and sensitivity analyses. The NRC staff finds that using the site grade elevation of 595 ft. MSL as the boundary between the "low likelihood" and "high likelihood" flood scenarios is reasonable for the Quad Cities site. Thus, flood elevations above the nominal site grade are considered to be "low likelihood" for the purpose of performing the integrated assessment called for in NTTF Recommendation 2.1.

The NRC staff reached this conclusion based on estimation of the 1E-3 AEP stage plus a factor (or margin), consistent with the current state of practice, its own independent analysis, and limited insights from the licensee's estimates of flood stage at 1E-4 AEP.

3.3.3 Effective Flood Protection for High Likelihood Events up to 595 ft. MSL

In the IA, the licensee stated that the resulting water surface elevations from a "high likelihood" combined event (stillwater elevation up to 595 ft. MSL) would have no impact on plant SSCs. The NRC staff notes that Quad Cities UFSAR Section 3.4.1.1 states that:

> *For a flood occurring to the level of the plant grade elevation of 594.5 feet, any mode of operation is also possible, and no additional protective measures are needed to maintain structural integrity. Stresses in the structures would, in some cases exceed the 33% increased allowable stress used in the initial criteria. However, these higher stresses would not exceed the allowables corresponding to .85 f′c (f′c = concrete compressive strength) and .90f_y (f_y = reinforcing steel yield strength).*

With regard to the wind-wave runup, and other associated effects and flood event duration parameters that may contribute to the stillwater elevation, the licensee stated in the IA that a maximum wave height of 3.3 ft. could occur above the stillwater level at a sustained wind speed of 44 mph (39 knots). However, the wind-generated waves under this scenario would only cause intermittent "splash" above site grade since waves would break at the top of the slope along the river channel. Furthermore, the licensee stated that wind speed measurements from the Moline/Quad Cities Airport indicate that the annual wind speed frequency exceeding 21 knots is approximately 3.7×10^{-3} for the critical west-northwest fetch direction. As a result, combining this probability with the 1E-4 AEP that the stillwater elevation will reach plant grade (at the 95 percent confidence limit), produces an extremely low probability. Therefore, the licensee concluded in the IA that wind-wave runup can be considered negligible in the probabilistic characterization of the river flood.

As part of the NRC staff's review, it was confirmed that the combined event flood-causing mechanism, including AEs and FEDs parameters, were not revised as part of the IA. Given the use of the same flood mechanism as previously evaluated, the NRC staff's review of AEs and FEDs described in Section 4 of the FHRR staff assessment is still valid and applicable to the review of this IA. Furthermore, the NRC staff also agrees that the impact of FEDs and AEs on the powerblock is expected to be limited and not impact any SSCs that provide KSFs.

The NRC staff also reviewed the adequacy of the APM described for this flooding scenario using the guidance described in Appendix B of NEI 16-05, Revision 1, as endorsed. Specifically, the licensee is crediting the use of engineering features credited in the design or licensing basis (in this case the site grade) as having a flood protection function. The NRC staff conservatively assumed that at elevation 595 ft. MSL, there was zero APM available between the "low vs. high likelihood" threshold water surface elevation and the site grade. However, even under this assumption, adequate APM can be justified given that:

- conservative inputs and assumptions were applied in the analysis, as described in Sections 3.3.2.1 and 3.3.2.2 of this assessment, and

- independent sensitivity analyses were performed that corroborated the adequacy of parameter selection.

3.3.3.1 Conclusion on Demonstration of Effective Flood Protection

The NRC concludes that based on the information provided by the licensee in the IA, as confirmed by its own independent analysis, the licensee has demonstrated that Quad Cities has effective flood protection, that there is APM, that its effective flood protection is reliable, and that it does not rely on human actions given that the site grade is a passive flood protection feature. As a result, the flood response to "high likelihood" events is considered to be adequate, and provides reasonable assurance that key SSCs that provide KSFs should continue to perform their intended function for the duration of the event.

3.3.4 Feasible Mitigation Response for Low Likelihood Events above 595 ft. MSL

The licensee stated in its IA that the feasible response scenario corresponding to floods above 595 ft. MSL and AEP of 1E-4 or lower, is based on the mitigating strategies described in Section 2 of this assessment. In its evaluation, the licensee concluded that adequate time exists to implement the design-basis flood mitigation strategy and that all flood preparation activities would be completed prior to the flood level exceeding the plant grade.

Section 3.4 of the Quad Cities UFSAR discusses the available time for a safe shutdown of both reactors prior to the flood reaching the plant grade (elevation 595 ft. MSL). The licensee described that the time available to prepare the site for a river flood event is estimated to be 172 hours, which conservatively relies only on river forecasting tools and does not take into consideration storm forecasting.

As part of the 50.54(f) review process, the NRC staff reviewed the Quad Cities flooding MSA, and documented its assessment in a letter dated October 4, 2017 (ADAMS Accession No. ML17269A049). In its assessment, the NRC staff stated that the mitigation strategies related to the combined events flood causing mechanism were not evaluated (similar manner to the reevaluated LIP hazard) given that the site response does not rely on the use of mitigation strategies equipment. The plant response instead relies on normal shutdown and licensing basis decay heat removal procedures. The staff's determination was primarily reached as a result of the anticipatory nature of the site response (prior to flood waters reaching site grade), and the availability of safety-related SSCs relied upon for normal shutdown and cooldown (i.e.: RHR system, see Section 3.3.1 of this assessment) to perform their intended function. Both the loss of normal access to the ultimate heat sink and extended loss of alternating current (ac) power correspond to the damage state postulated for Order EA-12-049 once the flood reaches site grade.

The NRC staff confirmed that no changes to the CDB shutdown strategy described in Section 3.3.1 of this assessment were made by the licensee in the IA. Because the site's shutdown procedures are embedded in the licensing basis of the site, any changes to the shutdown procedure that affect the licensing basis would be evaluated in accordance with the provisions described in 10 CFR 50.59, "Changes, tests, and experiments."

Section 3.3.1 of this assessment provides the licensing basis actions for floods above 595 ft. MSL. The licensee stated in its December 1, 2016, MSA that the licensing basis of 603 ft. MSL is a stillwater elevation and noted that the reevaluated flood level of 605 ft. MSL is based on a 600.9 ft. stillwater elevation with 4.1 ft of wave runup. Therefore, the reevaluated flood level expected inside buildings is 600.9 ft. MSL. If water were to enter the building through openings above 603 ft. MSL from wind wave runup, it would have a minimal effect on the calculated

600.9 ft. MSL stillwater elevation because the water inside of the building is in communication with the floodwater outside through openings and will seek a common level. The staff concludes that the current licensing basis strategies inside buildings, including connection points, that are described in Section 3.3.1 of this assessment are not impacted by the reevaluated flood hazard.

With regard to the dynamic effects that the reevaluated hazard may have on the outside portion of the key structures, the licensee performed an evaluation (ADAMS Accession No. ML14155A387) and determined that the effects of wind generated waves, hydrodynamic loads, and debris-generated loads have negligible impact on the station's ability to reach and maintain safe shutdown. In addition to the review performed by the licensee, the staff also agrees that the structural loads associated with an additional 2 ft. of water (605 ft. – 603 ft) are negligible based on the robust nature of the reactor building, and the structural capacity of the building. In addition, if water were to enter the building through openings above 603 ft. MSL from wind wave runup, it would have a minimal effect on the calculated 600.9 ft. MSL stillwater elevation because the water inside of the building is in communication with the floodwater outside through openings and will seek a common level.

3.3.4.1 Conclusion on Feasible Response for Low Likelihood Events

The NRC concludes that, based on the information provided by the licensee in the IA, the licensee has a feasible approach for addressing a flood of 600.9 ft MSL stillwater elevation with 4.1 ft. of wave runup. The licensee has shown that the mitigation strategies related to the combined events flood causing mechanism (in a similar manner to the reevaluated LIP hazard) does not rely on the use of mitigation strategies equipment, and instead relies on normal shutdown and licensing basis decay heat removal procedures. The staff has confirmed that no changes are needed to the CDB shutdown strategy, that the strategies within buildings, including connection points, are not impacted by the reevaluated hazard, and that the dynamic effects from the reevaluated hazards on the outside portion of key structures will have negligible impact on the station's ability to reach and maintain safe shutdown.

3.3.5 Conclusion

Given that:

1. For the combined event flood-causing mechanism, the site has adequately characterized the "high" and "low" likelihood flooding scenario threshold as equivalent to site grade elevation of 595 ft. MSL.

2. For "high" likelihood (more frequent) flooding scenarios, the licensee has an effective flood protection strategy that does not rely on manual or time-sensitive actions, and will reasonably protect the plant in any mode of operation.

3. For "low" likelihood (less frequent) flooding scenarios, the licensee has a feasible flood mitigation strategy. This strategy relies on anticipatory actions taken well in advance of the flood waters reaching the site, such as performing the normal (current design-basis) shutdown and cooldown procedures, opening of doors to equalize water pressures, and the availability of additional offsite equipment, if needed.

4. The staff has inspected, audited, and reviewed, as appropriate, pertinent provisions of the licensee's strategy and found it acceptable.

The NRC staff concludes that no additional regulatory actions are warranted for addressing the reevaluated flood hazard elevation for the combined effects hazard of PMF with dam failure and wind wave run-up.

4.0 SENIOR MANAGEMENT REVIEW PANEL

In accordance with the September 21, 2016, memo described above, the technical team met with the SMRP and presented the results of the review including the recommendation that the Quad Cities combined effects flood be treated as a Group 1 hazard. The staff noted, and the SMRP agreed, that the LIP flood hazard was outside the scope of the SMRP decision because in accordance with NEI 16-05, Revision 1, as endorsed, only Path 4 and 5 hazards are subject to an SMRP review. Because LIP was evaluated using the Path 2 process, an SMRP decision for the treatment of this hazard was not necessary. The SMRP members asked questions and provided input to the technical team related to the Path 5 combined events flood hazard. The SMRP approved the staff's recommendation that the Quad Cities combined events flood hazard should be classified as a Group 1 hazard, meaning that no further response or regulatory action is required.

5.0 AUDIT REPORT

The NRC staff previously issued a generic audit plan dated July 18, 2017 (ADAMS Accession No. ML17192A452), that described the NRC staff's intention to conduct audits related to IAs and issue an audit report that summarizes and documents the NRC's regulatory audit of the licensee's IA. The NRC staff activities have been limited to performing the reviews described above. Because this staff assessment appropriately summarizes the results of those reviews, the NRC staff concludes that a separate audit report is not necessary, and that this document serves as the final audit report described in the July 18, 2017, letter.

6.0 CONCLUSION

The NRC staff concludes that the Quad Cities IA was performed consistent with the guidance described in Nuclear Energy Institute (NEI) 16-05, Revision 1, "External Flooding Assessment Guidelines" (ADAMS Accession No. ML16165A178), with the clarifications provided in the NRC's endorsement document, JLD-ISG-2016-01, "Guidance for Activities Related to Near-Term Task Force Recommendation 2.1, Flood Hazard Reevaluation" (ADAMS Accession No. ML16162A301). For LIP, the NRC staff has concluded that the licensee has demonstrated that effective flood protection, if appropriately implemented, exists and that the site is reasonably protected against this flood hazard.

For the combined event flood mechanism, the licensee has an effective mitigation strategy for floods up to 595 ft. MSL level, and a feasible mitigation strategy for higher, less frequent floods up to 605 ft. MSL. As such, in accordance with Phase 2 of the process outlined in the 50.54(f) letter, additional regulatory actions associated with the reevaluated flood hazard, are not warranted.

Table 3.1-1 – Summary of Non-Bounded Mechanisms To Be Evaluated in the Integrated Assessment

Mechanism	Water Surface Elevation		NEI 16-05, Revision 1 Path
	Current Licensing Basis (MSL)	Reevaluated Hazard Water Level (MSL)	
Local Intense Precipitation (LIP)	Not included	596.5 ft. to 598.4 ft.	2 (Effective Flood Protection)
Combined Effects (Riverine Flooding + Dam Failure + wind wave run-up)	Not included	605.0 ft.	5 (Scenario Based Approach)

Table 3.3-1. Licensees Perception Thresholds

Start Year	End Year	Low Threshold (cfs)	High Threshold (cfs)
600	1199	318,000[1]	Infinity
1200	1827	745,000[2]	Infinity
1828	1860	318,000[1]	Infinity
1863	1865	197,000	Infinity
1868	1869	189,000	Infinity
1872	1872	160,000	Infinity

1. Value corresponds to the recorded flood of record (1965).
2. Value corresponds to the Cool Season PMF at Quad Cities as presented in the licensee's FHRR submittal.

Table 3.3–2. Licensee Median Flowrates Derived from Alternative Probability Distributions with L-Moments Method

	Distribution				
	Log Normal	GEV	P Type III	LP Type III[3]	Kappa
AEP	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)
10^{-4}	401,000	365,000	392,000	364,000	368,000
10^{-3}	345,000	330,000	341,000	327,000	332,000
10^{-2}	285,000	282,000	284,000	279,000	283,000

3. Licensee Log Pearson Type III (LP-III) results here differ from the licensee's HEC-SSP analysis, as HEC-SSP uses the EMA method to fit the distribution, while the licensee's used the L-moment method here to fit the distribution. This results in slightly difference flow quantiles.

Table 3.3-3. Results of Licensees Bulletin 17C Flood Frequency Analysis and Stage Conversion

AEP	Average Recurrence Interval (years)	Peak Discharge (cfs)		Peak Flood Stage (ft.) (MSL 1912)		Peak Flood Stage (ft) (MSL 1912) plus 1.4 ft estimate of uncertainty	
		Median	90% CI Upper Limit	Median	90% CI Upper Limit	Median	90% CI Upper Limit
10^{-4}	10,000	385,000	490,000	589.6	593.2	591.0	594.6
10^{-3}	1,000	338,000	400,000	587.8	590.1	589.2	591.5
10^{-2}	100	283,000	314,000	585.3	586.8	586.7	588.2

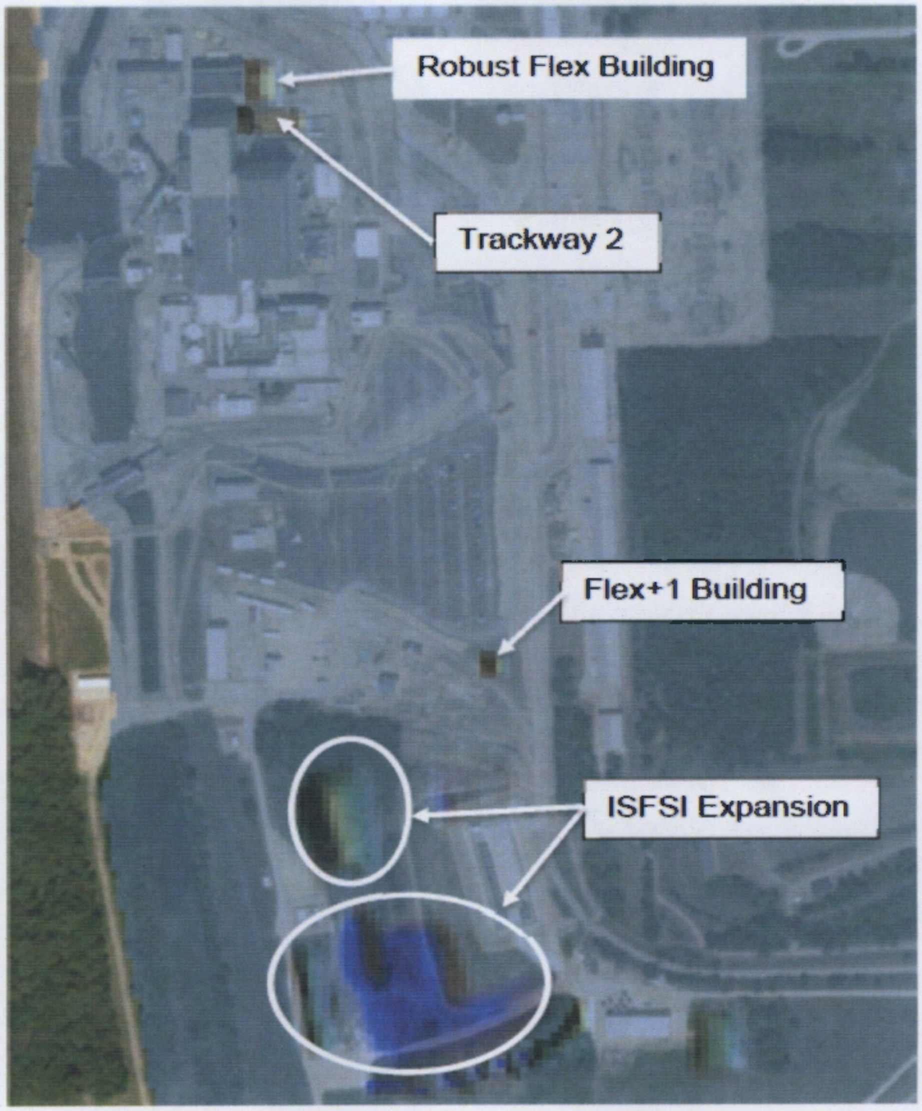

Figure 3.2-1 Differences in Digital Elevation Model used in FLO-2D due to site changes

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