Enclosure 2

Quad Cities Nuclear Power Station
Flood Hazard Reevaluation Report, Revision 0
In Response to the 50.54(f) Information Request Regarding
Near-Term Task Force Recommendation 2.1 Flooding

(23 Pages)

FLOOD HAZARD REEVALUATION REPORT

IN RESPONSE TO THE 50.54(f) INFORMATION REQUEST REGARDING NEAR-TERM TASK FORCE RECOMMENDATION 2.1: FLOODING

for the

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Contents

1. PURPOSE

a. Background

In response to the nuclear fuel damage at the Fukushima-Dai-ichi power plant due to the March 11, 2011, earthquake and subsequent tsunami, the United States Nuclear Regulatory Commission (NRC) established the Near Term Task Force (NTTF) to conduct a systematic review of NRC processes and regulations, and to make recommendations to the NRC for its policy direction. The NTTF reported a set of recommendations that were intended to clarify and strengthen the regulatory framework for protection against natural phenomena.

On March 12, 2012, the NRC issued an information request pursuant to Title 10 of the Code of Federal Regulations, Section 50.54(f) (10 CFR 50.54(f) or 50.54(f) letter) (NRC March 2012) which included six (6) enclosures:

1. [NTTF] Recommendation 2.1: Seismic
2. [NTTF] Recommendation 2.1: Flooding
3. [NTTF] Recommendation 2.3: Seismic
4. [NTTF] Recommendation 2.3: Flooding
5. [NTTF] Recommendation 9.3: EP
6. Licensees and Holders of Construction Permits

In Enclosure 2 of the NRC issued information request (NRC March 2012), the NRC requested that licensees 'reevaluate the flooding hazards at their sites against present-day regulatory guidance and methodologies being used for early site permits (ESP) and combined operating license (COL) reviews'.

On behalf of Exelon Generation Company, LLC (Exelon) for the Quad Cities Nuclear Power Station (QCNPS), this Flood Hazard Reevaluation Report (Report) provides the information requested in the March 2012, 50.54(f) letter; specifically, the information listed under the 'Requested Information' section of Enclosure 2, paragraph 1 ('a' through 'e'). The 'Requested Information' section of Enclosure 2, paragraph 2 ('a' through 'd'), Integrated Assessment Report, will be addressed separately if the current design basis floods do not bound the reevaluated hazard for all flood causing mechanisms.

b. Requested Actions

Per Enclosure 2 of the NRC issued information request, 50.54(f) letter, Exelon is requested to perform a reevaluation of all appropriate external flooding sources at (QCNPS), including the effects from local intense precipitation (LIP) on the site, probable maximum flood (PMF) on stream and rivers, storm surges, seiches, tsunami, and dam failures. It is requested that the reevaluation apply present-day regulatory guidance and methodologies being used for ESP and calculation reviews including current techniques, software, and methods used in present-day standard engineering practice to develop the flood hazard. The requested information will be gathered in Phase 1 of the NRC staff's two phase process to implement Recommendation 2.1, and will be used to identify potential 'vulnerabilities'. (See definition below.)

For the sites where the reevaluated flood exceeds the design basis, addressees are requested to submit an interim action plan that documents actions planned or taken to address the reevaluated hazard with the hazard evaluation.

Subsequently, addressees should perform an integrated assessment of the plant to identify vulnerabilities and actions to address them. The scope of the integrated assessment report will include full power operations and other plant configurations that could be susceptible due to the status of the flood protection features. The scope also includes those features of the ultimate heat sinks (UHS) that could be adversely affected by the flood conditions and lead to degradation of the flood protection (the loss of UHS from non-flood associated causes are not included). It is also requested that the integrated assessment address the entire duration of the flood conditions.

A definition of vulnerability in the context of [enclosure 2] is as follows: Plant-specific vulnerabilities are those features important to safety that when subject to an increased demand due to the newly calculated hazard evaluation have not been shown to be capable of performing their intended functions.

c. Requested Information

Per Enclosure 2 of NRC issued information request 50.54(f) letter, the Report should provide documenting results, as well as pertinent QCNPS information and detailed analysis, and include the following:

a. Site information related to the flood hazard. Relevant structures, systems and components (SSCs) important to safety and the UHS are included in the scope of this reevaluation, and pertinent data concerning these SSCs should be included. Other relevant site data includes the following:

   i. Detailed site information (both designed and as-built), including present-day site layout, elevation of pertinent SSCs important to safety, site topography, as well as pertinent spatial and temporal data sets;
   ii. Current design basis flood elevations for all flood causing mechanisms;
   iii. Flood-related changes to the licensing basis and any flood protection changes (including mitigation) since license issuance;
   iv. Changes to the watershed and local area since license issuance;
   v. Current licensing basis flood protection and pertinent flood mitigation features at the site;
   vi. Additional site details, as necessary, to assess the flood hazard (i.e., bathymetry, walkdown results, etc.)

b. Evaluation of the flood hazard for each flood causing mechanism, based on present-day methodologies and regulatory guidance. Provide an analysis of each flood causing mechanism that may impact the site including LIP and site drainage, flooding in streams and rivers, dam breaches and failures, storm surge and seiche, tsunami, channel migration or diversion, and combined effects. Mechanisms that are not applicable at the site may be screened-out; however, a justification should be provided. Provide a basis for inputs and assumptions, methodologies and models used including input and output files, and other pertinent data.

c. Comparison of current and reevaluated flood causing mechanisms at the site. Provide an assessment of the current design basis flood elevation to the reevaluated flood elevation for each flood causing mechanism. Include how the findings from Enclosure 2 of the 50.54(f) letter (i.e., Recommendation 2.1 flood hazard reevaluations) support this determination. If the current design basis flood bounds the reevaluated hazard for all flood causing mechanisms, include how this finding was determined.

d. Interim evaluation and actions taken or planned to address any higher flooding hazards relative to the design basis, prior to completion of the integrated assessment described below, if necessary.

e. Additional actions beyond Requested Information item 1.d taken or planned to address flooding hazards, if any.

2. SITE INFORMATION

The QCNPS site is located on the eastern bank of the Mississippi River approximately 506.8 miles upstream of the confluence of the Ohio River with the Mississippi River. Topographic relief at the site is low and relatively flat, with a mean station elevation of about 595 feet (ft), mean sea level (MSL) 1912. The site is located approximately equidistant between Lock & Dam Nos. 13 and 14, which are owned and operated by the U.S. Army Corps of Engineers (USACE). Other relevant site flooding data includes the following:

a. Current Design Basis Flood

The current design basis flood elevation for QCNPS is an elevation of 603 ft MSL 1912, which is eight (8) ft above the plant grade elevation as reported in the Updated Final Safety Analysis Report (UFSAR). The following is a list of flood causing mechanisms as derived from 50.54(f) letter, and their associated water surface elevations that were considered for the QCNPS current design basis.

1. **LIP** – LIP is addressed under separate report titled – *"Local intense Precipitation Evaluation Report for the Quad Cities Nuclear Power Station"* (Reference 16).
2. **Flooding in Streams and Rivers** – The UFSAR indicates that a flow rate of 587,000 cubic feet per second (cfs) in the Mississippi River at the QCNPS site would result in a stillwater flood elevation of 594.5 ft MSL 1912. As indicated in the UFSAR, this flow of 587,000 cfs was derived from a stage-discharge curve of the Mississippi River at the QCNPS site. The stage-discharge curve was plotted by calculating the river stages for 225,000 (1951 flood), 307,000 (1965 flood), 347,000 (100-year flood), 385,000 (200-year flood), 465,000; 500,000; 600,000; and 700,000 cfs flows as reported in the UFSAR.
3. **Dam Breaches and Failures** – The normal Mississippi river level is elevation 572 ft MSL 1912 with the expected low water to be elevation 570 ft MSL 1912. The river level at the QCNPS site, it is assumed, would drop to elevation 561 ft MSL 1912, if Lock & Dam No. 14 were to fail. Elevation 561 ft MSL 1912 is the normal river level downstream of Lock & Dam No. 14 as reported in the UFSAR.
4. **Storm Surge** – The UFSAR indicates flooding due to surges is not applicable. QCNPS has an inland location and does not connect directly with any of the water bodies considered for meteorological events associated with a storm surge. Flooding due to a surge is not plausible at QCNPS.
5. **Seiche** – The UFSAR indicates flooding due to seiche is not applicable. QCNPS has an inland location and does not connect directly with any of the water bodies considered for meteorological events associated with a seiche. Flooding due to a seiche is not plausible at QCNPS.
6. **Tsunami** – The UFSAR indicates flooding due to tsunamis is not applicable. QCNPS has an inland location and does not connect directly with any of the water bodies considered for tsunami events. Flooding due to a tsunami is not a plausible at QCNPS.
7. **Ice Induced Flooding** – An ice induced flooding evaluation beyond design basis event is not required under the current licensing basis. Therefore has not been previously addressed. .
8. **Channel Migration or Diversion** – The authority to control the Mississippi River is vested in the USACE. Should the need to control the river arise, Exelon will make the required notification to the USACE. These arrangements have been made with USACE and are detailed in the QCNPS emergency procedures as reported in the UFSAR.
9. **Combined Effect Flood (including Wind-Generated Waves)** – A combined effect flood (including wind-generated waves) flooding evaluation beyond design basis event is not required under the current licensing basis. Therefore has not been previously addressed.

b. Flood Related Changes to the License Basis

Flood Related Changes to the Licensing Basis Since License Issuance
The following is a summary of notable flood related changes to the licensing basis since license issuance. These changes were related to the external flood emergency response methodology:

- 1999 - This change revised equipment set-up details to facilitate a more flexible response regarding equipment selection and placement in response to a flooding event. (Reference 14, Section 3.4)
- 1999 - This change revised the method and timeline for transferring river water to the torus during the response to a flooding event. (Reference 14, Section 3.4)

The above changes pertained to the details of the process/sequence outlined in the UFSAR (Reference 14, Section 3.4) to place the plant in a safe shutdown condition prior to the flood exceeding the plant grade elevation.

Overall, there have been no significant changes to the QCNPS licensing basis with respect to an external flooding event.

Flood Protection Changes (including mitigation) Since License Issuance
The following is a summary of flood protection changes since license issuance:

- No physical modifications have been installed specifically in support of the external flooding response; however, "Quick" connection fittings installed under 10 CFR 50, Appendix R are also utilized in the external flood response.
- Plant procedures in response to external flooding have been revised to reflect the process/sequence changes described above.

c. Changes to the Watershed since License Issuance

The watershed contributory to the Mississippi River upstream of QCNPS is approximately 88,000 square miles (Exelon 2013a). Based on aerial images of the watershed, the most significant changes to the watershed include expansion and development of the greater Minneapolis-St. Paul Metropolitan Area, which is very small percentage of the overall watershed. There are approximately 28 dams that have been constructed since license issuance (1974). As discussed in dam failure analysis (Exelon 2013d), three of these 28 dams (Lake Carroll Dam, Smallpox Creek Dam, and Apple Canyon Lake Dam) are considered critical and are included in the reevaluated dam failure analysis (Exelon 2013d).

d. Current Licensing Basis Flood Protection and Pertinent Flood Mitigation Features at the Site

Current Licensing Basis flood protection and pertinent flood mitigation features at QCNPS are described in UFSAR (Reference 14, Section 3.4.1.1). QCNPS enters QCOA 0010-16 "Flood Emergency Procedure" immediately when the Mississippi River level exceeds 586 ft MSL 1912 or when the river level is predicted to be greater than 594 ft MSL 1912 in less than 72-hours. This procedure and the QCNPS UFSAR (Section 3.4) provides that the site can be safely shut down and maintained in a safe condition for flood levels up to 603 ft MSL 1912 based on the following criteria:

- For flood levels up to plant grade of 594.5 ft MSL 1912, any mode of operation is possible with no additional protective measures.
- For flood levels between 594.5 ft MSL 1912 and 603 ft MSL 1912, the plant is maintained in a safe condition by flooding plant buildings to match the river elevation and shutting down both reactors and establishing evaporative residual heat removal.

3. SUMMARY OF FLOOD HAZARD REEVALUATION

NUREG/CR-7046 *Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America* (NUREG/CR-7046), by reference to the American Nuclear Society (ANS), states that a single flood-causing event is inadequate as a design basis for power reactors and recommends that combinations should be evaluated to determine the highest flood water elevation at the site. For the QCNPS site, the combination that produces the highest flood water elevation at the site is the cool-season probable maximum precipitation (PMP) rainfall, the 100-year snowpack, upstream dam failure, and the effects of coincident wind wave activity.

NUREG/CR-7046 recommends that the effects of coincident wind wave activity be combined with the flood waves resulting from the breaches of upstream dams. QCNPS Calculation QDC-0085-S-2034 (Exelon 2013f) evaluated the water surface elevation due to PMF and dam failure coincident with wind wave activity.

Calculation QDC-0085-S-2032 (Exelon 2013d) defines the maximum stillwater flood elevation at QCNPS. This elevation is due to a cool-season PMP event coincident with snowmelt and dam failure. The revised maximum stillwater elevation is above the site grade elevation of 595 ft MSL 1912, but below the existing design basis flood elevation of 603 ft MSL 1912.

Calculation QDC-0085-S-2034 (Exelon 2013f) defines the coincident wind wave runup. The maximum water surface elevation of the PMF coincident with wind wave activity is determined by adding the wind setup and wind wave runup to the PMF with dam failure water surface elevation (i.e. PMF elevation including effects of dam failure and snowmelt + wave runup). The revised water surface elevation including the effects of coincident wind wave for the PMF elevation is above the existing design basis flood elevation of 603 ft MSL 1912. Waves are negligible inside buildings.

The methodology used in flooding reevaluation for QCNPS is consistent with the following standards and guidance documents:

- NRC Standard Review Plan, NUREG-0800, revised March 2007 (NUREG-0800);
- NRC Office of Standards Development, Regulatory Guides, RG 1.102 – Flood Protection for Nuclear Power Plants, Revision 1, dated September 1976 (NRC RG1.102);
- NRC RG 1.59 – Design Basis Floods for Nuclear Power Plants, Revision 2, dated August 1977 (NRC RG 1.59);
- NUREG/CR-7046 "Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America", dated November 2011 (NUREG/CR-7046);
- American National Standard for Determining Design Basis Flooding at Power Reactor Sites (ANSI/ANS 2.8-1992), dated July 28, 1992;

The following provides the flood causing mechanisms and their associated water surface elevations that are considered in the QCNPS flood hazard reevaluation.

1. **Flooding in Streams and Rivers** – The PMF in rivers and streams adjoining the site are determined by applying the PMP to the drainage basin in which the site is located. The PMF is based on a translation of PMP rainfall on a watershed to flood flow. The PMP is a deterministic estimate of the theoretical maximum depth of precipitation that can occur at a time of year of a specified area. A rainfall-to-runoff transformation function, as well as runoff characteristics, based on the topographic and drainage system network characteristics and watershed properties are needed to appropriately develop the PMF hydrograph. The PMF hydrograph is a time history of the discharge and serves as the input parameter for other hydraulic models which develop the flow characteristics including flood flow and elevation.

   a. **<u>Basis of Inputs</u>:** The inputs used in PMP, Snowmelt and PMF analysis are based on the following:

   PMP & Snowmelt analysis

- Historic rainfall and other meteorological data collected by the National Weather Service (NWS) at numerous recording and cooperative climate stations and available from the National Climatic Data Center (NCDC).
- NWS Hydrometeorological Report No. 52 (HMR-52), standard isohyetal patterns, storm orientation, percentage of 6-hour increment of PMP, and standard isohyetal geometry information.
- Snow depth data from Global Historic Climatology Network Daily (GHCND) stations were downloaded from the NCDC.
- Snow melt-rate (energy budget) equations and constants are based on USACE Engineering Manual EM-1110-2-1406.

PMF analysis (Hydrologic & Hydraulic Analysis)

- PMP and associated snow melt - 72-hour all-season and cool-season (with coincident snow melt) PMPs for the watershed area.
- United States Geologic Survey (USGS) stream and flow gage data.
- Bridge Structure Information from Illinois Department of Transportation and Iowa Department of Transportation.
- Hourly precipitation data at 95 NWS cooperative stations throughout and adjacent to the watershed in Illinois, Iowa, Wisconsin, Minnesota, and South Dakota. This data is distributed by the NCDC.
- Natural Resources Conservation Service (NRCS, formerly Soil Conservation Service (SCS)) Soil Data- The soil types within the watershed are developed using NRCS soil information.
- Manning's Roughness Coefficients (Manning's n) are based on visual assessment of aerial photography and selected using published literature.
- Dam Information provided by the USACE for Lock & Dams on Mississippi River.
- Riverine and floodplain geometry from USGS topographic maps.

b. <u>Computer Software Programs</u>

PMP & Snowmelt analysis

- Storm Precipitation Analysis System (SPAS)
- AutoCAD MAP 3D 2010
- ArcGIS Desktop 10

PMF analysis (Hydrologic & Hydraulic Analysis)

- ArcGIS Desktop 10
- AutoCAD MAP 3D 2010
- HEC-HMS 3.5
- HEC-RAS 4.1
- VERTCON 2.0

c. <u>Methodology</u>

The PMF analysis included the following steps:

- Delineate watershed, sub-watersheds and calculate sub-watershed areas for input into USACE HEC-HMS rainfall-runoff hydrologic computer model.
- Determine PMP.
- Identify rainfall-runoff model calibration and verification candidate floods.
- Estimate HEC-HMS rainfall-runoff model initial input parameters: Clark unit hydrograph method - Time of concentration and storage coefficient.

- Calculate HEC-HMS model initial loss input parameters: Initial Loss and constant loss rate.
- Calculate precipitation gage weights for calibration and verification floods.
- Calculate HEC-HMS river reach routing model initial input parameters: Muskingum Method - Muskingum K, Muskingum X and number of sub-reaches.
- Calibrate and verify HEC-HMS rainfall-runoff model utilizing observed USGS stream flow data by optimization of model input parameters: Time of concentration, storage coefficient, initial loss, constant rate, Muskingum K, Muskingum X and number of sub-reaches.
- Perform PMF simulation with PMP input using calibrated and verified HEC-HMS model.

Watershed Delineation

The Upper Mississippi River watershed is divided into 10 sub-watersheds based on location of major tributaries to the Mississippi River, and location of USGS stream gages located on the main stem of the Mississippi River.

Site-Specific PMP & Snowmelt

The location of the QCNPS watershed is within the domain of the HMR-51 and HMR-52 guidance. Generally, the all-season PMP is determined using the generalized PMP estimates defined by HMR-51 and HMR-52 guidance. However, the use of HMR-51 for developing PMP values is not applicable due to its watershed area size limitation of 20,000 square miles. The watershed contributory to the Mississippi River upstream of QCNPS is approximately 88,000 square miles. Therefore, a site-specific PMP study was developed for the QCNPS site.

The method of analysis for determining the PMP included the following:

- Develop a Site Specific PMP Study
- Calculate Site Specific Depth-Area-Duration data for various PMP storm centering.
- Calculate 6-hour incremental 72-hour PMP values.
- Calculate 100-year snowpack and snowmelt rates for cool-season PMP

The purpose of the site-specific PMP study was to calculate PMP values specific to entire 88,000 square mile contributory watershed of the Mississippi River upstream of QCNPS. This included an all season and cool-season (rain-on-snow) PMP analysis. The approach used to derive the site-specific PMP values is a storm based approach that utilizes many of the procedures used by the NWS in the development of the HMRs. These same procedures are recommended by the World Meteorological Organization (WMO) for PMP determination. This approach identifies extreme rainfall events that have occurred in a region that has meteorological and topographical characteristics similar to extreme rain storms that could occur over the QCNPS watershed. The largest of these rainfall events are selected for the developing the site-specific PMP for the QCNPS watershed.

HMR procedures for maximization, transposition, and elevation moisture adjustments are used with minor changes (e.g. average vs. persisting dew points and 1,000 foot transposition limitations). Updated techniques and databases are used in the site-specific PMP analysis to increase accuracy and reliability, while adhering to the basic procedures in the HMRs and in the WMO Manuals.

Each storm on the all-season and cool-season short storm lists (the final 31 storms used to derive the PMP values) is maximized, transpositioned, and elevation adjusted to the basin centroid and to each of the 20 grid points used to distribute PMP across this large basin. Depth-Area (DA) plots are made for durations of 6-, 12-, 24-, 48-, and 72-hour for area sizes of 10-, 200-, 1,000-, 5,000-, 10,000-, 20,000-, 50,000-, and 100,000-square miles. Enveloping curves are constructed using storm rainfall values at each grid point and the basin centroid. Depth-Duration (DD) plots are plotted and envelope curves constructed. These final curves provide PMP values for each grid point and the basin centroid. The final step is to spatially interpolate the resulting values using a Geographic Information System (GIS) and manual adjustments to ensure continuity in space and time across the 88,000 square mile basin. The results of this final step allow PMP values for standard durations and area sizes to be determined from any point within the entire basin. This process is completed separately for the all-season analysis and cool-season analysis, resulting in a unique set of PMP values for the entire basin for both data sets.

The all-season PMP values were determined using procedures described in HMR-51. In addition, because the size of the watershed is well beyond the 20,000 square mile upper size limit in HMR-52, the all-season PMP values are determined for area sizes upto 100,000 square miles. Further, analysis results are provided to allow for movement of the design storm during PMF calculations, unlike the stationary design storm center provided in HMR-52. Design storm movement allows for a more realistic storm scenario to be used for the application of the PMP values for PMF determination.

To properly quantify the snowmelt component, a meteorological parameter time series is developed for each of the 10 major sub-watersheds within the overall basin. This included daily and hourly temperature, dew point, wind speed, and rainfall data sets for use in the snowmelt calculations. These data sets are to be used with the cool-season PMP as appropriate. As with the warm-season PMP values, analysis results are provided to allow for movement of the design storm throughout the watershed to maximize flow values in PMF calculation.

100-year Snowpack and Snowmelt

The 100-year snowpack for the watershed is calculated from historical snow depth data from weather gages located throughout the watershed, and calculated on a sub-watershed level. The 100-year snowpack is calculated by applying the Fisher-Tippett Type I, or more commonly named Gumbel distribution to the snow depth data at each gage. This is judged to be a conservative approach for the large watershed, as the actual recurrence interval for each gage to have a coincident 100-year snowpack for the 88,000 square mile watershed is likely to be greater than one-in-one- hundred years. The cool-season PMP is considered to be an April event. The Thiessen polygon method is used to calculate the 100-year snowpack for each sub-watershed by using an area-weighted average of the 100-year snow depth from the stations.

Snowmelt is included in two of the alternatives. Snowmelt is determined using the USACE energy budget method. The energy budget method accounts for six (6) external sources of heat energy that contribute to snowmelt. The energy budget method yields a set of six equations; the selection of the appropriate equation is dependent upon a rain-on-snow or rain-free melt period and the percent forest cover within the drainage area. The available water in the snowpack is calculated based on Federal Energy Regulatory Commission (FERC) guidelines, "*water equivalence data are rarely recorded. If total snowpack depth is available, assume a 100- year* *snowpack for the month on the cool-season Probable Maximum Storm and a starting water equivalence of 30 percent."*

PMF

The PMF is a function of the combined events defined in NUREG/CR-7046 for floods caused by precipitation events.

Alternative 1 – Combination of:

- Mean monthly base flow
- Median soil moisture
- Antecedent of subsequent rain: the lesser of (1) rainfall equal to 40 percent of PMP and (2) a 500-year rainfall
- The PMP
- Waves induced by 2-year wind speed applied along the critical direction

Alternative 2 – Combination of:

- Mean monthly base flow
- Probable maximum snowpack
- A 100-year, snow-season rainfall
- Waves induced by 2-year wind speed applied along the critical direction

Alternative 3 – Combination of:

- Mean monthly base flow
- A 100-year snowpack
- Snow-season PMP
- Waves induced by 2-year wind speed applied along the critical direction

Alternative 1 – All-Season PMP

The largest of the all-season PMF analysis as described in Calculation QDC-0085-S-1990 (Exelon 2013b) resulted from an antecedent storm equal to 40-percent of the PMP, and a PMP. The all-season PMF resulted in a flow of 576,900 cfs.

An antecedent storm equivalent to 40-percent of the all-season PMP is applied to the HEC-HMS model with a 72-hour dry period between the antecedent storm and the PMP event.

The all-season PMP as described above is applied to the HEC-HMS model to determine flow hydrographs at key points in the model.

The all-season PMF is determined not to be the controlling PMF scenario and additional combined event analysis is not performed.

Alternative 2 – Probable Maximum Snowpack and 100-Year Cool-Season Rainfall

The 100-year rainfall would be significantly less rainfall than the PMP, resulting in the majority of the snowmelt occurring as rain-free. The rain-free snowmelt rates are typically close to or lower than the verified constant losses for each sub-watershed, most of the snowmelt would be lost through the constant losses and would not be available for runoff. For similar reasons, given the large size of the QCNPS watershed (approximately 88,000 square miles), calculating the probable maximum snowpack covering the entire watershed from the cool-season PMP precipitating as snow would result in comparable snow-water equivalent available for melting as that used in Alternative 3. Thus, this alternative is not the controlling flooding scenario at QCNPS.

Alternative 3 – 100-Year Snowpack and Cool-Season PMP

The 100-year snowpack and a cool-season PMP resulted in the controlling PMF at QCNPS.

Hydrologic Model (HEC-HMS)

USACE HEC-HMS hydrologic software is used to convert rainfall to runoff. Rainfall is applied to each sub-watershed and transformed to runoff using Clark unit hydrograph methodology. The sub-watershed parameters are calibrated and validated with historic extreme events for which sufficient stream flow and rainfall data is available. The HEC-HMS software is used to model and calibrate Clark unit hydrograph parameters and Muskingum reach routing parameters. Baseflow is obtained from gage data and monthly average base flow is used in the HEC-HMS model.

For the all season PMF, the highest of the all season (May to November) monthly averaged flow is calculated for each stream gage for the period of record and is used in the HEC-HMS model as a baseflow. For the cool-season PMF, the average March monthly flow is used as a baseflow. April monthly flows are ignored as to not double count snowmelt effects.

A small portion of the QCNPS watershed is ungaged. The parameters for ungaged sub-watershed are either scaled based on similar upstream watershed and/or judged to be the similar to the parameters located in the same geographic area.

The constant loss rates are calculated as a weighted average of the areas of all four hydrologic soil groups, A through D. Constant loss rates are calibrated and verified through the optimization process in the HEC-HMS model.

The calibrated unit hydrographs for each sub-watershed are then modified to account for the effects of nonlinear basin response in accordance with NUREG/CR-7046. The peak of each unit hydrograph is increased by one-fifth and the time-to-peak is reduced by one-third. The remaining hydrograph ordinates are adjusted to preserve the runoff volume to a unit depth over the drainage area. In this case, hydrographs with nonlinear basin adjustment resulted in lower flows. Therefore, to be conservative hydrographs without nonlinear adjustments are used in the PMF analysis.

Hydraulic Model (HEC-RAS)

The controlling PMF scenario is determined to be from Alternative 3, a snow or cool-season PMP with a 100-year snowpack. The unsteady flow module within HEC-RAS model is used to transform the resulting flow hydrographs from the controlling alternative into a water surface elevation hydrograph under unsteady flow conditions. For reference and comparison, the all-season PMP scenario, Alternative 1, is also evaluated with the HEC-RAS model.

The hydraulic model is based on the USACE's UNET model for the Mississippi River. The USACE's UNET model covers approximately 400 river miles (River mile 218.01 to 614.9). The geometry from the UNET model is imported into the HEC-RAS model. The HEC-RAS model is truncated based on Lock & Dam locations which provide natural breakpoints. Upstream and downstream limits of the HEC-RAS model are initially selected at Lock & Dam structures based on engineering judgment. Sensitivity analyses are conducted to support the selection of upstream and downstream model limits (i.e, water surface elevations at the QCNPS do not change significantly when boundary conditions at model extents are varied).

The selected upstream boundary location of the HEC-RAS model is River Mile 614.9, which is located approximately 108 miles upstream of QCNPS (River Mile 506.9).

The selected downstream limit of the HEC-RAS model is River Mile 457.2, which is located about 50 miles downstream of QCNPS. Cross section 457.2 is located at Pool No. 16 immediately upstream of Lock & Dam No. 16

The HEC-RAS modeling is different from UNET in some aspects and the imported data is modified to match HEC-RAS modeling approach. These changes are:

- Remove "Lids"
- Remove "Lateral Structures" and replace "Obstructions" related to levees with "Levees defined in HEC-RAS cross-sections
- Modify "Ineffective Flow" and "Obstructed Area" data
- Validate cross-section data

The HEC-RAS model includes five (5) USACE dam structures as listed below. The dams are included based on the USACE operation manuals. Major bridge structures within the modeled reach of the Mississippi River are also incorporated into HEC-RAS. Bridge geometry data is based on aerial images and Illinois Department of Transportation and Iowa Department of Transportation drawings.

- Lock & Dam No. 11
- Lock & Dam No. 12
- Lock & Dam No. 13
- Lock & Dam No. 14
- Lock & Dam No. 15

The hydraulic model is calibrated for unsteady state flow using extreme historic flow data at multiple gage locations. Model calibration is the process of selecting and refining HEC-RAS input parameters to produce a simulated profile for a given flood that shows consistent agreement with an observed profile for the same flood. The consistency of agreement is ultimately based on engineering judgment; however, for this calculation a target elevation difference of 0.5 ft or lower is utilized. The main parameter that is adjusted in the calibration is the Manning's n.

The PMF flow hydrographs are entered into the HEC-RAS model at the upstream end of the model and at the intermediate points representing other tributary rivers/streams.

The HEC-RAS model is evaluated using unsteady-state flow for both all-season PMP (Alternative 1) and cool-season PMP (Alternative 3).

d. **<u>Results</u>**

For Alternative 1, the maximum water surface elevation is 595.2 ft MSL 1912 with a corresponding flow of 551,800 cfs.

Alternative 3 is the controlling PMF and is a result of the cool-season PMP and snowmelt from 100-year snowpack. The maximum PMF peak elevation at QCNPS is 600.5 ft MSL 1912, with a corresponding flow of 744,700 cfs. The maximum duration of flooding above elevation 595 ft MSL 1912 for the analyzed scenarios is approximately ten days.

2. **Dam Breaches and Failures**

a. **<u>Basis of Inputs:</u>** Inputs used for Dam Breach and Failure evaluation include:

- QCNPS HEC-HMS and HEC-RAS models developed in the PMF analysis.

- Dam Information - The National Atlas and the National Inventory of Dams (NID) are used to identify the watershed dams. It is determined that there are total of 1,558 dams located in the watershed.

b. **Computer Software Programs**

- ArcGIS Desktop 10
- HEC-HMS 3.5
- HEC-RAS 4.1
- VERTCON 2.0

c. **Methodology**

The criteria for flooding from dam breaches and failures evaluation is provided in NUREG/CR-7046. Two scenarios of dam failures are recommended and discussed in NUREG/CR-7046, Appendix D including:

- Failure of individual dams (i.e., group of dams not domino-like failures) upstream of the site
- Cascading or domino-like failures of dams upstream of the site

Three scenarios are evaluated in the dam failure analysis for QCNPS including:

- PMF
- Sunny day
- Seismically induced

The PMF scenario for QCNPS bounds the Sunny Day and Seismically Induced failure modes. The Sunny Day and Seismically Induced dam failure scenarios are evaluated due to requirements in the Combined-Effect Flood evaluation discussed in NUREG/CR-7046.

The Sunny Day scenario evaluated in this dam failure analysis conservatively corresponds to Alternative 1 discussed in PMF analysis earlier.

The Seismically Induced scenario corresponds to "Alternative 2" of the Section H-2-Floods Caused by Seismically Induced Dam Failures in NUREG/CR-7046, Appendix H, which is combination of-

- The lesser of one-half of the PMF or the 500-year flood
- A flood caused by dam failure resulting from an operating basis earthquake (OBE) and coincident with the peak of flood
- Waves induced by a 2-year wind speed applied along the critical direction

Two approaches were considered to evaluate flooding at QCNPS resulting from upstream dam failure. The first approach evaluated the failure of a subset of the upstream dams within the QCNPS watershed to develop a conservative, representative upstream dam failure scenario. This approach evaluated the failure of a subset of the upstream dams within the QCNPS watershed to develop a conservative, representative upstream dam failure scenario, based on the Hierarchical Hazard Assessment (HHA) methodology (NUREG/CR-7046, Section 3.4.1) and ANSI/ANS 2.8 guidance, which states that some dams can be eliminated from dam failure analysis based on "*low head differential, small volume, distance from plant site, and major intervening natural or reservoir detention capacity.*"

The second approach conservatively evaluated the failure of all of the upstream dams within the QCNPS watershed. This approach conservatively evaluated all of the 1,558 of the upstream dams within the QCNPS watershed. This approach was evaluated based on ongoing discussions of dam failure analysis methodology between the NRC and the Nuclear Energy Institute (NEI). This second approach is not the approved regulatory guidance by the NRC.

Approach 1 – Evaluated Failure of a Subset of all Upstream Dams

Due to the large number of dams upstream of QCNPS, the application of the two scenarios of dam failure discussed in NUREG/CR-7046, Appendix D was performed on selected individual dams.

- Failure of individual dams (i.e., group of dams not domino-like failures) upstream of the site – Lake Carroll dam, Apple Canyon Lake Dam, Smallpox Creek Dam, and Eau Galle Reservoir
- Cascading or domino-like failures of dams upstream of the site – Lock & Dam No. 11, Lock & Dam No. 12, and Lock & Dam No. 13

The methodology for selecting the individual dams in the flooding assessment at QCNPS due to dam failures follows the methodology in NUREG/CR-7046 and ANSI/ANS 2.8-1992 and is described as follows:

- Review the characteristics of dams located in the watershed.
- Identify upstream dams with significant height and storage (greater than 60 ft and 5,000 acre-ft) within a 100 mile radius of QCNPS to be used as a representation of the other relatively nearby existing dams in the QCNPS watershed.
- Dams located greater than 100 miles upstream are judged to be unlikely to significantly contribute to flooding at QCNPS. This is because that dam failure flood waves attenuate as they travel downstream, and the flood-carrying capacity of the Mississippi River and its 88,000 square-miles drainage area at QCNPS is able to accommodate significant flow below site grade elevation. Most dams in the watershed are relatively low-head or low-storage due to the limited topographic relief in the watershed. The largest dam in the watershed within 250 miles from QCNPS (Eau Galle Reservoir), based on a combination of height and storage, was incorporated into the HEC-HMS rainfall-runoff model.
- Perform dam failure analysis for the Lake Carroll Dam, Apple Canyon Lake Dam, Smallpox Creek Dam, and Eau Galle Reservoir Dam under three scenarios including: PMF, Sunny Day, and Seismically Induced using HEC-HMS.
- Perform domino failure analysis of the Lock & Dam No. 13, Lock & Dam No. 12, and Lock & Dam No. 11 plus the dam breach flows from Lake Carroll Dam, Apple Canyon Lake Dam, Smallpox Creek Dam, and Eau Galle Reservoir Dam on tributaries to the Mississippi River developed in HEC-HMS under three scenarios including: PMF, Sunny Day, and Seismically Induced.

Approach 2 – Evaluated Failure of all Upstream Dams (Sensitivity Study Only):

Additional dam failure analysis was performed for all of the dams listed on the NID within the contributory watershed to QCNPS. The dams were grouped by sub-watershed. A single hypothetical reservoir was created for each sub-watershed to represent all dams in each respective watershed and incorporated into the HEC-HMS rainfall-runoff model developed as part of PMF analysis. The hypothetical reservoirs were inserted at the outlet of each respective sub-watershed. Dams that were analyzed individually (as discussed above in Approach 1) were not included in the calculation of the hypothetical reservoir/dam characteristics in each sub-watershed. However, the failure of the individual dams (as discussed above in Approach 1) were separately incorporated into the HEC-HMS model for the failure of the hypothetical dams to account for the failure of all the NID listed dams. The dam failure analysis in this approach was performed under the PMF and Seismically Induced scenarios using HEC- HMS. The dam failure output hydrograph from HEC-HMS was incorporated as the inflow hydrograph to the HEC-RAS model to establish the water surface elevation at QCNPS.

This approach is considered a sensitivity study as it is significantly more conservative than the published methodology in NUREG/CR-7046 and ANSI/ANS 2.8-1992 and contains unrealistically conservative assumptions. Results from Approach 2 (sensitivity study) are not included in Table 1.

The method of analysis used in the dam breach simulation is summarized as:

- Identify the dams upstream of QCNPS and select the dams to be included in the dam failures analyses.
- *Perform dam failure analysis of* Lake Carroll Dam, Apple Canyon Lake Dam, Smallpox Creek Dam, and Eau Galle Reservoir Dam in HEC-HMS.
- Perform domino failure analysis of Lock & Dam No. 13, Lock & Dam No. 12, and Lock & Dam No. 11 using the QCNPS HEC-RAS model and dam breach flows from Lake Carroll Dam, Apple Canyon Lake Dam, Smallpox Creek Dam, and Eau Galle Reservoir Dam from the previous step.
- Perform additional dam failure analysis for all of the dams located within the QCNPS watershed.
- Estimate peak flow at QCNPS resulting from hypothetical dam failures in HEC-HMS. Establish the water surface elevation at QCNPS using HEC-RAS.

d. **Results:** The following summarizes the results and conclusions:

Approach 1 –

- Sunny-day and Seismically Induced dam failures evaluated in Approach 1, as defined in NUREG/CR-7046 are not anticipated to effect flooding at the site, as the peak water surface elevation is 582.9 ft MSL 1912 and 589.8 ft MSL 1912 respectively, which are below site grade.
- The peak PMF water surface elevation including dam failures is 600.9 ft MSL 1912 which is 5.9 ft above site grade, elevation 595.0 ft MSL 1912, but is 2.1 ft below the current design flood basis elevation of 603.0 ft, MSL 1912. The PMF peak flow at QCNPS with upstream dam failures after hydraulic routing within HEC-RAS is 757,500 cfs.

Approach 2 (Sensitivity Study Only)–

- The Seismically Induced dam failure evaluated in Approach 2, is not anticipated to effect flooding at the site, as the peak water surface elevation is 592.5 ft MSL 1912, which is below site grade.
- The peak PMF water surface elevation including dam failures as evaluated in Approach 2 is 602.8 ft MSL 1912 which is 7.8 ft above site grade, elevation 595.0 ft MSL 1912, but is 0.2 ft below the current design flood basis elevation of 603.0 ft MSL 1912. The PMF peak flow at QCNPS with upstream dam failures after hydraulic routing within HEC-RAS is 826,400 cfs.

Downstream Dam Failure

The Mississippi River comprises the overall UHS for QCNPS. The UFSAR provides assessment of low water conditions by assumed failure of the Lock & Dam No. 14. As described in UFSAR, a hydraulic study of the Mississippi River stage at the QCNPS was performed to evaluate the effect of failure of Lock & Dam No. 14. It was predicted that during periods where historic flow rates exist in the river, 90 hours are required to draw the river stage down to elevation 565 ft from 572 ft at QCNPS, following a catastrophic loss of the lock miter gates.

3. **Storm Surge –** QCNPS has an inland location and does not connect directly with any of the water bodies considered for meteorological events associated with surge. Flooding due to a surge is not plausible at QCNPS.
4. **Seiche –** QCNPS has an inland location and does not connect directly with any of the water bodies considered for meteorological events associated with seiche. Flooding due to a seiche is not plausible at QCNPS.
5. **Tsunami –** QCNPS has an inland location and does not connect directly with any of the water bodies considered for Tsunami events. Flooding due to a tsunami is not a plausible at QCNPS.
6. **Ice Induced Flooding –**
   a. **Basis of Inputs** Calculation inputs include the following:
      - USACE Ice Jam Database
      - Bridge geometry, (upstream and downstream of QCNPS)- Information relative to the bridge structures provided by the Illinois Department of Transportation and the Iowa Department of Transportation
      - Zero gage height elevation for gages identified in the Ice Jam Database. The elevation information is located in the ice jam database, USACE's Water Levels of Rivers and Lakes, or NOAA's North Central River Forecast Center.
      - QCNPS HEC-HMS and HEC-RAS models developed in the PMF analysis.
      -

   b. **Computer Software Programs**
      - HEC-RAS 4.1

   c. **Methodology**

      As identified by NUREG/CR-7046, ice jams and ice dams can form in rivers and streams adjacent to a site and may lead to flooding by two mechanisms:

      - Collapse of an ice jam (formed at the first bridge upstream of QCNPS) that can result in a dam breach-like flood wave that may propagate to the site.
      - An ice jam (formed at the first bridge downstream of QCNPS) that may impound water upstream of itself, thus causing a flood via backwater effects.

      Per NUREG/CR-7046, ice induced flooding is assessed by reviewing the USACE National Ice Jam Database to determine the most severe historical events that have occurred on the Upper Mississippi River, in the vicinity of QCNPS (i.e., in Illinois and Iowa). The period of record available is from 1892 through January 2012. The ice jam resulting in the highest water surface elevation is selected. The highest water surface elevation is estimated from the difference in elevation between the reported flood stage elevation and the reported normal pool surface elevation at the location of the ice jam. Note that the Upper Mississippi River elevation is normally controlled by a series of USACE operated and maintained locks and dams, which create a series of near-level pools for navigation. The historic ice induced flood is calculated to be the result from the December 13, 1945, ice jam occurring in Clinton, Iowa. A river stage of 13.5 ft is recorded with a calculated water surface elevation of 579.8 ft MSL 1912.

The maximum ice jam is determined by selecting the historic event that produced the maximum flood stage relative to the normal water surface elevation at that location. Regardless of specific conditions that produced the historic flood stage at a specific location, the full height is conservatively assumed to represent the ice jam.

The peak water surface elevation at QCNPS as a result of an upstream ice jam breach (i.e., failure of ice dam) is estimated. An ice jam based on the largest historical ice jam is incorporated into the HEC-RAS model at the location of the first bridge upstream of QCNPS as an inline structure. The top of the ice jam is calculated as the height of the ice dam added to the normal pool elevation of the Mississippi River at the first upstream bridge. Ice dam breach parameters are selected so the entire ice jam within the main channel would breach when the water level behind the ice jam reached the top of the ice jam. A constant inflow hydrograph is input for the upstream boundary condition for the HEC-RAS model to simulate flows corresponding to the normal pool elevation.

d. **Results**

The maximum water surface elevation at QCNPS resulting from the upstream ice jam breaching was calculated to be 573.7 ft MSL 1912, 21.3 ft below site grade.

The maximum water surface elevation at QCNPS resulting from backwater from a downstream ice jam is 579.8 ft MSL 1912, 15.2 ft below site grade. Significant margin exists between maximum historic ice jam and site grade at QCNPS.

7. **Channel Migration or Diversion** –The authority to control the river is vested in the USACE. Should the need to control the river arise, Exelon will make the required notification to the USACE. These arrangements have been made and are detailed in the QCNPS emergency procedures as provided in the UFSAR.

8. **Combined Effect Flood (Including Wind Generated Waves)**

a. **Basis of Inputs**

- Probable maximum stillwater surface elevation from PMF analysis
- *Maximum water surface elevation as a result of dam failure analysis*

b. **Computer Software Programs**

Software programs were not used to evaluate combined effect flooding. Hand calculations are used to analyze the effects of wind generated waves and combined with the flood causal mechanism results previously discussed.

c. **Methodology**

The following flood mechanisms are analyzed based on NUREG/CR-7046 recommendations and the location of QCNPS along the Mississippi River. The other combined effect mechanisms described in NUREG/CR-7046 are applicable to site located along an open or semi-enclosed body of water. Therefore those combinations do not apply to QCGNS and are not discussed in this section

Floods Caused by Precipitation Events

Alternative 1 – Combination of:

- Mean monthly base flow
- Median soil moisture
- Antecedent of subsequent rain: the lesser of (1) rainfall equal to 40 percent of PMP and (2) a 500-year rainfall
- The PMP

- Waves induced by 2-year wind speed applied along the critical direction

Alternative 2 – Combination of:

- Mean monthly base flow
- Probable maximum snowpack
- A 100-year, snow-season rainfall
- Waves induced by 2-year wind speed applied along the critical direction

Alternative 3 – Combination of:

- Mean monthly base flow
- A 100-year snowpack
- Snow-season PMP
- Waves induced by 2-year wind speed applied along the critical direction

Alternatives 1, 2, and 3 are discussed in detail earlier. The effect of added wind wave activity is discussed in this section.

Floods Caused by Seismic Dam Failures

Alternative 1 – Combination of:

- A 25-year flood
- A flood caused by dam failure resulting from a safe shutdown earthquake (SSE) and coincident with the peak of the 25-year flood
- Waves included by 2-year wind speed applied along the critical direction

Alternative 2 – Combination of:

- Lesser of one-half PMF or the 500-year flood
- A flood caused by a dam failure resulting from an operating basis earthquake (OBE), and coincident with the peak of the flood selected
- Waves induced by 2-year wind speed applied along the critical direction

Alternative 1 and Alternative 2 are discussed in detail earlier. As discussed in Section 2d, the peak water surface elevation at QCNPS resulting from Approach 1 of the PMF dam failure (600.9 ft MSL 1912) is significantly higher than the peak water surface elevation resulting from Approach 1 of the one-half PMF as described in NUREG/CR-7046 (589.8 ft MSL 1912) dam failure alternative. The peak water surface elevation at QCNPS resulting from Approach 2 (sensitivity study only) of the PMF dam failure (602.8 ft MSL 1912) is significantly higher than the peak water surface elevation resulting from Approach 2 (sensitivity study only) of the one-half PMF (592.5 ft MSL 1912) dam failure alternative.

Wind Wave Activity

The wind-wave effects are calculated for exterior portions of QCNPS only. Wind wave effects are not anticipated to significantly add to stillwater levels in interior buildings unless substantial pathways for wave penetration into buildings are present (i.e. through large open doors, etc).

The simplified method for wave forecasting as outlined in the USACE Coastal Engineering Manual is used to determine the inputs (significant wave height, wave period, wind speed, and wavelength) for calculating the wave runup at QCNPS (Exelon 2013f).

The wave setup is the elevation of the water surface due to wave action, in particular, wave breaking. As waves propagate shoreward, their wavelength (L) decreases and height (H) increases, leading to an increase in wave steepness (H/L). When a wave reaches the limiting steepness, (a function of relative depth and beach slope), it breaks at the breaking wave height (Hb) and at the breaker depth (db). Based on topography and bathymetry at QCNPS, the waves will not break, therefore eliminating the necessity to calculate the wave setup (Exelon 2013f).

In accordance with NUREG/CR-7046, different external flooding mechanisms are combined to analyze to calculate the design basis at QCNPS. The results of the combined events analysis (Exelon 2013f) yielded that floods caused by precipitation events based on the following combination of mechanism resulted the highest water level:

- PMF for the Upper Mississippi River watershed contributory to QCNPS
- Dam failures
- Waves induced by 2-year wind speed applied along the critical direction

Debris Loading - Hydrodynamic and Impact Loads

Debris loading at QCNPS was analyzed using the guidelines described in FEMA P-259. The hydrodynamic forces for low velocity flow (less than 10 ft per second) are converted into an equivalent hydrostatic force. Impact loads on exterior portions of structures were calculated using the guidelines described in FEMA P-259 and by considering debris weight recommended in ASCE/SEI-7-10 (Exelon 2013f).

d. <u>Results</u>

Two set of results are reported corresponding to the two dam failure analysis approaches discussed earlier. The following summarizes the results of the combined events analysis (Exelon 2013f) for QCNPS:

Wind Wave Activity

- The probable maximum wind generated wave runup at QCNPS is calculated to be –
  - Approach 1- 4.1 ft.
  - Approach 2 (sensitivity study only) - 4.0 ft.
- The probable maximum water level at QCNPS including wave effects is calculated to be -
  - Approach 1- 605 ft MSL 1912 outside of safety-related structures. The effects of wave action inside buildings would be negligible. Thus the maximum water surface elevation inside of the building would be 600.9 ft MSL 1912.
  - Approach 2 (sensitivity study only) - 606.8 ft MSL 1912 outside of safety-related structures. The effects of wave action inside buildings would be negligible. Thus the maximum water surface elevation inside of the building would be 602.8 ft MSL 1912.

Debris Loading - Hydrodynamic and Impact Loads

- The equivalent hydrostatic loading (low velocity hydrodynamic force) is:
  - Approach 1- 3.6 lbs/ft acting at elevation 598 ft MSL1912.
  - Approach 2 (sensitivity study only) - 4.1 lbs/ft acting at elevation 598.9 ft MSL 1912.
- The impact loading is 480 lbs acting at the water surface elevation for both Approach 1 and Approach 2 (sensitivity study only) based on probable maximum velocity at the site of 0.6 ft/sec.

4. COMPARISON WITH CURRENT DESIGN BASIS

The revised PMF stillwater elevation of 600.9 ft MSL 1912 validates the current flood mitigation strategy as the current license basis states that the site can be maintained in a safe condition for water levels up to 603 ft MSL 1912. As discussed earlier, QCNPS enters QCOA 0010-16 "Flood Emergency Procedure" immediately when the river level exceeds 586 ft or when the river level is predicted to be greater than 594 ft MSL 1912 in less than 72-hours. This procedure and the QCNPS UFSAR Section 3.4.1.1 states that the site can be safely shut down and maintained in a safe condition for flood levels up to 603 ft MSL 1912 based on the following criteria:

- For flood levels up to plant grade of 594.5 ft MSL 1912 any mode of operation is possible with no additional protective measures.
- For flood levels between 594.5 ft MSL 1912 and 603 ft MSL 1912 the plant is maintained in a safe condition by flooding plant buildings to match the river elevation and shutting down both reactors and establishing evaporative residual heat removal.

Evaluation of flood causing mechanism such as dam breach, wind wave, ice induced flooding, and combined effects were beyond design basis events which were not required under the current licensing basis and therefore have not been previously addressed.

The comparison of existing and reevaluated flood hazard is shown in Table 1.

Table 1 - Comparison of Existing and Reevaluated Flood Hazard at QCNPS

Flood Causing Mechanism	Design Basis	Comparison	Flood Hazard Reevaluation Elevation
Flooding in Streams and Rivers (PMF)	Design Basis Flood Elevation – 603 ft MSL 1912	Bounded	All-Season PMF Elevation – 595.2 ft MSL 1912 All-Season PMF Flow - 551,800 cfs Cool-Season PMF Elevation – 600.5 ft MSL 1912 Cool-Season PMF Flow-774,700 cfs
Dam Breaches and Failures	The UFSAR does not address the effects of upstream dam failure	This flood causing mechanism is not described in the UFSAR	PMF + Dam Failure - Elevation – 600.9 ft MSL Corresponding Flow - 757,500 cfs These flows are routed using HEC-RAS model and account for attenuation and are therefore lower than the PMF flows which are from HEC-HMS model
Storm Surge	Not Plausible	Not Plausible	Not Plausible
Seiche	Not Plausible	Not Plausible	Not Plausible
Tsunami	Not Plausible	Not Plausible	Not Plausible

Flood Causing Mechanism	Design Basis	Comparison	Flood Hazard Reevaluation Elevation
Ice Induced Flooding	This flood causing mechanism is not described in the UFSAR	Bounded	Upstream Ice Jam – Corresponding Elevation at QCNPS – 573.7 ft MSL 1912 Downstream Ice Jam – Corresponding Elevation at QCNPS – 579.8 ft MSL 1912 Ice Induced flood is bounded by the PMF on the Mississippi River
Channel Migration or Diversion	As indicated in UFSAR - The authority to control the river is vested in the USACE. Should the need to control the river arise, Exelon will make the required notification to the USACE. These arrangements have been made and are detailed in the QCNPS emergency procedures	Bounded	Same procedures as discussed in UFSAR
Combined Effect Flood (including wind generated waves)	This flood causing mechanism is not described in the UFSAR	This flood causing mechanism is not described in the UFSAR	PMF + Dam Failure + Wave Runup - Elevation – 605 ft MSL 1912 The effects of wind acting inside buildings would be negligible. Thus the maximum water surface elevation inside of the buildings would be 600.9 ft MSL 1912
Debris Loading – Hydrodynamic and Impact Loads	Criteria Not Described in the UFSAR	Criteria Not Described in the UFSAR	Hydrodynamic Load due to PMF + Dam Failure - 3.6 lbs/ft acting at elevation 598 ft MSL 1912 Impact Load due to PMF + Dam Failure – 480 lbs based on probable maximum velocity at the site of 0.6 ft/sec

5. REFERENCES

1. (Exelon June 2012) Exelon Letter to U.S. Nuclear Regulatory Commission. *Exelon Generation Company, LLC's 90-Day Response to March 12, 2012 Request for Information Pursuant to Title 10 of the Code of Federal Regulations 50.54(f) Regarding Recommendations 2.1 and 2.3, of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident (Flooding).* June 11, 2012.

2. (NRC March 2012) U.S. Nuclear Regulatory Commission. Letter to Licensees (NRC 50.54 (f) Letter). *Request for Information Pursuant to Title 10 of the Code of Federal Regulations 50.54(f) Regarding Recommendations 2.1, 2.3, and 9.3 of the Near Term Task Force Review of Insights from the Fukushima Dai-ichi Accident.* March 12, 2012.

3. (NUREG-0800) U.S. Nuclear Regulatory Commission (NRC). 2007. NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition – Site Characteristics and Site Parameters (Chapter 2)," ML070400364, March 2007.

4. (NUREG/CR-7046)U.S. Nuclear Regulatory Commission (NRC). 2011. NUREG/CR-7046, PNNL-20091, *Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America.* ML11321A195, November 2011.

5. (NRC RG 1.59) U.S. Nuclear Regulatory Commission (NRC). 1977. *Design Basis Flood for Nuclear Power Plants.* Regulatory Guide 1.59, Rev. 2, Washington, D.C.

6. (NRC RG 1.102), U.S. Nuclear Regulatory Commission (NRC). 1976. *Flood Protection for Nuclear Power Plants.* Regulatory Guide 1.102, Rev. 1, Washington, D.C.

7. (ANSI ANS 2.8-1992), American Nuclear Society (ANS). 1992. *American National Standard for Determining Design Basis Flooding at Power Reactor Sites.* Prepared by the American Nuclear Society Standards Committee Working Group ANS-2.8, La Grange Park, Illinois.

8. (Exelon 2013a) Exelon Calculation QDC-0085-S-1989, *Probable Maximum Precipitation (PMP) for the Upper Mississippi River Watershed Contributory to QCNGS.*

9. (Exelon 2013b) Exelon Calculation QDC-0085-S-1990 *Probable Maximum Flood (PMF) for the Upper Mississippi River Watershed Contributory to QCNGS.*

10. (Exelon 2013c) Exelon Calculation QDC-0085-S-1991, *Calculation of Probable Maximum Flood (PMF) Water Surface Elevation: Evaluation of Riverine Hydraulics for the Upper Mississippi River at QCNGS.*

11. (Exelon 2013d) Exelon Calculation QDC-0085-S-2032, *Upstream Dam Failure Flood Evaluation at QCNGS.*

12. (Exelon 2013e) Exelon Calculation QDC-0085-S-2033, *Ice Induced Flooding Evaluation at QCNGS.*

13. (Exelon 2013f) Exelon Calculation QDC-0085-S-2034, *Combined Events Flood Assessment at QCNGS.*

14. (UFSAR) Exelon QCNPS Updated Final Safety Analysis Report (UFSAR), Revision 11, October 19, 2011.

15. Exelon QCOA 0010-16, *Flood Emergency Procedure,* Revision 17.

16. Exelon, *Local intense Precipitation Evaluation Report for the Quad Cities Nuclear Power Station,* Revision 0, March 2013.

Enclosure 3

CD-R labeled:

AMEC

Project No. 783170000

Quad Cities Nuclear Power Station
Pertinent Site Data

Enclosure 4

SUMMARY OF REGULATORY COMMITMENTS

The following table identifies commitments made in this document. (Any other actions discussed in the submittal represent intended or planned actions. They are described to the NRC for the NRC's information and are not regulatory commitments.)

COMMITMENT	COMMITTED DATE OR "OUTAGE"	COMMITMENT TYPE	
		ONE-TIME ACTION (Yes/No)	PROGRAMMATIC (Yes/No)
The Quad Cities Nuclear Power Station current design basis flood does not bound the reevaluated hazard for all flood causing mechanisms. Specifically, combined-effects (dam failure and wind-generated waves), hydrodynamic/debris loads, and local intense precipitation flooding were not considered in and not bounded by the current design basis flood hazard. Therefore, Quad Cities Nuclear Power Station plans to prepare a full Integrated Assessment Report (Scenario 4).	March 12, 2015	Yes	No