UNITED STATES
NUCLEAR REGULATORY COMMISSION
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August 5, 2016

Mr. Joseph W. Shea
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1101 Market Street, LP 3R-C
Chattanooga, TN 37402-2801

SUBJECT: BROWNS FERRY NUCLEAR PLANT, UNITS 1, 2 AND 3 – STAFF ASSESSMENT OF RESPONSE TO 10 CFR 50.54(f) INFORMATION REQUEST – FLOOD-CAUSING MECHANISM REEVALUATION (CAC NOS. MF6034, MF6035 AND MF6036)

Dear Mr. Shea:

By letter dated March 12, 2012, the U.S. Nuclear Regulatory Commission (NRC) issued a request for information pursuant to Title 10 of the *Code of Federal Regulations*, Section 50.54(f) (hereafter referred to as the 50.54(f) letter). The request was issued as part of implementing lessons-learned from the accident at the Fukushima Dai-ichi nuclear power plant. Enclosure 2 to the 50.54(f) letter requested that licensees reevaluate flood-causing mechanisms using present-day methodologies and guidance. By letter dated March 12, 2015 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML15072A130), Tennessee Valley Authority (TVA, the licensee) responded to this request for Browns Ferry Nuclear Plant, Units 1, 2, and 3.

By letter dated September 3, 2015 (ADAMS Accession No. ML15240A183), the NRC staff sent TVA a summary of the staff's review of the licensee's reevaluated flood-causing mechanisms. The enclosed staff assessment provides the documentation supporting the NRC staff's conclusions summarized in the letter. As stated in the letter, the reevaluated flood hazard results for local intense precipitation was not bounded by the current design-basis flood hazard. In order to complete its response to Enclosure 2 to the 50.54(f) letter, the licensee is expected to submit a focused evaluation to address this reevaluated flood hazard, as described in the NRC letter issued September 1, 2015 (ADAMS Accession No. ML15174A257). This closes out the NRC's efforts associated with CAC Nos. MF6034, MF6035, and MF6036).

If you have any questions, please contact me at (301) 415-3809 or e-mail at Juan.Uribe@nrc.gov.

Sincerely,

Juan Uribe, Project Manager
Hazards Management Branch
Japan Lessons-Learned Division
Office of Nuclear reactor Regulation

Docket Nos. 50-259, 50-260, and 50-296

Enclosure:
Staff Assessment of Flood Hazard
Reevaluation Report

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STAFF ASSESSMENT BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO FLOODING HAZARD REEVALUATION REPORT

NEAR-TERM TASK FORCE RECOMMENDATION 2.1

BROWNS FERRY NUCLEAR PLANT, UNITS. 1, 2, AND 3

DOCKET NOS. 50-259, 50-260, AND 50-296

1.0 INTRODUCTION

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

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

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 is necessary, as described in the 50.54(f) letter and COMSECY-15-0019, "Mitigating Strategies and Flooding Hazard Reevaluation Action Plan" (NRC, 2015b). The Browns Ferry Nuclear Plant (BFN, Browns Ferry), Units 1, 2, and 3 FHRR (TVA, 2015) and audit report "Nuclear Regulatory Commission Report for the Audit of Tennessee Valley Authority's Flood Hazard Reevaluation Report Submittals Relating to the Near-Term Task Force Recommendation 2.1-Flooding for: Browns Ferry Nuclear Plant, Units 1, 2, and 3; Sequoyah Nuclear Plant, Units 1 and 2; and Watts Bar Nuclear Plant, Units 1 and 2" (NRC 2015c), provide the flood hazard input necessary to complete this additional assessment consistent with the process outlined in COMSECY-15-0019 and the associated guidance.

By letter dated March 12, 2015 (TVA, 2015), the Tennessee Valley Authority (TVA, the licensee) provided its FHRR for BFN, Units 1, 2, and 3. In connection with this response, the licensee identified certain interim actions. The licensee stated in FHRR Section 12 that interim actions and procedures exist to ensure that the plant will be safe during a flood event, and that these interim actions and procedures will be reevaluated and updated as determined by additional assessments of plant response associated with NTTF Recommendation 2.1.

The reevaluated flood hazard results for the local intense precipitation (LIP) flood-causing mechanism is not bounded by the plant's CDB hazard. Therefore, the NRC staff anticipates that the licensee will perform an additional assessment of plant response. Consistent with the process outlined in COMSECY-15-0019 and associated guidance, staff anticipates that the licensee will perform and document a focused evaluation for LIP and associated site drainage that assesses the impact of the LIP hazard on the site and evaluates and implements any necessary programmatic, procedural, or plant modifications to address this hazard exceedance.

By letter dated September 3, 2015, the NRC issued an Interim Staff Response (ISR) letter to the licensee (NRC, 2015d). The purpose of the ISR letter is to provide flood hazard information suitable for the assessment of mitigating strategies developed in response to Order EA-12-049. That letter also made reference to this staff assessment, which documents the staff's basis and conclusions. The flood hazard mechanism values presented in the letter's enclosures match the values in this staff assessment without change or alteration. As mentioned in the ISR letter and discussed below, the licensee is expected to develop flood event duration parameters to conduct the mitigating strategies assessment (MSA), as discussed in the latest revision to the Nuclear Energy Institute (NEI) guidance document NEI-12-06, Appendix G. The staff will evaluate the flood event duration parameters (including warning time and period of inundation) during its review of the MSA.

On April 4, 2016, TVA notified the NRC in a public meeting that errors had been found in the application of the hydraulic model used for the streams and rivers flood hazard analyses and the errors affected all three TVA sites (Watts Bar, Sequoyah, and Browns Ferry) (TVA, 2016b; NRC, 2016b). In the public meeting, TVA stated that the errors involved the calculation of reservoir storage volumes in the Tennessee River and its tributaries, with the largest impacts at Douglas and Cherokee Reservoirs located upstream of the WBN and SQN sites. As indicated by TVA, they do not expect to complete the resolution of the model errors and preparation of submittals for the 50.54(f) review by NRC staff until after July 2017. The licensee also stated in the public meeting that the probable maximum precipitation (PMP) for the analysis of the flood hazard for streams and rivers has been revised using current methodologies, and that the revised precipitation has a margin (i.e., is smaller) compared with the PMP used in the FHRR. The NRC staff expects that following the resolution of the model errors and revision of the flood hazard analyses for streams and rivers, including the revised precipitation, the results will be bounded by the water surface elevations reported in the FHRR (TVA, 2015). As such, TVA indicated that they would use the information from the BFN FHRR (TVA, 2015), which was the basis of the ISR letter, for the MSA at the BFN site, and that they expect the MSA to be completed by December 2016.

Based on TVA's approaches and the proposed schedule to resolve the model errors presented at the public meeting, it is staff's view that completion of the staff assessment for the BFN site using the currently available information will best serve the 50.54(f) process and provide timely completion of staff review of the currently available 50.54(f) submittals. Consequently, this staff assessment reflects the staff's 50.54(f) review of the BFN external flood hazards as provided in the BFN FHRR (TVA, 2015) and from the staff's audit (NRC, 2015c). Additional information about the reported modeling error based on the public meeting with TVA is included in

Sections 3.3.11 and 3.4.6 of this staff assessment to indicate NRC's understanding of the modeling errors and the anticipated approaches to error resolution by TVA. This additional information (1) describes staff's understanding of the modeling errors (2) indicates TVA's expected resolution of the modeling errors, and (3) provides the staff's understanding of the expected reduction in the maximum flooding water level at the site following resolution of the modeling errors.

2.0 REGULATORY BACKGROUND

2.1 Applicable Regulatory Requirements

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

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

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

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

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

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

2.2 Enclosure 2 to the 50.54(f) Letter

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

2.2.1 Flood-Causing Mechanisms

Enclosure 2 of the 50.54(f) letter (NRC, 2012a) discusses the flood-causing mechanisms that licensees should address in the FHRR. Table 2.2-1 lists the flood-causing mechanisms that the licensee should consider. Table 2.2-1 also lists the corresponding Standard Review Plan (SRP) (NRC, 2007) sections and applicable interim staff guidance (ISG) documents containing acceptance criteria and review procedures. The licensee should incorporate and report associated effects per Japan Lessons-Learned Directorate (JLD) JLD-ISG-2012-05, "Guidance for Performing the Integrated Assessment for External Flooding" (NRC, 2012c), in addition to the maximum water level associated with each flood-causing mechanism.

2.2.2 Associated Effects

In reevaluating the flood-causing mechanisms, the "flood height and associated effects" should be considered. Guidance document JLD-ISG-2012-05 (NRC, 2012c), defines "flood height and associated effects" as the maximum stillwater surface elevation plus:

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

2.2.3 Combined Effects Flood

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

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

If two less severe mechanisms are plausibly combined (per ANSI/ANS-2.8-1992 (ANSI/ANS, 1992), then the staff will document and report the result as part of one of the hazard sections. An example of a situation where this may occur is flooding at a riverine site located where the river enters the ocean. For this site, storm surge and river flooding should be plausibly combined.

2.2.4 Flood Event Duration

Flood event duration was defined in JLD-ISG-2012-05 (NRC, 2012c) as the length of time during which the flood event affects the site. It begins when conditions are met for entry into a flood procedure, or with notification of an impending flood (e.g., a flood forecast or notification of dam failure), and includes preparation for the flood. It continues during the period of inundation, and ends when water recedes from the site and the plant reaches a safe and stable state that can be maintained indefinitely. Figure 2.2-1 illustrates flood event duration.

2.2.5 Actions Following the FHRR

For the sites where the reevaluated flood hazard is not bounded by the CDB flood hazard for all flood-causing mechanisms, the 50.54(f) letter (NRC, 2012a) requests licensees and construction permit holders to:

- Submit an interim action plan with the FHRR documenting actions planned or already taken to address the reevaluated hazard.
- Perform an integrated assessment subsequent to the FHRR to: (a) evaluate the effectiveness of the current licensing basis (i.e., flood protection and mitigation systems); (b) identify plant-specific vulnerabilities; and (c) assess the effectiveness of existing or planned systems and procedures for protecting against, and mitigating consequences of, flooding for the flood event duration.

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

COMSECY-15-0019 (NRC, 2015b) 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 an approach in which licensees with a LIP hazard exceeding their CDB flood will not be required to complete an integrated assessment, but would instead perform a focused evaluation. As part of the focused evaluation, licensees will assess the impact of the LIP hazard on their sites and then evaluate and implement any necessary programmatic, procedural, or plant modifications to address the hazard exceedance. For other flood hazard mechanisms that exceed the CDB, licensees can assess the impact of these reevaluated hazards on their site by performing either a focused evaluation or an integrated assessment (NRC, 2015b) consistent with JLD-ISG-2016-01 "Guidance for Activities Related to Near-Term Task Force Recommendation 2.1, Flooding Hazard Reevaluation" (Agencywide Document Accession Management System (ADAMS) ML16162A301).

3.0 TECHNICAL EVALUATION

The NRC staff reviewed the information provided for the flood hazard reevaluation of BFN. The licensee conducted the hazard reevaluation using present-day methodologies and regulatory guidance used by the NRC staff in connection with ESP and COL reviews. The staff's review and evaluation are provided below.

To provide additional information in support of the summaries and conclusions in the BFN FHRR (TVA, 2015), the licensee made several calculation packages available to the staff via an electronic reading room. When the staff relied directly on any of these calculation packages in its review, they or portions thereof were cited, as part of the "Nuclear Regulatory Commission Report for the Audit of Tennessee Valley Authority's Flood Hazard Reevaluation Report Submittals Relating to the Near-Term Task Force Recommendation 2.1-Flooding for: Browns Ferry Nuclear Plant, Units 1, 2, and 3; Sequoyah Nuclear Plant, Units 1 and 2; and Watts Bar Nuclear Plant, Units 1 and 2" (NRC, 2015c), in the discussion below. Other calculation packages were found only to expand upon and clarify the information already provided on the docket, and so are not docketed or cited.

3.1 Site Information

The 50.54(f) letter (NRC, 2012a) included the SSCs important to safety and the ultimate heat sink in the scope of the hazard reevaluation. Per the 50.54(f) letter, Enclosure 2, "Requested Information, Hazard Reevaluation Report," Item a, the licensee included pertinent data concerning these SSCs in the BFN, Units 1, 2 and 3 FHRR (TVA, 2015). Enclosure 2 (Recommendation 2.1: Flooding), "Requested Information, Hazard Reevaluation Report," Item a, describes site information to be contained in the FHRR. The staff reviewed and summarized this information as follows in the sections below.

3.1.1 Detailed Site Information

The FHRR (TVA, 2015) states that the BFN site is located on the north bank of Wheeler Reservoir at Tennessee River Mile (TRM) 294.0 (river kilometer (RK) 473.1) (Figure 3.1-1). Wheeler Reservoir is the impoundment of Wheeler Dam, which is located 19 river miles (31 kilometers (km)) downstream of the BFN site (Figure 3.1-1). The BFN site is located approximately 30 mi (48 km) west of Huntsville, AL, and 55 river miles (88 km) downstream of

Guntersville Dam (TRM 349 (RK 562)) (NRC, 2015c). The BFN site encompasses 1.31 square miles (mi^2) (3.39 km^2) (Figure 3.1-2).

The NRC staff noted that the BFN FHRR does not reference a vertical datum; though, as discussed in the staff's audit summary (NRC, 2015c) and in the UFSAR (TVA, 2007), the vertical datum of mean sea level (msl) is used. The site grade elevation at the powerblock is 565.0 ft (172.21 m) msl (TVA, 2015).

Several locations on the BFN site are identified in the FHRR as having openings at critical elevations and include the reactor buildings, the diesel generator buildings, the intake pumping station, and the radwaste building (TVA, 2015) (Figure 3.1-2). As stated in the FHRR, the reactor buildings have a finished floor elevation of 565.0 ft (172.21 m) msl and have inflatable door seals or watertight doors to prevent major leakage. The diesel generator buildings, the intake pumping station (containing the residual heat removal service water (RHRSW) pumps), and the radwaste building also have finished floor elevations of 565.0 ft (172.21 m) msl and have water-tight doors used to prevent major leakage (TVA, 2015). The turbine building is allowed to flood (TVA, 2015).

The BFN plant draws cooling water via the RHRSW pumps from the recirculating cooling canal, which is located southwest of the Lower Plant and extends to the northwest around the cooling towers (Figure 3.1-2). The cooling canal lies between the lower plant and the Tennessee River (Figure 3.1-2). Examination by staff of the site topography shows that the site and adjacent areas range from 560 ft (172.21 m) msl to 580 ft (176.78 m) msl in the lower plant area and above 580 ft (176.78 m) msl north of the switchyard area (Figure 3.1-3).

Numerous dams impound the Tennessee River (Figure 3.1-4). The licensee owns and operates many of the dams upstream of BFN and the U.S. Army Corps of Engineers (USACE), the Nantahala Power and Light Company, or Brookfield Smokey Mountain Hydro Power own the remaining dams upstream of BFN (TVA, 2015). The dams on the Tennessee River system were constructed for flood control, navigation, and hydropower generation and can include gates to control reservoir water levels, navigation locks, and turbines. The dams are constructed of concrete structures and earth embankments, and several dams include saddle dams to maintain water surface elevations (WSEs) above the grade of connecting valleys. The Douglas Saddle Dams (Figure 3.1-5) and the Watts Bar west Saddle Dam (Figure 3.1-6) were important to the reevaluation of the flood hazard at the BFN site, as discussed in Section 3.3.7 of this staff assessment. The overtopping and failures of the Douglas Saddle Dams controlled the outflow from Douglas Reservoir, a major dam on the French Broad River. The overtopping and failure of the Watts Bar west Saddle Dam controls the outflow from the Watts Bar Reservoir and prevents the failure of Watts Bar Dam.

According to the FHRR, 21 major TVA dams have been evaluated for stability on the Tennessee River and tributaries upstream of the BFN site (TVA, 2015). Several of these TVA dams have a low safety margin during all evaluated storm events, unless otherwise indicated, which leads to the assumption of dam failure. The following dams were evaluated for stability (Figure 3.1-4):

- Apalachia (Hiwassee River; low margin during the 21,400 mi^2 (55,426 km^2) storm)
- Blue Ridge (Hiwassee River)

- Boone (Holston River; low margin)
- Chatuge (Hiwassee River)
- Cherokee (Holston River)
- Chickamauga (Tennessee River)
- Douglas (French Broad River)
- Fontana (Little Tennessee River)
- Fort Loudoun (Tennessee River)
- Fort Patrick Henry (Holston River; low margin)
- Guntersville (Tennessee River; low margin)
- Hiwassee (Hiwassee River)
- Melton Hill (Clinch River; low margin during the 7,980 mi^2 (20,668 km^2) storm)
- Nickajack (Tennessee River; low margin)
- Norris (Clinch River)
- Nottely (Hiwassee River)
- South Holston (Holston River)
- Tellico (Little Tennessee River)
- Tims Ford (Elk River)
- Watauga (Holston River)
- Watts Bar (Tennessee River)

In addition, the following seven major dams are not owned by TVA, as indicated in Figure 3.1-4:

- Calderwood (Little Tennessee River)
- Cheoah (Little Tennessee River)
- Chilhowee (Little Tennessee River)
- Mission (not shown) (Hiwassee River)
- Nantahala (Little Tennessee River)
- Santeetlah (Little Tennessee River)
- Thorpe (Little Tennessee River)

As described in its FHRR, TVA manages the river system through the River Operations (RO) division (TVA, 2015). The role of the RO division is to forecast flows and floods in the TVA system, as well as monitoring gate operations and the gate maintenance program.

3.1.2 Design-Basis Flood Hazards

The CDB flood levels are summarized by flood-causing mechanism in Table 3.1-1. The CDB[1] included the flood hazards from the stillwater probable maximum flood (PMF) of 572.5 ft (174.50 m) msl in streams and river and includes hydrologic dam failure due to the runoff from the PMP over the Tennessee River watershed. Consideration of wind wave runup and wind wave setup increased the PMF elevation by 5.5 ft (1.68 m), giving the CDB of 578.0 ft (176.17 m) msl for the flood hazard related to streams and rivers. Seismic dam failure was not considered in the CDB of BFN. The CDBs for storm surge, seiche, tsunami, ice-induced

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[1] Based on staff discussions during the audit with TVA, the current licensing basis (CLB) and CDB are equivalent (NRC, 2015c). The staff assessment uses the term CDB throughout the document.

flooding, and channel migration were not included because these flood mechanisms were not applicable to the BFN site.

3.1.3 Flood-Related Changes to the Licensing Basis

Changes to the licensing basis, as discussed in the FHRR, are primarily for flooding from streams and rivers and include dam safety modifications, river operation studies, and reanalysis of hydrology (TVA, 2015). While reexaminations of potential flooding from LIP have been made since the initial licensing of the plant, there has been no change to the licensing basis for LIP since the original design-basis was established. Maximum flood elevations from seismic dam failure were not considered in the CDB of BFN. In consideration of these facts, the following discussion of flood-related changes to the licensing basis focuses on those for streams and rivers.

According to the FHRR, the design-basis controlling event at BFN for the PMF on streams and rivers was derived in 1972 for a maximum winter storm in the eastern United States that was transposed over the Browns Ferry watershed (TVA, 2015). The original modeling analyses were made using a computer code described in Garrison et al (1969)[2]. The unsteady flow model routed reservoir flows and included upstream boundaries, local inflows, and headwater discharge relationships at the downstream boundary. The hydraulic routing included reservoir rules of operations as well as dam and embankment failures.

During 1997 and 1998, a reassessment of the PMF was made to assess several dam safety modifications completed since the establishment of the original design-basis. The reassessment of the PMP at BFN included a 12,030 mi^2 (31,158 km^2) flood event, which was analyzed along with the 7,980 mi^2 (20,668 km^2) and 21,400 mi^2 (55,426 km^2) flood events in the original analysis. The licensee found the 12,030 mi^2 (31,158 km^2) PMP to be the controlling event (TVA, 2015). The dam safety modifications on the main stem generally involved increasing the crest elevations of embankment and concrete structures for the Fort Loudoun-Tellico, Watts Bar, Nickajack, and Guntersville Dams (TVA, 2015). An uncontrolled spillway was also added to Tellico Dam (TVA, 2015). Modifications to tributary dams included increasing embankment crest elevations, addition of spillways, and dam post-tensioning (TVA, 2015).

In the period from 2008 through 2012, TVA updated the PMF analyses and reassessed the flood hazard (TVA, 2015). The reassessment resulted in the 21,400 mi^2 (55,426 km^2) flood event being controlling. Updates to the PMF analyses included several items, with the most significant being the migration of hydraulic routing analyses in the main stem and most of the tributaries to the Hydrologic Engineering Center-River Analysis System (HEC-RAS) model (USACE, 2010a). The updates also included, among others, the following items (TVA, 2015):

- Inclusion of flood barriers to Cherokee, Fort Loudoun, Tellico, and Watts Bar Dams,
- Inclusion of recent bathymetric survey data to define the main stem channel for modeling purposes,
- Updating operational guides to reflect current policies,
- Updating dam rating curves so they are based on test data,

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[2] Staff understand that this is the Simulation of Channel Hydraulics (SOCH) model.

- Input of Watts Bar west Saddle Dam failure flows at the confluence of Yellow Creek and the Tennessee River; and,
- Route Dallas Bay rim leak flows during the PMF using a reach connecting Dallas Bay to the main stem channel downstream of Chickamauga Dam.

In addition to the PMF analyses, all of the 21 dams upstream of BFN that are owned by TVA (see Section 3.1.1 of this staff assessment) were evaluated for dam stability (TVA, 2015). Nine tributarie dams that were not evaluated for stability were assumed to fail (see Section 3.3.7 of this staff assessment). License conditions were added for the following five dams:

- Cherokee (post-tensioning and raising the embankment elevation),
- Douglas (post-tensioning and raising saddle dam embankment elevations),
- Fort Loudoun (post-tensioning non-overflow dam),
- Tellico (reinforcing non-overflow dam and raising embankment elevations), and
- Watts Bar (reinforcing portions of the non-overflow dam and lock, raising embankment elevations, and reducing west Saddle Dam crest elevations to 752 ft (229.2 m) msl).

With the exception of the Watts Bar west Saddle Dam, these five dams were assumed not to fail in the analysis of flooding for streams and rivers because of the actions to strengthen the dams and to prevent overtopping (see Section 3.3 of this staff assessment). The NRC staff notes that the purpose for lowering of the west Saddle Dam crest elevation was to reduce the maximum water surface elevation upstream of Watts Bar Dam during a PMF event.

Generally, TVA has initiated a process to move all design basis calculations to computer codes and software that are in line with current engineering practice. The staff notes that the process has been on going and will likely continue into the near future.

3.1.4 Changes to the Watershed and Local Area

The FHRR examined the changes to land uses and impervious area in the Tennessee River watershed. From the analysis of National Land Cover Data, the change in impervious area upstream of Wheeler Dam was from 1.74 percent to 1.97 percent from 2001 through 2011, an annual rate of increase of 0.23 percent (TVA, 2015).

3.1.5 Current Licensing Basis Flood Protection and Pertinent Flood Mitigation Features

The FHRR lists the following flood protection and flood mitigation items (TVA, 2015):

- The tributary dams located upstream of BFN;
- Protective structures for flood mode operation of BFN;
- Flood response procedures at BFN;
- Notification and annunciation of water level exceedances at the site or in Wheeler Reservoir; and,
- TVA's RO forecasting and flood warning capabilities.

To handle flood mode operation, the FHRR states that the reactor building wall adjacent to the turbine building is designed to withstand loads from a PMF with elevation of 572.5 ft (174.50 m) msl. The reactor building is protected from flooding during a PMF by an equipment access flood gate and a watertight personnel access door (TVA, 2015). The radwaste building, as stated in the FHRR, is protected from flooding by sealed doors and sealed piping penetrations. The pumps in the RHRSW intake pumping station structure have outside walls that protect them to an elevation of 578.0 ft (176.17 m) msl and personnel access doors are normally closed and sealed (TVA, 2015). The access doors to the diesel generator buildings are normally closed and locked with rubber seals in place (TVA, 2015). The radwaste evaporator building has its interface with the radwaste building sealed up to 578.0 ft (176.17 m) msl. The turbine building is allowed to flood because it does not contain any safety-related equipment (TVA, 2015).

Generally, BFN flood protection is handled by the abnormal operating instruction, 0-AOI-100-3 R038. The licensee's RO monitors and forecasts floods in order to identify potential flooding conditions that may exceed plant grade elevations (TVA, 2015). Shutdown of all three units begins (if it has not already begun) and flood preparations are executed if RO predicts a flood elevation greater than 565.0 ft (172.21 m) msl. The flood preparations begin, as defined by the abnormal operating instructions, at BFN if one of the following occurs (TVA, 2015):

1. If the water level in the forebay exceeds 558.0 ft (176.17 m) msl, plant personnel issue a notification,
2. If the Wilson Load Dispatcher (or other reliable source) issues a notification of impending river conditions,
3. Annunciation from the Unit 1 Control Room of the lake level exceeds 564.0 ft (171.91 m) msl,
4. When water is detected in the corridor between the lunchroom and the turbine building during a PMP.

3.1.6 Additional Site Details to Assess the Flood Hazard

The licensee provided bathymetry of the Tennessee River in the vicinity of the BFN site in the FHRR (TVA, 2015). Additionally, TVA provided electronic copies of input files related to flood hazard reevaluations as part of an audit of BFN FHRR (NRC, 2015c).

3.1.7 Results of Plant Walkdown Activities

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

By letter dated November 27, 2012, TVA provided the flood walkdown report for BFN (TVA, 2012a). The staff prepared a staff assessment report, dated June 27, 2014 (NRC, 2014), to document its review of the walkdown report. The NRC staff concluded that the licensee's implementation of the flooding walkdown methodology met the intent of the walkdown guidance.

3.2 Local Intense Precipitation and Associated Site Drainage

The licensee reported in its FHRR that the reevaluated flood hazard for LIP and associated site drainage is based on a maximum stillwater-surface elevation in the lower plant area of 566.6 ft (172.70 m) msl and in the switchyard area of 578.2 ft (176.24 m) msl.

This flood-causing mechanism is discussed in the licensee's CDB. The current design-basis probable maximum flood elevation for LIP and associated site drainage is based on a stillwater-surface elevation in the lower plant area of <565.0 ft (172.21 m) msl and in the switchyard area of less than 578.0 ft (176.17 m) msl.

3.2.1 Site Drainage

The FHRR states that the local site drainage area is 1.39 mi^2 (3.60 km^2), which for the analysis of site drainage from LIP, was divided into 12 sub-basins (Figures 3.2-1, 3.2-2, and 3.2-3). The licensee used light detection and ranging (LiDAR) data to construct a digital terrain model (DTM) of the local site (Figure 3.1-3). As part of the topographic data analyses, the licensee estimated that the root mean square error of the LiDAR was less than 0.12 ft (0.04 m) in comparison with field survey data (NRC, 2015c). The DTM was used to delineate drainage basins and storage areas (Figures 3.2-1, 3.2-2, and 3.2-3). Cross sections were also extracted from the DTM for the west channel and east switchyard channel hydraulic analyses of site drainage (Figures 3.2-4 and 3.2-5) (NRC, 2015c).

The licensee set up the LIP drainage analysis into the following four different areas: west channel, east switchyard channel, lower plant, and cooling tower areas (NRC, 2015c). The west channel carries flow from upstream contributing areas around the cooling towers (Figures 3.2-1 and 3.2-4) (NRC, 2015c). Overflow from the west channel into the east switchyard channel was possible, but in the LIP analysis, TVA showed it did not to occur even with blocked culverts. The east switchyard channel routes flow from the switchyard and its contributing areas around the lower plant area with a portion of the runoff overflowing into the cooling tower area (Figures 3.2-2 and 3.2-5) (NRC, 2015c). The lower plant area handles drainage around the nuclear plant (Figures 3.2-3) (NRC, 2015c). The cooling tower area includes the "hot-water" channel and has the potential to create a backwater for flows from the lower plant area (see Figure 3.2-3) (NRC, 2015c). There is a potential for blockage of culverts or debris accumulation at the Old Shaw road bridge crossing in the west channel that could lead to spillage into the east switchyard channel area (NRC, 2015c). The analysis of the lower plant area is potentially affected by backwater conditions in the cooling tower area to which it discharges (NRC, 2015c). As previously mentioned, the east switchyard channel has a connection to the cooling tower area, and so indirectly affects the lower plant area (NRC, 2015c).

The NRC staff reviewed (NRC, 2015c) the sub-basin delineation and storage areas as input to the HEC Hydrologic Modeling System (HMS) model (USACE, 2010b), and the channel cross sections, sub-basin delineation, layout, and connectivity of the sub-areas as input to HEC-RAS (USACE, 2010a). The staff noted that the storage areas were delineated based on the presence of roads and topographic divides (NRC, 2015c).

3.2.2 Local Intense Precipitation

The licensee followed the procedures provided in U.S. National Weather Service Hydrometeorological Report (HMR) 52 (NOAA, 1982) and HMR 56 (NOAA, 1965) to develop a PMP for a 1-hour duration and a 1-mi^2 (2.59 km^2) storm area (TVA, 2015). The licensee used

HMR 56 to estimate a PMP depth of 16.47 in (41.83 cm) for the smooth terrain roughness around the BFN area (NRC, 2015c).

Within the 1-hour duration, the licensee examined three LIP time-distributions (hyetographs) in which the peak precipitation was near the beginning, middle, and end of the 1-hour duration. The licensee used the procedures in HMR 52 to determine the time distributions and found that a late-peak hyetograph, with 5-min intervals, produced the highest results from the site drainage analysis (NRC, 2015c) (see Section 3.2.4 of this staff assessment).

The staff examined the methods from HMR 56 and 52 used by the licensee, including terrain distribution, hyetograph time interval, rainfall depth reduction ratio, and moisture index, and found them to be appropriate. Based on the examination of the steps of the HMR 56 and 52 method, staff found the depths and time distribution of the PMP for local drainage to be reasonable.

3.2.3 Runoff Analyses

To estimate runoff at BFN, TVA computed the times of concentration and channel travel times for each sub-area, including the effects of sheet flow, shallow concentrated flow, and channel flow (NRC, 2015c). To transform precipitation to runoff in each sub-area, TVA used the Soil Conservation Service (SCS) unit hydrograph (UH) method (NRCS, 2004), which includes the use of the time of concentration (NRC, 2015c).

The licensee initially computed standard UHs using HEC-HMS (NRC, 2015c). Then, to account for potential non-linear hydrologic effects resulting from the PMP, the licensee synthesized peaked UHs by increasing the peak flows of the UHs by 20 percent, reducing the times-to-peak by one-third, and adjusting the other UH ordinates to match the total volume of the standard UH. This method follows NUREG/CR-7046 (NRC, 2011d). The synthetic UH method used a Pearson Type III function to create a runoff temporal distribution whose volume matches that of the SCS UH (NRC, 2015c). The licensee used the synthetic UHs as input into the HEC-HMS model to compute runoff during the LIP event for all lag-time-related sub-areas in the west channel drainage, the east switchyard channel drainage, and the lower plant areas. Within HEC-HMS, TVA used an isolated unit-area sub-basin to compute an instantaneous runoff ratio with units of cubic feet per second/alternating current (cfs/ac) (NRC, 2015c). The licensee used the unit-area runoff ratio to compute inflows by multiplying the ratio times the areas between each cross section and including the result as lateral inflows to the east switchyard channel. In addition to the times of concentration, elevation-storage, and elevation-discharge curves were input for sub-areas (NRC, 2015c).

TVA examined two cases of site grading and conveyance capacity (NRC, 2015c), which were based on the guidance from NUREG/CR-7046 (NRC, 2011d). Case 1 considered that the site was effectively draining runoff to passive drainage channels, and that the drainage channels and weirs were unblocked (NRC, 2015c). Case 2 differs from Case 1 by assuming that the drainage channels and weirs were partially blocked (NRC, 2015c).

The NRC staff examined the licensee's calculation of times of concentration and found the methods were appropriate. The staff inspected the HEC-HMS model and found the inputs for time of concentration and drainage area used to generate the standard SCS UH were consistent with that reported in the NRC audit report (NRC, 2015c). The staff also inspected the spreadsheet calculations for UH peaking and found them appropriate (NRC, 2015c). The staff inspected the HEC-HMS user specified UH, which derive from the UH peaking calculations and found them to be appropriate (NRC, 2015c). The staff examined the HEC-HMS inputs for Cases 1 and 2 and found them appropriately implemented with relevant weir lengths reduced by 50 percent to represent blockage by debris.

3.2.4 Hydraulic Model

As discussed in the NRC audit report (NRC, 2015c), TVA examined two cases of site grading and conveyance capacity, which were based on guidance from NRC (2011d). Case 1 considered the site to drain runoff to passive drainage channels, with the drainage channels and weirs unblocked but with culverts and storm drainage structures blocked. Case 2 differed from Case 1 by assuming that the drainage channels and weirs carrying water away from the site were partially blocked. Case 2 results were the focus of staff's review of the flood hazard due to LIP, because they were reported by TVA as producing larger results.

For the flood hazard reevaluation, the licensee used two HEC-RAS (USACE, 2010a) models: one of the west channel and the other of the east switchyard channel, which included upstream storage areas (NRC, 2015c). For the lower plant drainage area, the licensee used a HEC-HMS model with storage pond routing for each of the three drainage sub-basins (Lower west, Lower Middle, and Lower east) (NRC, 2015c). The licensee also initially used a HEC-HMS model of the west drainage area (the source of flow to the west channel) to evaluate the potential of overflow into the east switchyard drainage area (NRC, 2015c). For the cooling water channel, the licensee used storage routing to compute the potential tailwater condition for the lower plant drainage area analysis (NRC, 2015c).

The licensee used channel cross sections from previous HEC-RAS analyses for the flood hazard reevaluation, and these were updated with cross section data extracted by TVA from the DTM to develop more accurate channel bottom elevations (NRC, 2015c). The HEC-HMS models were the same as those developed for the runoff analyses (see Section 3.2.3 of this staff assessment), but included culvert blockages (NRC, 2015c).

For the HEC-RAS models, TVA assumed steady-state conditions for the west channel and unsteady-state conditions for the east switchyard channel drainage areas (NRC, 2015c). For the HEC-HMS model, TVA also used unsteady-state conditions (NRC, 2015c).

For both the west channel and east channel HEC-RAS models, TVA used Manning's roughness coefficients based on Chow (1959). The Manning's roughness coefficients were as follows (NRC, 2015c): well-maintained grassed areas were set to 0.03, asphalt paved areas were set to 0.016, graveled areas were set to 0.023, coarse riprap (channel bottoms and overbanks) was set to 0.036, channel bottom growth was set to 0.080, and heavy brush on the North bank was set to 0.1. The expansion and contraction coefficients specified in the HEC-RAS inputs were set to represent gradual transitions (NRC, 2015c).

As stated previously, TVA used the west drainage HEC-HMS model to calculate potential overflow of the Nuclear Plant Road into the east Switchyard Drainage Area (NRC, 2015c). The licensee also analyzed the potential for debris accumulation at, and failure of, the Old Shaw

Road Bridge (Figure 3.2-1) (NRC, 2015c). Neither of these west drainage area analyses with blockages resulted in overflow from the west channel into the east Switchyard Drainage Area (NRC, 2015c).

For the east switchyard channel HEC-RAS model, TVA explicitly included the vehicle barrier system (VBS) as a portion of the cross-section profiles at three adjacent cross sections (NRC, 2015c). For Case 2 condition, the licensee assumed a car-sized vehicle (20 ft (6.10 m) long and 6 ft (1.83 m) high) blocked the VBS cross sections, as well as a cross section in the channel bend (NRC, 2015c).

For the west channel HEC-RAS modeling, TVA set the downstream boundary with Wheeler reservoir as a normal depth boundary condition (NRC, 2015c). For the east channel downstream boundary condition at wheeler reservoir in HEC-RAS, TVA set it as a stage-flow curve (rating curve) (NRC, 2015c). The wheeler reservoir WSE for the LIP event was assumed to be 556.41 ft (169.59 m) msl (the maximum WSE during the 1973 flood), which is much lower than the minimum outfall elevation of 564.0 ft (171.91 m) msl (NRC, 2015c) at lower middle drainage area.

For the steady-state west channel HEC-RAS model, TVA used the peak flow of 16,658 cfs (471.7 m^3/s), computed by the HEC-HMS model, as a constant inflow at the upstream boundary (NRC, 2015c). In the east channel HEC-RAS model, the flows from the upstream storage areas were included by TVA as unsteady inflows to downstream storage areas and channel cross sections (NRC, 2015c). The licensee's analyses also included instantaneous inflows generated by HEC-HMS as direct runoff of precipitation over a unit area (see Section 3.2.3 of this staff assessment) (NRC, 2015c). These inflows were input as lateral inflows to the east switchyard channel HEC-RAS model and scaled by the representative area (NRC, 2015c).

From the HEC-RAS and HEC-HMS modeling analyses, TVA found the maximum WSE exceeded critical elevations at two locations. The first location was the east Switchyard area. The reevaluated maximum WSE was 578.2 ft (176.24 m) msl, which exceeded the CDB of less than 578.0 ft (176.17 m) msl. TVA noted in the FHRR that, at this elevation, overflow into the lower plant area is prevented because it is below the area's crest elevation of 578.6 ft (176.36 m) msl north of the turbine building. The second location was the lower plant area, where the reevaluated maximum WSE was 566.6 ft (172.70 m) msl, which also exceeded the critical elevation of 565.0 ft (172.21 m) msl.

The NRC staff examined the channel cross sections and storage areas in the licensee's HEC-HMS and HEC-RAS models and found the geometry layout, component connectivity, and cross section profiles to be appropriate and representative of the site. The staff noted that interpolated cross sections were present in the HEC-RAS models and are typically included to address numerical instabilities and/or model warnings. The staff noted that the use of Manning's roughness of 0.08 for channel bottom growth was used for most of the east channel (NRC, 2015c), which staff considers conservative.

The staff compared the HEC-RAS model inflows with runoff flows computed in HEC-HMS from non-linear UH hydrologic methods and found them to be consistent. Also, because the hydraulic analyses were made using unsteady-state conditions, staff found the use of time-varied runoff as drainage inflows to be appropriate.

The staff found from the examination of the west channel HEC-RAS model that Case 2 was implemented by the blockage of channels with debris accumulation upstream of a bridge (NRC, 2015c). The staff found in the HEC-RAS model that debris accumulation was simulated by creating an obstruction below elevation 572.4 ft (174.47 m) (NRC, 2015c). The staff noted that the channel bottom elevation was 565 feet (NRC, 2015c). The staff found the representation of the debris blockage was reasonable and produced an appropriate reduction in conveyance.

In the HEC-RAS model of the east Switchyard channel, the staff found the inclusion of the VBS system at appropriate cross sections (NRC, 2015c). For Case 2, staff found the representations of the blockages by a car at the VBS and at the channel bend were appropriate (NRC, 2015c). For the Lower Plant Drainage area, the staff noted that for Case 2 the licensee reduced the weir flow between sub-basins and for the weir outfall into the cooling channel (NRC, 2015c), which would increase the maximum flood elevations around the plant, which was appropriate.

The NRC staff found the HEC-RAS model boundary conditions for the west and east Channels at Wheeler Reservoir were conservative for the local site drainage. The staff noted that for the west channel, because the model was run in steady state, the use of a normal depth downstream boundary (NRC, 2015c) was appropriate and conservative. In the east Switchyard channel, the use of a rating curve downstream boundary was appropriate because the channel's invert elevation was higher than the 556.41 ft (169.59 m) msl boundary elevation based on the maximum flood level in Wheeler Reservoir (NRC, 2015c).

Because the receiving water downstream of the lower plant area was the Cooling Canal, the staff examined the HEC-HMS model and found that the Cooling Water channel was assumed to have no tailwater effect on outflow (NRC, 2015c). The staff found that typical operations in River Mode of the Cooling Canal supported the assumption of no tailwater effects on outflow from the lower plant area (NRC, 2015c). The staff found the maximum critical WSE of 566.6 ft (172.70 m) msl occurred in the Lower east Power Plant Area for Case 2 with the late peaking hyetograph. The staff examined the input parameters and coefficients of the HEC-HMS models of the lower plant area and found they were appropriate.

3.2.5 Sensitivity Analyses

The staff made no sensitivity runs on the HEC-HMS and HEC-RAS models supplied by the licensee. The staff considered the licensee's analyses for Case 2 conditions to be sufficiently conservative with respect to the blockage of weirs, culverts, and channels and to the specification of Manning's roughness in channels and overbanks.

3.2.6 Conclusion

The staff confirmed the licensee's conclusion that the reevaluated flood hazard for LIP and associated site drainage is not bounded by the CDB flood hazard. Therefore, staff expects that the licensee will submit a focused evaluation for local intense precipitation and associated site drainage consistent with the process and guidance discussed in COMSECY-15-0019 (NRC, 2015b).

3.3 Streams and Rivers

The licensee reported in its FHRR that the reevaluated flood hazard for streams and rivers is based on a stillwater surface water elevation of 572.1 ft (174.38 m) msl, which includes the overtopping failure of Douglas Saddle Dams Nos. 1 and 3 (Figure 3.1-5). Including wind waves and wave runup resulted in an elevation of 577.2 ft (175.93 m) msl at the following locations: diesel generator buildings (1, 2, and 3), radwaste building, and reactor building.

This flood-causing mechanism is discussed in the licensee's CDB. The CDB PMF elevation for streams and rivers is based on a stillwater-surface elevation of 572.5 ft (174.50 m) msl. Including wind waves and runup results in an elevation of 578.0 ft (176.17 m) msl, which the FHRR states is representative of wave runup against a vertical wall at a critical structure.

3.3.1 Probable Maximum Precipitation

The FHRR states that HMR 41 (NOAA, 1965) was used for the calculation of PMP on the Tennessee River watershed. The licensee determined that two PMP configurations were applicable to the BFN site (NRC, 2015c): (1) a downstream-centered configuration with an area of 21,400 mi^2 (55,426 km^2) and (2) a configuration centered on Bulls Gap, TN (near Douglas Dam) with an area of 7,980 mi^2 (20,668 km^2). The FHRR stated that other PMP events had been examined previously (e.g., 7,980 mi^2 (20,668 km^2) Sweetwater-centered event); however, the licensee continued the examination of the two listed PMP configurations for the flood hazard reevaluation because they maximized rainfall over the watershed.

For the flood hazard reevaluation, TVA reanalyzed the PMP configurations using current geographical information systems methods and found the subbasins PMP depths to match very closely with previous analyses (NRC, 2015c). As discussed in the NRC audit report (NRC, 2015c), the watershed wide average PMP depth for the 21,400 mi^2 (55,426 km^2) downstream PMP configuration is 13.77 in (34.98 cm), while that for the 7,980 mi^2 (20,668 km^2) Bulls Gap configuration is 13.04 in (33.12 cm). For the flood hazard reevaluation, the licensee utilized a tapering residual rainfall depth outside the isohyetal area consistent with HMR 41 (NRC, 2015c).

The NRC staff examined the PMP calculations made by the licensee using HMR 41 (NOAA, 1965). The main factor controlling the flood hazard is the PMP depth upstream of BFN, which includes local tributaries upstream of Wheeler Dam. The staff checked the results provided in the NRC audit report (NRC, 2015c) and found the methods appropriate and the results reasonable.

The 21,400 mi^2 (55,426 km^2) storm provided the maximum rainfall depth for the watershed. However, the licensee determined the 7.980 mi^2 (20,668 km^2) storm was the controlling event that generated the maximum flood elevation at BFN based on the storm centering, the storm isohyet distribution, the basin geometry, and flood routing (see Section 3.3.8 of this staff assessment).

3.3.2 Runoff Estimation

For the CLB, the Antecedent Precipitation Index (API) runoff methodology was used to compute effective rainfall depths (TVA, 2015). For the flood hazard reevaluation, the API was replaced by the Natural Resources Conservation Service (NRCS, 2004) runoff curve numbers (CN) to calculate precipitation losses and effective rainfall depths for each sub-watershed (TVA, 2015; NRC, 2015c). The licensee computed the cumulative and incremental runoff volumes using the NRCS CN methods. The licensee adjusted the CN values to match the sub-basin volumes calculated using the API method (NRC, 2015c). The licensee made CN adjustments for the antecedent and main storms (NRC, 2015c). As stated in its FHRR, the licensee compared the resulting CN values for both events to CN values generated based on soil types and characteristics of land use in each sub-basin. The maximum difference of the runoff depths between the API and CN methods was less than 0.1 percent for both the antecedent and main storm events (NRC, 2015c). The licensee validated the CN values for antecedent PMP; these were approximately 15.7 percent higher than the CN values based on soil type and land use, while for the main PMP were 4.3 percent higher (TVA, 2015).

According to the licensee (TVA, 2015; NRC, 2015c), the development of surface runoff hydrographs for the flood hazard reevaluation used previously developed UHs to transform the effective rainfall to runoff (NRC, 2015c). The UHs were the same as those used for analysis of the CDB, which had been validated by TVA against flood records (NRC, 2015c). As discussed in the NRC's audit report (NRC, 2015c), the UHs were for 1-hour, 2-hour, 4-hour, and 6-hour durations. For the flood hazard reevaluation, the licensee used spreadsheets to calculate the surface runoff hydrographs for each sub-basin using the convolution method (NRC, 2015c). The licensee computed surface runoff hydrographs from each sub-basin for the two PMP storms occurring in March: the 21,400 mi^2 (55,426 km^2) downstream centered storm and the 7,980 mi^2 (20,668 km^2) Bulls Gap centered storm (TVA, 2015). The licensee also included stream base flows derived from monthly average flows of March for each sub-watershed (TVA, 2015).

The NRC staff reviewed the licensee's CN methods and the CN values calculated by the licensee and found them appropriate. The staff noted that the CN values were more conservative than those estimated theoretically using soil type and land use information. In general, the conservative CNs also resulted in larger runoff volumes than the API method used for the CDB. On average, the staff found that the licensee validated CN values used in the FHRR are larger than 70 for the antecedent PMP, and 80 for the main PMP (NRC, 2015c).

The staff had previously evaluated the UHs for the Watts Bar license amendment (NRC, 2015a). To evaluate the application of the convolution method for the flood hazard reevaluation, staff examined the spreadsheet calculations used to compute surface runoff from effective precipitation and UHs. The staff found the use of unit hydrographs and the convolution method for calculating surface runoff to be appropriate.

3.3.3 National Inventory of Dams Inflows for PMF Event

Based on NRC guidance for assessing flood hazards due to dam failure (NRC, 2013b), TVA used the information from the National Inventory of Dams (NID) (USACE, n.d.-b) to identify upstream dams that were not included in the TVA flood control system (TVA, 2015). The licensee identified approximately 1,100 critical dams from the NID database upstream of the BFN (TVA, 2015). Figure 3.3-1 shows the region where a high density of dams is located. The licensee excluded the Thorpe and Nantahala reservoirs, which are regulated by Federal Energy Regulatory Commission (FERC), from the NID volumes for a PMF event, because the projects are required to be able to pass the peak inflows without dam failures (NRC, 2015c). Inflows from dams between Wheeler and Wilson Dams, both downstream of the BFN site, were also excluded (NRC, 2015c).

The licensee aggregated the volumes of the identified dams and these volumes were assumed to become dam failure inflows (NRC, 2015c). The discharge of the NID volumes were set as rectangular-shape hydrographs with a duration of 6 days starting 2 and 1/2 days after the beginning of antecedent precipitation and extending into the main PMP event (NRC, 2015c). The licensee assumed all the dams identified from the NID database failed completely (NRC, 2015c). Due to the number and the location of these dams, the licensee assumed that the time distribution of the hydrographs were constant flows due to the assumed range of the flood wave travel times and the effect of flood wave attenuation, which resulted in the rectangular hydrograph (NRC, 2015c). The inflows were included along with surface runoff to the upstream input points of the Tennessee River HEC-RAS model for PMF analyses (NRC, 2015c).

Based on the assumption that complete failure of the critical dams from the NID would occur just after the peak of the antecedent precipitation period, staff considers that TVA made a conservative assumption for NID failures during a PMF event. The NRC staff considers the use of rectangle hydrographs to represent the aggregation of flow from hydrologic failures of dams was appropriate because the location of most of the NID projects are in the upstream ends of the sub-basins (Figure 3.3-1), which would tend to attenuate the dam failure hydrographs by the time the peak flows reached the model input locations. Additionally, the staff agrees that cascading failures of NID projects would tend to spread the flood waves through time.

The NRC staff agrees that the exclusion of FERC-regulated dams is appropriate. The staff found that the licensee had added the failure inflows from the identified NID projects to the input points of the HEC-RAS model without using flood-wave routing, which the staff considers to be practical and acceptable since the licensee applied one of the methods recommended by NRC JLD-ISG-2013-01 (NRC 2013b).

With the inclusion of inflows from NID dam failures, Cherokee Dam and Douglas Saddle Dams were found by the licensee (see Section 3.3.7 of this staff assessment) to overtop during the PMF event with wind waves. The licensee conducted sensitivity tests of the headwater level changes for two 3-day duration cases. One case was for the Cherokee Dam watershed, and the other case was for the Douglas Dam watershed. Results of the tests indicated that the differences of headwater levels at the dams were minimal (NRC, 2015c). Based on the minimal changes of headwater elevations at the dams, staff found that use of a 6-day duration rectangular hydrographs of NID failure flows to be a reasonable assumption.

3.3.4 Tributary Routing

As discussed in the NRC audit report (NRC, 2015c) and the BFN FHRR (TVA, 2015), tributary routing was required in several instances to route sub-basin hydrographs for input to the HEC-RAS model. The licensee applied routing methods to tributaries outside the model extents developed for the HEC-RAS analysis of the PMF (NRC, 2015c). The routing methods included Muskingum, lag time, and autoregressive moving average (ARMA). The licensee used the Muskingum method for a portion of the French Broad River, and the lag time method for the Pigeon River, Nolichucky River, North Fork Holston River, and Sequatchie River, as well as the

Cotaco and Limestone Creeks (NRC, 2015c). The licensee used the ARMA method for the Paint Rock and Flint Rivers (NRC, 2015c). The routing methods for these tributaries were the same as the one described in the CLB (NRC, 2015c). The HEC-RAS hydraulic routing is used for all remaining tributaries (NRC, 2015c).

The staff recently reviewed the routing methods utilized for the WBN supplemental LAR (TVA, 2014). The staff concluded that application of the licensee's selected routing methods for tributaries outside the extents of the HEC RAS model was appropriate, and that the coefficients of the routing methods were appropriately calibrated and validated against historical flow data (NRC, 2015a).

3.3.5 HEC-RAS Model Setup: Geometry and Calibration

The licensee used the same HEC-RAS model geometry for the flood hazard reevaluation at BFN as it was used for the recent supplemental LAR for WBN (TVA, 2014), and the SQN flood hazard reevaluation (NRC, 2016c), which included the setup of the model cross sections, dam geometry, and model calibration. The additional portion of the HEC-RAS that affected BFN (which was not included in the supplemental LAR for WBN and the SQN flood hazard reevaluation) included the main stem of the Tennessee River downstream of Chickamauga Dam and the Elk River, which joins the Tennessee River approximately 10.5 mi (16.9 km) downstream of the BFN site. Similarly to the 2014 supplemental LAR for WBN (TVA, 2014), the licensee calibrated each of the main stem reservoirs separately, and for the PMF analysis at BFN the calibration included reservoirs downstream of Chickamauga Dam.

The NRC staff recently reviewed the HEC-RAS model calibration as part of the WBN LAR (NRC, 2015a) and the SQN FHRR staff assessment (NRC, 2016c), and found it to be appropriate for the flood hazard reevaluation for the BFN site. For the reservoir reaches downstream of Chickamauga Dam, the licensee calibrated the HEC-RAS model to the March 1973 and May 2003 flood events, with the exception for Wheeler Reservoir that used the December 2004 flood event (NRC, 2015c). The licensee's goal was to calibrate results within 1 ft (0.30 m) above observed elevations (NRC, 2015c). The Nickajack Reservoir calibration was within 1 ft (0.30 m) above the observed WSEs for the 1973 flood event and within 2 ft (0.61 m) above the observed WSEs during the 2003 flood event (NRC, 2015c). The Guntersville Reservoir calibration was within 1 ft (0.30 m) above the observed WSEs for the 1973 flood event and slightly greater than 1 ft (0.30 m) above the observed WSEs during the 2003 flood event (NRC, 2015c). The Wheeler Reservoir calibration was within 6 in above the observed WSEs for both the 1973 and 2004 flood events (NRC, 2015c). The staff noted that while Nickajack Reservoir calibration exceeded 1 ft (0.30 m) for the 2003 flood event, it was within 1 ft (0.30 m) for the 1973 flood event, which was the larger of the two floods. Consequently, staff considers the calibration of the HEC-RAS model for the main stem and tributaries to be appropriate for the flood hazard reevaluation at the BFN site.

As a component of model setup for the PMF analysis, all flows described in Sections 3.3.2, 3.3.3, and 3.3.4 of this staff assessment were used as input by the licensee into the full HEC-RAS via an HEC data exchange file after summing the various inflow components using Microsoft Excel spreadsheets (NRC, 2015c). The inflow components included surface runoff, rain-on-reservoir, and additional volume from NID failure inflows (NRC, 2015c). The staff had previously reviewed the HEC-RAS model setup for the WBN LAR (NRC, 2015a), and the staff considers that the HEC-RAS model with the extensions added for the flooding analysis at the BFN site was appropriate for the flood hazard reevaluation.

3.3.6 HEC-RAS Model Unsteady Flow Rules for Dam Rating Curves and Flood Operational Guides

The unsteady flow rules included in the HEC-RAS input define the dam rating curves and flood operational guides and were previously evaluated in the recent supplemental LAR for WBN (NRC, 2015a). The following statements summarize the purpose of the dam rating curves and flood operational guides. The flood flow simulation required dam rating curves as input data, which described a reservoir discharge as a function of the dam's headwater and tailwater levels. The flood operational guides included a primary operation curve for flood control and a recovery operation curve for storage volume recovery after an antecedent storm. The flood operational guides were for dams to be operated in prescribed ranges of reservoir levels or discharges during storms. If the PMF inundated an operations deck, the initial dam rating curve was used to determine the overtopping flow that occurred at headwater levels greater than the flood operational guides. The licensee included hydrologic dam failure as part of the unsteady flow rules (see Section 3.3.7 of this staff assessment). For the BFN PMF analyses, the rules reflected the assumptions for hydrologic dam failure upstream of the BFN site (NRC, 2015c). The licensee also used the unsteady flow rules to monitor the computed incremental discharge in each simulation time step for controlling the numerical stability (NRC, 2015c).

The NRC staff recently reviewed the unsteady flow rules included in the HEC-RAS input for the WBN LAR (NRC, 2015a) and SQN staff assessment (NRC, 2016c) PMF simulations. The staff notes that the licensee used the same HEC-RAS model and inputs for the BFN PMF analyses as were used for the WBN and SQN PMF analyses, with rules modifications reflecting the scenarios analyzed for the BFN PMF. Based on that review, staff finds the application of the rules for the flood hazard reevaluation at BFN acceptable.

3.3.7 Hydrologic Dam Failure

During PMF events, the licensee postulated a dam would fail if: (a) the dam stability criteria had not been evaluated or (b) the stability criteria was evaluated and the results showed the dam had a low safety margin (NRC, 2015a). The following provides a list of the hydrologic dam failures assumed by the licensee and includes, in parentheses, a brief description of the failure (NRC, 2015c):

- Boone (low safety margin)
- Fort Patrick Henry (low safety margin)
- Melton Hill (low safety margin; total failure for 7,980 mi^2 (20,668 km^2) storm; South Embankment failure only for 21,400 mi^2 (55,426 km^2) storm)
- Watts Bar west Saddle (overtopped)
- Calderwood (not evaluated)
- Cheoah (not evaluated)
- Chilhowee (not evaluated)
- Ocoee 1 (not evaluated)
- Ocoee 2 (not evaluated)

- Ocoee 3 (not evaluated)
- John Sevier (not evaluated)
- Mission (not evaluated)
- Wilbur (not evaluated)
- Douglas Saddle Dams (overtopped)
- Apalachia (low safety margin; total failure only for 21,400 mi^2 (55,426 km^2) storm)
- Fort Loudon (overtopped)
- Nickajack Dam North and South Embankments (low safety margin; overtopped)
- Chickamauga Dam North and South Embankments (low safety margin; overtopped)
- Guntersville Dam North and South Embankments (overtopped)

The hydrologic dam failures listed above were assumed by the licensee to be total and instantaneous. Generally, the licensee considered several factors to determine the mode of dam failure for earth embankments and concrete structures, including whether a stability analysis has been made on the embankment or structure (NRC, 2015c). For an earth embankment or a concrete structure, if a stability analysis has not been done, or if the analysis has found the structure to have a low margin of stability, then it is assumed to fail at the peak headwater elevation. If the earth embankment had a stability analysis and it was overtopped, it could be failed at the time of peak overtopping headwater or at a time computed by a DBREACH failure analysis, which is a validated and verified code developed by TVA and incorporated into the HEC-RAS unsteady rules. The code is based on U.S. Bureau of Reclamation methods to compute the time of failure. If the embankment of a TVA-owned dam is not overtopped and if it is not a low safety margin embankment, then no embankment failure is assumed. For concrete structures, if a stability analysis found the structure to not be stable at peak headwater elevations, it was assumed to fail at the peak overtopping headwater elevation. If no stability analysis was done, the concrete structure was failed if water level reached the upper limit of its discharge rating curve, or at peak headwater elevation if no rating curve were available.

For the analyses of PMF at BFN, both the Von Thun and Gillette (1990) and the DBREACH failure methods were used (NRC, 2015c). The licensee used the Von Thun and Gillette failure method to compute failure cross sections for Douglas Saddle Dam Nos. 1 and 3 (NRC, 2015c). The licensee used the DBREACH[6] program to determine the headwater elevations at the time of failure for both the north and south embankments at Chickamauga Dam, for both the north and south embankments at Nickajack Dam, and for both the north and south embankments at Guntersville Dam (NRC, 2015c). The staff did not review the DBREACH model, but the staff recognized that the licensee has previously developed the DBREACH model based on soil erosion principles applied to a breach of an earth embankment. The licensee-postulated dam failures are consistent with the 2014 supplemental LAR for WBN (TVA, 2014) for which NRC issued a corresponding amendment to the UFSAR (NRC, 2015a).

Following dam failure, the licensee used a weir flow equation in the unsteady flow rules to compute the dam embankment breach outflows (NRC, 2015c). In cases of embankment failure (but not total and instantaneous failure), the licensee used the empirical equation of Von Thun and Gillette (1990) to compute the breach opening dimension for dam embankment failure (TVA, 2015). Otherwise, with cases of total dam failure, the license used the downstream cross section as the hydraulic control for the dam (NRC, 2015c).

Guntersville Dam, located 55 river miles (88 km) upstream of the BFN site, is the nearest dam upstream of the site. As discussed previously, the PMF analyses includes failure of the Guntersville, Nickajack, and Chickamauga Dams.

The NRC staff recently reviewed the hydrologic dam failure from WBN PMF simulations included in the HEC-RAS input for the 2014 supplemental LAR review (NRC, 2015a) and the SQN staff assessment (NRC, 2016c). Based on recent findings, review supporting information during the audit, and the licensee's conservative assumptions of total and instantaneous failure of dams with low or unknown safety margins, staff finds the methods used for hydrologic dam failure for the flood hazard reevaluation acceptable.

3.3.8 Probable Maximum Flood Elevations

As described in its FHRR, the licensee used the HEC-RAS model to simulate the unsteady flows and to compute discharges and flood elevations in the Tennessee River system above Wilson Dam. For the analyses, the licensee examined flood elevations obtained from the use of two PMP configurations derived from HMR 41 (NOAA, 1965): a 21,400 mi^2 (55,426 km^2) downstream-centered storm and a 7,980 mi^2 (20,668 km^2) storm centered at Bulls Gap (see Section 3.3.1 of this staff assessment).

Using the information discussed in Sections 3.3.2 through 3.3.7 of this staff assessment, the licensee computed the stillwater PMF elevations at the BFN site as 572.1 ft (174.38 m) msl for a 7,980 mi^2 (20,668 km^2) storm centered at Bulls Gap and 571.7 ft (174.25 m) msl for a 21,400 mi^2 (55,426 km^2) storm (TVA, 2015). Both results included hydrologic dam failures (see Section 3.3.7 of this staff assessment) including overtopping and failure of Douglas Saddle Dams (TVA, 2015). Consequently, the licensee determined that the controlling flood elevation at BFN for a PMF event was 572.1 ft (174.38 m) msl from the 7,980 mi^2 (20,668 km^2) storm (TVA, 2015). The staff noted that the controlling scenario for the BFN PMF is bounded by the CDB of 572.5 ft (174.50 m) msl.

The portion of TVA's Tennessee River HEC-RAS model used to simulate flood conditions in the watershed upstream of Chickamauga Dam was recently reviewed by staff and found to be acceptable (NRC, 2015a; NRC, 2015d; NRC, 2016c). For the BFN FHRR review, staff noted modifications to the unsteady flow rules of the HEC-RAS model to account for additional failures of Chickamauga, Nickajack, and Guntersville Dams. The staff noted that the inclusion of the inflows from NID dams resulted in the failures of the Douglas Saddle dams, though the result at the BFN site did not exceed the CDB. Consequently, the staff considers the application of the HEC-RAS model and the inputs used for the PMF simulation to be appropriate and the results to be reasonable.

3.3.9 Coincident Wind and Wave Activity

According to its FHRR, the licensee examined wind-wave effects at the BFN site and at several dams upstream of the BFN site. The licensee used two different approaches to compute wind-induced wave heights (NRC, 2015c): (1) USACE methods were applied to compute wave run-up and setup at multiple buildings around the BFN site (USACE, 1966) and (2) U.S. Bureau of

Reclamation methods at upstream dams (USBR, 2012). Both methods are consistent with JLD-ISG-2012-05 (NRC, 2012c).

The licensee analyzed wind speed data provided by the National Climatic Data Center from five surrounding airports wind data stations for the period of January 2000 to 2014 (NRC, 2015c). The analysis results provided the peak speed for a 20 min wind duration. The fetch length and the wind speed above the water surface (USACE, 2008) were controlling parameters in the wave height calculations (NRC, 2015c).

The computational results for the wave run-up and setup at various locations around BFN site are shown in Table 3.3-1. In the analyses of upstream dams, the maximum wave height during the PMF was found to overtop Cherokee Dam (TVA, 2015), but the licensee's analyses found that the overtopping flow would not damage the embankments based on calculations of the allowable overtopping flow rate and the provided free-board height (NRC, 2015c).

The NRC staff reviewed the computed 2-year wind speeds and found the methods appropriate and the results reasonable. Also, the staff reviewed the analysis of effective fetch lengths and found them acceptable and also found the computation of effective fetch length appropriate.

The staff noted that the licensee used an earlier methodology (USACE, 1966) to compute the wind-induced wave height at the BFN site. As part of the audit, the licensee provided results computed at the WBN site as an example using present-day method (USACE, 2008) for a comparison (NRC, 2015c). The comparison between the present-day and earlier methods found that the wave heights using the earlier methodology (as described in the FHRR) (USACE, 1966) were more conservative (i.e., wave heights were lower using the present-day methods). Consequently, the staff considers that the methods used by the licensee to compute the wave heights at the BFN site are acceptable and the results are reasonable. For the evaluation of overtopping of Cherokee Dam from wind waves, the staff also found these methods to be appropriate and the results reasonable.

3.3.10 Model Application Error Identification and the Effect on Riverine Hydraulic Analyses

As noted in Section 1.0 of this staff assessment, on April 4, 2016, TVA informed the NRC in a public meeting that there were computational errors with reservoir storage volumes used for the HEC-RAS modeling analysis of the flood hazard for streams and rivers (TVA, 2016b; NRC, 2016b). During the public meeting, TVA stated that the model errors resulted from several factors, as follows: (1) the continuance of cross section locations developed from previous hydraulic analyses using the SOCH model with relatively long distances between cross sections, (2) limiting the use of ineffective flow areas to only one side of a river even if an embayment was located on the opposite of the river, and (3) the internal computation in HEC-RAS of reservoir storage volumes based on the average distance of left and right overbank distances and the average cross sectional area of overbank flow. The third factor differs from the method used by TVA, who computed the left and right overbank volumes externally using post-processor output. According to TVA, these factors produced reservoir-storage volume errors that became large for the Cherokee and Douglas Reservoirs (TVA, 2016b; NRC, 2016b).

The licensee stated during the public meeting that after identification of the model errors, a bug report was submitted to USACE-HEC, which led to discussions between TVA and USACE-HEC on the cause of the model error and possible methods of resolution (NRC, 2016b; TVA, 2016b). According to TVA, the USACE-HEC indicated that the methods used by TVA to compute reservoir storage volume using post-processer output from HEC-RAS were not consistent with internal computation methods used in HEC-RAS (NRC, 2016b). As stated by TVA during the public meeting, the errors resulted in overestimation of storage volumes by 7.2 percent and 19.5 percent when the Douglas and Cherokee Reservoirs, respectively, were at the highest (PMF) water surface elevations (TVA, 2016b). The volumes of other reservoirs were also examined but were found to have errors of less than 2 percent (TVA, 2016b; NRC, 2016b). The licensee stated that since the Douglas and Cherokee Reservoirs are upstream of the BFN site, the WSEs at the site will change following resolution of the modeling errors.

As presented during the public meeting, TVA plans to revise reservoir geometry and other model errors by (1) using additional cross sections in Cherokee and Douglas Reservoirs, (2) calculating ineffective flow areas using equations consistent with HEC-RAS internal calculations, and (3) representing embayments using storage areas and extended floodplain cross sections (TVA, 2016b; NRC, 2016b). TVA also indicated they plan to update the precipitation depth for the PMF storm events using site-specific methodology.

3.3.11 Conclusion

Based on the available information provided in the BFN FHRR (TVA, 2015) and the NRC staff's audit of that information (NRC, 2015c), the staff confirmed the licensee's conclusion that the reevaluated hazard from flooding from streams and rivers was bounded by the CDB flood hazard. This indicates that additional assessments are not required per the guidance discussed in COMSECY-15-0019 (NRC, 2015b). The NRC staff anticipates that TVA will complete the PMF analysis by September 2017 following the resolution of the modeling errors, use of a site specific PMP, and completion of PMF analyses for the BFN site, as based on information provided during the April 4, 2016, public meeting (NRC, 2016b).

3.4 Failure of Dams and Onsite Water Control/Storage Structures

The licensee reported in its FHRR that the reevaluated flood hazard for failure of dams and onsite water control or storage structures is based on a stillwater-surface elevation of 560.9 ft (170.96 m) msl. Hydrologic dam failure was evaluated in Section 3.3 of this staff assessment as a component of the PMF analyses and is not discussed in this section. Among the scenarios of seismic and sunny-day dam failures, the largest flooding condition resulted from a scenario combining half of the 10^{-4} annual exceedance probability seismic ground motion coincident with a 500-year flood. The scenario resulted in a stillwater-surface elevation of 560.9 ft (170.96 m) msl. The scenario included the total and instantaneous seismic failure of Chickamauga Dam, the seismic failure of Nickajack Dam's powerhouse, and the hydrologic overtopping failure of Nickajack Dam's north embankment. Guntersville Dam does not fail in the controlling scenario. The scenario includes the assumption of the Watts Bar Dam failing at the maximum headwater level. Wind wave run-up at the BFN site was not calculated by the licensee for the seismic or sunny-day flood events because the stillwater elevations were bounded by the flood hazard results from streams and rivers. This flood-causing mechanism is not included in the licensee's CDB.

3.4.1 Seismic Dam Failure Scenarios

According to its FHRR, the licensee provided results of multiple-dam failure scenarios from a deaggregation analysis on the effect of the 10^{-4} and half of the 10^{-4} annual exceedance probability (AEP) seismic ground motion on concrete dams and earthen embankments. According to the NRC audit summary report (NRC, 2015c), the licensee examined the stability of dams under load conditions based on FERC and nuclear regulatory guidelines. Due the large number of possible combinations of dam failures, the licensee used a volume analysis to screen for possible dam failure combinations that could affect the BFN site (NRC, 2015c). The licensee evaluated these screened dams for seismic failures at the 10^{-4} AEP seismic ground motion associated with a 25-year flood and half of the 10^{-4} AEP seismic ground motion associated with a coincident 500-year flood (NRC, 2015c). Using the results of seismic dam failure analyses, the licensee retained dams as critical dams based on their potential flooding hazard to the BFN plant site (NRC, 2015c). The licensee examined the two seismic failure scenarios by considering the combinations of dam failures, seismic events, and flood frequencies (NRC, 2015c). In addition, the licensee examined a single seismic dam failure scenario combined with a 500-yr flood at Guntersville Dam and at Watts Bar Dam and found that they did not result in flooding of the BFN site. The licensee found the governing scenario to be a Douglas-centered seismic event with the half of the 10^{-4} annual exceedance probability seismic ground motion with a 500-year flood. The scenario included the following dam failures: Apalachia, Blue Ridge, Chatuge, Chickamauga, Fort Loudoun, Fort Patrick Henry, Melton Hill, Nickajack, Tellico, Watts Bar Dams, and the Watts Bar west Saddle Dam (TVA, 2015). All scenarios also included failures of the following dams which have had no stability analyses conducted on them: John Sevier, Wilbur, Cheoah, Calderwood, Chilhowee, Mission, Ocoee 1, Ocoee 2, and Ocoee 3 dams.

The staff notes that reviews of individual dam stability or the deaggregation methodology were not made for the BFN flood hazard reevaluation. The staff reviewed the licensee's screening procedure and methodology to identify critical dams for seismic failure and found them to be adequate since the procedures and methodology used were consistent with the Federal Emergency Management Agency (FEMA) National Dam Safety program (FEMA, 2005) for dam safety evaluations, and followed JLD-ISG-2013-01 (NRC, 2013b) and NRC NUREG/CR-7046 (NRC, 2011d) for nuclear power plant safety. The staff reviewed the licensee's flood hazard scenarios for the 10^{-4} annual exceedance probability seismic ground motion associated with 25-year and half of the 10^{-4} annual exceedance probability seismic ground motion associated with 500-year floods and found the selection of the controlling seismic-dam failure scenario appropriate.

3.4.2 Seismic Inflows

For seismic inflows, the licensee included inflows of 25-year and 500-year floods, as well as inflows from assumed failures of dam identified from the NID database.

3.4.2.1 Inflows of 25-year and 500-year Floods for Seismic Dam Failures

As stated in Section 3.4.1 of this staff assessment, the licensee used either 25-year or 500-year flood flows in the seismic dam failure analyses. As stated in the NRC audit report (NRC, 2015c), the licensee computed the inflow hydrographs using a scaled hydrograph method using precipitation from NOAA Atlas 14 (NOAA, 2004). Because the NOAA Atlas 14 (NOAA, 2004) precipitation is for local point rainfall and is limited up to 400 mi^2, the licensee's method called for adjusting it to provide areal rainfall for use in computing surface runoff (NRC, 2015c). The licensee started with an analysis of flood frequency for stream gages using the historical stream flow-volumes for various flow-durations (1 day through 5 days) and determined the 25-year and 500-year volume from aggregated inflows (NRC, 2015c). Then the licensee computed prototype hydrographs for individual sub-basins using the NOAA point rainfall applied uniformly over the whole watershed (NRC, 2015c). To obtain the inflow hydrographs for use in the seismic analyses, the licensee scaled the prototype inflow hydrographs to match the aggregated stream flow volumes of the 25-year and 500-year floods associated for stream gage data (NRC, 2015c). As determined by the licensee's seismic flooding analyses (see Section 3.4.3 of this staff assessment), the inflows for the governing scenario were from the 500-year flood for the June period (TVA, 2015).

The staff reviewed the scaled hydrograph method and found that the approach to estimate the 25-yr and 500-year flood inflows by adjusting the ordinates of a prototype hydrograph was appropriate because the hydrograph adjustment was derived from flood frequency analysis of the historical stream gage data and reflected the hydrological characteristics of the watershed.

3.4.2.2 NID Inflows for Seismic Dam Failures

In addition to the 25-year or 500-year flood flows discussed in Section 3.4.2.1 of this staff assessment, the licensee included the inflows from upstream dam failures of the approximately 1,100 dams listed in the NID database (TVA, 2015). For the PMF analyses (see Section 3.3.3 of this staff assessment), the licensee accounted for the upstream reservoir volumes of the many dams included in the NID database, and the licensee accounted for the volumes in the seismic dam failure analyses. As stated in the NRC audit report (NRC, 2015c), the licensee converted those volumes into aggregated triangular hydrographs that were added to the 25-year and 500-year floods as inflows in the HEC-RAS model. The licensee grouped the reservoirs identified from the NID database to each upstream sub-basin. The licensee developed the minimum travel time and maximum drawdown time, which determined the duration of the hydrograph, from individual dams of each group (NRC, 2015c). The peak flow and time-of-peak were developed by the licensee for each group of reservoirs identified from the NID database (NRC, 2015c).

The staff reviewed the licensee's methodologies and procedures of converting reservoir volumes identified from the NID database into aggregated inflow hydrographs as dam breach flow hydrographs. Staff found the methodologies and procedures applied by the licensee to be appropriate and based on current engineering practice.

3.4.3 Seismic Dam Failure Maximum Flood Elevation

To evaluate flooding at BFN due to either single or multiple seismic dam failure, the licensee used the HEC-RAS hydraulic model developed for the PMF analysis of streams and rivers (see Section 3.3 of this staff assessment) with appropriate modifications to inputs to account for seismic dam failures (NRC, 2015c). According to the NRC audit report (NRC, 2015c), the inputs to HEC-RAS included the seismic dam failure combinations (see Section 3.4.1 of this staff assessment) for the 25-year and 500-year floods, with the combinations input to HEC-RAS via unsteady flow rules (NRC, 2015c). The primary hydrologic inflows were the 25-year and 500-year flood hydrographs (see Section 3.4.2.1 of this staff assessment). Additional inflows were included from the assumed seismic failures of dams identified from the NID database (see Section 3.4.2.2 of this staff assessment) (NRC, 2015c). To provide conditions when reservoir elevations would be at their highest, reservoir volumes were set in HEC-RAS to those typical of June as starting conditions for the flooding analyses (NRC, 2015c). For the controlling seismic scenario (with the 500-yr flood as one of the inflows), the HEC-RAS model resulted in a flood peak discharge of 678,817 ft^3/s (19,222 m^3/s) and a maximum flood elevation of 560.9 ft (170.96 m) msl at the BFN site (TVA, 2015). The controlling seismic dam failure scenario included the failure of Chickamauga Dam and component failures of Nickajack Dam, but it did not include failure of Guntersville Dam (NRC, 2015c). Seismic dam failure is currently not included in the CDB of the BFN site (TVA, 2015).

The licensee also completed an analysis of a single seismic dam failure of Guntersville Dam and of Watts Bar Dam combined with a 500-yr flood and found in both cases the results were bounded by the multiple dam failure scenario (NRC, 2015c). The single seismic failure analyses included hydrologic failures of dams that have had no stability analysis (listed in Section 3.4.1 of this staff assessment) (NRC, 2015c).

In the sections covering the inputs to the seismic dam failure (see Sections 3.4.1 and 3.4.2 of this staff assessment), the staff had found the methods and results of those input calculations appropriate and reasonable. The staff reviewed the HEC-RAS model and found the input data and model setup for dam breach flows to be acceptable. The model setup was based on calibrations with historical stream gage data and adjustments of current updated stream sections (see Section 3.3.5 of this staff assessment).

During the NRC staff's review of the seismic dam failure for the governing seismic scenario, it was noted that most of the seismic dam failures were assumed total and instantaneous. The staff noted that some of the main stem dams upstream of BFN were also assumed to fail, but their failures were not necessarily total, although they were considered to be instantaneous. Inclusion of these main stem dam failures is considered by staff to be reasonable.

The staff notes that even with the failures of main stem dams upstream of BFN, the maximum flood elevation of 560.9 ft (170.96 m) msl was below the plant grade elevation of 565.0 ft (172.21 m) msl. Because the controlling seismically-induced dam failure scenario included the combination of dam failures based on the greatest cumulative reservoir volume, a 500-yr flood, and additional inflows from failures of dams not controlled by the licensee, the staff considers the results reasonable.

3.4.4 Sunny-Day Dam Failure

The screening analyses for sunny-day dam failures was based on NRC guidance (2013b) using a simplified reservoir-storage-volume method, to identify either single dam failure or multiple dam failures that impact the downstream nuclear power plants (TVA, 2015). Seven dams were identified whose failure could potentially flood the BFN site. These were as follows: Cherokee, Fontana, Guntersville, Norris, Nottely, South Holston, and Watauga Dams (see Figure 3.1-4 for their relative location). The licensee eliminated three of these dams from sunny-day failure analyses because they were bounded by other analyzed scenarios. The first two dams, the

Watauga and South Holston Dams, are on the same river system (Figure 3.1-4), have similar storage characteristics (NRC, 2015c), and would be expected to produce similar results at the BFN site following a sunny-day failure of one or the other dam. Because the results from the Watauga Dam project-specific PMF bounded the maximum WSE from a sunny-day failure of South Holston Dam (and would be expected to bound a sunny-day failure of Watauga Dam), the licensee eliminated the sunny-day failures for both Watauga and South Holston Dams (NRC, 2015c). The third dam eliminated from a sunny-day dam failure was Guntersville Dam, because its sunny-day failure scenario is bounded by the single seismic failure (TVA, 2015) (see Section 3.4.3 of this staff assessment).

The remaining TVA-owned dams, Cherokee, Fontana, Norris, and Nottely Dams, were analyzed for sunny-day dam failure. For these remaining dams, the maximum WSE at BFN was 557.5 ft (169.93 m) msl from a Fontana Dam failure (TVA, 2015). The licensee concluded that none of these sunny-day dam failure scenarios could impact the BFN site because the maximum WSE is below the plant grade elevation of 565.0 ft (172.21 m) msl (TVA, 2015; NRC, 2015c).

The staff reviewed the licensee's analyses of sunny-day failure scenarios and agrees with the licensee's conclusion that all postulated sunny-day failures would not flood the BFN site. The staff also agrees with the licensee's conclusion that a sunny-day failure of Guntersville Dam would be bounded by the single seismically-induced dam failure of Guntersville Dam as well as by the controlling seismic dam failure scenario (see Section 3.4.3 of this staff assessment) because those scenarios also include larger river discharges from either a 25-year or a 500-year flood event.

3.4.5 Model Application Error Identification and the Effect on Dam Failure Analyses

As noted in Sections 1.0 and 3.3.11 of this staff assessment, on April 4, 2016, TVA informed NRC in a public meeting that computational errors had been identified related to the reservoir storage volumes used in the application of the HEC-RAS model to the BFN site (TVA, 2016b; NRC, 2016b). The staff noted in Section 3.4.3 of this staff assessment, that for the FHRR analyses, the HEC-RAS model used for the flood hazard analysis of streams and rivers was also used for the flood hazard analyses of dam failure. As indicated in Section 3.4.1 of this staff assessment, Douglas and Cherokee Dams are not included in the list of dams analyzed and are not expected to fail in the controlling seismic scenario. However, the controlling seismic dam-failure case could be revised, as indicated by TVA in the public meeting (TVA, 2016b). The NRC expects that resolution of the model errors will not change the controlling flood-hazard at the BFN site, which is based on flooding from streams and rivers and includes hydrologic dam failure.

3.4.6 Conclusion

Based on the available information provided in TVA's 50.54(f) response (TVA, 2015, NRC 2015c), the NRC staff confirmed the licensee's conclusion that the reevaluated flood hazard for failure of dams and onsite water control or storage structures is bounded by the CDB flood hazard. After the model errors (noted in Section 3.4.5 of this staff assessment) are resolved by the licensee, the NRC staff expects that the revised modeling result from the seismic dam failure analysis will remain bounded as described in the FHRR.

3.5 Storm Surge

In the BFN FHRR (TVA, 2015), the licensee reported that the reevaluated hazard, including associated effects, for storm surge does not inundate the plant site, and did not report a probable maximum flood elevation for storm surge alone. This flood causing mechanism is not discussed in the licensee's CDB.

The licensee reported that the BFN site is not located on a large or open water body and the plant grade is approximately 9 ft (2.74 m) above the normal maximum pool levels of the Wheeler Reservoir. The Wheeler Reservoir level during non-flood conditions would not exceed approximately 556.0 ft (169.47 m) msl at the plant (TVA, 2015).

The staff reviewed the licensee's FHRR and agrees that flooding as a result of storm surge would not be a mechanism of concern for the BFN site. The staff confirmed the licensee's conclusion that the reevaluated hazard for flooding from storm surge is bounded by the current design basis.

3.6 Seiche

In the BFN FHRR (TVA, 2015), the licensee reported that the reevaluated hazard, including associated effects, for seiche does not inundate the plant site, but did not report a probable maximum flood elevation for seiche alone. This flood-causing mechanism is not discussed in the licensee's CDB.

The licensee reported that the BFN site is not located on a large or open water body and the plant grade is approximately 9 ft (2.74 m) above the normal maximum pool levels of the Wheeler Reservoir (TVA, 2015). The Wheeler Reservoir level during non-flood conditions would not exceed approximately 556.0ft (169.47 m) msl at the plant.

Additionally, the licensee considered a seismically-induced seiche and a seiche generated from landslides. The licensee reported that the largest seismically-induced seiche in lakes and reservoirs in Tennessee and Kentucky were less than 1 foot in amplitude. The licensee reviewed landslide hazards information relevant to the location of the BFN site from the United States Geological Survey (USGS). The licensee stated that the landslide activity reported by the USGS was considered moderate with a low incidence.

The staff reviewed the BFN FHRR and agrees that flooding from a seiche would not be a mechanism of concern for the site. The staff confirmed the licensee's conclusion that the reevaluated hazard for flooding from seiche is bounded by the current design basis.

3.7 Tsunami

In the BFN FHRR (TVA, 2015), the licensee reported that the reevaluated hazard, including associated effects, for tsunami does not inundate the plant site, but did not report a probable maximum flood elevation for tsunami alone. This flood-causing mechanism is not discussed in the licensee's CDB. The licensee reported in its FHRR that tsunami effects are not a safety-related concern due to the site's inland location. The BFN site is approximately 400 mi (644 km) inland from the Atlantic coast, 470 mi (756 km) inland from the Great Lakes, and 1,300 river miles (2,092 km) inland from the Gulf of Mexico.

The licensee considered seismically-induced hill-slope failure as a source of tsunami-like wave (TVA, 2015). Based on a stability review of the local geology near the BFN site, the licensee determined that hill-slope failure was not a potential source of tsunami-like waves.

The staff reviewed the location of the site in relation to the Atlantic Coast, Great Lakes, and the Gulf of Mexico, as well as the licensee's findings in the BFN FHRR and agrees that flooding as a result of tsunami would not be a mechanism of concern for the site. The staff confirmed the licensee's conclusion that the reevaluated hazard for flooding from tsunami is bounded by the current design basis.

3.8 Ice-Induced Flooding

In the BFN FHRR (TVA, 2015), the licensee reported that the reevaluated hazard, including associated effects, for ice-induced flooding does not inundate the plant site, but did not report a probable maximum flood elevation (TVA, 2015). This flood-causing mechanism is not discussed in the licensee's CDB. The licensee noted in the BFN FHRR that there have not been any recorded incidences of ice near the plant site or ice-induced flooding. The licensee noted that ice has formed along the shore and across protected inlets, but does not form ice jams on the main river reservoirs.

The staff independently searched the USACE Cold Regions Research and Engineering Laboratory (CRREL) Ice Jam Database (USACE, n.d-a) for current and historical ice jams near BFN site and found no current or historical ice jams in the vicinity. The staff reviewed the licensee's findings in the BFN FHRR and confirmed the licensee's conclusion that the reevaluated hazard for ice-induced flooding of the site is bounded by the CDB flood hazard.

3.9 Channel Migrations or Diversions

In the BFN FHRR (TVA, 2015), the licensee reported that the reevaluated hazard, including associated effects, for channel migrations or diversions does not inundate the plant site, but did not report a probable maximum flood elevation (TVA, 2015). This flood-causing mechanism is not discussed in the licensee's CDB. The licensee stated in its FHRR that the reservoir in the vicinity of BFN has been stable for many years and there are no indications of the potential for migration or diversion.

The staff reviewed basin topography and noted there was no evidence of channel migration or diversion along nearby streams or tributaries that could threaten the site. Accordingly, the staff agrees that channel diversions or migrations is not a flood-causing mechanism of concern for the BFN site. The staff confirmed the licensee's conclusion that the reevaluated hazard for flooding from channel migrations or diversions is bounded by the CDB flood hazard.

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

4.1 Reevaluated Flood Height for Hazards Not Bounded by the CDB

Section 3 of this staff assessment documents staff review of the licensee's flood hazard water height results. Table 4.1-1 contains the maximum results, including waves and runup, for flood mechanisms not bounded by the CDB, which is provided in Table 3.1.1. The NRC staff agrees with the licensee's conclusion that LIP is the only hazard mechanism not bounded by the CDB. Consistent with the process and guidance discussed in COMSECY-15-0019 (NRC, 2015b), NRC staff anticipates the licensee will submit a focused evaluation for LIP and associated site drainage.

4.2 Flood Event Duration for Hazards Not Bounded by the CDB

The staff reviewed information provided in TVA's 50.54(f) response (TVA, 2015, NRC 2015c) regarding the flood event duration (FED) parameters needed to perform the additional assessments of plant response for flood hazards not bounded by the CDB. The FED parameters for the flood-causing mechanisms identified in Section 4.1 of this staff assessment are summarized in Table 4.2-1.

The licensee did not provide FED parameters for LIP. The licensee is expected to develop flood event duration parameters to conduct the MSA as discussed in NEI 12-06 (revision 2), Appendix G (NEI, 2015), and outlined in COMSECY-15-0019 (NRC, 2015b).

4.3 Associated Effects for Hazards Not Bounded by the CDB

The staff reviewed information provided in TVA's 50.54(f) response (TVA, 2015, NRC 2015c) regarding associated effects (AE) parameters needed to perform future additional assessments of plant response for flood hazards not bounded by the CDB. The AE parameters directly related with maximum total water height, such as waves and runup, are provided in Table 4.1-1 of this staff assessment. The AE parameters not directly associated with total water height are listed in Table 4.3-1. The AE parameters not submitted as part of the FHRR are noted as "not provided" in this table. The NRC staff will review these AE parameters as part of future additional assessments of plant response, if applicable to the assessment and hazard mechanism.

4.4 Conclusion

Based upon the preceding analysis, NRC staff confirmed that the reevaluated flood hazard information defined in the Section 4.1 is appropriate input to the additional assessments of plant response as described in the 50.54(f) letter and COMSECY-15-0019, "Mitigating Strategies and Flooding Hazard Reevaluation Action Plan" (NRC, 2015b).

The licensee is expected to develop flood event duration parameters and applicable flood associated effects to conduct the MSA, as discussed in the NEI 12-06 (Revision 2), Appendix G (NEI, 2015). The staff will evaluate the flood event duration parameters (including warning time and period of inundation) and flood-related associated effects marked as "not provided" in these tables during its review of the MSA.

5.0 CONCLUSION

The NRC staff has reviewed the information provided for the reevaluated flood-causing mechanisms of Browns Ferry, Units 1, 2, and 3. Based on the review of the above available information provided in TVA's 50.54(f) response (TVA, 2015; NRC, 2015c), the staff concludes that the licensee conducted the hazard reevaluation using present-day methodologies and regulatory guidance used by the NRC staff in connection with ESP and COL reviews.

Based upon the preceding analysis, the NRC staff confirmed that the licensee responded appropriately to Enclosure 2, Required Response 2, of the 50.54(f) letter, dated March 12, 2012. In reaching this determination, staff confirmed the licensee's conclusions that (a) the reevaluated flood hazard result for local intense precipitation is not bounded by the current design-basis flood hazard, (b) an additional assessment of plant response will be performed for the local intense precipitation, and (c) the reevaluated flood-causing mechanism information is appropriate input to the additional assessment of plant response as described in the 50.54(f) letter and COMSECY-15-0019, "Mitigating Strategies and Flooding Hazard Reevaluation Action Plan" (NRC, 2015b).

Based on the April 4, 2016, public meeting, the staff found that TVA planned to correct storage volume errors and to adopt an updated PMP for flood hazard evaluation (TVA, 2016b), NRC, 2016b), which will be reflected in the focused evaluation for the streams and rivers flood-causing-mechanism. According to the information provided by TVA in the public meeting, NRC staff anticipates that the correction of the reservoir storage volume errors and the adoption of an updated PMP would not increase the flood elevations as shown in the current FHRR.

6.0 REFERENCES

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

Flood-Causing Mechanism	SRP Section(s) and JLD-ISG
Local Intense Precipitation and Associated Drainage	SRP 2.4.2 SRP 2.4.3
Streams and Rivers	SRP 2.4.2 SRP 2.4.3
Failure of Dams and Onsite Water Control/Storage Structures	SRP 2.4.4 JLD-ISG-2013-01
Storm Surge	SRP 2.4.5 JLD-ISG-2012-06
Seiche	SRP 2.4.5 JLD-ISG-2012-06
Tsunami	SRP 2.4.6 JLD-ISG-2012-06
Ice-Induced	SRP 2.4.7
Channel Migrations or Diversions	SRP 2.4.9

SRP is the Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition (NRC, 2007)

JLD-ISG-2012-06 is the "Guidance for Performing a Tsunami, Surge, or Seiche Hazard Assessment" (NRC, 2013a)

JLD-ISG-2013-01 is the "Guidance for Assessment of Flooding Hazards Due to Dam Failure" (NRC, 2013b)

Table 3.0-1. Summary of Controlling Flood-Causing Mechanisms

Reevaluated Flood-Causing Mechanisms and Associated Effects that May Exceed the Powerblock Elevation (565.0 ft (172.21 m))[1]	Elevation, msl
Local Intense Precipitation and Associated Drainage	
lower plant area	566.6 ft (172.70 m)
Switchyard Drainage Area	578.2 ft (176.24 m)

[1] Flood height and associated effects are as defined in JLD-ISG-2012-05 (NRC, 2012c)

Table 3.1-1. Current Design-Basis Flood Hazards

Mechanism	Stillwater Elevation	Waves/ Runup	Design Basis Hazard Elevation	Reference
Local Intense Precipitation				
east switchyard	578.0 ft msl	Minimal	578.0 ft msl	FHRR Section 3.4.1
lower plant area	565.0 ft msl	Minimal	565.0 ft msl	FHRR Section 3.4.1
west Channel	592.0 ft msl	Minimal	592.0 ft msl	FHRR Table 11-1
Streams and Rivers	572.5 ft msl	5.5 ft	578.0 ft msl	FHRR Section 3.4.2 FHRR Section 3.4.8.1
Failure of Dams and Onsite Water Control/Storage Structures	Not included in DB	Not included in DB	Not included in DB	FHRR Sections 3.4.3
Storm Surge	Not included in DB	Not included in DB	Not included in DB	FHRR Section 3.4.4
Seiche	Not included in DB	Not included in DB	Not included in DB	FHRR Section 3.4.4
Tsunami	Not included in DB	Not included in DB	Not included in DB	FHRR Section 3.4.5
Ice-Induced Flooding	Not included in DB	Not included in DB	Not included in DB	FHRR Section 3.4.6
channel Migrations/Diversions	Not included in DB	Not included in DB	Not included in DB	FHRR Section 3.4.7

Note: Reported values are rounded to the nearest one-tenth of a foot.

Table 3.3-1. Stillwater and Wind Wave Results from the Analysis of PMF for Streams and Rivers Based on 7,980 mi^2 (20,668 km^2) PMP Centered at Bulls Gap, TN. Derived from FHRR Table 9-7.

Location	Stillwater PMF Elevation, msl	Total Wind Wave Height (Wave Runup + Wind Setup)	Final PMF Elevation, msl
Intake	572.1 ft (174.38 m)	4.6 ft (1.40 m)	576.7 ft (175.66 m)[1]
diesel generator 1 & 2 building	572.1 ft (174.38 m)	5.1 ft (1.55 m)	577.2 ft (175.93 m)
diesel generator 3 building	572.1 ft (174.38 m)	5.1 ft (1.55 m)	577.2 ft (175.93 m)
radwaste building	572.1 ft (174.38 m)	5.1 ft (1.55 m)	577.2 ft (175.93 m)
reactor building	572.1 ft (174.38 m)	5.1 ft (1.55 m)	577.2 ft (175.93 m)

[1] FHRR Table 9-7 reports a value of 576.3 ft. Staff provide the correct sum of stillwater elevation and total wind wave height.

Table 4.1-1. Reevaluated Hazard Elevations for Flood-Causing Mechanisms Not Bounded

Mechanism	Stillwater Elevation	Waves/ Runup	Reevaluated Hazard Elevation	Reference
Local Intense Precipitation				
Switchyard	578.2 ft msl	Minimal	578.2 ft msl	FHRR Section 9.1.2
Lower plant area	566.6 ft msl	Minimal	566.6 ft msl	FHRR Section 9.1.2

Note 1: Reevaluated hazard mechanisms bounded by the current design basis (see Table 1) are not included in this table.

Note 2: Reported values are rounded to the nearest one-tenth of a foot.

by the CDB

Table 4.2-1. Flood Event Duration Parameters for Flood-Causing Mechanisms Not

Flood-Causing Mechanism	Time Available for Preparation for Flood Event	Duration of Inundation of Site	Time for Water to Recede from Site
Local Intense Precipitation and Associated Drainage	Not provided [1]	Not provided	Not provided

[1] The staff will evaluate the flood event duration parameters that were not provided in the FHRR as part of future additional assessment.

Bounded by the Plant's CDB

Table 4.3-1. Associated Effects Parameters not Directly Associated with Total Water Height for Flood-Causing Mechanisms not Bounded by the CDB

	Flooding Mechanism
Associated Effects Factor	**Local Intense Precipitation**
Hydrodynamic loading at plant grade	Not provided[1]
Debris loading at plant grade	Not provided
Sediment loading at plant grade	See NRC2015c
Sediment deposition and erosion	See NRC2015c
Concurrent conditions, including adverse weather	Not provided
Other pertinent factors (e.g., waterborne projectiles)	Not provided

[1] The staff will evaluate associated effects parameters that were not provided in the FHRR as part of future additional assessments.

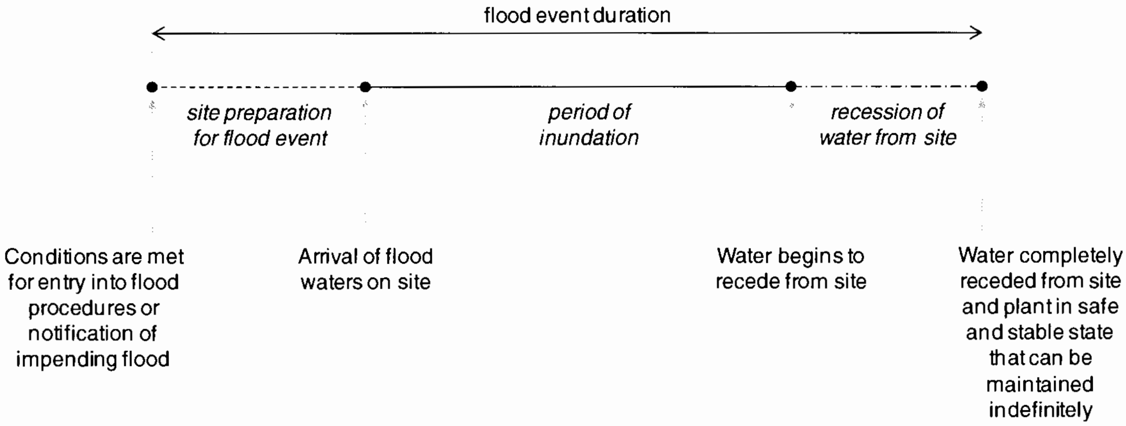

Figure 2.2-1. Flood Event Duration (NRC, 2012c)

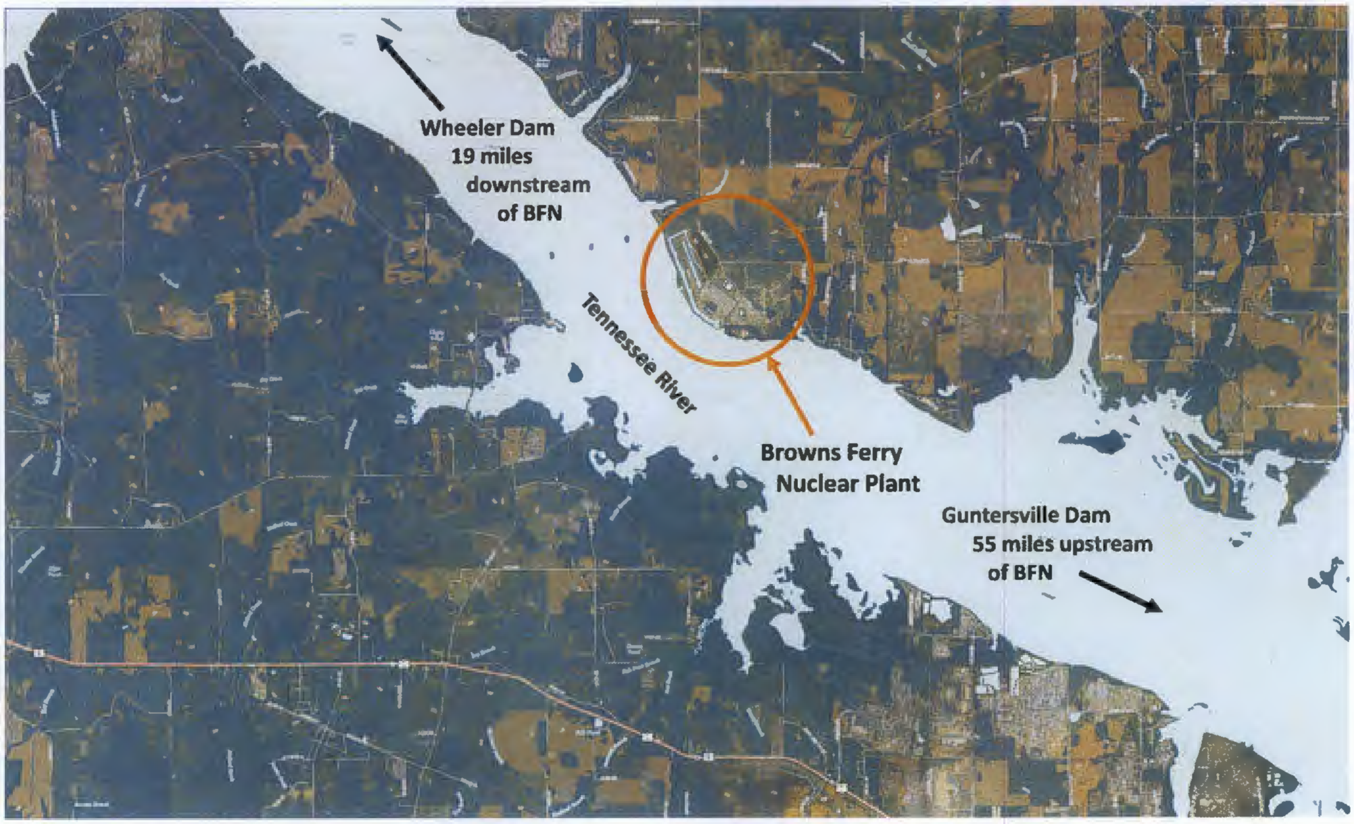

Figure 3.1-1. Location of Browns Ferry Nuclear Plant.
(Derived from Hillsboro, AL 2011 and Jones Crossroads, AL 2011 7.5 minute quadrangle maps (USGS, 2015a and USGS, 2015b)).

Figure 3.1-2. Browns Ferry Nuclear Plant Site Layout (Derived from FHRR Figure 3-3 (TVA, 2015))

Figure 3.1-3. Browns Ferry Nuclear Plant Site Topography (Derived from FHRR Figure 3-4 (TVA, 2015))

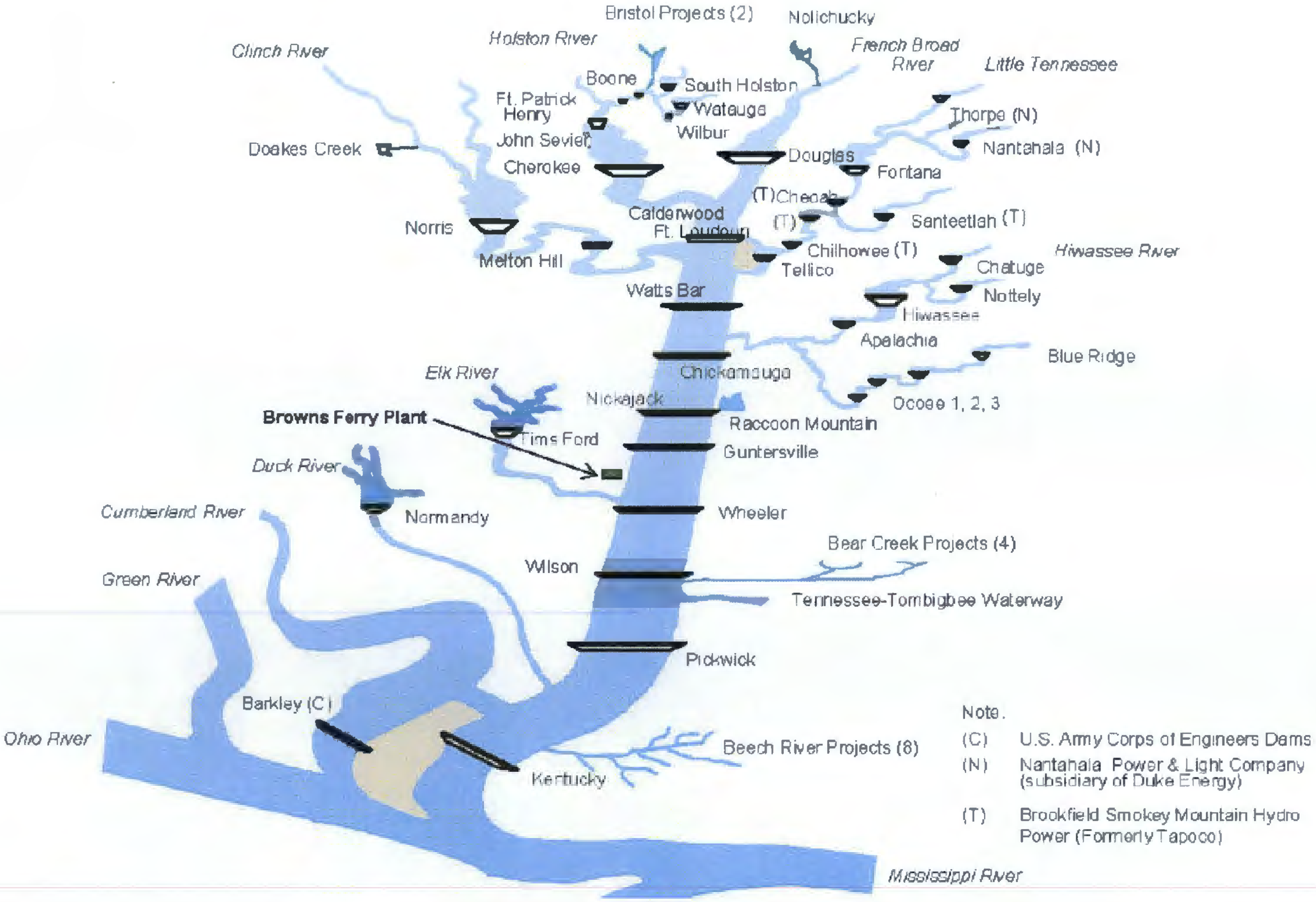

Figure 3.1-4 TVA River System Schematic (Derived from FHRR Figure 2-1 (TVA, 2015))

Figure 3.1-5. Topography and Features at Douglas Dam
(Derived from Douglas Dam, TN, 7.5 minute quadrangle map (USGS, 2015b).

Figure 3.1-6. Locations of west Saddle Dam, Yellow Creek and its Confluence, Watts Bar Nuclear Plant, and Watts Bar Dam.

The blue arrows indicate the approximate flow paths of flood waters around the plant during the PMF, While the relative sizes are indicative of the relative discharge. (Derived from Decatur, TN, 7.5 minute quadrangle map (USGS, 2015c).

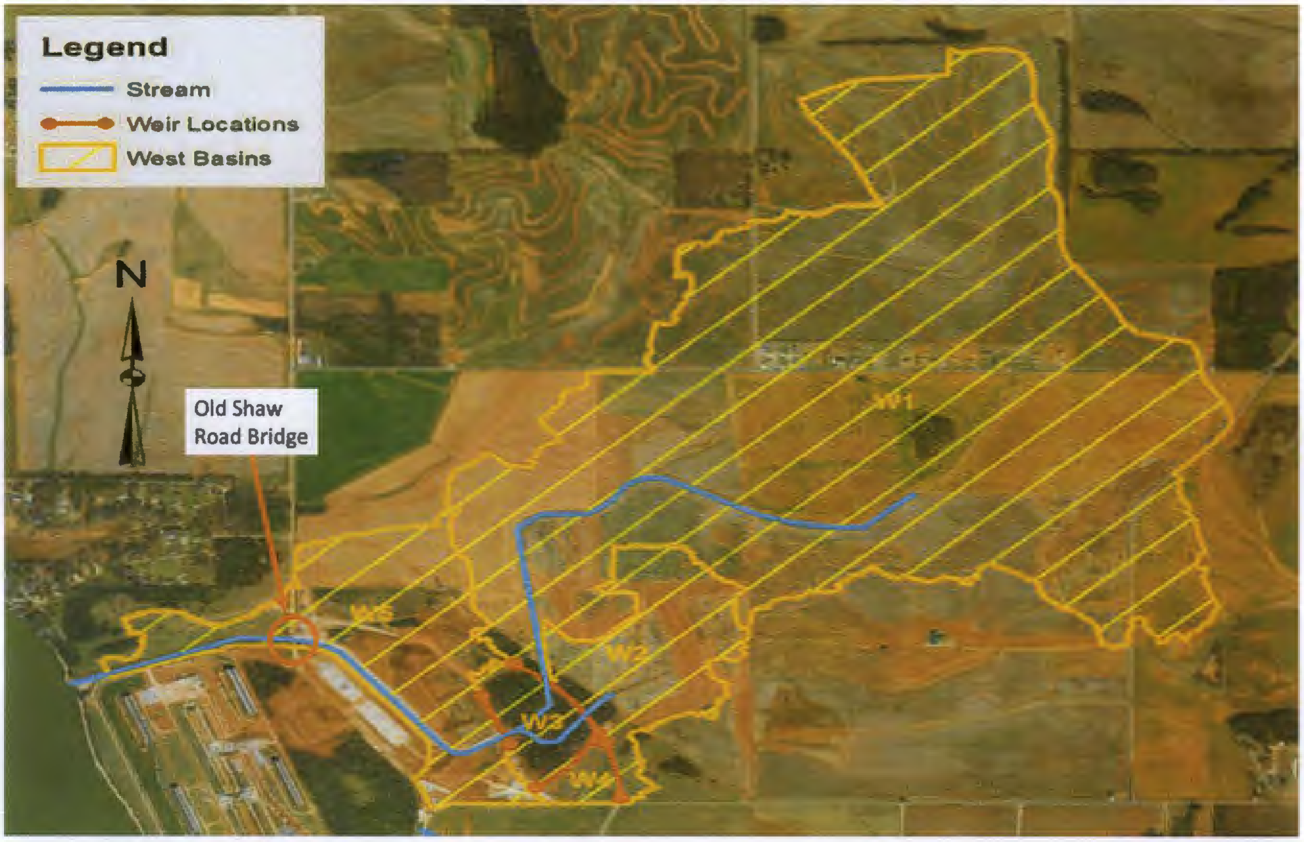

Figure 3.2-1 west channel Drainage Areas Used for LIP Site Drainage Analyses (Derived from FHRR Figure 7.3 (TVA, 2015))

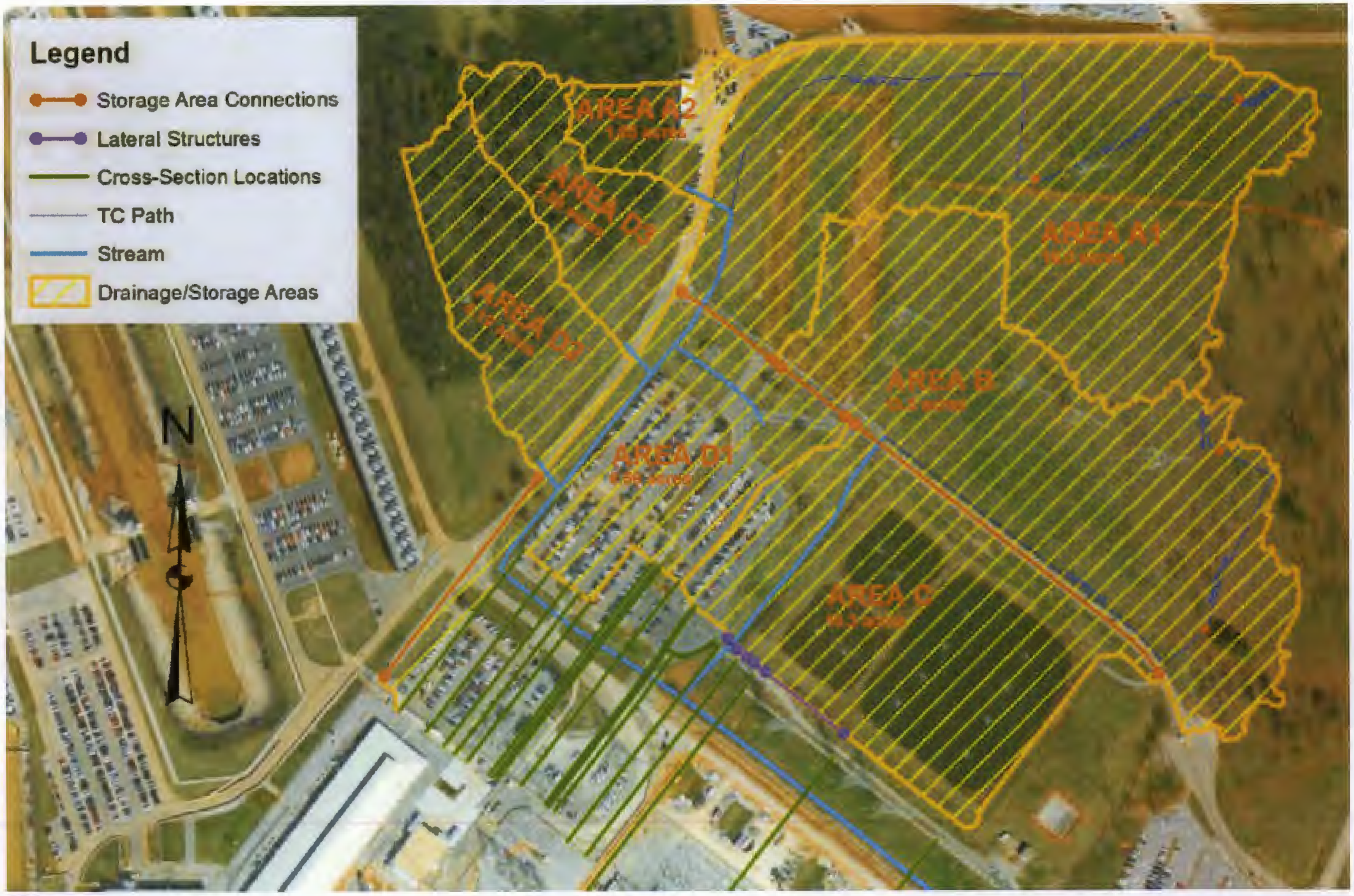

Figure 3.2-2 east Switchyard Drainage Areas Used for LIP Site Drainage Analyses (Derived from FHRR Figure 7.4 (TVA, 2015))

Figure 3.2-3 Lower Plant Drainage Areas Used for LIP Site Drainage Analyses (Derived from FHRR Figure 7.5 (TVA, 2015))

Figure 3.2-4 Layout of HEC-RAS Cross Sections for the west channel Site Drainage Analyses (NRC, 2015c)

Figure 3.2-5 Layout of HEC-RAS Cross Sections and Storage Areas for the east Switchyard channel Site Drainage Analyses (NRC, 2015c)

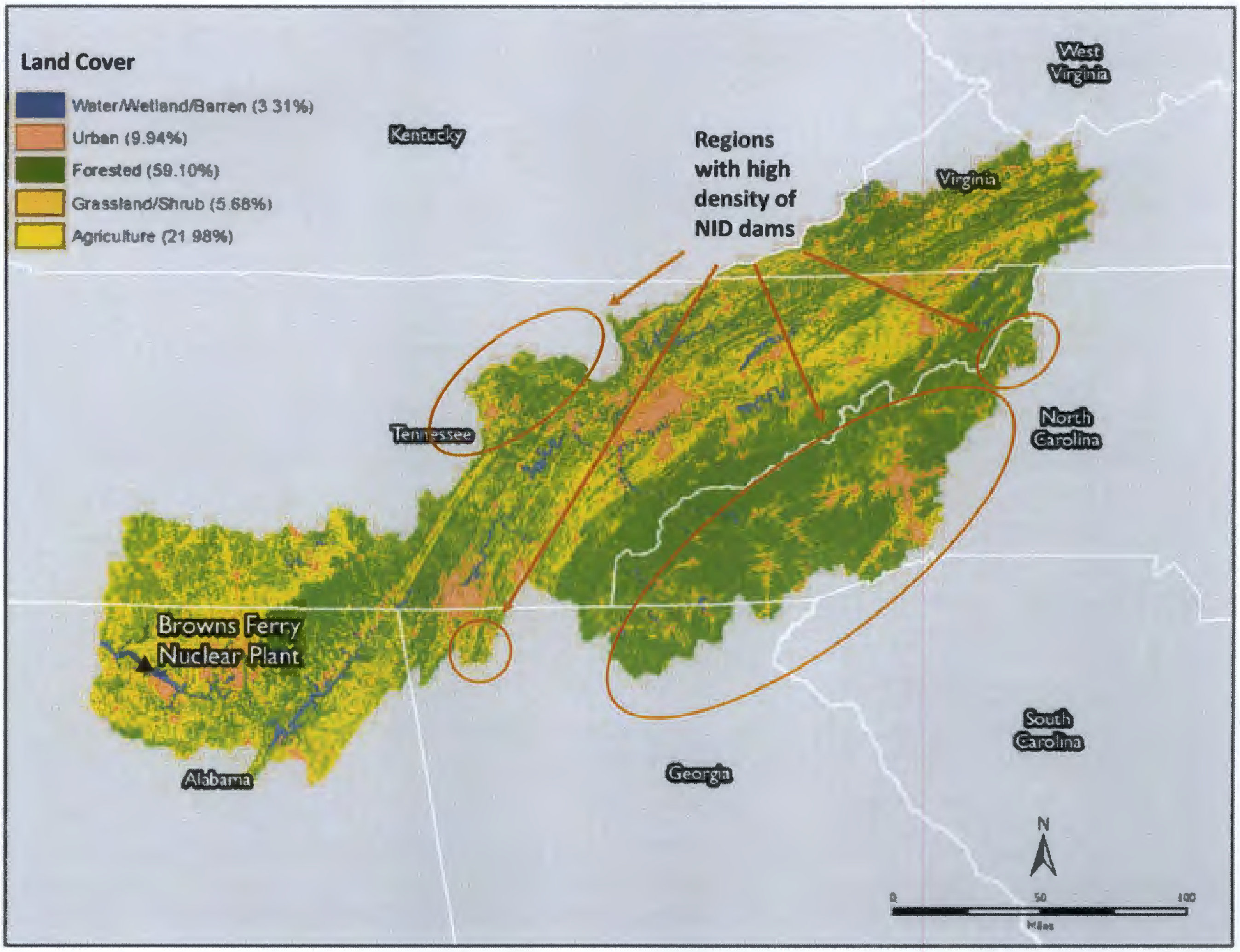

Figure 3.3-1. Regions of the Tennessee River Watershed Upstream of Wheeler Dam with High Density of Dams from the NID Database (based on FHRR Figure 4-1 (TVA, 2015))

If you have any questions, please contact me at (301) 415-3809 or e-mail at Juan.Uribe@nrc.gov.

Sincerely,

/RA/

Juan Uribe, Project Manager
Hazards Management Branch
Japan Lessons-Learned Division
Office of Nuclear reactor Regulation

Docket Nos. 50-259, 50-260, and 50-296

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