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

April 3, 2017

Mr. Thomas A. Vehec
Site Vice President
NextEra Energy
Duane Arnold Energy Center
3277 DAEC Road
Palo, IA 52324-9785

SUBJECT: DUANE ARNOLD ENERGY CENTER – STAFF ASSESSMENT OF RESPONSE TO 10 CFR 50.54(f) INFORMATION REQUEST – FLOOD-CAUSING MECHANISM REEVALUATION (CAC NO. MF3686)

Dear Mr. Vehec:

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 licensees to reevaluate flood-causing mechanisms using present-day methodologies and guidance. By letter dated March 10, 2014 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML14072A019), NextEra Energy Duane Arnold, LCC (NextEra, the licensee) responded to this request for Duane Arnold Energy Center (Duane Arnold).

By letter dated March 31, 2016 (ADAMS Accession No. ML16084A767), the NRC staff sent the licensee a summary of its review of Duane Arnold'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, because local intense precipitation and streams and rivers at Duane Arnold are not bounded by the plant's current design basis, additional assessments of the flood hazard mechanisms are necessary.

The NRC staff has no additional information needs at this time with respect to Exelon's 50.54(f) response related to flooding.

This staff assessment closes out the NRC's efforts associated with CAC Nos. MF3686.

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

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

Sincerely,

Lauren Kate Gibson

Lauren K. Gibson, Project Manager
Hazards Management Branch
Japan Lessons-Learned Division
Office of Nuclear Reactor Regulation

Docket No. 50-331

Enclosures:

1. Staff Assessment of Flood Hazard Reevaluation Report (Non-public, security-related information)
2. Staff Assessment of Flood Hazard Reevaluation Report (public)

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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

DUANE ARNOLD ENERGY CENTER

DOCKET NO. 50-331

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) (hereafter referred to as the "50.54(f) letter"). The request was issued in connection with implementing lessons learned from the 2011 accident at the Fukushima Dai-ichi nuclear power plant as documented in the Near-Term Task Force (NTTF) report (NRC, 2011a). Recommendation 2.1 in that document recommended that the NRC 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 SECY-11-0124 (NRC, 2011c) and SECY-11-0137 (NRC, 2011d), directed the NRC staff to issue requests for information to licensees pursuant to 10 CFR 50.54(f) to address this recommendation.

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

By letter dated March 10, 2014 (NextEra, 2014a), NextEra Energy Duane Arnold, LLC (NextEra, licensee) provided its FHRR for the Duane Arnold Energy Center (Duane Arnold). The NRC staff conducted an audit with the licensee between July 2015 and March 2016. The licensee provided responses to information requests made by staff during the audit, and the licensee provided responses by letter dated August 12, 2016 (Next Era, 2016c). The NRC staff issued an audit summary report summarizing additional information obtained during this audit (NRC, 2016d).

On March 31, 2016, the NRC issued an interim staff response (ISR) letter to the licensee (NRC, 2016b). The purpose of the ISR letter is to provide the flood hazard information suitable for the assessment of mitigating strategies developed in response to Order EA-12-049 (NRC, 2012b) and the additional assessments associated with Recommendation 2.1-Flooding. The ISR letter also made reference to this staff assessment, which documents NRC 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, the reevaluated flood hazard results for the local intense precipitation (LIP) and streams and rivers flood-causing mechanisms are not bounded by the plant's current design basis (CDB). Consistent with the 50.54(f) letter and amended by the process outlined in COMSECY-15-0019 (NRC, 2015b), Japan Lessons-Learned Division (JLD)

Interim Staff Guidance (ISG) JLD-ISG-2012-01, Revision 1 (NRC, 2016b), and JLD-ISG-2016-01, Revision 0 (NRC, 2016c), the staff anticipates that for LIP, the licensee will perform and document a focused evaluation to assess the impact of the LIP hazard on the site and evaluate and implement any necessary programmatic, procedural, or plant modifications to address this hazard exceedance. Additionally, for the streams and rivers flood-causing mechanism, the staff anticipates that the licensee will submit either: (a) a revised integrated assessment; or (b) a focused evaluation confirming the capability of existing flood protection or implementing new flood protection consistent with the process outlined in COMSECY-15-0019 (NRC, 2015b), and JLD-ISG-2016-01, Revision 0 (NRC, 2016c).

Additionally, for any reevaluated flood hazards that are not bounded by the plant's CDB hazard, the licensee is expected to develop any flood event duration (FED) and associated effects (AE) parameters currently not provided to conduct the Mitigating Strategies Assessment (MSA)[1] and focused evaluations or revised integrated assessments.

2.0 REGULATORY BACKGROUND

2.1 Applicable Regulatory Requirements

As stated above, Enclosure 2 to the 50.54(f) letter (NRC, 2012a) requested that licensees reevaluate flood hazards for their sites using present-day methods and regulatory guidance used by the NRC staff when reviewing applications for ESPs and COLs. This section of the staff assessment 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 reports, 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 10 CFR 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 the 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 the 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.

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[1] By letter dated January 25, 2017 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML17026A415), the licensee submitted the MSA for Duane Arnold. It is currently under review.

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, which 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 site 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, in part, that 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

Attachment 1 to Enclosure 2 of the 50.54(f) letter discusses flood-causing mechanisms for the licensee to address in its FHRR (NRC, 2012a). Table 2.2-1 lists the flood-causing mechanisms the licensee should consider and lists the corresponding Standard Review Plan (SRP) (NRC, 2007) section(s) and applicable ISG documents containing acceptance criteria and review procedures.

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, 2012d) 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". It should also be noted that for the purposes of this staff assessment, the terms "combined effects" and "combined events" are synonyms. 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 licensee 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 are plausible combined events and should be considered.

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.

2.3 <u>Actions Following the FHRR</u>

For the sites where the reevaluated flood hazard is not bounded by the CDB flood hazard elevation for any 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; and
- Perform an integrated assessment to: (a) evaluate the effectiveness of the CDB (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 all flood-causing mechanisms at the site, licensees were 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 LIP hazards exceeding their CDB flood will not be required to complete an integrated assessment, but instead will 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 a revised integrated assessment (NRC, 2015 and NRC, 2016a).

3.0 TECHNICAL EVALUATION

The NRC staff reviewed the information provided for the flood hazard reevaluation of Duane Arnold site. The licensee conducted the flood hazard reevaluation using present-day methodologies and regulatory guidance used by the NRC staff in connection with ESP and COL reviews. To provide additional information in support of the summaries and conclusions in the FHRR, the licensee made calculation packages available to the NRC staff. These calculation packages were used to expand upon and clarify the information provided on the docket, and so those calculation packages were not docketed or cited.

Finally, there were some licensee documents reviewed in connection with the staff's 2016 audit of the Duane Arnold FHRR. Many of those documents examined as part of the audit were also not docketed by the licensee; that additional information was made available to the NRC staff via the electronic reading room. Nevertheless, those documents reviewed by the staff as part of the audit were cited in the audit summary report prepared by the staff (NRC, 2016d). As noted earlier, the licensee did provide additional information on the docket by letter dated August 12, 2016 (ADAMS Accession No. ML16229A159).

3.1 Site Information

The 50.54(f) letter (NRC, 2012a) includes the SSCs important to safety in the scope of the hazard reevaluation. The licensee included pertinent data concerning these SSCs in the Duane Arnold FHRR. The NRC staff reviewed and summarized this information in the sections below.

The nominal grade of the Duane Arnold site on which the reactor unit and other safety-related structures rest is 757 feet (ft) Mean Sea Level (MSL). Unless otherwise noted, all elevations in this staff assessment are given with respect to MSL. The licensee stated that the most recent site survey uses the North American Vertical Datum of 1988 (NAVD88) as the vertical datum, whereas the CLB and historical drawings use vertical elevations referenced to MSL. Any elevation transformation between the two datums was made using the National Oceanic and Atmospheric Administration's (NOAA's) software for the national vertical datum transformation database of "VDatum" (NOAA, 2012). The licensee stated that the offset between MSL and NAVD88 is -0.38 ft.

3.1.1 Detailed Site Information

The Duane Arnold site is located on the western shore of the Cedar River in Linn County, Iowa. The controlled area for the reactor complex, which includes the powerblock, encompasses approximately 500 acres in a rural agricultural area approximately 2.5 miles (mi) north-northeast of the village of Palo. The geographic setting for the Duane Arnold site is the 'Iowan Surface,' a region defined by gently rolling hills of moderate topographic relief (Prior, 1976). The elevation in the vicinity of the plant is moderately flat and varies from 746 to 750 ft MSL. Geologically, the Duane Arnold site is underlain by glacially-deposited material deposited over a limestone bedrock. The reactor complex, however, is located on a relatively flat plain whose natural elevation is reported by the licensee to be about 750 ft MSL that slopes slightly towards the river.

The licensee reported that the Duane Arnold site relies on certain active, as well as passive, flood protection features and measures. Temporary features reported include: stoplogs augmented with plastic sheeting and sandbags; sump pumps; sealing of hatches (welding and caulking); installing extensions for diesel generator exhaust; and installing a cover for the auxiliary boiler louver. Incorporated features reported include: the sump system, walls, floors, roofs, penetration seals, water stops, membranes, and a watertight door. The pertinent features and measures were previously described in the 50.54(f) 2.3 walkdown report (NextEra, 2012) as well as the FHRR. Station drains within the power block yard are designed to collect site runoff in addition to roof drainage and route the effluent to ditch draining into the Cedar River. These features are intended to protect against flood waters to an elevation of 767 ft. Table 3.0-1 provides the summary of controlling reevaluated flood-causing mechanisms, including associated effects, the licensee computed to be higher than the respective power block elevations.

The primary hydrologic feature of interest at the Duane Arnold site is the Cedar River; it is the largest tributary of the Iowa River which ultimately flows into the Mississippi River. The Cedar River extends over a distance of 338 mi and is located immediately to the east of the reactor site in a well-defined flood plain that includes an oxbow-like meander containing a river island. The width of the Cedar River at the Duane Arnold location is estimated to be about 400 ft. Based on historic stream gauge data, the licensee reported that the water depth of the Cedar River at the reactor site location is about 10 ft with a variable river elevation ranging from 731 to 737 ft MSL.

The Cedar River also serves as the Ultimate Heat Sink for the Duane Arnold site; the reactor is not dependent on canals or man-made reservoirs for cooling water supply. The reactor's intake structure is located on the west bank of the river. The intake structure foundation is located at an elevation of 705.0 ft MSL; the grade elevation around the intake structure is about 750 ft MSL (IES Utilities, 1997); and the top deck elevation is 754.0 ft MSL. The licensee reported (NextEra, 2014a) that seismic category I equipment contained within the intake structure building is located above the peak stage of flood elevation 767.0 ft MSL.

Within the Cedar River watershed, the licensee previously reported there also are 12 low-head dams that are used primarily for hydroelectric generation or for thermal cooling of non-nuclear power plants. In addition, there are four natural and five man-made lakes in the upstream sub-basins that are used primarily for recreation.

3.1.2 Design-Basis Flood Hazards

The CDB flood levels are summarized by flood hazard mechanism in Table 3.1-1 of this staff assessment. The licensee reported that the CDB flood hazard for the Duane Arnold site is a probable maximum flood (PMF) of the Cedar River in combination with wind-generated waves. The licensee noted that the Duane Arnold site was not previously considered susceptible to floods resulting from LIP, ice-induced dams/jams, or channel migration. The licensee reported that there are several low-head dams located upstream of the site within the Cedar River watershed. During a PMF event, the licensee assumed that these dams would be submerged as they would be "drowned-out" having not failed and, as a result, flood elevations resulting from dam failure at the site were estimated to be less than that of the estimated PMF elevation. The licensee also reported that the Duane Arnold site was not in a geographic location subject to certain types of marine-induced flooding scenarios that might occur as a result of surges, seiches, and tsunamis; consequently, these flood-causing scenarios could be screened-out from further consideration for the purposes of licensing.

Lastly, the licensee noted that ground water ingress is not specifically mentioned in the CLB. In the UFSAR, no groundwater elevations are reported for the Duane Arnold site. In the UFSAR (IES Utilities, 1997), the licensee reported that the basemat for the reactor building foundation was set into bedrock which was encountered at the 705 to 707 ft. depth range below grade; the bedrock was later described by the licensee as the top of the artesian aquifer that underlies the site.[2]

The NRC staff reviewed the information provided in the FHRR and determined that sufficient information was provided to be responsive to Enclosure 2 of the 50.54(f) letter.

3.1.3 Flood-Related Changes to the Licensing Basis

The licensee noted that since the issuance of its 10 CFR Part 50 operating license, no revisions to the flood hazard analysis have occurred and no significant changes to the flood protection strategies described in the current UFSAR have taken place. Existing flood protection requirements described in the Duane Arnold UFSAR require that the below grade surfaces of all safety-related buildings be coated with an impervious waterproofing material below grade to protect against ground water ingress. To achieve the desired level of protection, the licensee reported that the joints between concrete slabs and structures were provided with bulb and dumbbell water stops since the issuance of the Part 50 operating license. The NRC staff reviewed the information provided in the FHRR and determined that sufficient information was provided to be responsive to Enclosure 2 of the 50.54(f) letter.

3.1.4 Changes to the Watershed and Local Area

The licensee reported that there are no reported changes to the Cedar River watershed and environs since issuance of the UFSAR. The reactor site does have a vehicle barrier system (VBS) but the date of installation of that feature is uncertain. The licensee does note that subsequent to plant construction, a Low-Level Radioactive Waste Processing and Storage Facility was erected within the controlled area. The licensee also now operates an independent spent fuel storage installation under a 10 CFR Part 72 license at the site, which accounted for

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[2] In the village of Palo, the licensee previously reported that the water table stood 12 ft below grade, at an elevation of about 733 ft MSL (IES Utilities, 1997). Groundwater flow is easterly towards the Cedar River.

some modification of the local topography at the Duane Arnold site.[3] This addition and any other unreported changes to the terrain have been implicitly accounted for in the hydrologic models used in the FHRR though the use of improved, higher-resolution topographic data for the region and site. The NRC staff reviewed the information provided in the FHRR and determined that sufficient information was provided to be responsive to Enclosure 2 of the 50.54(f) letter.

3.1.5 Current Licensing Basis Flood Protection and Pertinent Flood Mitigation Features

The CLB for all safety-related buildings is flood protection to a minimum elevation of 767 ft MSL. Additional site flood protection has been provided by the licensee to an elevation of 770.5 ft MSL on the northerly side of all safety-related buildings within the powerblock; on the southerly side of those structures, additional flood protection exists to an elevation 773.7 ft MSL; and for the sides of all other safety-related buildings, flood protection is in place to an elevation of 769 ft MSL.[4] Onsite floods are drained by a combination of both permanent and temporary features. In the flooding walkdown report (see Section 3.1.7 below), the licensee reported (NextEra, 2012) that there is a permanent storm drain system in-place capable of discharging flood waters associated with a 10-year storm. The licensee previously stated that a severe rainfall capable of producing a local PMF would exceed the capacity of the site drainage system, but that the rainfall/flooding event would nevertheless have no adverse effect on safety-related buildings (AEC, 1973). Furthermore, the licensee reported that the CLB water level inside the Turbine Building was 8.6 in. (NextEra, 2014a).[5] The licensee noted that the additional temporary protection measures consist of stop logs augmented with plastic sheeting to be held in place with sand bags to reduce leakage.

There are several different types of flood protection features credited in the Duane Arnold CLB. The site includes both interior and exterior barriers that are permanently in place, requiring no operator manual actions. These barriers include mitigation measures such as waterproof envelope systems for buildings, construction joint water stops, sump pumps, flood doors, floor drains, and watertight doors. There are also the aforementioned elevated earthen walls intended to provide additional flood protection against the Cedar River.

The NRC staff reviewed the flood hazard information provided and determined that sufficient information on CLB flood protection and pertinent flood mitigation features was provided to be responsive to Enclosure 2 of the 50.54(f) letter (NRC, 2012a).

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[3] NextEra has been authorized to store 2,829 fuel assemblies on-site in its spent fuel pool. There also is an independent spent fuel storage installation on site that houses Part 72 licensed spent fuel storage systems that can provide interim on-site storage of spent fuel, high-level radioactive waste, and reactor-generated greater-than-Class C waste.

[4] These flood protection measures were requested by the AEC (1973) during the original licensing of the Duane Arnold reactor complex.

[5] The licensee previously stated that any severe rainfall event would exceed the capacity of the site's drainage system (AEC, 1973); nevertheless, the licensee asserted that there would be no adverse effect on Duane Arnold SSCs important to safety as a result of a LIP event. The specific SSCs identified to be at risk are the Turbine Building, the Reactor Building, the Control Building, the Pump House, the Radwaste Building, the Recombiner Room, the Intake Structure, and the storage portion of the Low-Level Radwaste Processing and Storage Facility (IES Utilities, 1995) However, no rainfall magnitude was used by the licensee to quantifiably define a LIP flood elevation in either the original safety analysis report (SAR) or the UFSAR.

3.1.6 Additional Site Details to Assess the Flood Hazard

The licensee submitted electronic copies of the input files for computer models related to the flood hazard reevaluations, and topographic and bathymetric data for use in the computer models.

3.1.7 Results of Plant Walkdown Activities

The 50.54(f) letter (NRC, 2012a) requested that licensees plan and perform plant walkdown activities to verify that current flood protection systems are available, functional, and implementable. Other parts of the 50.54(f) letter asked the licensee to report any relevant information from the results of the plant walkdown activities (NRC, 2012a).

By letter dated November 27, 2012, NextEra (2012) submitted a flooding walkdown report as requested in Enclosure 4 of the 50.54(f) letter for the Duane Arnold site. On June 17, 2014 (NRC, 2014), the staff issued its assessment of the walkdown report which documented its review of that licensee action and concluded that the licensee's implementation of the flooding walkdown methodology met the intent of the walkdown guidance.

3.2 <u>Local Intense Precipitation and Associated Site Drainage</u>

The licensee reported that the reevaluated flood hazard for LIP is based on a maximum water surface elevation (WSE) at multiple door locations of structures considered important to safety, and it ranged from 758.0 ft to 758.2 ft MSL (NextEra, 2014a). The maximum inundation depth attributed to LIP-related flooding occurred at the Turbine Building location. The effects of wind waves and runup were not included by the licensee in the flood reevaluation as the LIP inundation depths were considered too shallow to produce significant wind/wave effects. This flood-causing mechanism is discussed in the licensee's CDB, but no PMF elevation was reported. Thus, there currently is no CDB for LIP-based flooding. However, the CDB does allow for the accumulation of some meteoric water inside the Turbine Building's basement.

The licensee reevaluated the flood hazard due to an LIP event using the FLO-2D Pro computer code. The licensee performed its initial analysis using Build Number 13.11.06 of that computer code. The staff considers the selection of FLO-2D for LIP modeling to be reasonable. The licensee stated that its LIP flood analysis was consistent with the Hierarchical Hazard Assessment approach described in NUREG/CR-7046 (NRC, 2011e).

3.2.1 Site Drainage and Elevations

The licensee reevaluated the flood hazard resulting from LIP due to a storm over an immediate drainage area of about 0.9 square miles (mi^2) that included the footprint of the Duane Arnold powerblock, the site's VBS, and all contiguous natural drainage areas that could potentially effect flooding of the site. The licensee used a digital terrain model (DTM) to approximate the topographic ground surface corresponding to the Duane Arnold site and environs (Figure 3.2-1). Data for that topographic model were acquired from two such surveys conducted for the purposes of the FHRR. The DTM grid has a resolution of 15 ft, with elevation information interpolated from bathymetry and topography data points; similarly, the resolution of the FLO-2D computational grid model is 15-ft-by-15-ft.[6] The topography for the powerblock area was based on recent site survey data, while topography outside of the plant survey area was augmented

[6] This grid system consisted of 113,722 cells covering an area of 587 acres that includes the Duane Arnold powerblock and controlled area.

with regional topography obtained from the U.S. Geological Survey (USGS) *National Elevation Dataset* (USGS, 2016). The regional topography data obtained from the USGS have a horizontal resolution of about 32.8 ft and the site survey topography is from Light Detection and Ranging (LiDAR) data with a horizontal resolution of 1 ft (NextEra, 2014b).

The staff reviewed the licensee's approach to the development of the computation grid for FLO-2D model against relevant regulatory criteria based on present-day methodologies and regulatory guidance. Generally, the staff considers the approach described to be reasonable.

3.2.2 Local Intense Precipitation

For ESPs and COLs, current NRC guidance for LIP evaluation is to select the appropriate probable maximum precipitation (PMP) event reported in the National Weather Service's Hydrometeorological Reports (or HMRs) applicable to the site. For the Duane Arnold site, the licensee used a 1-hour (h), 1-mi^2 precipitation depth for the analysis of flooding from LIP (NextEra, 2014a). Two methods were used by the licensee to estimate the precipitation depth: (a) those of HMR-51 (NOAA, 1982) and HMR-52 (NOAA, 1982); and (b) a site-specific analysis (or ssPMP) to estimate LIP depths (NextEra, 2014a). Using the HMR methodology, the estimated 1-h, 1-mi^2 precipitation depth was 17.9 in.; the site-specific methodology (NextEra, 2014a) produced an estimate of 14.1 in.

The licensee used the HMR guidance to distribute the 5-minute (min), 15-min, and 30-min precipitation depths for 1-mi^2 areas. The licensee-estimated 1-h, 1-mi^2 PMP depths for both the HMR and site-specific methods are reported in Table 3.2-1; the cumulative precipitation graphs associated with these two methods are shown in Figure 3.2-2. For the ssPMP, the licensee tested three peak rainfall distribution scenarios: the front-loaded; center-loaded; and end-loaded hyetograph shapes to find a bounding scenario. The licensee's analysis determined that the site-specific, end-loaded PMP temporal distribution produced the highest water depths at the Duane Arnold site; therefore, the licensee used this case as input for the final LIP flood hazard estimation.

In order to determine the significance of an ssPMP-derived number on estimated flood depths at the Duane Arnold site, the staff independently evaluated the sensitivity of the licensee's FLO-2D model to that scenario using the rainfall value obtained from HMR-52 (NOAA, 1982). As noted above, the HMR-based PMP value was 17.9 in. or about 21 percent larger than the licensee's ssPMP value. A scenario-based sensitivity analysis of flooding due to an HMR-derived LIP flood estimate was performed using the licensee's FLO-2D computer model. Aside from changing the PMP value, no other changes were made to the LIP model. The results of staff's sensitivity analysis show that the WSEs estimated using the HMR-based event were only slightly higher than the WSEs estimated using the licensee's ssPMP-based event. Differences in the respective WSE estimates varied from location-to-location within the powerblock, however the maximum differences were on the order of +0.06 ft. In light of these small differences, the staff determined that it was not necessary to review the manner in which the licensee's ssPMP estimate was derived. Correspondingly, the staff concluded that the licensee's ssPMP values were reasonable to use in the LIP runoff analysis discussed below.

3.2.3 Runoff Analysis

The FHRR and the complementary LIP flood calculation package describe the physical features of the Duane Arnold powerblock (i.e. permanent buildings, tanks, roadways, berms, the VBS, etc.) that were incorporated into the FLO-2D LIP model (NextEra, 2015). These documents also summarized the following details concerning the LIP model: (a) the runoff losses, such as initial and constant losses; (b) drainage system components (e.g., gravity storm drain systems, culverts, inlets); (c) runoff from building roofs; and (d) the use of area reduction factors (ARFs) and width reduction factors (WRFs) to moderate surface water flow. The FLO-2D model boundary and other key features of the LIP model are shown in Figure 3.2-3.

The licensee noted that the roofs of permanent buildings and other structures were elevated in the LIP model to allow roof drainage onto adjacent ground surfaces; roof drainage systems were assumed to be clogged. The LIP flood calculation package (NextEra, 2015) indicated that elevations of the building footprint inside the study area were increased by at least 5 ft higher than the surrounding land-surface elevation to simulate the taller roof drainage conditions necessary to discharge the rainfall, as well as to avoid the accumulation of meteoric water on rooftops. In addition, the licensee stated that the short duration of the precipitation event combined with the high precipitation rate allowed for negligible infiltration by ground surface materials. Another major site feature at the Duane Arnold is the VBS, which encircles the reactor powerblock. Figure 3.2-3 shows the layout of the permanent and temporary structures, and the VBS. The VBS consists of 12-ft-long concrete blocks that are 42-in. high; there are 2-ft gaps between the individual blocks. The licensee modeled drainage through these gaps along the barrier length by assigning a 90 percent reduction of inflow across the VBS boundary. The LIP calculation package (NextEra, 2015) stated that the flow width of the cells representing the barrier was reduced by 90 percent.

In conducting its independent review, the NRC staff confirmed that the physical obstructions present within the FLO-2D modeling domain for the Duane Arnold site were identified and confirmed using available aerial imagery of the site. Computational grid elements coinciding with buildings were modeled as obstructions that completely blocked the passage of flowing surface water. The staff determined that the locations of buildings and other structures were properly implemented in the FLO-2D computer model and that the representation of those features with higher elevations would both promote flow from those cells as well as prevent surface flow into those cells. However, in conducting its independent review, the staff noted the following modeling issues that were discussed with the licensee during the 2016 FHRR audit (NRC, 2016d).

3.2.3.1 Boundary Condition Treatment

The staff observed that no outflow elements were specified along the boundary of the FLO-2D model (i.e. the boundary of the modeling domain was treated as a vertical wall of infinite height as shown on Figures 3.2-4a and 3.2-4b). The staff conducted a sensitivity analysis to evaluate the significance of this boundary condition specification by introducing outflow elements along one portion of the boundary based on the recommendations in the FLO-2D *Reference Manual* (FLO-2D Software Inc., 2009); these outflow elements were added in the vicinity of the intake structure located along the Cedar River (Figure 3.2-4c). The staff found that the differences in maximum flood depths was coincident with the locations of the four Turbine Building doors listed in Table 3.2-2, but these differences did not exceed the reported values.

3.2.3.2 Representation of Roof Drainage

The licensee addressed precipitation falling on the roofs of permanent buildings and other structures by specifying a higher elevation for the roofs compared to the ground surface; in this fashion, roof runoff was allowed to drain evenly onto the surrounding ground surface. Following the 2016 staff audit, the licensee noted that it was possible that secondary scuppers located on the building roofs could concentrate flow above the rolling doors on the north and south sides of the Turbine Building (NRC, 2016d). The licensee showed that the estimated discharge in front of the affected Turbine Building doors would be about 1 cubic foot per second (cfs), but this would not occur at the time of the peak discharge during the LIP event. The licensee also stated that because the roof parapets are approximately 13.5 in. in height, minimal overtopping from the site-specific LIP depth of 14.1 in. would be expected. The FLO-2D model did not incorporate parapets and, therefore, did not credit rainwater that might accumulate on the roofs. Because the licensee's LIP modeling approach did not credit any rainfall storage on the roofs of Duane Arnold structures, the staff concludes that the licensee's treatment of roof drainage was reasonable and appropriate for the purposes of responding to this information request.

3.2.3.3 Application of Area Reduction Factors and Width Reduction Factors

The licensee used ARFs to account for reduced surface area and obstacles to flow caused by structures within the FLO-2D modeling domain. In its review of the licensee's input/output (I/O) files, the staff could not ascertain whether Duane Arnold structures were explicitly modeled consistent with the ARF and WRF methods described in the FHRR. During the 2016 audit, the licensee confirmed that ARFs were not implemented in the LIP model and that the effects of using the WRFs on WSEs were inconsequential. Therefore, the staff determined that the licensee's handling of flow obstructions by structures is consistent with present-day guidance and methodology.

3.2.3.4 Treatment of the VBS

The LIP calculation package (NextEra, 2015) stated that the flow width of the cells corresponding to the location of the VBS would be reduced by 90 percent; however, the manner in which this reduction is achieved was not explicitly described in the FHRR. Upon review of the FLO-2D I/O files, the staff found that the ARF/WRF option had in fact been turned 'off'. To resolve this inconsistency, the licensee modeled all structures as raised grid cells that did not require specification of ARFs (NRC, 2016d). The licensee also acknowledged that the original FLO-2D model was incorrectly configured to exclude WRFs. The licensee performed a second LIP analysis with an updated version of the FLO-2D computer code (designated Build Number 14.08.09) in which the WRFs were correctly specified. The licensee reported that this parametric sensitivity analysis indicated that the differences in WSEs at the locations of critical doors in the powerblock area was insignificant. The staff subsequently verified that including WRFs for grid cell locations containing the VBS resulted in a minimal difference in the WSEs at the door locations of interest.

Lastly, the FHRR stated that Manning's roughness coefficient values were selected based on the recommendations of the FLO-2D Reference Manual (FLO-2D Software, Inc., 2009). Identification of land cover types by the licensee at the site was based primarily on a visual examination of available topographic maps and aerial photography. The licensee estimated that most of the modeling area corresponding to the Duane Arnold powerblock is covered by roads, buildings, concrete, and other types of impervious surfaces; for these areas, a Manning's roughness coefficient value of 0.02 was used. For areas surrounding the site consisting of mixed impervious and maintained pervious land, a Manning's roughness coefficient value of 0.05 was used. Non-concrete, asphalt, and non-forested areas were considered to consist of "open ground with debris" and a Manning's roughness coefficient value of 0.02 was used by the licensee. Lastly, the FLO-2D Reference Manual notes that flow resistance generally decreases in proportion to increasing flow depths; to account for this behavior, the FLO-2D computer code has the ability to automatically adjust Manning's roughness coefficient values during a simulation when flow depths increase. The licensee's reasoning for the values of the Manning's roughness coefficients selected was discussed during the 2016 audit (NRC, 2016d). In light of those discussions, the staff confirmed that the selection of the Manning's roughness coefficient values were within the ranges recommended in the FLO-2D Reference Manual consistent with the types of land covers identified by the licensee. The staff reviewed the recommended Manning's roughness coefficient values described in either Chow (1959) or Bedient and Huber (1988), and concluded that the values used by the licensee were reasonable. Consequently, staff determined that the land use classification and Manning's roughness coefficient values used in the model were reasonable.

3.2.4 Water Level Determination

The licensee reported that the LIP event is considered to occur while the plant is in normal operating mode (i.e. not in flood preparedness mode). Under this condition, excess or accumulated runoff could enter openings, penetrations, or pathways to SSCs. For the purpose of the LIP analysis, the Duane Arnold plant drainage system, including catch basins, floor drains, and associated piping, was conservatively assumed to be nonfunctional (NextEra, 2014a). The licensee identified multiple potential flow path locations around the reactor unit and other structures by which LIP-generated flood water could potentially affect plant safety. Table 3.2-2 lists the maximum flood depths and the corresponding maximum WSEs at the four Turbine Building door locations; these locations are depicted in Figure 3.2-5. The maximum WSE attributed to the LIP-based flooding mechanism, 758.2 ft MSL, occurred at doors 136 and 137. Because the CDB does not include WSEs for the LIP-based flood, the reevaluated flood elevations cannot be directly compared to the CDB. The licensee reported the reevaluated flood hazard as a maximum WSE ranging from 0.61 to 0.84 ft at the four locations identified. The licensee compared the estimated flood depth to the inlet height of doors and hatches at each of the potential pathway locations. The licensee reported that maximum flood depths were greater than some door/hatch inlet heights for safety-related structures (NextEra, 2014a). The licensee also acknowledged that there was a temporal aspect to those flood depths that varied by location when the drainage characteristics and geometry of the powerblock were taken into account.

After independently executing the licensee's FLO-2D computer code input files, the staff confirmed the depths and locations of the maximum WSEs reported in the FHRR. The staff found that: (a) mass balance errors were acceptably small; (b) flow pathways and areas of inundation appeared reasonable; (c) flow velocities were reasonable; and (d) no indication of numerical instabilities nor unexpected supercritical flow conditions were identified near potential flooding pathways. Based on these results, the staff concluded the licensee's LIP FLO-2D simulations are reasonable and appropriate for the purposes of responding to the information request.

3.2.5 Conclusion

In summary, the NRC 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, the NRC staff expects that the licensee will submit a focused evaluation for LIP and associated site drainage for Duane Arnold.

3.3 <u>Streams and Rivers</u>

The licensee reported that the reevaluated flood hazard for streams and rivers is based on a PMF stillwater surface elevation on the Cedar River of 765.2 ft MSL. When wind wave and runup effects are considered, the reevaluated flood hazard elevation is 767.8 ft MSL (NextEra, 2016a). The CDB PMF elevation for streams and rivers is based on a stillwater surface elevation of 764.1 ft MSL. Including wind-wave and runup effects results in an elevation of 767.0 ft MSL.

The licensee's reevaluation of flooding on streams and rivers described in the Duane Arnold FHRR included three analysis components: (a) defining a PMP event; (b) simulating the PMF associated with the PMP event, and (c) evaluating the effect of combined flooding events. The licensee's PMF evaluation was limited to the portion of the Cedar River watershed geographically above the Duane Arnold site. The overall Cedar River watershed can be divided into 34 sub-basins; 29 of those sub-basins occur upstream of the reactor site (Figure 3.3-1) and account for 6,250 mi^2 (or about 80 percent of the total watershed). The licensee used the topographic data from the USGS National Elevation Dataset [approximately 32.8-ft resolution] to define the watershed and sub-basins for PMP analysis and runoff modeling. Bathymetric data obtained from the Iowa Flood Center and the local site LiDAR survey were used to develop a channel and floodplain geometry data set, from which cross sections of the channel and floodplain were created. The licensee stated that the methods used in reevaluating flooding on streams and rivers at the Duane Arnold site were consistent with NUREG/CR-7046 (NRC, 2011).

For the purposes of the streams and rivers flooding analysis, the licensee modeled overland flow within the Cedar River watershed following a simulated PMP event using the U.S. Army Corps of Engineers' (USACE) Hydrologic Engineering Center (HEC) Hydrologic Modeling System (HEC-HMS) software (USACE, 2010a). Using the synthetic Clark unit hydrographs produced by the computer software as input, the licensee estimated runoff volumes and discharges at upstream and tributary locations within the respective Cedar River sub-basins. The output from that computer analysis was subsequently used by the licensee to route the river flow within the Cedar River and estimate WSEs at the Duane Arnold site using the HEC River Analysis System (HEC-RAS) software (USACE, 2010b).

3.3.1 Probable Maximum Precipitation

The licensee used two methods to estimate the PMP over the Cedar River watershed. The first method relied on NOAA-standards HMR-51 (NOAA, 1982) and HMR-52 (NOAA, 1982). The second method involved performing a site-specific, basin-wide PMP analysis (NextEra, 2014a; and NextEra, 2014b); the site-specific methodology analysis was similar to HMR approach but it relies on incorporating the most recent data available for extreme rainfall events occurring in the Midwestern United States.

In developing a PMF estimate, NUREG/CR-7046 (NRC, 2011) recommends that three hydrologic scenarios be considered to ascertain which precipitation scenario would produce the maximum WSE at a reactor site:

- PMP Alternative 1 – a combination of mean monthly base flow; median soil moisture; antecedent rain; the all-season PMP; and the 2-yr wind waves along the critical direction;
- PMP Alternative 2 – a combination of mean monthly base flow; snowmelt from the probable maximum snowpack; a 100-yr, cool-season rainfall event; and 2-yr wind waves along the critical direction; and
- PMP Alternative 3 – a combination of mean monthly base flow; snowmelt from a 100-yr snowpack; the cool-season PMP; and 2-yr wind waves along the critical direction.

Following HMR methodology, the licensee developed a depth-area-duration (DAD) curve for the Cedar River watershed using HMR-52 (Table 3.3-1). For its site-specific PMP estimate, the licensee examined past extreme rainfall events occurring in the Midwestern United States, using storm maximization and transposition techniques to estimate the maximum precipitation depth that a storm could produce if it was centered on the Cedar River watershed. The licensee developed all-season DAD curves using 26 storm events and used 11 of those storm events to derive the cool-season-only DAD curves.

The licensee calculated peak flows for all three PMP for the purposes of the Duane Arnold FHRR PMF analysis. The PMP Alternative 3 was found to have the highest peak flow at the location of the Duane Arnold site, thus was selected by the licensee to be the controlling scenario for the FHRR PMF computation.

3.3.1.1 PMP Alternative 1

For Alternative 1, the all-season (non-snow) events, the licensee used the same approach to develop runoff hydrographs for both the HMR-based PMP and the basin-wide PMP; this PMP alternative considered the entire Cedar River watershed area of 7,820 mi^2. The licensee used HMR-52 software to evaluate 35 candidate storm events, which were generated by varying storm centers, size, orientation, and precipitation distribution over time. The licensee developed the 35 candidate events from a combination of seven storm centers (shown on Figure 3.3-1) and five temporal distribution patterns. The licensee also considered an antecedent event defined as 40 percent of the 72-h PMP; therefore, each candidate PMP event had a corresponding antecedent event. The critical basin-wide PMP event resulted in a peak flow of 331,970 cfs.

3.3.1.2 PMP Alternative 2

For Alternative 2, the cool-season (snow) scenario of the 100-year cool-season rainfall on the probable maximum snowpack, the licensee estimated a total precipitation depth of 10 in. based on an average 100-year cool-season precipitation depth of about 4 in. plus snowmelt runoff of about 6 in. during the event (NextEra, 2014a). The peak flow resulting from this scenario was smaller than that from Alternative 3, the 100-year snowpack coincident with the snow-season PMP (NextEra, 2014a); this alternative considered the entire Cedar River watershed.

3.3.1.3 PMP Alternative 3

For Alternative 3, the licensee determined the precipitation hyetographs for all sub-basins of the watershed area immediately above the reactor site location using a revised DAD relationship, shown in Table 3.3-1. This scenario was determined to be the critical cool-season scenario, with a peak flow of 408,380 cfs (NRC, 2016d).

3.3.1.4 Basin-Wide Site-Specific PMP Review

The licensee developed the basin-wide PMP by first identifying the most extreme storms that have occurred in, or can be reasonably transpositioned in the past to, the area of interest and then refining that catalog to a short list. This refinement process involves enforcing several objective and subjective criteria to produce a reduced set of appropriate historical storms which may influence the basin-wide PMP values and which require further evaluation. Once the "short list" has been derived, additional actions are taken to transposition and maximize each storm cited in the short list catalog to the location of interest. The process used to develop the PMP applicable to the Cedar River watershed were the subject of a February 2015 audit of an Applied Weather Associates (AWA) technical report (NRC, 2015a).

The climate in Iowa may be generally regarded as humid subtropical, and the potential exists for significant snow coverage and rain-on-snow flooding in the Duane Arnold watershed. As a consequence, the licensee developed both a cool-season as well as warm-season PMPs for the basin. The resulting basin-wide PMP values were presented in Tables 4-12 and 4-13 of the Duane Arnold FHRR, and a comparison of those basin-wide PMP values to the HMR-derived value is provided in Figure 3.3-2.

In order to better assess the reasonableness of the licensee's basin-wide PMP estimates, the staff conducted detailed review and independent analysis to evaluate both the warm-season and the cool-season basin-wide PMP estimate. While evaluating the licensee's basin-wide PMP, staff performed a review of the following as part of the 2015 AWA audit (NRC, 2015a):

- the licensee's initial storm "long list";
- the Quad Cities FHRR short list of storms [also prepared by AWA (ORNL, 2015)];
- the USACE 'Black Book' storm catalog (USACE, 1973); and
- an independent evaluation of the short list storms.

Following review of the licensee's initial storm long lists, two cool-season storms were identified as potentially critical, but were not included in the licensee's short storm list. The staff subsequently discussed the basis for this omission during the December 2015 AWA audit (NRC, 2015a); and as a result of that audit, the staff determined that inclusion of the two storms in question would not impact the magnitude of the estimated basin-wide PMP value at the Duane Arnold site (NRC, 2015a). Due to the close proximity of the two sites (approximately 80 mi), the staff also reviewed the Quad Cities FHRR (Exelon, 2013) short list storms to ensure the accuracy of unadjusted rainfall values and the comprehensiveness of the Duane Arnold short list of storms. This review identified no major concerns. Next, the staff reviewed all historical rainfall observations documented in the USACE 'Black Book' storm catalog. This review identified two cool-season storms as potentially critical; however, the licensee considered, and justifiably excluded, both storms in the cool-season initial storm long list. In addition, one warm-season storm was identified as potentially critical, but following subsequent discussion during the December 2015 audit, the staff determined that inclusion of this storm would not impact the PMP estimates and that exclusion of this storm by the licensee was reasonable. Lastly, the staff conducted a detailed independent analysis to assess the warm-season and cool-season short list storms. As a part of its assessment, staff independently computed storm elevation, storm dew point (including storm representative, in-place maximum, and transpositioned maximum dew point values), and total adjustment factors following methodologies similar to those used by the licensee (ORNL, 2016). The most notable difference between the staff's and licensee's methodologies relates to the way in which the dew point climatology values (in-place maximum and transpositioned maximum) are determined. While the licensee determined dew point climatology values using smoothed maps produced by AWA, staff relied on its independent gauge-based calculations of climatology values to infer appropriate values.

For some storms, the two approaches resulted in noticeably different maximized DAD values. While no concerns were identified for the overall, enveloped warm-season basin-wide PMP, the controlling cool-season storm (Alley Spring, MO) was found to have higher basin-wide rainfall depth compared to the staff's results. During the December 2015 audit, the reasons for these differences were discussed. In order to understand how the larger rainfall depths would impact the WSEs at the Duane Arnold site, staff performed sensitivity analysis. Those results (ORNL, 2016) indicated that the change in maximum flood levels was reasonably low and hence the licensee's basin-wide PMP values were reasonable given this lack of sensitivity in flood stage.

3.3.2 Probable Maximum Flood

In estimating the PMF, the licensee modeled a 56-mi section of the Cedar River watershed, extending both upstream and downstream of the Duane Arnold site. For each of the three basin-wide PMP alternatives, the three PMP estimates were converted to surface or direct runoff runoff using Version 3.5 of the USACE's HEC-HMS computer code (USACE, 2010b). The direct runoff eventually reaches channels within the Cedar River watershed and is routed to model the stream network. The HMS discharges from that stream network were then used by the HEC-RAS computer code (USACE, 2010b) to predict WSEs at the reactor site. Bathymetric and topographic data were obtained from multiple sources. The licensee developed a total of 416 cross sections to represent the river channel and the corresponding floodplain, and incorporated bridges and flow control structures (Figure 3.3-3). The Duane Arnold powerblock structures were modeled as blocked obstructions that would only affect flow when the water-surface elevation reached its location (NextEra, 2014a; NextEra, 2014b). The licensee used existing precipitation and streamflow observations for the Cedar River watershed to calibrate the HEC-HMS model and initial and constant losses to account for infiltration and other losses that might occur. The Clark Unit Hydrograph method, with the unit hydrographs adjusted for nonlinear effects during large-scale flooding events, was used to estimate the time distribution of runoff from each sub-basin; the Muskingum routing method was used to route flows through the stream reaches. The licensee used a constant monthly base flow for the Cedar River watershed. The licensee included upstream dams and reservoirs in its hydrologic model, but stated that the dams were assumed to have no storage potential because they were small and that "dam storage and release rates do not have a significant impact on the flows on the major streams and rivers in the basin" (NextEra, 2014a). Based on the three alternatives discussed in Section 3.3.1, the licensee determined that the maximum discharge in the Cedar River at the Duane Arnold site location was 408,380 cfs, and would occur in connection with PMP Alternative 3, when the site-specific, cool-season PMP occurred coincident with the 100-year snowpack. Using the calibrated HEC-RAS model, the licensee determined that the maximum stillwater WSE at the Duane Arnold site was 765.2 ft MSL (NRC, 2016d).

To complete its review of the licensee's PMF flood analysis, the staff requested that the licensee provide the HEC-HMS computer files used to produce the results described in the FHRR. In response, the licensee provided the requested I/O files associated with the PMF calculation. The files provided consisted of a series of computer simulation cases all relying on conservative modeling assumptions. The staff evaluated the licensee's basis for the infiltration-loss model, the unit hydrograph approach, and the channel routing in the calculation of PMF discharge using the HEC-HMS model. Using the input files obtained from the licensee, the staff also evaluated the configuration of the HEC-HMS models used in the licensee's evaluation of flood depth and duration. While reviewing those input files, the staff identified several modeling issues that were discussed and resolved with the licensee during the 2016 audit of the Duane Arnold FHRR (NRC, 2016d).

Lastly, the licensee initially selected the Manning's roughness coefficient values for the stream and overbank areas from the HEC-RAS Reference Manual (USACE, 2010b). The licensee manually calibrated the Manning's roughness coefficient value for the stream using the flood event of March 2010 and those of May 2013 and June 2008 as the validation events (NextEra, 2014a). The licensee reported the calibrated Manning's roughness coefficient for the stream areas to be 0.034. The staff reviewed the licensee's calibration method and determined that the licensee used methods currently accepted in engineering practice. After a review of the licensee's HEC-RAS model, the staff performed a series of computer simulations to evaluate what effect changes in the Manning's roughness coefficient and the Muskingum routing parameter might have on the licensee's estimated WSEs. These independent sensitivity runs were based on reasonably accepted ranges for these two variables and later found to result in no significant change in predicted maximum WSEs at the Duane Arnold site. The staff concluded that the licensee's choice of HEC-RAS model parameter values were reasonable and that the main source of variability (i.e. sensitivity) in the estimated (stillwater) WSE at the Duane Arnold site was the magnitude of the flood discharge, which would be controlled by the amount of runoff, which in turn would be controlled by the amount of precipitation and snowmelt and infiltration losses in the watershed. Using the input files provided by the licensee, the staff confirmed the licensee's estimated PMF WSE results.

3.3.3 Combined Effects Flood

The licensee also evaluated wind-wave and runup effects coincident with the Cedar River PMF at the Duane Arnold site using the peak PMF stillwater WSE of 765.2 ft MSL. The licensee used the U.S. Army Corps of Engineers' *Shore Protection Manual* (USACE, 1984) and the Coastal Engineering Manual (USACE, 2008) to estimate those effects. The wind-wave activity was estimated for the south, southwest, west, northeast, east, and southeast azimuths relative to the Duane Arnold site. The licensee excluded the north and northwest directions from consideration because there are no safety-related SSCs on those sides of the powerblock. The licensee-estimated wind-wave activity and resulting total flood water-surface elevations reported in connection with the 2016 audit (NRC, 2016) are provided in Table 3.3-2. The licensee estimated the combined maximum WSE as 767.8 ft MSL (NextEra, 2016b, and NRC, 2016d): this scenario corresponds to fetch originating from the south of the Duane Arnold site.

The staff reviewed the licensee's wind-wave evaluation for the stream and river flooding and determined that the licensee followed methods consistent with the NRC guidance and with standard engineering practice. The staff also consulted currently-accepted hydrologic equations described in the USACE Shore Protection Manual and the Coastal Engineering Manual for evaluating wind-wave and runup effects. The staff's estimated wave runup values indicate total water levels similar to, or slightly below, those reported by the licensee. The staff concluded that the licensee's wind-wave estimates were reasonable

3.3.4 Summary

In summary, the staff confirmed the licensee's conclusion that the reevaluated flood hazard for streams and rivers is not bounded by the CDB flood. Therefore, the staff expects that the licensee will submit a focused evaluation for streams and rivers and associated site drainage for the Duane Arnold site.

3.4 <u>Failure of Dams and Onsite Water Control/Storage Structures</u>

The licensee reported in the FHRR that the reevaluated flood hazard for failure of dams and onsite water control or storage structures is based on a stillwater elevation of [redacted] wind waves and runup effects were not included in the calculation. This flood-causing mechanism was not quantitatively evaluated for the purposes of the licensee's CDB.

The licensee reported that there are about a dozen dams of interest in the Cedar River drainage basin for the purposes of the FHRR. The dams were reported to have been built primarily for power purposes either as hydroelectric facilities or as a source of water for thermal plant cooling. The licensee reported that the dams in question have small hydraulic heads, as well as small impoundments. In considering the risk significance of these structures to the FHRR, the licensee considered three dam failure scenarios using the HEC-RAS computer code:

overtopping; loss of containment due to a seismic-induced breach; and sunny day. These failure modes are described JLD-ISG-2013-01 (NRC, 2013b). The licensee reported that based on its HEC-RAS analyses, the "Alternative C1: Worst-case individual or cascading dam failures" scenario described in JLD-ISG-2013-01 produced the highest flood elevation (NextEra, 2014a). However, the licensee reported that the estimated flood elevation from the failure of any or all of the dams identified would not exceed an elevation of [redacted] which is less than the CDB for a riverine flood. Furthermore, the licensee noted that the failure of upstream dams in the FHRR would not materially affect the magnitude of the PMF at the Duane Arnold site because of the relatively small reservoir capacities.

The NRC staff reviewed the flooding hazard due to the failure of upstream dams and onsite water control or storage structures against the relevant regulatory criteria based on present-day methodologies and regulatory guidance. In connection with its independent review of the FHRR, the NRC staff examined data reported in the *National Inventory of Dams* (NID) (USACE, 2014a). The NRC staff confirmed that the dams identified by the licensee are located within the same Cedar River watershed as the Duane Arnold site. The staff also confirmed that the dam heights and reservoir capacities reported in the NID were the same as those described in the FHRR. Given those dimensions, the staff independently estimated dam failure-based WSEs at the reactor site using a bounding calculation approach based on empirical hydraulic equations.

Two different methods were used; both relied on estimating river discharges at the Duane Arnold site using the U.S. Bureau of Reclamation's (USBR's) recommended dam breach flow equations (USBR, 1982 and 1983). In the first method, a mathematical expression using the USBR river discharge estimates, the shallow-water wave celerity approximation, and the dimension of the Cedar River channel in the vicinity of the Duane Arnold site (about 400 ft) were used to estimate a WSE at that location. In the second method, the USBR river discharge estimates were used again to develop a mathematical expression that now relied on the Manning's velocity equation and the river distance the dam was from the Duane Arnold site. As a conservatism, no fluid mass losses due to infiltration or attenuation were assumed. The results of the staff's Excel spreadsheet analysis found that the estimated WSE due to dam failure was less than the WSE estimated by the licensee and below the site grade of the powerblock. As an additional review measure, the staff repeated the analysis described above using the licensee's estimated peak flow discharge estimates reported in Table 4-20 of the FHRR; the results of that analysis also confirmed the estimated WSE due to dam failure was still less than that estimated by the licensee.

In summary, the staff confirmed the licensee's conclusion that the PMF from dam failure will not impact the Duane Arnold site. Therefore, the NRC staff determined that flooding due to dam failure does not need to be analyzed in a focused evaluation or a revised integrated assessment for the Duane Arnold site.

3.5 Storm Surge

In the Duane Arnold FHRR, the license reported that the reevaluated hazard for storm surge-related flooding effects are not applicable at this particular site. The Duane Arnold site is not in a geographic location amenable to the occurrence of marine-driven storms capable of generating a storm surge. The site is inland, in the approximate center of the continent, and is located about 200 mi from Lake Michigan, the nearest large body of water, and 800 mi from the Gulf of Mexico, the next nearest large body of water capable of generating storm surge. Consequently, this flood-causing mechanism is not considered physically plausible and thus was not considered in the licensee's CDB. Based on hydrological evidence in the site region, the licensee concluded that storm surge-related flooding will not affect the Duane Arnold site.

In connection with its examination of the Duane Arnold FHRR, the NRC staff reviewed the potential hazard from storm surge-related flooding against the relevant regulatory criteria based on present-day methodologies and regulatory guidance. Based on geographic evidence in the site region, the NRC staff concluded that there is no potential for storm surge-like flooding to occur at the Duane Arnold site.

In summary, the NRC staff confirmed the licensee's conclusion that the PMF from flooding due to storm surge does not impact the Duane Arnold site. Therefore, the NRC staff determined that flooding due to storm surge does not need to be analyzed in a focused evaluation or a revised integrated assessment for Duane Arnold.

3.6 Seiche

The licensee reported in the Duane Arnold FHRR, that the reevaluated hazard for seiche-related flooding effects are not applicable at this particular site. The Duane Arnold site is not adjacent to any large body of water (marine or non-marine) with a free surface area large enough to generate seiche-driven waves. Consequently, this flood-causing mechanism is not considered physically plausible and thus was not considered in the licensee's CDB. Based on hydrological evidence in the site region, the licensee concluded that storm seiche-related flooding will not affect the Duane Arnold site.

In connection with its examination of the Duane Arnold FHRR, the NRC staff reviewed the potential hazard from seiche-related flooding against the relevant regulatory criteria based on present-day methodologies and regulatory guidance. Based on geographic evidence in the site region, the staff concluded that there is no potential for seiche-like flooding to occur at the Duane Arnold site.

In summary, the staff confirmed the licensee's conclusion that the PMF from seiche-induced flooding does not impact the Duane Arnold site. Therefore, the NRC staff determined that flooding due to seiche does not need to be analyzed in a focused evaluation or a revised integrated assessment for Duane Arnold.

3.7 Tsunami

The licensee reported that the reevaluated hazard for tsunami-related flooding effects is not applicable at this particular site. The Duane Arnold site is not in a geographic location amenable to the occurrence of tsunamis. The site is inland and not located on or near a coastline where tsunami-like waves can make landfall following a tectonic disturbance on the ocean floor. The Duane Arnold site is approximately 860 mi and 900 mi inland from the two nearest potential tsunamigenic sources, the Gulf of Mexico and Atlantic Ocean, respectively. Consequently, this flood-causing mechanism is not considered physically plausible and thus was not considered in the licensee's CDB. Based on hydrological evidence in the site region, the licensee concluded that tsunami-related flooding will not affect the Duane Arnold site.

In connection with its examination of the Duane Arnold FHRR, the NRC staff reviewed the potential hazard from tsunami-related flooding against the relevant regulatory criteria based on present-day methodologies and regulatory guidance. Based on geographic evidence in the site region, the NRC staff concluded that there is no potential for tsunami-like phenomena to affect the Duane Arnold site. The inland location is far from the influence of recognized tsunamigenic sources (e.g., Gutenberg, 1939).

In summary, the staff confirmed the licensee's conclusion that the PMF from tsunami-induced flooding does not impact the Duane Arnold site. Therefore, the NRC staff determined that flooding from tsunami does not need to be analyzed in a focused evaluation or a revised integrated assessment for Duane Arnold.

3.8 Ice-Induced Flooding

The licensee reported that ice-induced flooding effects do not impact the Duane Arnold site. In both the original SAR and the subsequent Individual Plant Examination of External Events (IPEEE) review, the NRC licensee considered the possibility of ice jams creating a higher WSE along the Cedar River at a location close to the reactor location. See discussions in, respectively, AEC (1973) and IES Utilities (1995). Upon evaluation of the topography of the Cedar River flood plain, the licensee determined that no features exist along the Cedar River that could support the formation of an ice jam and generate flood elevations approaching the elevation of the PMF. Later, in an update to its SAR, the licensee concluded that even if ice jams were to form, they would not generate a flood wave elevation comparable to that of the PMF (IES Utilities, 1997).

As part of its FHRR, the licensee conducted two calculations to estimate the magnitude of an ice dam-induced flood at the Duane Arnold site; one was at an upstream location from the site and the other was at a downstream location. The licensee queried the Cold Regions Research and Engineering Laboratory (CRREL) ice jam database containing historic reports of ice jams on waterways found within the contiguous 48 states and Alaska (USACE, 2014b), and concluded past ice jam heights of 11.3 ft NAVD88 and 12.5 ft NAVD88 at the upstream and downstream locations of interest, respectively. The licensee used the HEC-RAS computer code to develop a hydraulic model that could be to analyze the effects of an ice jam-induced flood on the Duane Arnold site at the two locations. The licensee reported that the highest ice jam-induced flood elevation at the site was associated with a hypothetical upstream ice dam [Scenario E1 from NUREG/CR-7046 (NRC, 2011e)]; the ice dam at that location was reported to produce a WSE of 737.7 ft NAVD88, which is less than the Duane Arnold site grade elevation of 757 ft. As a consequence, the licensee argued that this flood-causing mechanism could be screened-out from further consideration for the purposes of the Duane Arnold FHRR analysis as it was a substantially lower elevation than the currently-estimated PMF.

The NRC staff independently reviewed the potential for flooding due to ice jams on the Cedar River. This review revealed that there were no reports of ice jams on the Cedar River near the Duane Arnold site (Patterson, 1966; Matthai, 1968; and Patterson and Gamble, 1968). The NRC staff also reviewed the CRREL database and noted multiple reports of ice jams having formed at two locations along the Cedar River in the immediate vicinity of the Duane Arnold site. From 2003 to 2013, there were seven records of ice jams in Cedar Rapids, 13 mi downstream (south) of the site. The largest of the jams reported in the city of Cedar Rapids was 13 ft. There was one report of an ice jam at Mt. Auburn, 24 mi upstream (north) of the Duane Arnold site; however, the elevation was not reported. The NRC staff observed that an east-west, continuous span, girder type bridge on the Blair Ferry Road traverses the Cedar River approximately 2 mi downstream from the Duane Arnold site. This engineering feature may represent a potential site for the formation of ice jams given that aerial imagery reveals the presence of shallow point bars at this location and other near-by riverine locations when the river stage is low. During a 2016 audit of the Duane Arnold FHRR, the licensee's ice dam-induced flooding analysis was discussed (NRC, 2016d). During the audit, the licensee acknowledged that it considered the potential for an ice jam at the Blairs Ferry Road bridge location and described its analysis that demonstrated that backwater effects would not inundate the Duane Arnold powerblock (NRC, 2016d). Accordingly, the licensee reported that the estimated WSE was bounded by the CDB flood elevation and staff found this response to be reasonable and acceptable for the purposes of responding to this information request.

In summary, the NRC staff confirmed the licensee's conclusion that the reevaluated hazard for flooding due to ice-induced flooding effects is bounded by the CDB flood hazard at the Duane Arnold site. Therefore, the NRC staff determined that ice-induced flooding effects flooding does not need to be analyzed in a focused evaluation or a revised integrated assessment for Duane Arnold.

3.9 Channel Migrations or Diversions

The licensee reported that the reevaluated hazard for channel migration or diversion effects does not impact the Duane Arnold site. Further, this flood-causing mechanism is not described in the licensee's CDB.

The potential for this flood-causing mechanism was previously considered during initial licensing for the Duane Arnold site (AEC, 1973) as well as in the subsequent IPEEE (IES Utilities, 1995). During both reviews, the licensee determined that portions of the Cedar River could be diverted as a result of natural processes responsible for governing this type of behavior (e.g., Leopold and Wolman, 1957; Leopold and Wolman, 1960). However, the licensee noted that this particular flooding scenario would be a slow-developing event such that adequate time would be available to safely shut down the plant.

NUREG/CR-7046 (NRC, 2011e) acknowledges that there are no well-established predictive models for estimating the potential for channel diversion in a riverine environment. However, the potential for channel migrations or diversions can be assessed by visually-inspecting available topographic maps for topographic/geomorphic evidence of past channel migrations or diversions (Fairbridge, 1968). In its independent evaluation of the Duane Arnold FHRR, the staff performed its review in two phases to examine both historic and current topographic maps of the Cedar River basin for evidence of meandering or channel diversion. Examination of both sets of topographic maps of the area suggest that the course of the Cedar River has remained relatively fixed for the last century. Based on these comparisons, the staff concludes that there is no evidence of river meandering and/or channel diversion for at least the last century.

In summary, the staff confirmed the licensee's conclusion that the reevaluated hazard for flooding due to PMF from channel migration or diversions is bounded by the CDB flood hazard at the Duane Arnold site. Therefore, the NRC staff determined that channel migration or diversion-related flooding does not need to be analyzed in a focused evaluation or a revised integrated assessment for Duane Arnold.

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

4.1 Reevaluated Flood Elevation for Hazards Not Bounded by the CDB

Section 3 of the staff assessment documents the NRC staff review of the licensee's flood hazard water height results. Table 4.1-1 contains the maximum flood height results, including wave effects, for flood mechanisms not bounded by the CDB. The NRC staff agrees with the licensee's conclusion that the LIP and streams and rivers are the flood hazard mechanisms not bounded by the CDB.

The NRC staff anticipates the licensee will submit a focused evaluation for LIP. For the streams and rivers flood-causing mechanisms, the NRC staff anticipates the licensee will perform additional assessments of plant response, either a focused evaluation or an integrated assessment.

4.2 Flood Event Duration for Hazards Not Bounded by the CDB

The NRC staff reviewed information provided in NextEra's 50.54(f) response (NextEra, 2014) regarding the FED parameters needed to perform the additional assessments of the plant response for flood hazards not bounded by the CDB. The FED parameters for the flood-causing mechanisms not bounded by the CDB are summarized in Table 4.2-1; the NRC staff views the values reported reasonable based on the magnitudes of the estimated flooding hazards.

However, the licensee did not provide the FED values for the time for the LIP event to reach the maximum reported WSE at the impacted door locations (Table 3.2-3), as well as the recession time for water egress from those locations. The licensee is expected to develop FED parameters for these flood-causing mechanisms in order to conduct the MSA[7] and focused evaluations or revised integrated assessments. The NRC staff will review these FED parameters as part of future additional assessments of plant response, if applicable to the assessment and hazard mechanism.

4.3 Associated Effects for Hazards Not Bounded by the CDB

The NRC staff reviewed information provided in NextEra's 50.54(f) response (NextEra, 2014) regarding 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 water elevation, such as wave effects, are provided in Table 4.1-1 of this staff assessment. The AE parameters not directly associated with total water elevation 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 licensee reported hydrostatic and hydrodynamic loads at impacted door locations due to LIP-related flooding at the Duane Arnold site. Based on the relatively low flood depths and corresponding flow velocities, the NRC staff agreed that these associated effects are minimal and the results reported in Table 4.3-1 are reasonable. The licensee is expected to develop the missing AE parameters for the streams and rivers flood-causing mechanism to conduct the MSA[8] and focused evaluations or revised integrated assessments. The NRC staff will review the values for these parameters as part of future assessments of the plant response to the identified flood-causing mechanism, if applicable.

4.4 Conclusion

Based upon the preceding analysis, the NRC staff confirms that the reevaluated flood hazard information defined in Section 4.1 is an appropriate input to the additional assessments of plant response as described in the 50.54(f) letter, COMSECY-15-0019 (NRC, 2015a), and associated guidance.

[7] By letter dated January 25, 2017 (NextEra, 2017), the licensee submitted the Mitigating Strategies Assessment for Duane Arnold. It is currently under review.

[8] By letter dated January 25, 2017 (NextEra, 2017), the licensee submitted the Mitigating Strategies Assessment for Duane Arnold. It is currently under review.

The licensee is expected to develop FED parameters and AE parameters to conduct the MSA and the focused evaluations or revised integrated assessments as discussed in NEI 12-06, Revision 2, Appendix G (NRI, 2015b), JLD-ISG-2012-05 (NRC, 2012d), and JLD-ISG-2016-01, Revision 0 (NRC, 2016c), respectively. The staff will evaluate the missing FED and AE parameters marked as "not provided" in Tables 4.2-1 and 4.3-1 during its review of future additional assessments.[9]

5.0 CONCLUSION

The NRC staff reviewed the information provided for the reevaluated flood-causing mechanisms for Duane Arnold. Based on its review of the above available information provided in NextEra's 50.54(f) response (NextEra, 2014), the NRC 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, the NRC staff confirmed the licensee's conclusions that: (a) the reevaluated flood hazard results for LIP and streams and rivers are not bounded by the CDB flood hazard; (b) additional assessments of plant response will be performed for the local intense precipitation and for flooding from streams and rivers; and (c) the reevaluated flood-causing mechanism information is appropriate input to the additional assessments of plant response as described in the 50.54(f) letter, COMSECY-15-0019, and associated guidance. The NRC has no additional information needs at this time with respect to NextEra's 50.54(f) response.

[9] By letter dated January 25, 2017 (NextEra, 2017), the licensee submitted the Mitigating Strategies Assessment for Duane Arnold. It is currently under review.

6.0 REFERENCES

Notes: ADAMS Accession Nos. refers to documents available through NRC's Agencywide Documents Access and Management System (ADAMS). Publicly-available ADAMS documents may be accessed through http://www.nrc.gov/reading-rm/adams.html.

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

FLOOD-CAUSING MECHANISM	STANDARD REVIEW PLAN (SRP) SECTION(S) AND/OR 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 refers to the "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition" (NRC, 2007).

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

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Table 3.0-1. Summary of Controlling Flood-Causing Mechanism Elevations at the Duane Arnold Site.

REEVALUATED FLOOD-CAUSING MECHANISMS AND ASSOCIATED EFFECTS THAT MAY EXCEED THE POWERBLOCK ELEVATION 757.0 ft MSL (1)		WSE (MSL)
Local Intense Precipitation and Associated Drainage *(Turbine Building)*	*Door Location #124*	758.0 ft
	Door Location #136	758.2 ft
	Door Location #137	758.2 ft
	Door Location #154	758.0 ft
Streams and Rivers *(Cool-Season PMP)*	*Stillwater*	765.2 ft
	Wind/Wave Effects	767.8 ft
(1) Flood height and associated effects as defined in JLD-ISG-2012-05.		

Table 3.1-1. Current Design Basis Flood Hazard Elevations at Duane Arnold

FLOOD-CAUSING MECHANISM	STILLWATER ELEVATION	WAVES/RUNUP	CDB FLOOD ELEVATION	REFERENCE(S)
Local Intense Precipitation and Associated Drainage (1)	Not included in Design-Basis [DB (2)]	Not included in DB	Not included in DB	FHRR Section 3.1
Streams and Rivers	764.1 ft	2.9 ft	767.0 ft	FSAR Section 2.4.3, and FHRR Section 3.9
Failure of Dams and Onsite Water Control/Storage Structures	No Impact to the Site Identified	No Impact to the Site Identified	No Impact to the Site Identified	FHRR Sections 3.3
Storm Surge	Not Included in the DB*	Not Included in the DB*	Not Included in the DB*	FHRR Sections 3.4
Seiche	Not Included in the DB*	Not Included in the DB*	Not Included in the DB*	FHRR Sections 3.5
Tsunami	Not Included in the DB*	Not Included in the DB*	Not Included in the DB*	FHRR Sections 3.6
Ice-Induced	No Impact to the Site Identified	No Impact to the Site Identified	No Impact to the Site Identified	FHRR Sections 3.7
Channel Migrations or Diversions	No Impact to the Site Identified	No Impact to the Site Identified	No Impact to the Site Identified	FHRR Sections 3.8

(1) LIP-related flood waters do enter the Turbine Building and the licensee has a licensing condition that allows for water in the basement of that structure.
(2) Considered by the licensee to not be applicable to the Duane Arnold site.

Table 3.2-1. HMR-52 and Site-Specific 1-hr, 1-mi^2 PMP Depths. Taken from Tables 4-1 and 4-2 of the Duane Arnold FHRR (NextEra, 2014a).

TIME	PMP DEPTH	
	HMR-52	SITE-SPECIFIC
60 min	17.9 in.	14.1 in.
30 min	13.8 in.	10.7 in.
15 min	9.7 in.	7.5 in.
5 min	6.1 in.	4.7 in.

Table 3.2-2. Comparison of Maximum Flow Depths at Four Critical Doors at the Turbine Building Location (Site-Specific LIP case). Door locations depicted in Figure 3.2-5. Taken from NextEra (2016a).

TURBINE BUILDING		MAXIMUM FLOW DEPTH	MAXIMUM WSE
DOOR ID	DOOR LOCATION		
124	Rollup Door (North Building)	0.50 ft	758.0 ft
136	Stairwell 14 to Yard Door	0.84 ft	758.2 ft
137	Rollup Door(South Building)	0.84 ft	758.2 ft
154	Yard Walkout Door (North Building)	0.61 ft	758.0 ft

Table 3.3-1. HMR 51/52 and Basin-Specific 72-h PMP Values.

AREA SIZE (mi^2)	**72-h PMP DEPTH**		
	HMR 51/52, ALL-SEASON (1)	**SITE-SPECIFIC, ALL-SEASON** (1)	**SITE-SPECIFIC, COOL-SEASON** (2)
10	37.0 in.	29.3 in.	15.6 in.
200	29.0 in.	24.7 in.	14.5 in.
1,000	23.2 in.	21.4 in.	13.3 in.
5,000	17.4 in.	16.8 in.	11.6 in.
10,000	15.1 in.	14.8 in.	10.6 in.
20,000	12.9 in.	12.2 in.	9.4 in.

Notes:
(1) Taken from Tables 4-7 and 4-12 of the Duane Arnold FHRR (NextEra, 2014a).
(2) NRC (2016d).

Table 3.3-2. Licensee-Estimated Wind-Wave Results for Various Fetch Directions, Based on an Estimated 2-Yr Wind Speed of 40 mph for Flooding due to Streams and Rivers. Critical fetch direction generating the maximum WSE at the Duane Arnold site indicated by asterisk (*). Taken from NRC (2016d).

FETCH DIRECTION	FETCH LENGTH	PMF STILLWATER ELEVATION (MSL)	WIND SETUP (1)	WAVE SETUP	WAVE RUNUP	TOTAL WSE (MSL)
		A	*B*	*C*	*D*	*(A+B+C+D)*
South*	11,200 ft	765.2 ft	0.1 ft	0.3 ft	2.2 ft	767.8 ft
Southwest	10,000 ft	765.3 ft	0.1 ft	0.3 ft	2.0 ft	767.7 ft
West	1,600 ft	765.3 ft	0.03 ft	0.1 ft	0.8 ft	766.2 ft
Northeast	6,400 ft	765.2 ft	0.08 ft	0.2 ft	1.7 ft	767.2 ft
East	3,600 ft	765.2 ft	0.05 ft	0.2 ft	1.3 ft	766.7 ft
Southeast	3,600 ft	765.2 ft	0.05 ft	0.2 ft	1.3 ft	766.7 ft

(1) Based on Sibul equation (Brater and King, 1976).

Table 4.1-1. Reevaluated Flood Hazards for Flood-Causing Mechanisms Not Bounded by the CDB

FLOOD-CAUSING MECHANISM	STILLWATER ELEVATION	WAVES/RUNUP	REEVALUATED FLOOD HAZARD	REFERENCE
Local Intense Precipitation				
Turbine Building – Door Location # 124	758.0 ft	Minimal	758.0 ft	Email from NextEra Energy (ML16089A396)
Turbine Building – Door Location # 136	758.2 ft	Minimal	758.2 ft	Email from NextEra Energy (ML16089A396)
Turbine Building – Door Location # 137	758.2 ft	Minimal	758.2 ft	Email from NextEra Energy (ML16089A396)
Turbine Building – Door Location # 154	758.0 ft	Minimal	758.0 ft	Email from NextEra Energy (ML16089A396)
Streams and Rivers *(Cool Season Flood)*	765.2 ft	2.6 ft	767.8 ft	NRC (2016d)

Note 1: The licensee was expected to develop flood event duration parameters and applicable flood associated effects to conduct the MSA. The staff will evaluate the flood event duration parameters (including warning time and period of inundation) and flood associated effects during its review of the MSA. The licensee submitted the MSA on January 25, 2017 (NextEra, 2017), and it is under review.
Note 2: Reevaluated hazard mechanisms bounded by the current design basis (see Table 1) are not included in this table.
Note 3: Reported values are rounded to the nearest one-tenth of a foot.

Table 4.2-1. Flood Event Duration for Flood-Causing Mechanisms Not Bounded by the CDB

FLOOD-CAUSING MECHANISM	TIME AVAILABLE FOR PREPARATION FOR FLOOD EVENT	DURATION OF INUNDATION OF SITE	TIME FOR WATER TO RECEDE FROM SITE
Local Intense Precipitation and Associated Drainage (1) *(Turbine Building Location)*	24 h	Not Provided	Not Provided
Streams and Rivers(2)	113 h	72 h	28 h

(1) The licensee has the option to use NEI guideline 15-05 (NEI, 2015a) to estimate the warning time necessary for flood preparation.
(2) The durations were taken from the licensee's MSA, which was submitted on January 25, 2017 (NextEra, 2017), and is under review.

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

FLOOD-CAUSING MECHANISM		MAXIMUM VELOCITY	MAXIMUM FLOW DEPTH	MAXIMUM HYDROSTATIC LOAD	MAXIMUM HYDRODYNAMIC LOAD	DEBRIS LOADING EFFECTS	SEDIMENT LOADING EFFECTS
Local Intense Precipitation and Associated Drainage *(Turbine Building Location)*		< 7.35 fps	< 0.84 ft	Minimal	Minimal	Minimal	Minimal
Streams and Rivers	*Site (Overbank Area)*	Not Estimated	Not Estimated	113 lb/ft^2	37 lb/ft^2	Not Provided	Not Provided
	Intake Structure (River Channel)	Not Estimated	Not Estimated	20,000 psi	547 psi	Not Provided	Not Provided

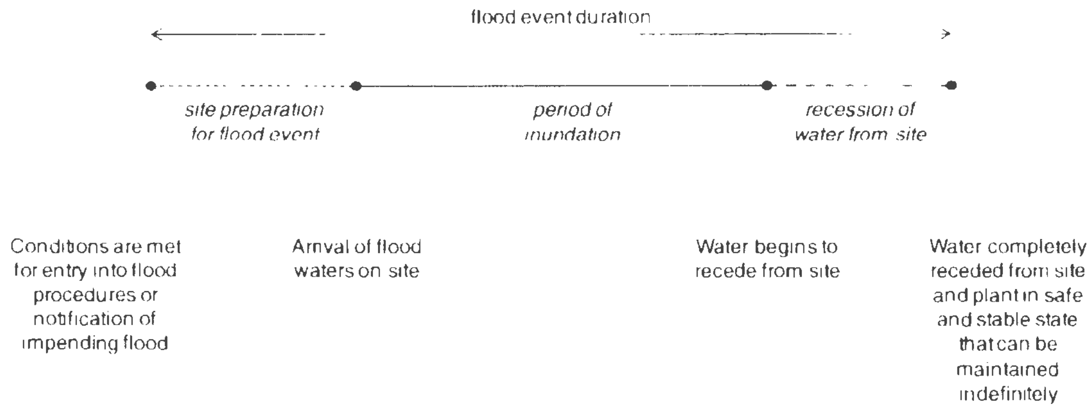

Figure 2.2-1. Flood Event Duration (NRC JLD-ISG-2012-05, Figure 6)

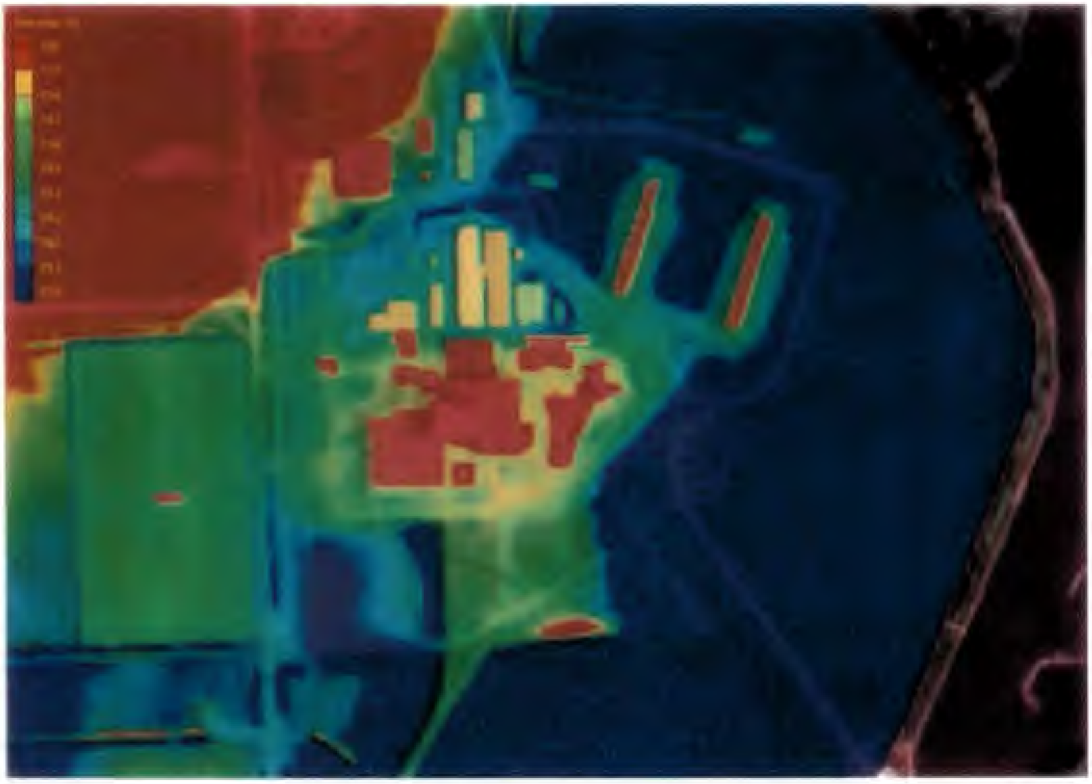

Figure 3.2-1. Duane Arnold Site Elevation Map Based on FLO-2D Model Grid Information. Figure generated by NRC staff using licensee's FLO-2D input files.

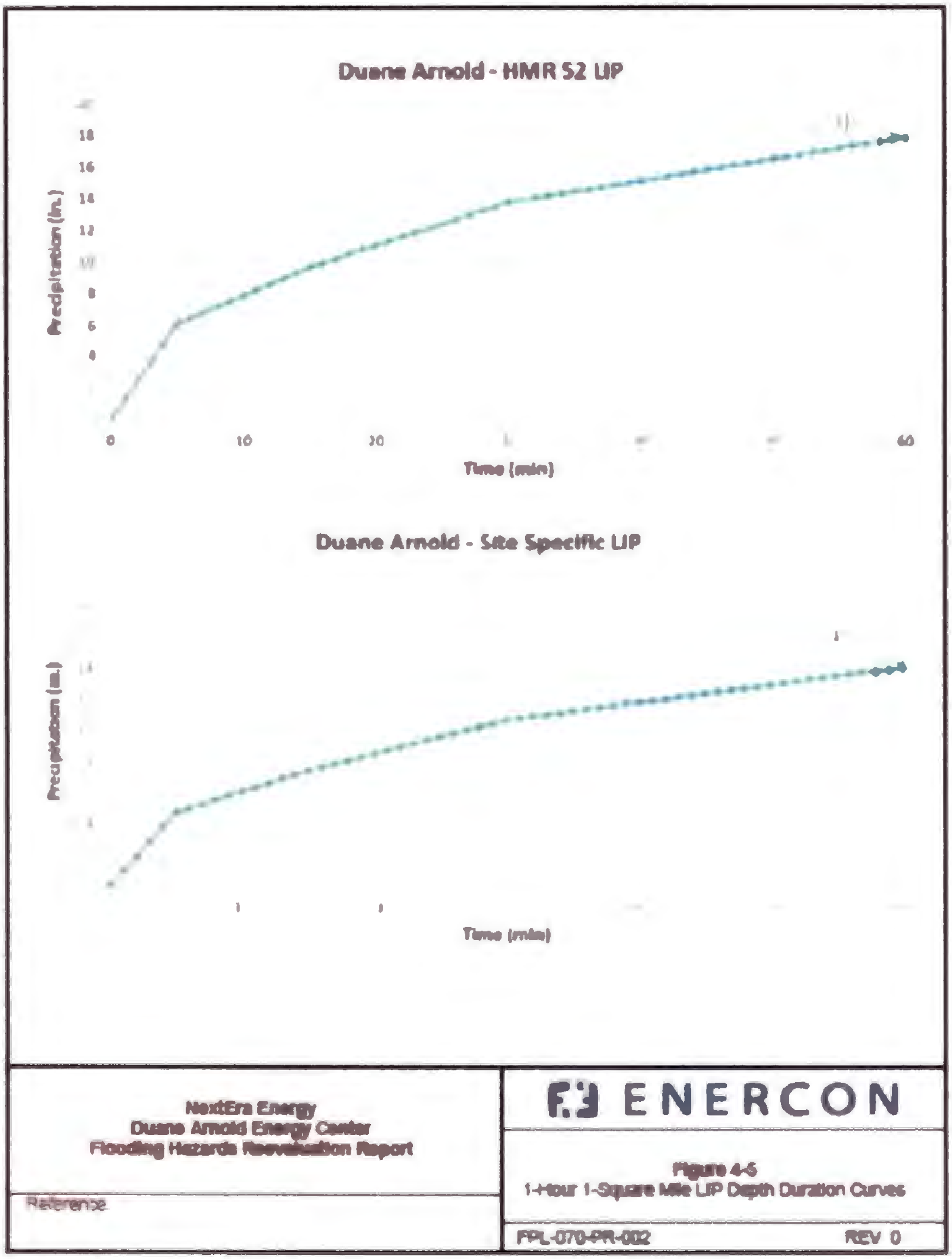

Figure 3.2-2. Comparison of 1-h, 1-mi² LIP Cumulative Precipitation Depth Based on HMR 51/52 and ssPMP Evaluation Methods (NextEra, 2014a, Figure 4-5).

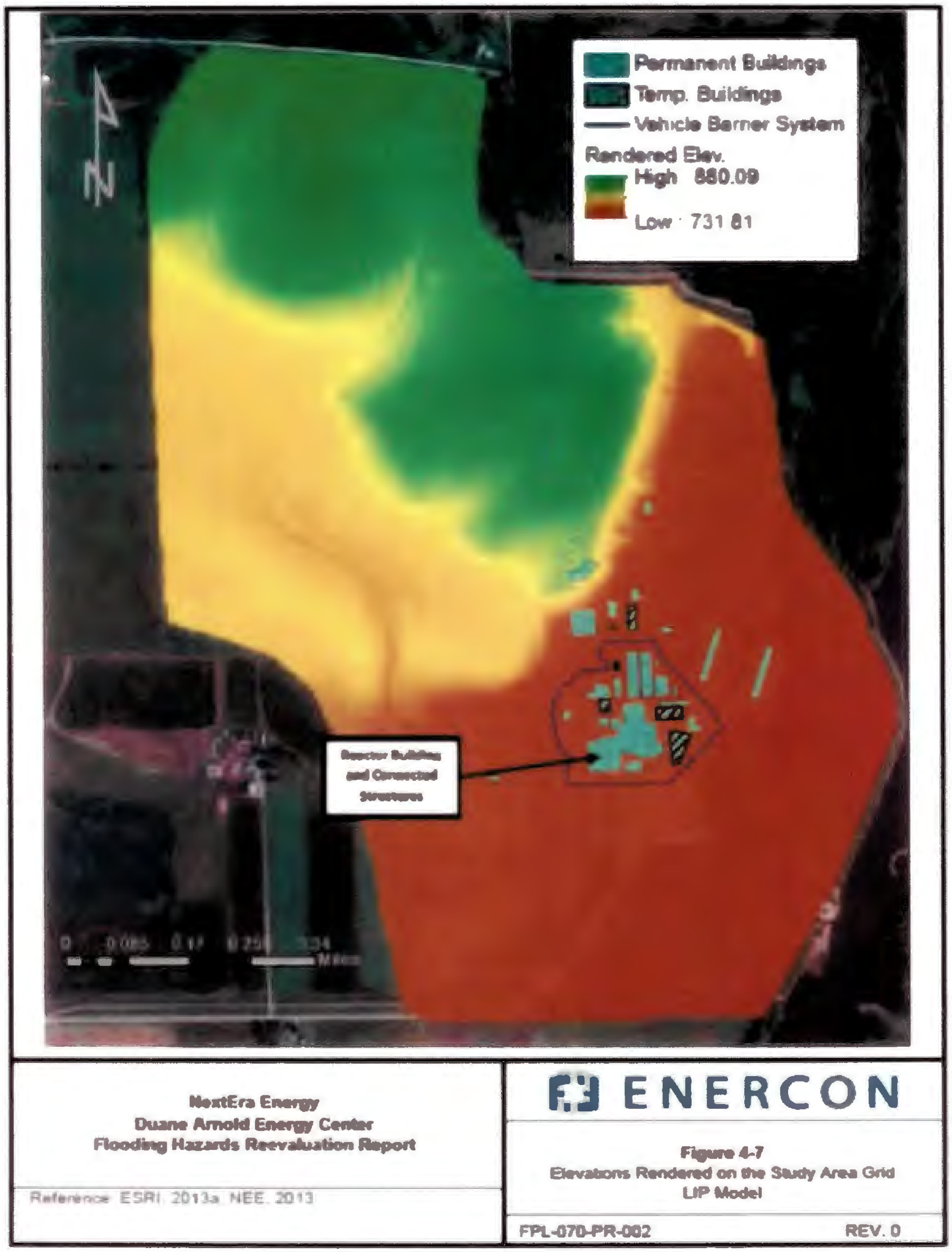

Figure 3.2-3. Building and VBS Structures Identified for the Duane Arnold FLO-2D Model (NextEra, 2014a, Figure 4-7).

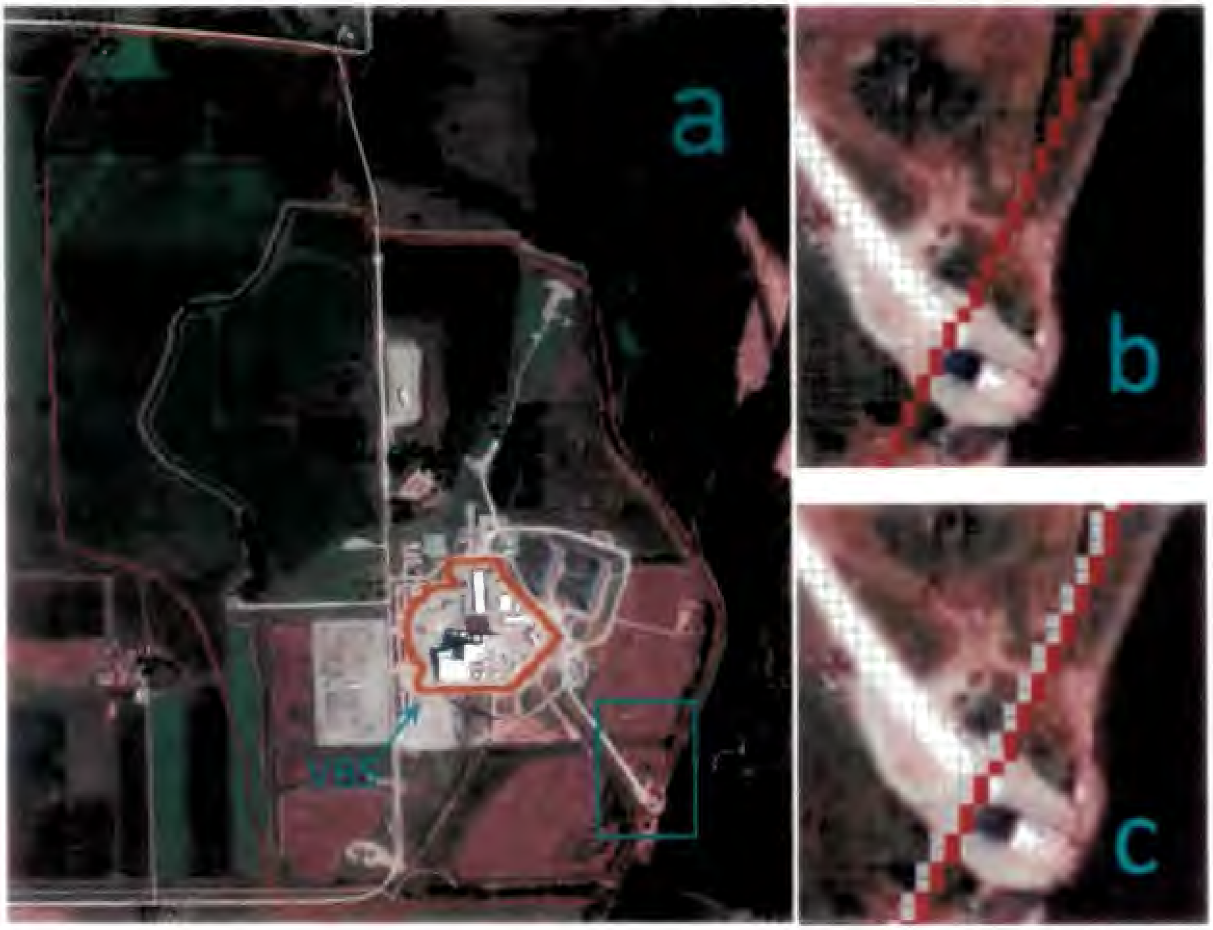

Figure 3.2-4. FLO-2D Model Domain. (a) Overlaid on Aerial Imagery with VBS Modeled Using the ARF/WRF Option in FLO-2D. The two insets show the boundary configuration by the licensee (b) compared to the revised configuration by the staff (c). The red markers in (b) and (c) indicate the model boundary and blue hatched markers in (c) denote outflow boundary elements added by the staff.

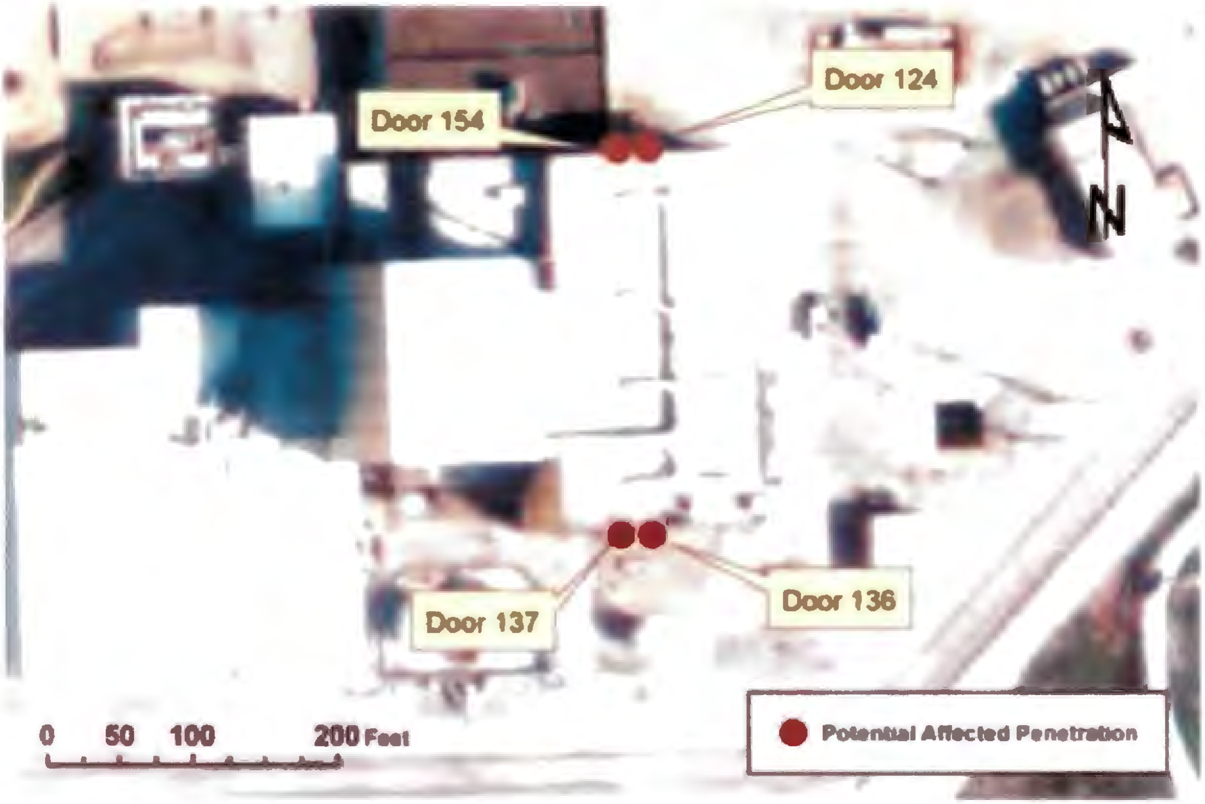

Figure 3.2-5. Turbine Building Door Locations were the CDB is exceeded due to LIP (NextEra, 2016a, Figure 4-9).

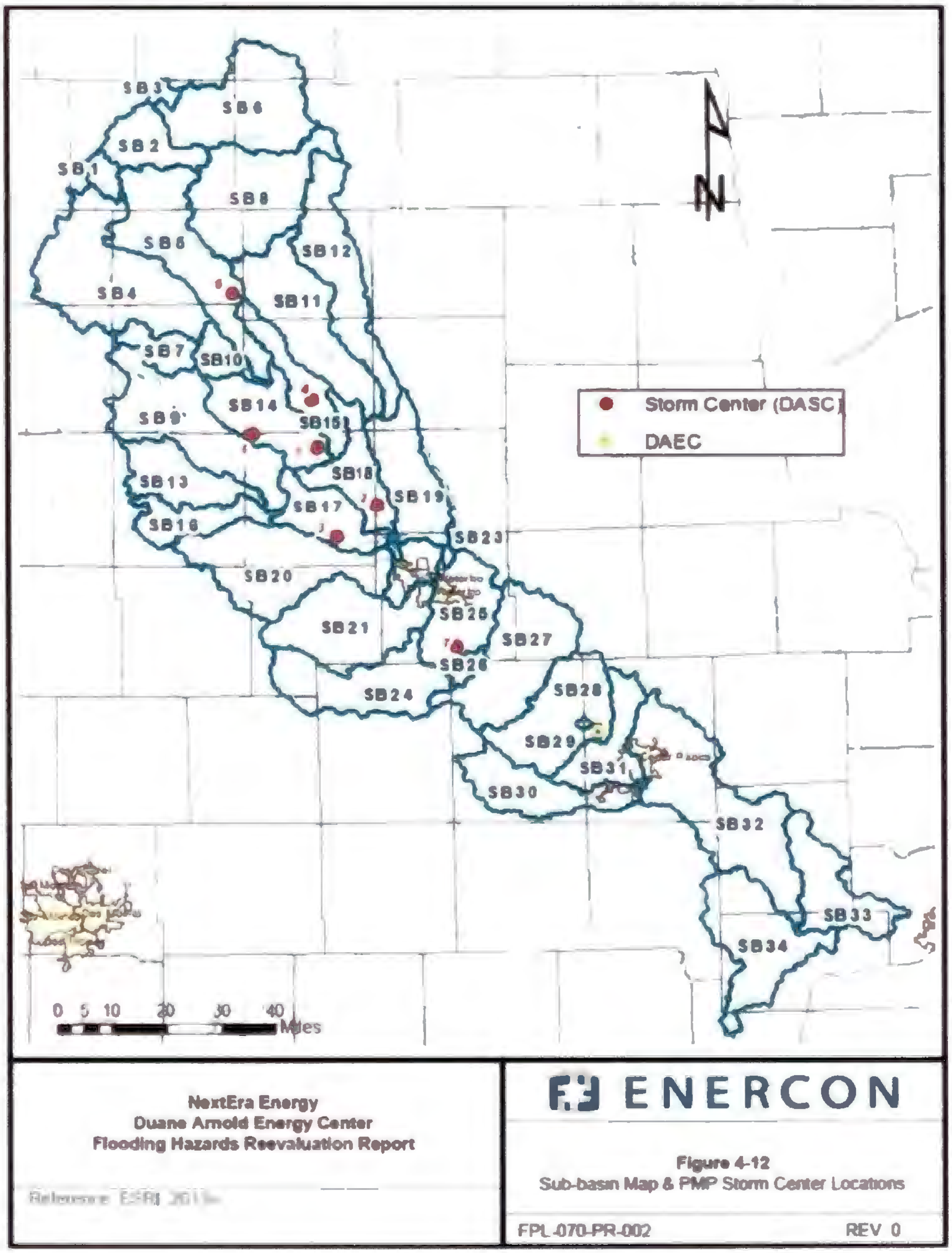

Figure 3.3-1. Cedar River Watershed and its Sub-basins at the Confluence of Cedar and Iowa Rivers, Showing Positions of the Seven Storm Centers (•) used to Develop Estimates of a Probable Maximum Precipitation (NextEra, 2014a, Figure 4-12).

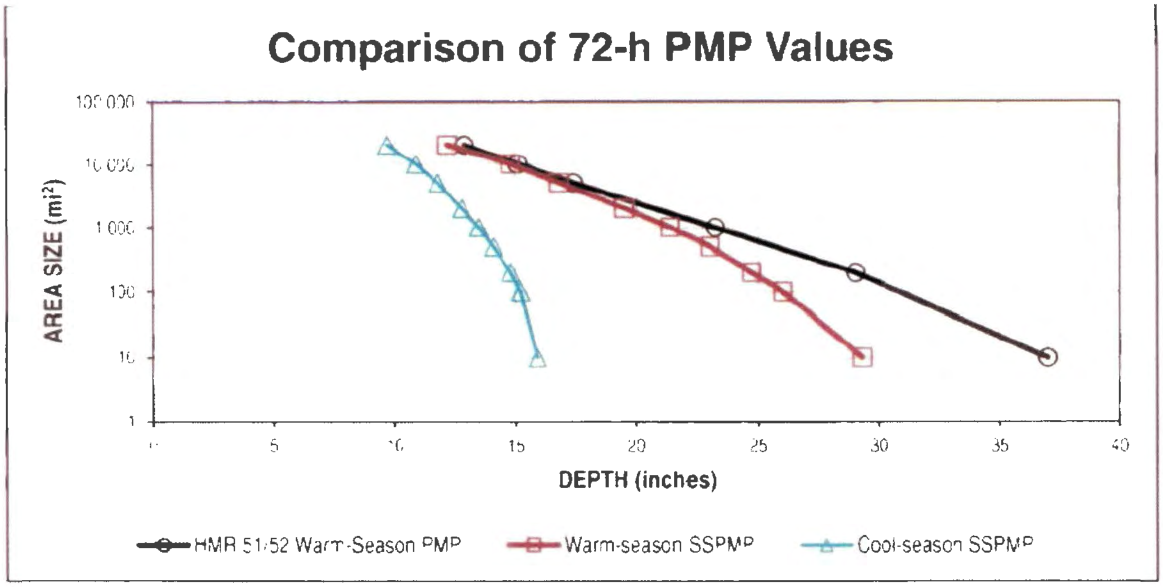

Figure 3.3-2. Comparison of HMR Warm-season PMP with the Warm-season and Cool-Season SSPMP. Adapted from Tables 4-7, 4-12, and 4-13 of the Duane Arnold FHRR (NextEra, 2014a).

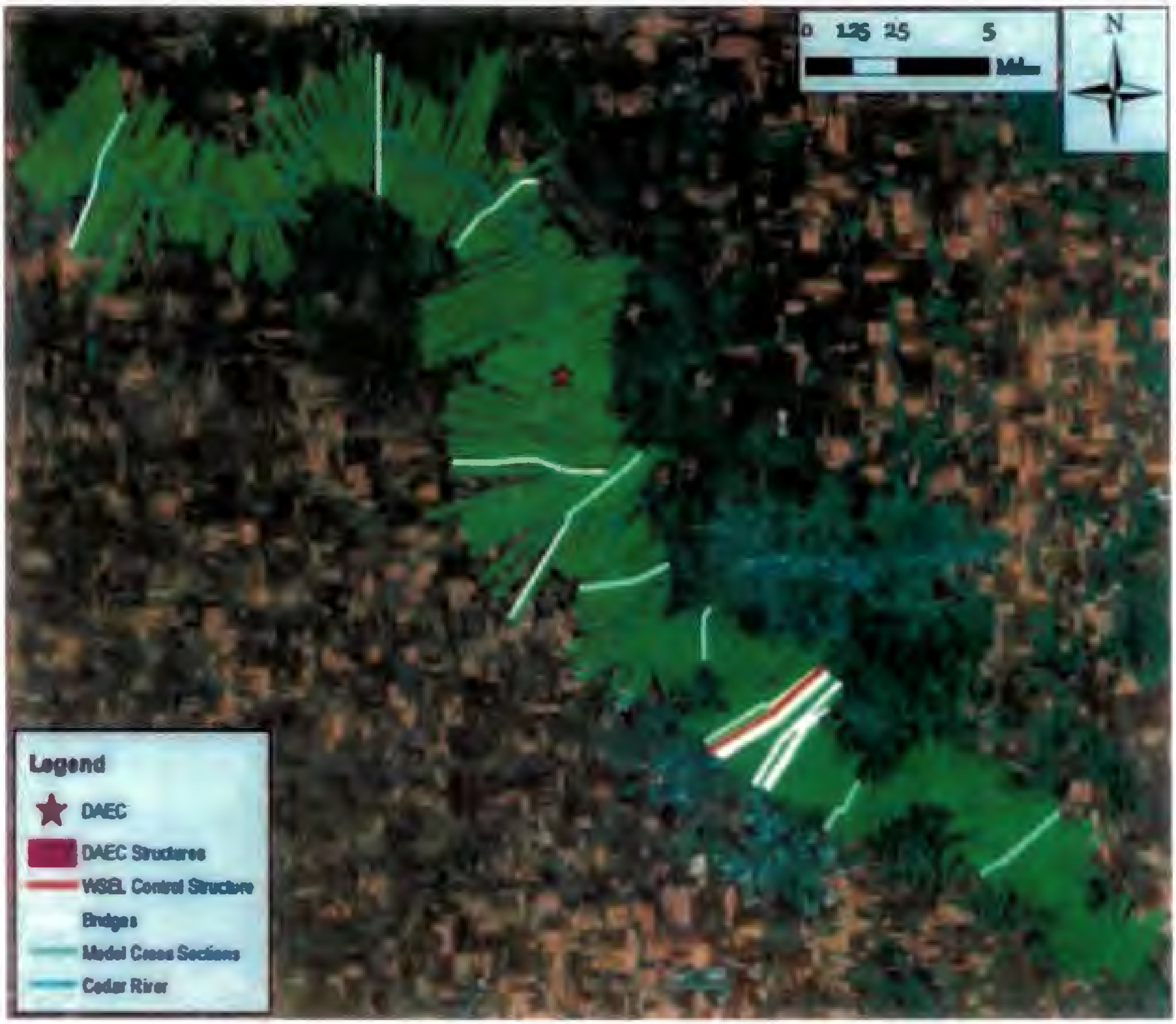

Figure 3.3-3. HEC-RAS Model for the Cedar River near Duane Arnold (NextEra, 2014a, Figure 4-33).

DUANE ARNOLD ENERGY CENTER – STAFF ASSESSMENT OF RESPONSE TO 10 CFR 50.54(f) INFORMATION REQUEST – FLOOD-CAUSING MECHANISM REEVALUATION DATED APRIL 3, 2017

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