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Screening Analysis Report for the Proposed Generic Issue on Flooding of Nuclear Power Plant Sites Following Upstream Dam Failures

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List of Acronyms

ADAMS: Agencywide Documents Access and Management System
ANSI: American National Standards Institute
ASDSO: Association of Dam Safety Officials
FSAR: Final Safety Analysis Report
IPEEE: Individual Plant Examinations of External Events
MSL: Mean Sea Level
NOAA: National Oceanic and Atmospheric Administration
NRC: Nuclear Regulatory Commission
PMF: Probable Maximum Flood
USACE: United States Army Corps of Engineers

1. Introduction

This analysis report is provided as part of the Generic Issue Program screening stage for a proposed Generic Issue related to flooding of nuclear power sites following upstream dam failures. The proposed issue was accepted[1] on August 9, 2010. Analysis was conducted per U.S. Nuclear Regulatory Commission (NRC) Management Directive 6.4, "Generic Issues Program," and considered these seven criteria as outlined therein:

1. The issue affects public health and safety, the common defense and security, or the environment.
2. The issue applies to two or more facilities and/or licensees/certificate holders, or holders of other regulatory approvals.
3. The issue cannot be readily addressed through other regulatory programs and processes; existing regulations, policies, or guidance; or voluntary industry initiatives.
4. The issue can be resolved by new or revised regulation, policy, or guidance.
5. The issue's risk or safety significance can be adequately determined (i.e., it does not involve phenomena or other uncertainties that would require long-term studies and/or experimental research to establish the risk or safety significance).
6. The issue is well-defined, discrete, and technical.
7. Resolution of the issue may potentially involve review, analysis, or action by the affected licensees, certificate holders, or holders of other regulatory approvals.

For the proposed issue to be recommended as a formal Generic Issue, the issue must have the potential to meet all seven of the above criteria. As explained in Management Directive 6.4, the screening review is not required to argue that the issue decisively meets the criteria. Rather, the screening analysis is intended to determine whether a reasonable possibility exists that the criteria are met and whether continued evaluation of the issue under the program is warranted. With this guidance in mind, the staff must provide a recommendation to either accept the issue as a bona fide Generic Issue or reject it.

The scope of the review is not limited by the content of the original issue proposal (USNRC 2010d) but the proposal serves as the basis for the review. The proposal lists 20 currently operating sites where the issue is suggested to be a factor. All of the sites are potentially affected by upstream (flooding) or downstream (loss of ultimate heat sink) dam failures. The scope of this screening analysis is limited to external flooding due to upstream dam failures. Of the 20 sites listed, the proposal provides additional discussion of two sites: Oconee Nuclear Station and Fort Calhoun Station. Regulatory activity related to flooding and/or dam failure analysis recently occurred at these stations.

With regard to Oconee Nuclear Station, recent estimates of the resulting flood levels from failure of the upstream dam have increased substantially relative to previous estimates, and the site is theorized to enter station blackout due to loss of offsite and station power (ONS 1995, p. 5-23) and the final remaining power source in the Standby Shutdown Facility as it is overcome by high water levels(Duke

[1] The acceptance review is the first stage of review as specified in MD 6.4.

2008, att. 2, p.10). Section 2 discusses this matter in greater detail. Fort Calhoun Station was issued a yellow finding for failure to maintain external flooding procedures. Under certain flood conditions, procedures call for the placement of sandbags and other pre-fabricated flood barriers to protect critical equipment from floodwaters up to 1,014 feet (ft) above mean sea level (MSL). However, the finding indicated that it was not clear that the procedures could be readily executed if required during a flooding scenario. Upstream dam failures would exacerbate the current flooding issue (USNRC 2010h).

As part of the screening analysis, a review was performed of the existing NRC regulatory framework addressing flood hazard. Plant[2]-specific documents were reviewed including Final Safety Analysis Reports[3] (FSARs), Individual Plant Examinations of External Events (IPEEE) submittals, and regulatory enforcement documents. These documents are referenced and discussed throughout the report. Section 2 provides detailed discussions of Fort Calhoun Station and Oconee Nuclear Station. Knowledge gained from the review of plant-specific documents suggests that comparable conditions may exist at other sites with similar physical characteristics. In Section 3, the existing NRC regulatory framework is described as it applies to flooding because of upstream dam failure. In addition, the report describes the evolution of regulations and the implications of these changes. Section 4 provides a recommendation regarding the placement of this issue in the Generic Issues Program.

2. Background and Implications of Recent Regulatory Activity at Fort Calhoun Station and Oconee Nuclear Station

2.1. Fort Calhoun Station

Fort Calhoun Station is located on the west bank of the Missouri River 19 miles north of Omaha. Figure 1 shows an aerial photograph of Fort Calhoun Station relative to the adjacent river. The base plant elevation (1,004ft MSL) is not substantially higher than normal river levels. The Updated Safety Analysis Report (USAR) specifies that the design flood elevation is 1,006ft MSL (FCS 2010, p. 8). In 1993, the U.S. Army Corps of Engineers estimated the probable maximum flood (absent upstream dam failure) to be 1,009.3ft MSL (FCS 2010, p.7). Without special provisions, safety-related components at the plant are protected from flooding by hardened features up to an elevation of 1,007ft MSL. Floodgates permanently mounted adjacent to openings can be installed to provide further flood protection of most components up to an elevation of 1,009.5ft MSL (FCS 2010, p.8). The intake structure is located at an elevation of 1,007.5ft MSL (FCS n.d., p. 5-24). Protection of the intake structure to an elevation of 1,009.5ft MSL is accomplished through a combination of both floodgates and sandbags (FCS 2010, p.8). The licensee has indicated that it will use sandbags, temporary earth levees, and other methods to allow safe shutdown up to an elevation of 1,013ft MSL (FCS 2010, p. 8). Based on more recent information (USACE 2004), NRC documents (USNRC 2010d, USNRC 2010h) have questioned the accuracy of existing flood estimates included in plant specific documents. Figure 2 illustrates the flood water levels for a variety of flood events (based on estimates produced by different agencies, as indicated in plant specific documents) as well as flood protection elevations.

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[2] Throughout this report, the term “plant(s)” means United States nuclear power plant(s).

[3] Several different terminologies are used by licensees to describe these reports including Final Safety Analysis Report (FSAR), Updated Safety Analysis Report (USAR), Safety Analysis Report (SAR), and Updated Final Safety Analysis Report (UFSAR). In this report, the preferred term is FSAR; however, when discussing individual plants, this report uses the term used by the licensee.

Figure 1: Aerial Photograph of Fort Calhoun Station

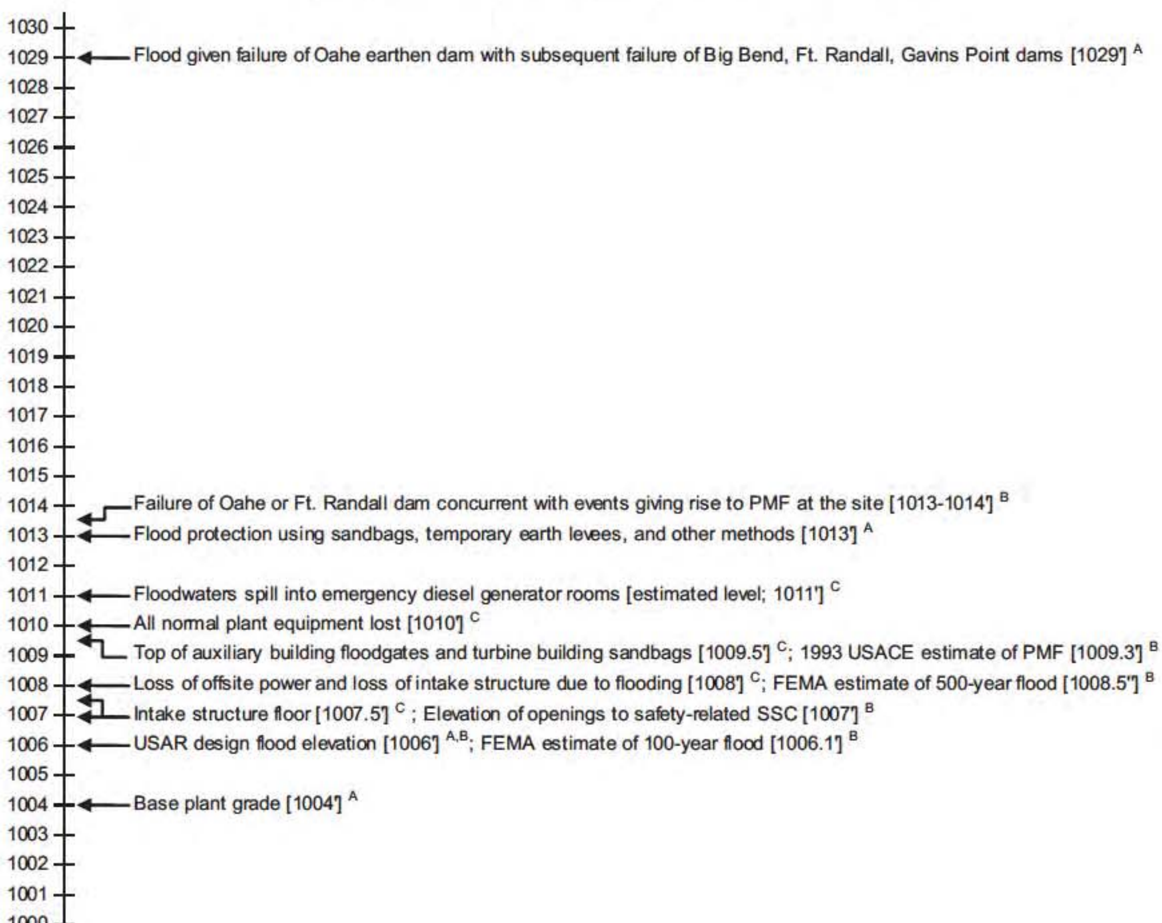

Figure 2: Flood Water and Flood Protection Elevations at Fort Calhoun Station
Citations: [A]**(FCS n.d., p. 5.19-5.20, 5-24)**; [B]**(FCS 2010, p.7-8)**; [C]**(USNRC 2010h)**

Inspectors have identified an apparent violation of Technical Specification 5.8.1.a at Fort Calhoun Station for failure to maintain adequate procedures to protect the intake structure and auxiliary building during external flooding events. It was determined that it is not sufficient to stack and/or drape sandbags on floodgates to protect the aforementioned structures up to an elevation of 1,013ft MSL (as credited in the USAR and in station operating procedures). The flat surface on the top of the floodgates is too narrow to support a stacked sandbag configuration capable of retaining 4 feet static head of water. Moreover, the required actions pose a safety risk to plant personnel (USNRC 2010h). The Significance Determination Process has resulted in the issuance of a yellow finding regarding this apparent violation (USNRC 2010b).

The Significance Determination Process results described above are based on consideration of external flooding due to events that exclude dam failures. Figure 3 shows the location of Fort Calhoun Station with respect to upsteam dams. Figure 2 provides the water levels associated with dam failure events. The IPEEE submittal (referencing an Army Corps of Engineers study) indicates that failure of Oahe dam, with subsequent failure of Big Bend, Fort Randall, and Gavins Point dams, will cause a flood at the site with a peak elevation of 1,029ft MSL (FCS n.d., 5-20); this event was screened out due to low probability of occurrence in the IPEEE. This flood level is in excess of the flood elevation reported in the USAR. The flood levels projected in the IPEEE submittal will overtop all permanent and temporary barriers, though the distance between the dams and the site provides warning time. As illustrated above, recent regulatory activity suggests that Fort Calhoun Station may not have been protected from flooding even without consideration of upstream dam failure. An upstream dam failure further exacerbates this condition. Details about the ongoing activities at Fort Calhoun Station in response to the above yellow finding can be found in a letter from Omaha Public Power District to NRC (OPPD 2010).

Figure 3: Location of Fort Calhoun Station Relative to Upstream Dams[4]

2.2. Oconee Nuclear Station

Oconee Nuclear Station (ONS) is located about 30 miles west of Greenville, South Carolina. The site is downstream from Jocassee Dam and adjacent to Keowee Dam (Figure 4 provides a map and Figure 5 provides aerial photographs of Oconee Nuclear Station). Jocassee Dam is located about 11 miles upstream of Oconee Nuclear Station (ONS 2009, p. 2.4-1). The full pond elevation of the water retained by Jocassee Dam is about 300 feet above Lake Keowee, which is retained by Keowee Dam. The Oconee Nuclear Station has a yard grade that is a few feet below the full pond level of Lake Keowee (ONS 1995, p. 5-19).

[4] Maps, aerial photographs, and overhead images used in the report are created using Google Maps (Google 2011) and Bing Maps (Microsoft 2011)

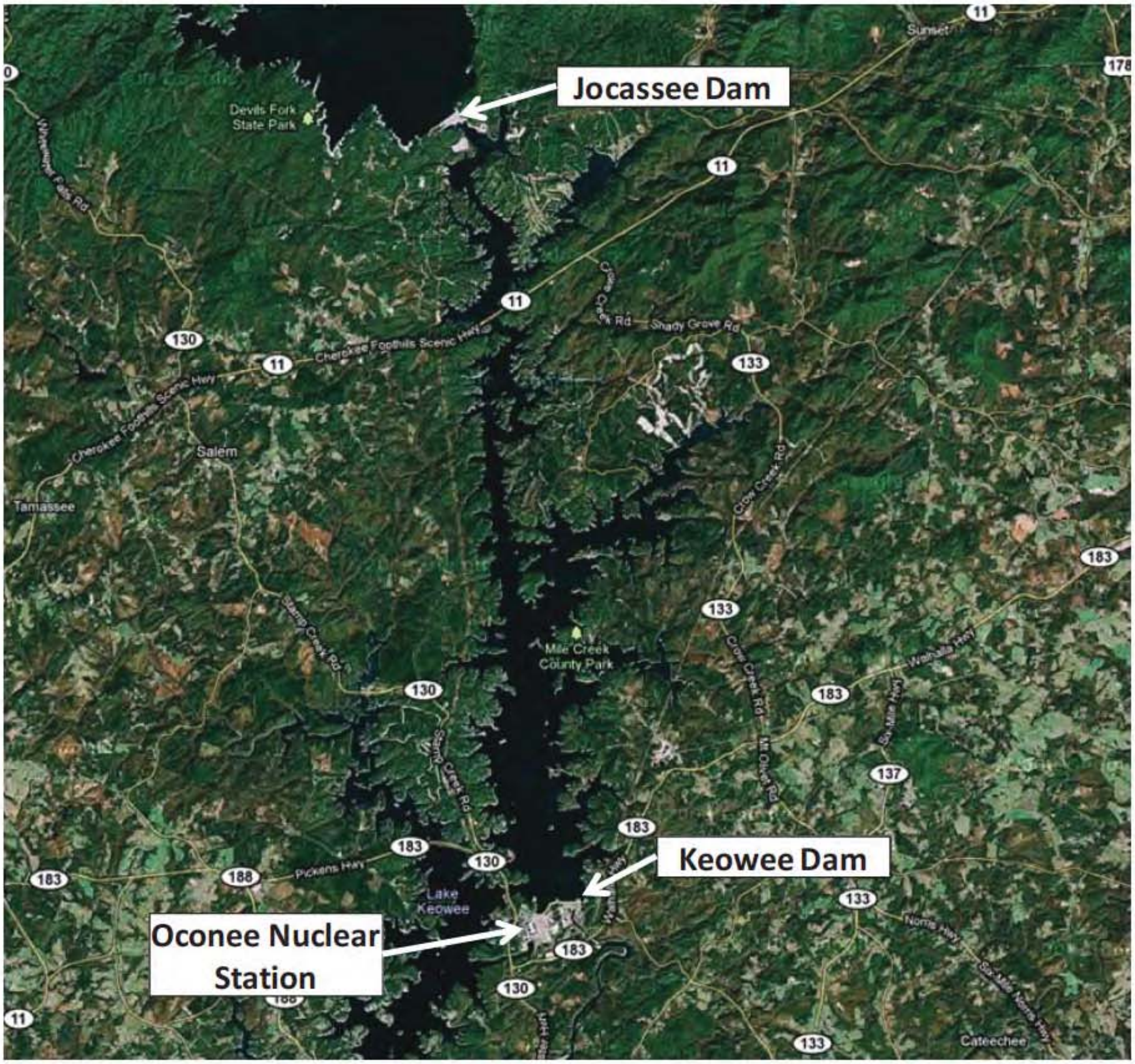

Figure 4: Location of Keowee and Jocassee Dams Relative to Oconee Nuclear Station

Figure 5: Aerial Photographs of Oconee Nuclear Station

The current licensing basis for Oconee Nuclear Station did not consider the impact of failure of Jocassee Dam when calculating potential flood levels at the site. Based on a letter written by Duke Energy in 2008, failure of Jocassee Dam has been considered a beyond design basis event and managed as a risk assessment issue (Duke 2008, att. 1, p. 7). A more recent NRC letter (USNRC 2009) indicates that the NRC staff's position is that a Jocassee Dam failure is a credible event and needs to be addressed deterministically. In the same letter, NRC staff expressed concerns that Duke has not demonstrated that the Oconee Nuclear Station units will be adequately protected.

A sudden catastrophic failure of the Jocassee Dam is postulated to result in a flood wave that would overtop Keowee Dam as well as overtop the Oconee intake dike and would flood the plant (ONS 1995, 5-19). Flooding of the plant yard is expected to inundate the switchyard and eliminate offsite and station power (ONS 1995, 5-23). With station, offsite, and emergency hydropower from adjacent Keowee Dam unavailable, the Standby Shutdown Facility (an emergency generator facility) provides the only remaining shutdown power for all three units at Oconee Nuclear Station following loss of offsite and station power (ONS 2009, p. 9.6-1). If the Standby Shutdown Facility flood barriers overtop, the Standby Shutdown Facility will fail (Duke 2008, att. 2, p. 10), resulting in station blackout. This insight has led to a change in understanding with regard to the flooding protection capabilities of the plant given the original flooding studies and has resulted in ongoing regulatory activity related to Oconee Nuclear Station. The licensee has developed an action plan and has begun physical modification at the Oconee Nuclear Station site to mitigate the consequences of a potential Jocassee Dam failure.

In 1983, Duke Energy Corporation evaluated external flooding effects at Oconee Nuclear Station for risk assessment purposes. That study determined that the projected flood height in the Oconee Nuclear Station yard resulting from failure of Jocassee Dam was 4.71ft. In 1984, the licensee constructed a 5-foot high floodwall to protect the Standby Shutdown Facility as a mitigation measure (Duke 2008, att 1, p. 7).

In 1992, Duke Energy Corporation performed an inundation study at the request of the Federal Energy Regulatory Commission. The goal of the study was to evaluate the downstream effects of failure of Jocassee Dam under the “worst possible conditions” for inclusion in the emergency action plans of the hydroelectric facilities located downstream of Jocassee Dam. The study evaluated two conditions – a “sunny-day” break under normal operating conditions and a break during a probable maximum flood (PMF) event. The licensee considered both modes to be “not credible” and emphasized that the goal of the study was not to credibly compute flood levels at Oconee Nuclear Station (Duke 2008, att 2, p. 3,4). Instead, the inputs and assumptions used in the analysis were conservatively selected with the goal of computing bounding flood levels for use in the emergency action plans (Duke 2008, att 2, p. 8). The conditions assumed under the 1992 study resulted in postulated flood heights in the station yard in excess of the 5 feet estimated under the 1983 study (Duke 2008, att 1, p. 8, USNRC 2006a) and consequently above the flood protection elevation of the Standby Shutdown Facility. Studies that are more recent have also computed flood heights that exceed the flood protection elevation of the Standby Shutdown Facility (Duke 2009, Duke 2010). The following timeline (which begins with dam failure) is an excerpt from a Duke letter, which is based on results of the 1992 study:

> Notification from Jocassee would occur before a total failure of the dam; however, for purposes of this timeline, notification is assumed to be at the same time the dam fails. Following notification from Jocassee, the reactor(s) are shutdown within approximately 1 hour. The predicted flood would reach [Oconee Nuclear Station] in approximately 5 hours, at which time the [Standby Shutdown Facility] walls are overtopped. The [Standby Shutdown Facility] is assumed to fail, with no time delay, following the flood level exceeding the height of the [Standby Shutdown Facility] wall. The failure scenario results are predicted such that core damage occurs in about 8 to 9 hours following the dam break and containment failure in about 59 to 68 hours. When containment failure occurs, significant dose to the public would result. (Duke 2008, att 2, p.10)

The above timeline assumes that Oconee Nuclear Station is notified at the same time the dam fails. The licensee considers this assumption to be conservative because the plant expects notification before the dam fails (the dam is monitored 24 hours a day, 7 days a week). The licensee notes that the above timeline does not account for the recession of floodwaters, which is postulated to occur 10 hours following dam failure (5 hours following onset of flooding at the site) (Duke 2008, att 2, p.10).

In the Oconee Nuclear Station IPEEE submittal (ONS 1995, p.5.27), the licensee estimates that the conditional core damage frequency resulting from flooding due to failure of the Jocassee Dam is $7.0(10^{-6})/\text{year}$ (ONS 1995, p. 5-27). The contribution to core damage frequency from precipitation-induced external flooding is considered negligible (ONS 1995, p. 5-18). The licensee notes that this external flood core-damage frequency is of the same magnitude as other severe accident events (e.g., earthquakes, fires). Consequently, in the IPEEE, the licensee concluded that external flooding does not pose severe accident vulnerability (ONS 1995, p. 5-27).

The aforementioned estimate of conditional core-damage frequency is based on an estimate (made by the licensee) that the probability of a random failure of Jocassee Dam is $1.3(10^{-5})/\text{year}$ (ONS 1995, p. 5-21). This failure rate includes failures due to seepage, embankment slides, and structural failure of the foundation or abutments. It does not include failures due to earthquakes or overtopping (ONS 1995, p.5-21). In 2010, NRC staff produced a report that estimates a typical dam failure rate for large rock fill dams similar to the Jocassee Dam to be $2.8(10^{-4})/\text{year}$ (USNRC 2010c). This NRC estimate is an order of magnitude larger than the estimate reported in the Oconee Nuclear Station IPEEE submittal. The database used by NRC staff to calculate the estimated failure rate includes failures due to overtopping, internal erosion, and settlement. Due to a lack of earthquake-induced failures affecting dams with characteristics similar to Jocassee Dam, the database does not contain failures due to seismic events.

As illustrated above, several uncertainties exist with regard to the risk posed to Oconee Nuclear Station due to upstream dam failure. In particular, uncertainty exists about the flood levels at the site that would result from failure of Jocassee Dam. Moreover, hazard due to external flooding was “screened out” in the IPEEE based on a sufficiently small contribution to core damage frequency as calculated at the time. However, uncertainty exists about the appropriate probability of dam failure that should be used in computing the contribution of external flooding to core damage frequency. This is illustrated by the disparate results of the separate analyses described above that differ by an order of magnitude in estimating the probability of failure of Jocassee Dam.

2.3. Applicability of Proposed Generic Issue to Multiple Plants

It is notable that an exclusive review of FSAR and IPEEE submittals would not necessarily indicate a potential problem due to external flooding hazard in either of the above-described cases (i.e., Fort Calhoun Station or Oconee Nuclear Station). Problems at Fort Calhoun Station were recognized because of an NRC inspection that identified an apparent violation of Technical Specification 5.8.1.a for failure to maintain adequate procedures to protect the plant during external flooding events (USNRC 2010b). At Oconee Nuclear Station, attention was drawn to the elevated consequence from external flooding after staff identified a performance deficiency during maintenance activities that involved the installation of temporary electrical cables through an opening in the flood protection wall (USNRC 2006b, p. 1). This performance deficiency was of particular concern when coupled with flooding estimates that are significantly higher than previously assumed (USNRC 2006a). Thus, in these two cases, identification of flood-related issues resulted from particular scrutiny and analysis of flood protection preparations, assumptions, and procedures. It is unlikely that concerns related to dam-failure flooding at these two sites would have stood out based on the FSAR and IPEEE documents alone.

For other plants listed in the Generic Issue proposal, sufficient additional information is not readily available to the staff reviewers to support a conclusive assessment regarding risks posed by external flooding due to dam failure. Without detailed study and interaction with licensees, available information related to external flooding for these sites is generally limited to the FSARs and IPEEE submittals. As described above, exclusive consideration of these documents may not readily indicate a problem exists related to external flooding because of upstream dam failure. Consequently, it is useful to identify characteristics of Oconee Nuclear Station and Fort Calhoun Station that may make them susceptible to risks of flooding that are higher than initially estimated. Such characteristics can serve as indicators for identifying other plants that also may have external flood risks that are higher than originally estimated or assumed. This argument serves to demonstrate the applicability of the Proposed Generic Issue to multiple sites, which is an important component of passing a Proposed Generic Issue through the screening stage.

A significant contributor to the elevated risk at Fort Calhoun Station comes from its reliance on the placement of temporary barriers to protect the plant during a large external flood event. These protective measures require significant physical actions on the part of plant personnel. Consequently, a nontrivial probability exists that the procedures will be unsuccessful. In the case of Fort Calhoun Station, the physical characteristics of certain plant structures make it difficult to place the temporary barriers (USNRC 2010h, encl., p. 5). Fort Calhoun Station is not the only plant to rely on the placement of temporary protective measures. For example, Cooper Nuclear Station (CNS n.d., p. 5-11)[5], Vermont Yankee Nuclear Power Station (VYNPS 1998, p. 161)[6], and Arkansas Nuclear One (ANO2 2007, p. 2.4-17,18)[7] rely on the placement of temporary barriers or connections such as sandbags, wood planks, and temporary power cables. Three Mile Island Nuclear Station is another example of a plant that requires actions on the part of plant personnel (e.g., installation of flood gates and plugging of openings) (TMI 2010, p. 2.6-12 to 15). In addition, a subset of plants have technical specifications in place that require plant shutdown (or placement of the plant in hot standby) when floodwaters reach a predefined threshold. Examples of such plants include Prairie Island Nuclear Generating Plant (PINGP

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[5] Cooper Nuclear Station has an emergency procedure to install sandbags and wood planks (during certain flood conditions) to protect critical equipment from a large flood. The Cooper Nuclear Station IPEEE submittal notes that the procedure was successfully implemented at Cooper Nuclear Station during a flood in 1993. As a result, Cooper Nuclear Station has confidence in the ability of the plant staff and personnel to mitigate the flood event using these procedures.

[6] Vermont Yankee Nuclear Power Station Procedure OP 3127, “Natural Phenomena,” deals with external flooding. Actions required under this procedure include “constructing sandbag barricades around all plant doors; securing TBCCW sump pumps; verifying the valve on Oil Separator Manhole No. B is closed; installing plugs in the 4 kV Switchgear Room floor drain and the floor drain at the north door of the Service Building Addition; monitoring Switchgear Room manholes, monitoring CW and SW pump operation; and alternate cooling system startup” (VYNPS 1998, p. 161).

[7] Procedures specify that Arkansas Nuclear One will be shut down by the time flood levels reach 354ft (the elevation at which flooding of the turbine building will commence). The unit 2 FSAR indicates: “it will be necessary to install temporary connections over the 161 kV switchyard to connect Startup Transformer 2 directly to the 161 kV Pleasant Hill transmission line in the event that the flood level exceeds elevation 356 feet, six inches so as to maintain one source of off-site power to the plant. Since the plant will be shut down before the flood reaches an elevation of 354 feet, these temporary connections are not necessary to safely shut down the plant” (ANO2 2007, p. 2.4-18).

2010, p. 2.4-6), Beaver Valley Power Station (BVPS n.d., p. 5-11), Sequoyah Nuclear Plant (SNP, Sequoyah Nuclear Plant Updated Final Safety Analysis Report, Revision 20 2007, 2.4-6), and Watts Bar Nuclear Plant (WBNP 2010, p. 2.4-8). Maintenance of the shutdown or standby state is required for the duration of the flood event. Because it is necessary to consider the capability to maintain core cooling for the duration of a flood event, evaluation of plant safety must include factors such as the availability of site access given high floodwaters, integrity of compromised components (e.g., due to the effects of submergence, debris, sediment, and hydrodynamic forces), continuity of electricity, and the presence of electrical hazards. These factors are important even if the reactor is shutdown in response to anticipated flooding. Based on the documents reviewed for the screening assessment, it was not clear that the above factors were comprehensively and consistently considered for all plants.

In the cases of Oconee Nuclear Station and Fort Calhoun Station, it was additional data and analysis, beyond that provided in the FSAR and IPEEE documents that allowed more substantive safety questions to be identified and articulated regarding both the licensee response to — and site consequence from — upstream dam failures. The question raised about the viability of procedures in place at Fort Calhoun Station and the additional insight gained during the assessment of Oconee Nuclear Station suggests value in systematically investigating existing procedures at other similar sites with the benefit of more accurate and detailed information including evaluation of whether the licensee can maintain the plant in a safe shutdown condition throughout the duration of a flood event. This would provide a better quantification of the likelihood that established procedures will succeed (or fail) in protecting critical safety equipment.

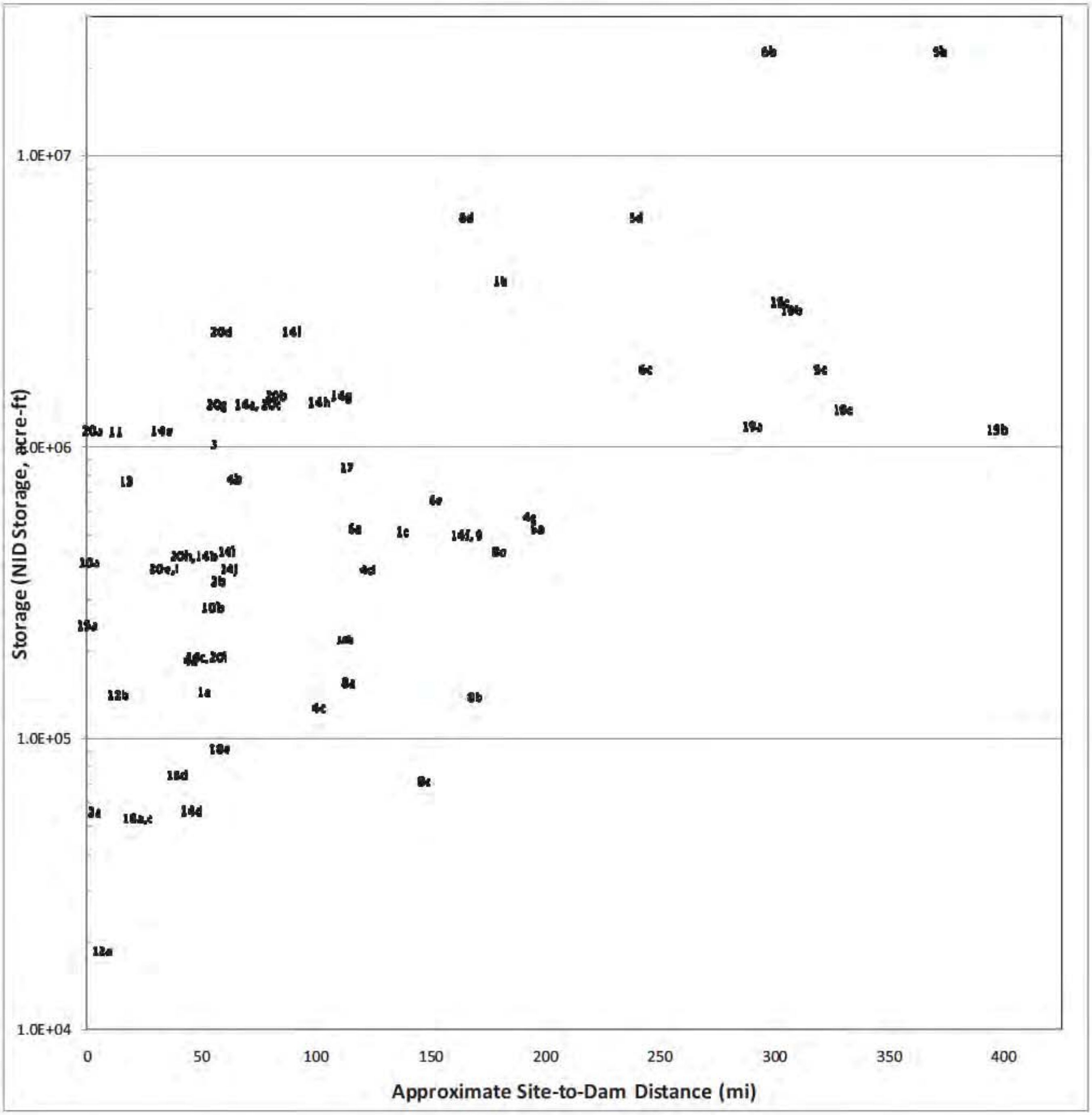
In addition to the reliability of temporary protection procedures (described above), it is also necessary to evaluate the reliability of hardened protective features including dikes/levees, flood doors, submarine hatches, waterstops at construction joints, and pipe penetration seals. At most nuclear power plants, flood protection dikes, levees, doors, and other features have not been tested against a flood. These features are all susceptible to failure and, consequently, such features should not be assumed to have a success probability of 1.0. The importance of considering the performance of hardened protective features was demonstrated during a flood at the Blayais Nuclear Power Plant (France) in 1999. During the flood event, protection of underground rooms containing safety equipment was insufficient and dikes were found to have insufficient height and shape (Fraguier 2010). Units 1 and 2 at the site were severely affected by the floodwaters. For example, an essential service water pump was lost due to the immersion of the motors. Utility galleries, the bottom of the fuel handling building, and rooms containing electrical equipment were also flooded (IAEA 2003). Moreover, the flood warning system was inadequate and detection of water in affected rooms was difficult (Fraguier 2010).

A major factor in the uncertainty associated with reliance on non-passive protective procedures is the amount of time available to take action following notification of a dam breach. The closer the dam is located to a site, the shorter the available response time following a dam breach. A “rule of thumb” is that a flood wave travels downstream at about 3-4 miles/hour (Welch 2007). This is a rough estimate and will vary based on the topography of the intervening river basin. However, using this rule, it is estimated that about a day of warning time exists for a dam that is about 100 miles upstream of a site. Many dams are operated by organizations other than the plant operator. Consequently, communication strategies and agreements between the operator of the dam and the nuclear power plant are necessary to maximize warning time and to optimize the quality of transmitted information. Variability in the rigor of these arrangements will affect the overall risk exposure to the plant, particularly if a given amount of lead-time is required to implement protective procedures. Regulatory Guides 1.102 and 1.59 address the use of temporary barriers and other procedures to provide protection of nuclear power plants during flood events. Subsequent sections of this report describe both documents.

Figure 6 shows upstream storage volumes[8] and approximate upstream distances[9] for selected nuclear power plant sites. Point 5a-f and 6a-f correspond to a set of dams that are located upstream of both Fort Calhoun and Cooper Nuclear Stations. Cooper Nuclear Station is about 85 miles from Fort Calhoun Station, located along the same river, and consequently subject to the same upstream dam failure events. However, because Cooper Nuclear Station is located farther downstream, the effects of failure of these dams are less extreme and further delayed. Because Cooper Nuclear Station, like Fort Calhoun Station, relies on procedures to protect the plant in the event of a large flood event, value exists in further evaluation of the plant to determine if it is affected by the same problems as Fort Calhoun Station.

[8] Storage volumes are collected from the Army Corps of Engineers National Inventory Dams (USACE 2009). The metric extracted from the database is "NID storage."

[9] When available, upstream distances are extracted from plant-specific documents (e.g., FSARs). Otherwise, upstream distances are computed from the straight-line distance using the latitude/longitude of the plant and dam (as given in the Army Corps of Engineers National Inventory of Dams). This distance will be shorter than a distance computed along the trace of a river.


1.0E+07
1.0E+06
1.0E+05
1.0E+04
Storage (NID Storage, acre-ft)
0
50
100
150
200
250
300
350
400
Approximate Site-to-Dam Distance (mi)

Index	Site	Dam	Index	Site	Dam
1a	Arkansas Nuclear	Ozark	12b	Peach Bottom	Safe Harbor
1b	Arkansas Nuclear	Eufala Lake	13	Prairie Island	Lock & Dam #2
1c	Arkansas Nuclear	Robert S. Kerr	14a	Sequoyah	Fontana
2a	Beaver Valley	Montgomery Lock & Dam	14b	Sequoyah	Hiwassee
2b	Beaver Valley	Conemaugh	14c	Sequoyah	Blue Ridge
3	Browns Ferry	Guntersville	14d	Sequoyah	Appalachia
4a	Columbia	Priest Rapids	14e	Sequoyah	Watts Bar
4b	Columbia	Wanapum	14f	Sequoyah	Norris
4c	Columbia	Rock Island	14g	Sequoyah	Cherokee
4d	Columbia	Rocky Reach	14h	Sequoyah	Douglas
4e	Columbia	Chelan	14i	Sequoyah	Tellico
4f	Columbia	Wells	14j	Sequoyah	Fort Loudoun
4g	Columbia	Chief Joseph	15a	South Texas	Main Cooling Reservoir Embankment
5a	Cooper	Gavins Point	15b	South Texas	Buchanan
5b	Cooper	Oahe	15c	South Texas	Mansfield
5c	Cooper	Big Bend	16	Surry	n/a
5d	Cooper	Ft. Randall	17	Three Mile Island	n/a
5e	Cooper	Fort Peck	18a	Vermont Yankee	Townshend
5f	Cooper	Garrison	18b	Vermont Yankee	Moore
6a	Fort Calhoun	Gavins Point	18c	Vermont Yankee	Ball Mountain
6b	Fort Calhoun	Oahe	18d	Vermont Yankee	North Springfield
6c	Fort Calhoun	Big Bend	18e	Vermont Yankee	North Hartland
6d	Fort Calhoun	Ft. Randall	19	Waterford	On-site Levee
6e	Fort Calhoun	Fort Peck	19a	Waterford	Enid
6f	Fort Calhoun	Garrison	19b	Waterford	Sardis
7	H.B. Robinson	n/a	19c	Waterford	Arkabulta
8a	Hope Creek/Salem	Francis E. Walter	20a	Watts Bar	Watts Bar
8b	Hope Creek/Salem	Neversink	20b	Watts Bar	Cherokee
8d	Hope Creek/Salem	Prompton	20c	Watts Bar	Douglas
8e	Hope Creek/Salem	Cannonsville	20d	Watts Bar	Norris
9	Indian Point	Ashokan	20e	Watts Bar	Tellico
10a	McGuire	McGuire embankment/Cowan's Ford	20f	Watts Bar	Fort Loudoun
10b	McGuire	Bridgewater/Linville	20g	Watts Bar	Fontana
11	Oconee	Jocassee	20h	Watts Bar	Hiwassee
12a	Peach Bottom	Holtwood	20i	Watts Bar	Blue Ridge

Figure 6: Maximum Dam Storage Capacity Versus Upstream Distance for Selected Dams and Nuclear Power Plants

Point 11 corresponds to Jocassee Dam upstream of Oconee Nuclear Station. As illustrated in Figure 6, Jocassee Dam is located in close proximity to the plant site and has a moderate storage capacity. The potential flood volume resulting from a potential dam breach is consequential, and the available warning time is relatively short. Figure 6 shows that other plant sites are located in close proximity to dams of similar maximum storage capacity[10] as Jocassee Dam. In particular, Watts Bar Nuclear Plant (about 1.9 miles downstream of Watts Bar Dam) and Prairie Island Nuclear Generating Plant (about 17 miles downstream of Lock and Dam #2) are associated with dams of similar maximum capacity as Jocassee Dam although with differing construction, dam heights (hydraulic head), and normal storage capacities.[11] Jocassee Dam is a large rockfill dam (Figure 7), Watts Bar Dam is an earth and concrete gravity structure (Figure 8), and Lock and Dam #2 has earth and concrete sections (Figure 9). Thus, the probability of failure associated with each dam may differ due to different structural classification

[10] The maximum storage capacity is the total storage space in a reservoir below the maximum attainable water surface elevation, including any surcharge storage, as specified in the National Inventory of Dams (USACE 2009).

[11] Normal storage capacity is the total storage space in a reservoir below the normal retention level, including dead and inactive storage and excluding any flood control or surcharge storage. The normal storage capacity of a dam may be significantly smaller than the maximum storage capacity.

and there may be significant differences in the potential consequences of failure; however, their similar maximum storage capacity and proximity suggests that there is value in further investigating the consequences of dam failure at the sites. Prairie Island Nuclear Generating Plant and Watts Bar Nuclear Plant (further described below) illustrate the divergent nature of the sites and associated upstream dams, including the consequences of failure.

Figure 7: Aerial Photograph of Jocassee Dam

Figure 8: Aerial Photograph of Watts Bar Dam

Figure 9: Aerial Photograph of Lock and Dam #2 (Earth and Concrete Sections)

2.3.1. Prairie Island Nuclear Generating Plant

Lock and Dam #2 is located 17 miles upstream of Prairie Island Nuclear Generating Plant. The difference in normal pool elevation across the dam is 12.2ft. The maximum storage capacity of the dam is 787,000 acre-ft and the normal storage capacity is 82,000 acre-ft (USACE 2009). The Prairie Island Nuclear Generating Plant USAR indicates “[t]here is no flood hazard resulting from a dam break at Lock and Dam #2” (PINGP 2010, p. 2.4-7,8). This conclusion is based on an analysis of stable water elevations at a dam located about 1.5 miles downstream of the plant site (Lock and Dam #3) when a sustained flow of water from Lock and Dam #2 is caused by the loss of 10 tainter gates. Given this sustained flow, the USAR concludes that a steady state upper pool elevation will be reached at Lock and Dam #3 consistent with a steady flow through the 10 spillway gates. The result of these conditions is a river level of 684.5 feet MSL in the lower pool of Lock and Dam #2 and 676.5 feet MSL in the upper pool of Lock and Dam #3. Consequently, the flood level at Prairie Island Nuclear Generating Plant resulting from this postulated scenario is in the range 676 to 685 feet MSL. These levels are substantially below the stated flood protection elevation at about 705 ft MSL. The USAR does not explicitly describe the postulated antecedent conditions for this dam failure scenario; however, it appears the analysis is based on a breach under normal operating conditions (PINGP 2010, p. 2.4-7,8).

Under the probable maximum flood affecting Prairie Island Nuclear Generating Plant, the estimated flood elevation at the site is 703.6ft MSL. Thus, under a probable maximum flood, excluding the effects of waves, Prairie Island Nuclear Generating Plant has a small margin between flood levels and flood protection elevation (<1.5 ft). By including wave effects, the water level increases to 706.7ft MSL

(PINGP 2010, p. 2.4-5) and the margin becomes negative.[12] This situation would be exacerbated if the flood event is augmented by the flood volume resulting from an upstream dam breach, though the amount of water that would be superimposed on the flood levels at the site is not known. The USAR states:

> The various locks and dams along the river have a negligible effect on the stage of a major flood. With all gates open the fall through the dam is generally less than a foot and for the probable maximum flood the embankments at the dams would be submerged (PINGP 2010, p. F.III-5).

The excerpt above is general in nature. Additional information is needed to determine the correlation between overtopping and possible failure of various locks, dam, embankments, and gates; and the contribution to downstream flood levels. Furthermore, the fall height through the various locks and dams may or may not correlate to similar flood level contributions at a downstream site since terrain and flow characteristics must be considered. The effect of cascading failures is not addressed above, nor is the effect of a sudden opening of gates releasing retained water during a large flood event.

Prairie Island Nuclear Generating Plant currently has protective procedures in place that require placement of the unit in Mode 3, Hot Standby when flood levels exceed 692 ft MSL[13] (PINGP 2010, p. 2.4-6).

2.3.2. Watts Bar Nuclear Plant

The maximum assessed flood for Watts Bar Nuclear Plant is caused by the probable maximum precipitation event critically centered on the watershed and results in a flood elevation of 738.8 ft MSL (and 741.2 ft MSL including wave runup).[14] The license indicates that, in the storm contributing to the PMF, "the West Saddle Dike at Watts Bar Dam would be overtopped and breached. No other [dam] failure would occur" (WBNP n.d., p. 2.4-12). The licensee indicates that "all safety related facilities, systems, and equipment are housed in structures which provide flood protection up to plant grade at Elevation 728ft MSL" (WBNP 2010, p. 2.4-8). This elevation is substantially below the design basis flood elevation. Consequently, the plant is required to be shutdown whenever floodwaters exceed this elevation. The licensee indicates that "[f]lood warning criteria and forecasting techniques have been developed to assure that there will always be adequate time to shut the plant down and be ready for floodwaters above plant grade." The licensee also indicates that the facilities, systems, and equipment located in the containment structure (protected by the shield building, which has accesses/penetrations

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[12] The licensee specifies that: "The top of substructure and/or superstructure flood protection walls are at 705.0 ft and are designed to resist the probable maximum flood. These structures are capable of withstanding the hydrostatic forces associated with the [PMF] and associated maximum wave run-up to 706.7 ft. Some leakage would occur whenever wave action exceeds 705 ft on certain portion of the turbine building and auxiliary building walls." (PINGP 2010, p. 2.4-5) The USAR also indicates that this leakage is not expected to cause a loss of any safety-related function because the quantity of water is small and can be handled by sump pumps, and the leakage is expected to occur at a "great distance" from safety-related equipment (PINGP 2010, p. 2.4-6).

[13] Operating procedures also require that the unit be placed in Mode 4 based on internal flood analysis, which is more restrictive than the action required for external flooding events. (PINGP 2010, p. 2.4-6)

[14] The FSAR for Unit 2 states "The maximum flood Elevation 738.8 would result from occurrence of the probable maximum storm" (WBNP n.d., p. 2.4-1). The FSAR for Unit 1 states "The maximum flood Elevation 734.9 would result from occurrence of the probable maximum storm" (WBNP 2010, p. 2.4-1) The IPEEE submittal states "The maximum flood level at the site from any cause is elevation 738.1" (WBNP n.d., section 5.6.2). Thus, there is a slight discrepancy between documents with regard to maximum flood estimates.

that are watertight) and the Diesel Generator Building (located above critical flood level) are both protected during a flood event. The Turbine, Control, and Auxiliary Buildings will be allowed to flood, but the licensee indicates that equipment required to maintain plant safety during a flood – and for 100 days following the flood – is “designed to operate submerged, is located above the maximum flood level, or otherwise protected” (WBNP 2010, p. 2.4-8).

The design basis flood described above does not include an upstream dam failure (other than the overtopping/breach of the West Saddle Dike at Watts Bar Dam) although seismic dam failures coincident with smaller floods were considered in establishing it. The licensee specifies that “dam safety modifications have eliminated the potential of a PMF at upstream tributary dams to cause maximum site flood levels,” with the exception of the West Saddle Dike at Watts Bar Dam (WBNP 2010, p. 2.4-12). There are 12 major dams upstream from Watts Bar Nuclear Plant (the locations of six of these dams are shown in Figure 10). As indicated above, Watts Bar Nuclear Plant is located less than 2 miles from Watts Bar Dam. The remaining 11 dams are located at further distances. In the plant UFSARs, seismically-induced dam failure is considered under the operating basis earthquake coincident with one-half the PMF as well as during a safe-shutdown earthquake coincident with a 25-year storm. The highest flood elevation at the site, based on several seismic dam failure permutations considered, results in a flood elevation of 727.5ft MSL (728.2-729 ft MSL including waves and runup) caused by failure of the Norris, Cherokee, and Douglas Dams during the safe-shutdown earthquake coincident with a 25-year flood (WBNP 2010, p. 2.4-29, WBNP n.d., p. 2.4-22). Under this event, the West Saddle Dike at Watts Bar Dam would be overtopped and breached (WBNP 2010, p. 2.4-38, WBNP n.d., p. 2.4-31). The licensee provides results that indicate arbitrary removal of Watts Bar Dam during a 25-year flood would result in a flood elevation of 723 ft MSL (5 ft below plant grade). In light of the concern about potentially high flood levels at Oconee Nuclear Station resulting from the failure of Jocassee Dam, it may be reasonable to understand the consequences of high flood events at Watts Bar Nuclear Plant resulting from failure of Watts Bar Dam and other upstream dams during an extreme precipitation event. Watts Bar Nuclear Plant is flood protected up to an elevation of 728ft and requires plant shutdown for flood elevations above this level. Given the close proximity of Watts Bar Dam to the plant site (Figure 11), very little warning time exists between the time of dam breach and the arrival of floodwaters at the site. The safety-related systems and components necessary for the maintenance of safe shutdown are protected up to the aforementioned design-basis flood level, which does not include a dam failure event (other than the West Saddle Dike at Watts Bar Dam).

Figure 10: Location of Watts Bar Nuclear Power Plant Relative to Upstream Dams (Approximate Locations)

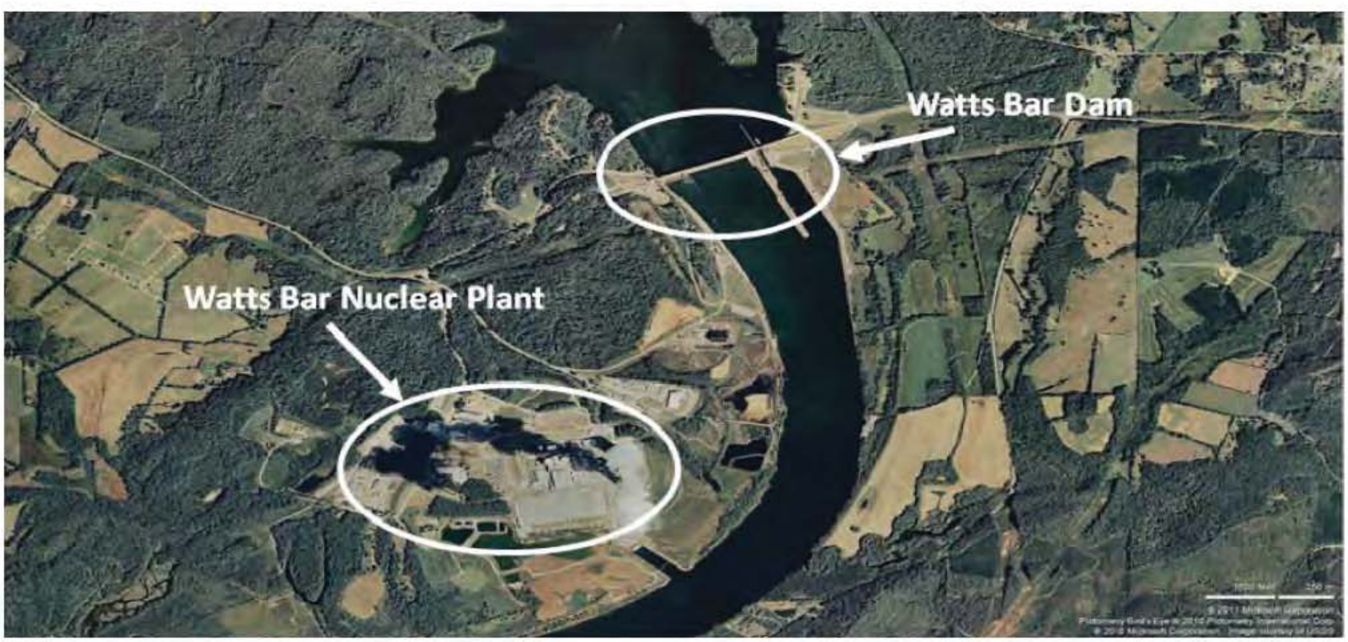


Figure 11: Watts Bar Nuclear Plant and Watts Bar Dam

Revised flood estimates at nuclear power plants operated by the Tennessee Valley Authority (i.e., Watts Bar Nuclear Plant, Sequoyah Nuclear Plant, and Browns Ferry Nuclear Plant) have resulted in increased PMF elevations that may require permanent modification of flood protection at the sites (pending the outcome of rigorous analyses to verify increases in the PMF elevation). In conjunction with the increases in precipitation-induced flooding, concerns have been raised regarding the structural integrity of the dams upstream of Watts Bar Nuclear Plant (these dams also are upstream of the other plants operated by the Tennessee Valley Authority). The Tennessee Valley Authority is currently performing finite element analyses to demonstrate dam stability. If analysis results are unfavorable, steps will be taken to modify the dams (USNRC 2010f, TVA 2010).

2.4. Available Margin

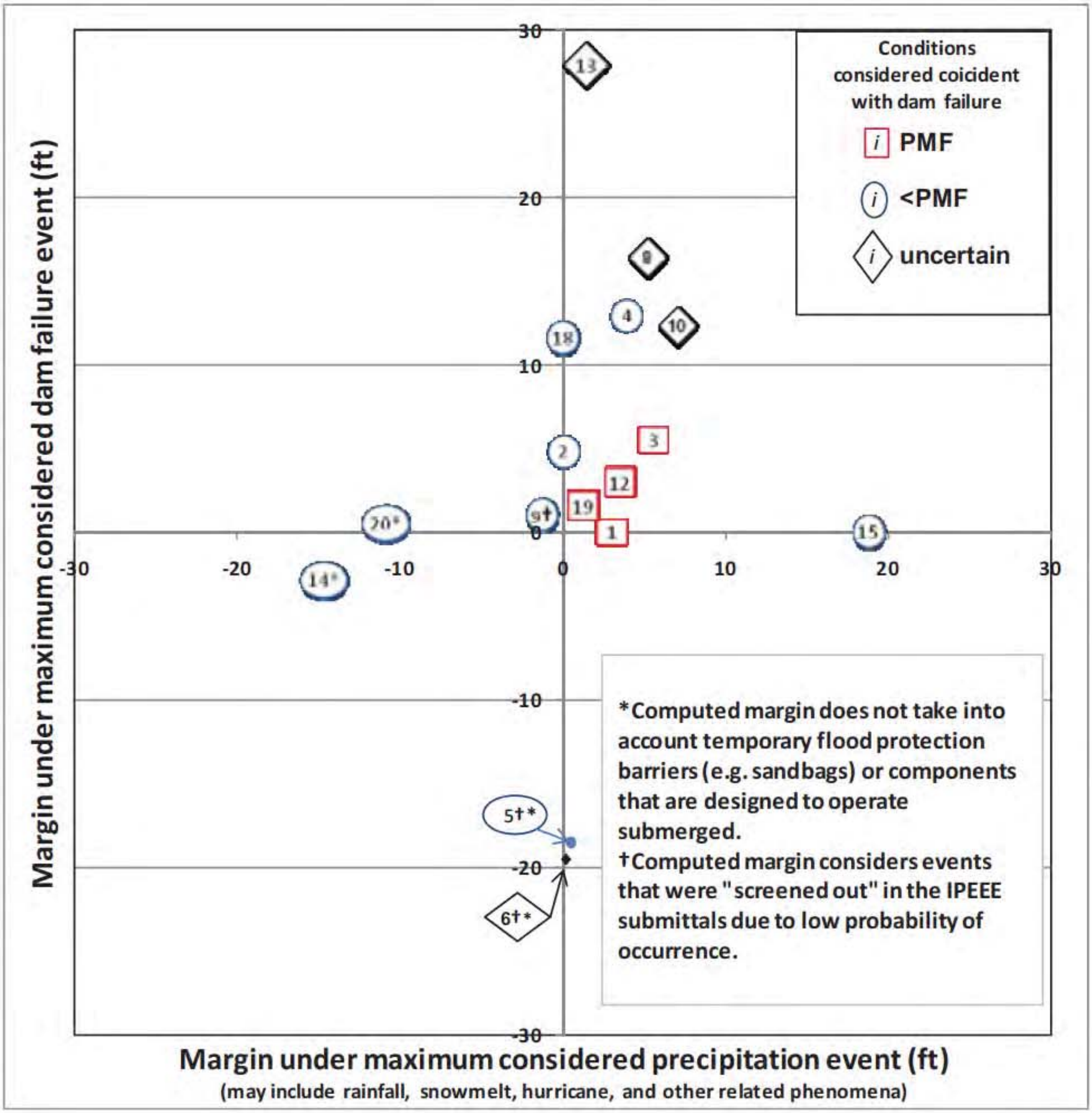
At Oconee Nuclear Station and Fort Calhoun Station, increased flood estimates have led to ongoing regulatory activity. Like many sites in the U.S. inventory of nuclear power plants, flood levels at these two stations were based on relatively outdated flood estimation methods and/or probable precipitation estimates. The evolution of hydrological modeling — including dam break analysis — and the availability of updated meteorological data are likely to yield flooding estimates that are different than those considered during the initial licensing reviews or IPEEE studies. In addition to changes in estimation methods, changes in regional land use and land cover (e.g., urban expansion and sprawl) may have a significant impact on the watershed of sites and dams. The National Oceanic and Atmospheric Administration's (NOAA) National Weather Service has historically produced hydrometeorological reports that provide estimates of probable maximum precipitation for different regions in the United States. However, NOAA's National Weather Service has discontinued probable maximum precipitation activities (NOAA 2009) and NOAA has not updated Hydrometeorological Report 51 (which covers most of the U.S. east of the 105th meridian) in over 30 years. Precipitation induced flood estimates for some plants have been based on these older estimates. A recent NRC project will provide NRC staff with an update to NOAA's existing National Weather Service hydrometeorological reports for a pilot region in North Carolina and South Carolina (USNRC 2010g, p. 98).

Figure 12 compares possible margins at selected plants under flood events, based on certain assumptions regarding the performance of features (as stated below). The x-axis corresponds to margin under the flood caused by the maximum considered precipitation-induced event (excluding wave effects in most though not all cases), which may include floods due to weather-related phenomena such as the probable maximum flood and hurricanes. The y-axis shows computed margins under the flood caused by the maximum considered dam failure event (excluding wave effects in most though not all cases), coincident with a concurrent flood (as indicated by shapes around numbers). In this report, margins are computed using the best numerical information that could be located in the FSAR and IPEEE submittals. In general, margins are computed relative to the minimum flood protection elevation of safety-related facilities, structures, systems, and equipment/components. The flood protection elevation of individual critical facilities, structures, systems, and components may be higher. Moreover, margins are generally computed crediting hardened features such as floodwalls and hatches/doors but not temporary barriers such as sandbags. In this report, the computed margin does not generally take into account components that are designed to operate submerged (e.g., see Watts Bar and Sequoyah Nuclear Power Plant FSARs). When conflicting information is found, the margin is computed using the lowest flood protection elevation and highest static water level available in existing documents (e.g., see FSAR and IPEEE submittals for Arkansas Nuclear One). Flood levels that result from events that were "screened out" in the IPEEE due to low probability of occurrence, if reported in the licensee's IPEEE submittal, are considered when computing available margin (e.g., see Fort Calhoun and Cooper IPEEE submittals).

Figure 12 also demonstrates whether dam failure was considered under the PMF or a lesser flood as indicated by shapes. A square around a number indicates the dam failure event was considered coincident with a PMF, a circle indicates that the dam failure event was considered with a different (typically smaller) flood, and a diamond indicates that it was not clear what flood conditions were considered coincident with dam failure. Table 1 gives the sources for data used to construct Figure 12. In cases where a flood less than the PMF is considered, several plants indicate that the dam is designed such that a PMF event will not fail the dam.

Sites plotted in the upper right quadrant of Figure 12 have a positive margin under both the maximum precipitation and dam failure events. However, several of the sites do not consider failure of the dam under a PMF event and thus the magnitude and sign of this margin may change if dam failure coincident with the larger flood is considered. Sites plotted in the lower left quadrant have a negative margin under both precipitation and dam failure events. However, as noted in Regulatory Guides 1.102 and 1.59, this negative margin is acceptable if the plant can be shutdown before floodwaters reach the site and safely maintained throughout the duration of the flood event. Sites plotted in the lower right quadrant have a positive margin under precipitation events but a negative margin under a dam failure event. These sites are controlled by flooding due to dam failure. Sites plotted in the upper left quadrant have a positive margin under dam failure events but a negative margin under precipitation events. Sites plotted in this quadrant consider a flood less than the PMF coincident with dam failure. These sites may have a lower (or negative) margin under dam failure if a large precipitation event (i.e., PMF) is considered coincident with dam failure.

Because of the extremely diverse methods used and disparate level of detail provided in plant documentation (i.e., FSAR and IPEEE submittals), care should be given to drawing strong conclusions from Figure 12 because it does not capture important distinctions and subtleties between the sites and the definitions used in plant-specific documentation. Because of the important differences between the sites and the estimation methods used, the original data source referenced in Table 1 should be consulted before drawing conclusions based on the numerical values in Figure 12. However, despite the disparate nature of the data, this figure serves to demonstrate that, for many plants, the reported margin between flood levels and flood protection is small for dam failure and/or precipitation and related weather events. This margin is further reduced when accounting for the effects of wind-generated waves and runup. Moreover, several sites do not consider dam failure coincident with a PMF event and, therefore, the available margin may degrade further if dam failure coincident the larger precipitation event is considered. The necessity of considering dam failure coincident with such extreme events is an area warranting further study.


Conditions considered coicident with dam failure
i PMF
i <PMF
i uncertain
Margin under maximum considered dam failure event (ft)
Margin under maximum considered precipitation event (ft)
(may include rainfall, snowmelt, hurricane, and other related phenomena)
*Computed margin does not take into account temporary flood protection barriers (e.g. sandbags) or components that are designed to operate submerged.
†Computed margin considers events that were "screened out" in the IPEEE submittals due to low probability of occurrence.
30
20
10
0
-10
-20
-30
-30
-20
-10
10
20
5†*
6†*
9†
20*
14*

Index	Plant	Index	Plant
1	Arkansas Nuclear	11	Oconee (data not available)
2	Beaver Valley	12	Peach Bottom
3	Browns Ferry	13	Prairie Island
4	Columbia	14	Sequoyah
5	Cooper	15	South Texas
6	Fort Calhoun	16	Surry (data not available)
7	H.B. Robinson (data not available)	17	Three-Mile Island (data not available)
8	Hope Creek	18	Vermont Yankee
9	Indian Point	19	Waterford
10	McGuire	20	Watts Bar

Figure 12: Available Margin Under Maximum Precipitation and Maximum Dam Failure Events Considered at Each Plant Site

Table 1: Data Sources for Information Contained in Figure 12

Plant	Flood Protection Elevation	Maximum Precipitation Event	Maximum Dam Failure Event
Arkansas Nuclear	(ANO1 1996, p. 5-38,39)	(ANO2 2007, p. 2.4-6, ANO1 n.d., p. 2.4-2)	(ANO2 2007, p. 2.4-8, ANO1 n.d., p.2.4-3)
Beaver Valley	(BVPS n.d., p. 2.3-5, BVPS n.d., p. 2.4-1)	(BVPS n.d., p. 2.3-31, BVPS n.d., p. 2.4-5)	(BVPS n.d., p. 2.3-30, BVPS n.d., p. 2.4-8)
Browns Ferry	(BFNP n.d., p. 2.4-10)	(BFNP n.d., p. 2.4A-11)	(BFNP n.d., p. 2.4A-11)
Columbia	(CGS 2009, p. 2.4-14, 3.4-2)	(CGS 2009, p. 2.4-9)	(CGS 2009, p. 2.4-11)
Cooper	(CNS n.d., p.5-11)	(CNS n.d., p.5-11)	(CNS n.d., p.5-12)
Fort Calhoun	(FCS 2010, sect. 2.7, p. 8)	(FCS 2010, sect. 2.7, p. 7)	(FCS n.d., p. 5-20)
H.B. Robinson	(HBR n.d., p. 2.4.4-2)	(HBR n.d., p. 2.4.4-2)	(HBR 1995, p. 5-16)
Hope Creek	(HCGS 2005, Table 3-4.1)	(HCGS 2005, Table 2.4-6)	(HCGS 2005, Table 2.4-6)
Indian Point	(IPNG 2008, Ch.2, p.30, IPNG 2009, Ch.2, p.70)	(IPNG 1995, p. 6-43)	(IPNG 2008, Ch.2, p.30, IPNG 2009, Ch.2, p.70)
McGuire	(MNS 2010, p. 2.4-11)	(MNS 2010, p. 2.4-5)	(MNS 2010, p. 2.4-7)
Oconee	n/a	n/a	n/a
Peach Bottom	(PBAPS 2009, p. 2.4-17)	(PBAPS 2009, p. 2.4-21)	(PBAPS 2009, p. 2.4-21)
Prairie Island	(PINGP 2010, p. 2.4-5)	(PINGP 2010, p. 2.4-5)	(PINGP 2010, p. 2.4-8)
Sequoyah	(SNP, Sequoyah Nuclear Plant Updated Final Safety Analysis Report, Revision 20 2007, p. 2.4-6)	(SNP, Sequoyah Nuclear Plant Updated Final Safety Analysis Report, Revision 20 2007, p. 2.4-12)	(SNP, Sequoyah Nuclear Plant Updated Final Safety Analysis Report, Revision 20 2007, p. 2.4-16)
South Texas	(STP n.d., p. 3.4-2, Table 3.4-1)	(STP n.d., p. 2.4-77)	(STP n.d., p. 2.4-33,34,77)
Surry	(SPS 2010, Table 2.3-7)	(SPS 2010, p. 2.3-5)	n/a
Three Mile Island	(TMI 1994, p. 5.2-3)	(TMI 2010, p. 2.6-10)	(TMI 2010, p. 2.6-2, TMI 1994, p. 5.2-1)
Vermont Yankee	(VYNPS 2010, p. 2.4-14,15)	(VYNPS 2010, p. 2.4-9)	(VYNPS 2010, p. 2.4-9)
Waterford	(WSES 2006, p. 2.4-1)	(WSES 2006, p. 2.4-14)	(WSES 2006, p. 2.4-7)
Watts Bar	(WBNP 2010, p. 2.4-8, WBNP n.d., p. 2.4-7)	(WBNP n.d., p. 2.4-7)	(WBNP 2010, p. 2.4-29, WBNP n.d., p. 2.4-22)

3. Regulatory Background

10 CFR 50, Appendix A, General Design Criteria-2 requires:

> Structures, systems, and components important to safety shall be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their safety functions. The design bases for these structures, systems, and components shall reflect: (1) Appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated, (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena and (3) the importance of the safety functions to be performed.

Existing NRC regulatory guidance related to the definition of external design basis floods and flood protection requirements are contained primarily in Regulatory Guide 1.59, the Standard Review Plan (Section 2.4), and Regulatory Guide 1.102. The first publication of Regulatory Guide 1.59 ("Design Basis Floods for Nuclear Power Plants") occurred in 1973. The Standard Review Plan (Section 2.4) and Regulatory Guide 1.102 ("Flood Protection for Nuclear Power Plants") were first published in 1975. Many of the 20 plants listed in the Generic Issue proposal were first licensed before these three documents became available for use by licensees and NRC staff in evaluating the risks posed to nuclear power plants due to external flooding. Figure 13 provides a timeline of operating dates of the plants listed in the Generic Issue Proposal as well as the dates of significant NRC publications (including revisions) addressing external flooding of nuclear power plants. Many of these documents are described briefly in the forthcoming sections. The review of these documents indicates that regulatory and staff guidance related to external flooding from upstream dam failures has evolved. However, existing plants have not been systematically reviewed against the updated criteria.[15]

Descriptions contained in this report focus primarily on the portions of the aforementioned documents addressing external flooding of sites located along streams and rivers, with a particular emphasis on events associated with upstream dam failure. Consequently, for brevity, this report does not include a discussion of the portions of the regulatory documents addressing flooding along seashores and lakes not impacted by dam failure (e.g., due to storm surge, tsunami).

[15] The IPEEE reviews for external flooding were based on evaluation against the 1975 Standard Review Plan criteria.

Figure 13: Timeline of Plant Operating License Issuance Dates (Left) and Publication Dates of Significant Documents Related to External Plant Flooding (Right)

3.1. Regulatory Guide 1.59

Regulatory Guide 1.59 discusses the "design basis floods that nuclear power plants should be designed to withstand without loss of capability for cold shutdown and maintenance thereof" (USNRC 1977, p. 1.59-5). The guide also addresses the acceptability of using alternatives to hardened facilities for flood protection. Regulatory Guide 1.59 was originally published in 1973, with revisions in 1976 and 1977 (with Errata added in 1980). Regulatory Guide 1.59 outlines four regulatory positions that are described below. The description contained herein is based on the 1977 version (revision 2) of Regulatory Guide 1.59.

3.1.1. Regulatory Position 1

Regulatory Position 1 of Regulatory Guide 1.59 specifies that safety-related structures, systems, and components identified in Regulatory Guide 1.29[16] should be designed to resist the worst flood probable at the site due to a range of phenomena including probable maximum flood (PMF), seismically-induced flood, hurricane, seiche, surge, and heavy local precipitation. These hazards should be considered coincident with attendant wind-generated wave activity (USNRC 1977, p. 1.59-7).

For sites located along streams and rivers, the PMF generally provides the design basis flood event. Appendices A and B of Regulatory Guide 1.59 provide an "acceptable level of conservatism for estimating the floods levels caused by severe hydrometeorological conditions" (USNRC 1977, p. 1.59-7). Appendix B provides alternative methods for estimating precipitation-induced flooding on streams and rivers that are less laborious but more conservative than the methods in Appendix A. Appendix A of the 1977 revision of Regulatory Guide 1.59 replaces material contained in previous versions of Regulatory Guide 1.59 with a reference to an NRC-endorsed standard produced by the American National Standards Institute (ANSI): ANSI Standard N170-1976, "Standards for Determining Design Basis Flooding at Power Reactor Sites." A brief description of an update to ANSI Standard N170-1976 is included in a subsequent section of this report. The content of Appendix A of Regulatory Guide 1.59 prior to the 1977 revision is not known because copies of older versions of the document are unavailable to the screening analysis group. Regulatory Position 1 of Regulatory Guide 1.59 contains no explicit discussion of flooding due to dam failures from extreme hydrometeorological events. However, ANSI Standard N170-1976, which is referenced in Appendix A, does address dam failure due to hydrological mechanisms.

Regulatory Position 1 of Regulatory Guide 1.59 explicitly specifies that "[f]lood conditions that could be caused by dam failures from earthquakes should also be considered in establishing the design basis flood." (USNRC 1977, p. 1.59-7) The guide notes that, along streams and estuaries, seismically induced floods may be produced by dam failures or landslides. Consideration of seismically induced flooding should be based on seismic events in "the same range" as the events considered for design of the nuclear power plant. Moreover, Regulatory Guide 1.59 specifies that an evaluation should be performed of flood waves that may be caused by cascading dam failures triggered by a seismically induced failure of a critically located dam (USNRC 1977, p. 1.59-6). Appendix A (through reference to

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[16] Regulatory Guide 1.29 ("Seismic Design Classification") develops a "seismic design classification system for identifying those plant features that should be designed to withstand the effects of the safe shutdown earthquake. Those structures, systems, and components that should be designed to remain functional if the safe shutdown earthquake occurs have been designated as Seismic Category I." (USNRC 1978, p. 1.29-1)

ANSI Standard N170-1976) provides acceptable techniques for evaluating hydrological effects of seismically induced dam failures.

3.1.2. Regulatory Position 2

Regulatory position 2 of Regulatory Guide 1.59 permits an alternative to designing hardened protection[17] for all safety-related structures, systems, and components requiring protection under Regulatory Position 1 if the following criteria are met (USNRC 1977, p. 1.59-7):

(1) Sufficient warning time is shown to be available to shut down the plant and implement adequate emergency procedures

(2) All safety-related structures, systems, and components are designed to withstand and remain functional during the flood conditions resulting from the Standard Project Flood (about 40-60 percent of the PMF) including wind-generated wave activity that may be produced during the worst winds of record

(3) In addition to (2), reasonable combinations of less-severe flood conditions are considered to the extent needed for a consistent level of conservatism

(4) In addition to (2), at least those structures, systems, and components necessary for cold shutdown, and maintenance thereof, are designed with hardened protective features to remain functional while withstanding the entire range of flood conditions up to and including the worst site-related flood probable (e.g.,, PMF, seismically-induced flood, hurricane, surge, seiche, heavy local precipitation) with coincident wind-generated wave action as discussed in Regulatory Position 1.

3.1.3. Regulatory Positions 3 and 4

Regulatory Position 3 of Regulatory Guide 1.59 requires that significantly adverse changes to the site environment, that may affect the design basis flood, be identified and used as the basis to develop or modify emergency operating procedures to mitigate potential effects of increased floods. Regulatory Position 4 of Regulatory Guide 1.59 permits deviation from the methods outlined in Appendices B-C of Regulatory Guide 1.59 if there is adequate verification and pending approval of NRC staff.

3.2. ANSI Standard N170-1976 and ANSI/ANS-2.8-1992

ANSI Standard N170-1976 ("American National Standard for Determining Design Basis Flooding at Power Reactor Sites") was published in 1976 to specify criteria for determining design basis flooding at power reactor sites (ANSI 1976). NRC endorsed ANSI Standard N170-1976 in Regulatory Guide 1.59 as an acceptable method of defining probable maximum and seismically induced floods on streams. An update to ANSI Standard N170-1976 was published in 1992 (ANSI 1992). The publisher withdrew ANS/ANSI-2.8-1992 in 2002. This report will refer to the updated Standard as ANSI/ANS-2.8-1992.

A brief review of the portions of the 1976 and 1992 standards related to dam failures indicates that few substantial differences exist between the two versions with regard to the portions of the documents

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[17] Hardened protective features are structural provisions in the plant design that are passive and in place during normal plant operations.

described here. As a result, the document description and associated references contained in this report are based on the 1992 revision (even though Regulatory Guide 1.59 references the 1976 version). Any substantial differences observed between the 1976 and 1992 versions of the standard with regard to the topics discussed in the forthcoming description are noted.

ANSI/ANS-2.8-1992 addresses dam failures due to hydrologic and seismic events as well as other mechanisms. Section 5.5 of ANSI/ANS-2.8-1992 addresses hydrological[18] dam failures. It specifies that potentially critical dams should be analytically subjected to the PMF from the contributing watershed of the dam. If it is shown that the dam can withstand this flood, then no further hydrological failure analysis is required. If hydrologic failure is likely, then the assessment must continue and ANSI/ANS-2.8-1992 offers guidance on performing the requisite failure analyses. In the case that an upstream dam is likely to fail under the PMF on its watershed, the degree and mode of failure should be estimated and the resulting flood wave, combined with the downstream flows that would prevail in this flood, should be routed to the plant site. The dam also shall be tested in the PMF applicable to the total plant watershed. Again, the resulting flood levels at the site must be calculated (ANSI 1992, p. 11).

The above load conditions are consistent between the 1976 and 1992 versions of the standard; however the 1992 revision of the standard includes an additional load condition not contained in the 1976 version: “If a significant portion of the plant site watershed lies below the dam, then the probable maximum precipitation centered over the intervening area should be combined with the dam failure wave from the same storm centering.” The resulting flood levels at the site shall again be calculated (ANSI 1992, p. 12). The critical flood level is selected as the most severe of the above three load conditions. ANSI/ANS-2.8-1992 also notes that a dam that is safe under its own PMF might fail when the flood is augmented by flood waves from a dam failure further upstream. Thus, when a dam is anticipated to fail under its own PMF, all downstream dams must be analyzed under the demands of the flood wave resulting from the failed dam. Unless safety from failure can be documented, failure of downstream dams shall be postulated and the resulting surge routed to the plant site (ANSI 1992, p. 12).

Section 6 of ANSI/ANS-2.8-1992 addresses nonhydrological dam failures. Potential nonhydrological hazards include dam failures resulting from deterioration, settlement, cracking, erosion, leakage, landslides, and mechanical/electrical breakdown of spillway gates as well as dam failures resulting from seismic mechanisms.

The treatment of nonhydrological, nonseismic dam failures in ANSI/ANS-2.8-1992 is terse when compared to the treatment of the hydrological and seismic mechanisms. ANSI/ANS-2.8-1992 generically specifies the following for failure analysis due to nonseismic, nonhydrological mechanisms:

> For any upstream dam, available records should be evaluated to appraise the likelihood of failure. If dam safety cannot be so ensured for the normal life of the nuclear plant, the dam shall be postulated to fail in a severe yet credible manner and the resulting flood wave should be routed to the plant site. Routing must accommodate induced failures of other dams on the path of the failure flood wave (ANSI 1992, p. 16).

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[18] The terminology “hydrologic dam failure” describes a failure necessarily involving a large inundation of water volume upon the dam.

With regard to load combinations related to non-seismic, non-hydrological failures (ANSI 1992, p. 33), the following is stated in Section 9.2.4 (Section 9 provides load combinations for severe events[19]):

> No specific guidance or specific event combinations are provided in this standard because of uncertainty in postulating a realistic dam failure from nonhydrologic and nonseismic causes (ANSI 1992, p. 33).

Section 6.2 provides guidance on considering dam failure due to seismic events. Specific seismic load combinations that must be considered are contained in Section 9 (“Combined Events Criteria”) of ANSI/ANS-2.8-1992. Section 9.2.1.2 (ANSI 1992, p. 32) specifies that the most severe of the following combinations provides an adequate design basis for consideration of seismic dam failures:

- Alternative 1:
  - 25-year flood
  - Dam failure caused by the safe shutdown earthquake (SSE) coincident with the peak of the flood
  - 2-year wind speed applied in the critical direction
- Alternative 2:
  - One-half the PMF or 500-year flood, whichever is less (The 1976 version of the standard does not include the option of using the 500-year flood in this load combination.)
  - Dam failure caused by the operating basis earthquake (OBE) coincident with the peak of the flood
  - 2-year wind speed applied in the critical direction

As shown above, there is a difference in the level of detail with which dam failures from hydrological, seismic, and other mechanisms are treated in existing regulatory documentation, particularly with regard to the explicit definition of load combinations. As expected, consistent with regulatory guidance existing at the time, there is a similar difference in the treatment of dam failure mechanisms in plant-specific submittals (i.e., FSAR and IPEEE submittals). Often, emphasis is placed on dam failures coincident with seismic events.

3.3. Standard Review Plan

The Standard Review Plan (SRP) has been prepared to establish criteria that the U.S. Nuclear Regulatory Commission staff responsible for the review of applications to construct and operate nuclear power plants intends to use in evaluating whether an applicant/licensee meets NRC's regulations. Section 2.4 of the Standard Review Plan focuses on site hydrology. The individual sections and topics contained in Section 2.4 (as defined in the most recent version of the document) are:

- Section 2.4.1: Hydrologic Description
- Section 2.4.2: Floods
- Section 2.4.3: Probable Maximum Flood (PMF) on Streams and Rivers
- Section 2.4.4: Potential Dam Failures
- Section 2.4.5: Probable Maximum Surge and Seiche Flooding

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[19] ANSI/ANS-2.8-1992 indicates the following with regard to combined events criteria: “No single flood-causing event, predictable by present technology, is adequate as a design flood base for power reactors. This section, therefore, embraces combinations of flood-causing events that, collectively, do provide adequate design flood bases” (ANSI 1992, p. 29).

- Section 2.4.6: Probable Maximum Tsunami Hazard
- Section 2.4.7: Ice Effects
- Section 2.4.8: Cooling Water Canals and Reservoirs
- Section 2.4.9: Channel Diversions
- Section 2.4.10: Flooding Protection Requirements
- Section 2.4.11: Low Water Considerations
- Section 2.4.12: Groundwater
- Section 2.4.13: Accidental Releases of Radioactive Liquid Effluents in Ground and Surface Waters
- Section 2.4.14: Technical Specifications and Emergency Operation Requirements

Pertinent to the proposed Generic Issue are Sections 2.4.2 – 2.4.4 and Section 2.4.10. The portions of the Standard Review Plan applicable to the proposed Generic Issue were first published in 1975 in NUREG-75/087 (USNRC 1975). These sections were subsequently revised in 1978, 1981, and 2007 (USNRC 1980, USNRC 1981, USNRC 2007). A subset of the applicable sections (2.4.2 and 2.4.3) also was revised in 1989. Figure 13 shows that many of the plants listed in the Generic Issue Proposal were granted operating licenses before 1975 and consequently before publication of the Standard Review Plan.

Overviews of Sections 2.4.2-2.4.4 are provided below. The descriptions contained in this report are based primarily on the 1975 version of the Standard Review Plan; however, several comments are provided relative to the revisions made in more recent versions.

3.3.1. Standard Review Plan Section 2.4.2

Section 2.4.2 (titled "Floods") summarizes and identifies the individual (or combinations of) flood-producing phenomena that should be considered in establishing the flood-design bases for safety-related plant features. With regard to stream flooding, Section 2.4.2 of the 1975 Standard Review Plan states that the following condition should be considered in establishing possible flood levels on a stream at the location of a nuclear power plant site: "Probable maximum flood (PMF) with coincident wind-induced waves, considering dam failure potential due to inadequate capacity, inadequate flood-discharge capability, or existing physical condition"[20] (USNRC 1975, p. 2.4.2-1). In Section 2.4.2 of the 1975 Standard Review Plan, no additional guidance beyond this statement is provided relative to hydrologically-induced dam failures. The most recent version of Section 2.4.2, published in 2007, provides a similar statement and specifies the following with regard to hydrological dam failures:

> In order to establish the design-basis floodwater elevation, the staff evaluates several severe flooding scenarios, which may include: (a) PMF coincident with upstream dam failure (single or multiple failures including cascading failures due to hydrological causes) and wind-induced waves… (USNRC 2007, p. 2.4.2-9).

With regard to seismic mechanisms, Section 2.4.2 of the 1975 Standard Review Plan states that the following should be considered when specifying possible flood levels at a site:

> Seismically-induced dam failures (or breaches), and maximum water level at site from:
> a. Failure of dam (or dams) during safe shutdown earthquake (SSE) coincident with 25-

[20] When establishing flood levels on a stream, this condition should be considered in addition to ice jams, tributary drainage, and combinations of less severe river floods.

> year flood, b. Failure during operating basis earthquake (OBE) coincident with standard project flood (SPF), c. Failure during other earthquakes, coincident with runoff, surge, or seiche floods where the coincidence is at least as likely as for [a] and [b] above (USNRC 1975, p. 2.4.2-2).

Section 2.4.3 of the Standard Review Plan (all editions) provides additional details related to definition of the PMF. Additional details related to seismically-induced dam failure are found in Section 2.4.4 of the Standard Review Plan (all editions).

3.3.2. Standard Review Plan Section 2.4.3

Section 2.4.3 of the Standard Review Plan (titled “Probable Maximum Flood (PMF) on Streams and Rivers”) addresses specification of the probable maximum flood on streams and rivers. There is no explicit discussion of dam failures in Section 2.4.3 with the exception of a reference to Regulatory Guide 1.59. Specifically, Section 2.4.3 of the 1975 Standard Review Plan specifies:

> The probable maximum flood as defined in Regulatory Guide 1.59 has been adopted as one of the conditions to be evaluated in establishing the applicable stream and river flooding design basis referred to in General Design Criterion 2, Appendix A, 10 CFR Part 50 (USNRC 1975, p. 2.4.3-1).

The content of Regulatory Guide 1.59 at the time the 1975 Standard Review Plan was published is not known. Therefore, it cannot be ascertained if the above reference required consideration of dam failures when specifying the PMF at a site. However, after the revision of Regulatory Guide 1.59 in 1977 (errata 1980), it is known that Appendix A of Regulatory Guide 1.59 references ANSI Standard N170-1976 that addresses dam failures from a variety of mechanisms. In addition, more recent versions of the Standard Review Plan make similar references to Regulatory Guide 1.59.

3.3.3. Standard Review Plan Section 2.4.4

Section 2.4.4 of the 1975 version of the Standard Review Plan (titled “Potential Dam Failures (Seismically Induced)”) addresses dam failures due to seismic events. The following statement was taken from Section 2.4.4 of the 1975 Standard Review Plan:

> The acceptable "worst conditions" to be postulated for analysis of upstream failures in lieu of substantiation of seismic resistance capability are: (1) a 25-year flood on a full reservoir coincident with the dam-site equivalent of the [safe-shutdown earthquake], and (2) a standard project flood (a flood about half the severity of a PMF) on a full reservoir coincident with the dam site equivalent of the [operating basis earthquake]. (USNRC 1975, p. 2.4.4-2).

Thus, the 1975 version of Section 2.4.4 of the Standard Review Plan requires consideration of dam failure under a seismic event coincident with a 25-year flood or standard project flood. The events should be considered with full flood control reservoirs. The 1978 revision (1980 publication) of Section 2.4.4 of the Standard Review Plan modifies the above statement slightly:

> The acceptable "worst conditions" to be postulated for analysis of upstream failures are: (1) dam able to withstand [safe-shutdown earthquake] (equivalent to seismic Category I structures)--assume no failures; (2) dam failure caused by [safe-shutdown earthquake]--assume dam failure coincident with 25-year flood and 2-year extreme wind speed at the site; and (3) dam failure caused by [operating basis earthquake]--assume dam failure

> coincident with SPF and 2-year extreme wind speed at the site. (USNRC 1980, p. 2.4.4-2).

The above statement indicates that, if a dam can be shown to withstand the safe shutdown earthquake, then no failure analysis of the dam coincident with a flood is necessary.

3.3.4. Discussion of Standard Review Plan

Both the 1975 and 1980 versions of Section 2.4.4 of the Standard Review Plan emphasize dam failures under seismic mechanisms (both in section title and in content) coincident with floods less than the PMF. NRC revised the Standard Review Plan and renamed it NUREG-0800 in 1981. In the 1981 and newer versions of the Standard Review Plan (including the most recent 2007 revision), the treatment of dam failures in Section 2.4.4 is not limited to seismically induced failures and the title of the section is revised to reflect this change. In the 1981 and 2007 revisions of the Standard Review Plan, Section 2.4.4 is titled “Potential Dam Failures” without reference to seismic events. The most recent versions of Section 2.4.4 explicitly require consideration of nonseismic mechanisms. For example, the 1981 and 2007 revisions specify the following as a required area of review: “Hydraulic failure as a result of overtopping for any reason.” Moreover, the 2007 revision requires consideration of the “[e]ffects of sediment deposition or erosion during dam failure-induced flood waves that may result in blockage or loss of function of SSC important to safety” (USNRC 2007, p. 2.4.4-2).[21] Thus, the revision of Section 2.4.4 represents an update in both content and emphasis. No requirement exists to reevaluate plants under the updated Standard Review Plans.

3.4. Regulatory Guide 1.102

Regulatory Guide 1.102 describes the “types of flood protection acceptable to NRC staff for safety-related structures, systems, and components identified in Regulatory Guide 1.29.” Regulatory Guide 1.102 documents three methods of flood protection (USNRC 1976, p. 1.102-3):

- **Dry site.** The plant is built above the design basis flood level and therefore safety-related structures, systems, and components are not affected by flooding. A dry site may be accomplished through natural terrain or engineered fills.
- **Exterior barrier.** Safety-related structures, systems, and components are protected from inundation and associated static and dynamic forces by engineered features that are external to the immediate plant area. Examples include levees, sea/floodwalls, bulkheads, revetments, and breakwaters.
- **Incorporated barrier.** Safety-related structures, systems, and components are protected from inundation and associated static and dynamic forces by engineered features at the structure/environment interface. Examples include reinforced walls designed to resist the static and dynamic forces associated with the design basis flood, waterstops at construction joints, sealed pipe penetrations, and submarine doors/hatches.

Regulatory Guide 1.102 specifies that, in general, temporary flood barriers that must be installed prior to the design basis flood (e.g., sandbags, plastic sheeting, and portable panels) are not acceptable for

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[21] While mentioned in the older Standard Review Plans, the treatment of the effects of sediment and erosion on safety-related components is not as explicit as in more recent versions. The adverse effects from debris, sediment, and erosion are not addressed in this screening analysis.

issuance of a construction permit. However, unusual circumstances with strong justification (e.g., post-construction changes in flood-producing characteristics of the area) may warrant consideration/acceptance of temporary barriers (USNRC 1976, 1.102-4).

3.5. Implications of Regulatory Framework

NRC regulatory documents described above focus most heavily on dam failures due to seismic mechanisms, particularly when considering the versions of the documents available at the time most nuclear power plants were licensed. It has been established in recent NRC studies (Ferrante et al. 2011) that actuarial data do not provide a basis for placing an unbalanced emphasis on dam failures due to seismic events. Hydrological failures (e.g., due to overtopping because of an extreme precipitation event) as well as other failures (e.g., failures due to internal erosion or mechanical/operational deficiencies) are statistically more common than seismically induced failures. The rarity of large seismic events has a strong influence on this statistic and, consequently, statistical data should not be used to conclude that seismic dam failures are not important. Dam failure modes can generally be grouped into the following categories (ASDSO 2011):

- **Overtopping** occurs when the level of the retained reservoir exceeds the capacity/height of the dam. Typically, overtopping is the result of a rapid rise in water level without substantial warning (e.g., during flash floods or following collapse of an upstream dam). About 30-40 percent of all dam failures are caused by overtopping or other weather-related phenomena (NPDP n.d., ASDSO 2011, WSDE n.d.).
- **Foundation defects and internal erosion** are responsible for about half of all dam failures (NPDP n.d., ASDSO 2011, WSDE n.d.). Foundation defects can cause a dam to settle unevenly and jeopardize the structural integrity**.** Piping and seepage occur when water seeps/leaks through the structure of a dam. This internal erosion weakens the structure of the dam and can lead to failure. Seepage often occurs around pipes, spillways, or other hydraulic structures. However, biological causes (e.g., animal burrows, vegetation) as well as cracking can lead to internal erosion (NPDP n.d., ASDSO 2011, WSDE n.d.).
- **Miscellaneous/other dam failure causes** include failures due to poor design and construction, inadequate materials, or lack of maintenance. Such deficiencies can result in loss of structural integrity and consequent dam failure. Seismic failures also fall under this category.

Dam failure incidents are common. Directly using data available in the National Performance of Dams Program Dam Incident Database, historically over 1000 dam incidents have been classified as failure (i.e., uncontrolled release of water) in the United States. The National Performance of Dams Program Dam Incident Database contains over 700 dam incidents classified as failure that have occurred since 1975(NPDP n.d.). The database includes diverse failure events associated with a wide variety of dams, many of which are small and associated with insubstantial consequences. A study performed by NRC (Ferrante et al. 2011) found that 148 large dam (dams with heights 40 ft or higher) failures have occurred in the United States. Of these failures, a subset is classified as events involving catastrophic large dam failure. For the set of larger dams that have failed, the data indicates that the dominant causes of failure are about the same as those for the entire population of dams (Ferrante et al. 2011). This creates some uncertainty regarding whether the regulatory guidance forming the licensing basis of most existing nuclear power plants comprehensively addressed the statistically most common dam failure modes.

The evolution of regulatory framework since the 1975 Standard Review Plan has implications beyond provision of the design basis for nuclear power plants. The IPEEE screening criteria, for high winds, floods, and transportation and nearby facility accidents, utilize the guidance contained in the 1975 version of the Standard Review Plan as the basis for "screening out" hazards. The IPEEE screening approach as specified as NUREG-1407 (USNRC 1991) consists of the following steps:

1. Review of plant-specific hazard data and licensing bases
2. Identification of significant changes since the operating license was issued
3. Determination if the plant and facilities meets the 1975 Standard Review Plan criteria

If the 1975 Standard Review Plan criteria are not satisfied, more extensive evaluations are needed (USNRC 1991, p. x). Figure 14 gives a graphical representation of the IPEEE screening methodology (extracted from NUREG-1407).

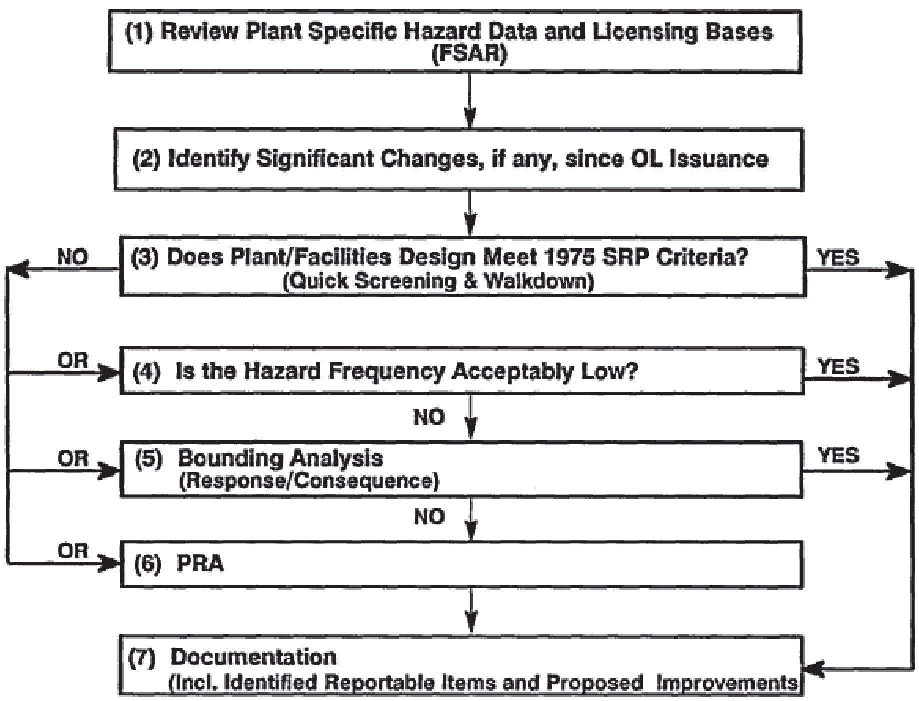

Figure 14: Graphical Representation of IPEEE Screening Methodology for Floods (USNRC 1991)

NUREG-1407 specifies that meeting the 1975 Standard Review Plan ensures that the contribution from a flood to core damage frequency is less than 10^{-6} per year:

> All licensees should compare the information obtained from the review discussed in Sections 5.2.1 [Review Plant-Specific Hazard Data and Licensing Basis] and 5.2.2 [Identify Significant Changes Since OL Issuance] for conformance to 1975 SRP criteria and perform a confirmatory walkdown of the plant. … If the comparison indicates that the plant conforms to the 1975 SRP criteria and the walkdown reveals no potential vulnerabilities not included in the original design basis analysis, it is judged that the contribution from that hazard to core damage frequency is less than 10^{-6} per year and the IPEEE screening criterion is met. (USNRC 1991, p. 17).

With regard to external flooding, the assurance of core damage frequency below $10^{-6}/\text{year}$ is based on a previous study by Chery (1985), which is referenced earlier in NUREG-1407:

> For plants designed against current criteria as described in Regulatory Guide 1.59 and applicable Standard Review Plan sections, particularly Section 2.4, floods pose no significant threat of a severe accident because the exceedance frequency of the design basis flood, excluding floods due to failure of upstream dams, is judged to be less than 10^{-5} per year (Chery, 1985), and the conditional core damage frequency for a design basis flood is judged to be less than 10^{-1}. Thus, core damage frequencies are estimated to be less than 10^{-6} per year for a plant designed against NRC's current criteria (USNRC 1991, p. 4).

The above conclusion regarding contribution of external flooding to core damage frequency is based on a study that excludes floods due to upstream dam failures.

The IPEEE submittals tended to treat the assessment of hazard due to external flooding as a qualitative screening against the 1975 Standard Review Plan rather than quantifying plant-specific risk. Based on the excerpts provided above, it is unclear if the basis for screening out hazards due to external flooding based on the 1975 Standard Review Plan considered risks associated with upstream dam failure due to all applicable mechanisms. Moreover, Section 2.4.4 of the 1975 Standard Review Plan emphasized dam failures due to seismic events. The treatment of other failure mechanisms in the 1975 Standard Review Plan is primarily through nested references to ANSI Standard N170-1976 that (as illustrated previously) treats hydraulic failures deterministically and provides limited guidance related to non-seismic, non-hydrologic failure mechanisms. Given available data, it is unclear if meeting the 1975 Standard Review Plan assures that the contribution of external flooding hazard core damage frequency, when accounting for upstream dam failure, is less than $10^{-6}/\text{year}$.

Since the last revision of most of the aforementioned regulatory documents, significant advances have occurred in the area of flood estimation resulting from the availability of larger and more accurate datasets, geographical information systems, and new analysis techniques. Consequently, NRC is currently in the process of revising Regulatory Guide 1.59 to more accurately reflect current state of practice (USNRC 2010a, USNRC 2010g, Prasad 2010). NUREG/CR-7046 (“Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States”) addresses a technical basis for revising Regulatory Guide 1.59. The report describes a hierarchical hazard assessment approach in which the licensee uses progressively refined analyses to demonstrate plant safety against flooding. Under the approach, the licensee uses the least intensive method available to demonstrate safety, i.e., the most demanding and accurate approaches are only used when simpler and more conservative approaches are not sufficient to demonstrate safety. With regard to dam failures, NUREG/CR-7046 specifies that the simplest and most conservative approach is to assume that all upstream dams fail under the PMF (regardless of their design capacity) and the peak discharge for all dams arrives simultaneously at the site. If safety against the flood resulting from this scenario (including wind-wave effects) can be demonstrated, no additional dam failure flood analysis is needed. However, if safety cannot be assured, site-specific data may be used to perform more refined failure analyses. For example, the number of failed upstream dams (and consequently volume of floodwaters routed to the site) may be reduced if strong justification is given to show that some upstream dams will not fail under PMF scenarios. NUREG/CR-7046 emphasizes failure assessment under PMF events rather than seismic events. Consistent with this emphasis, NUREG/CR-7046 provides an example case study in which the initiating event is a dam breach resulting from overtopping during a PMF event.

4. Conclusions / Closing

The reviewers recommend that the proposed issue related to nuclear power plant site flooding, caused or exacerbated by upstream dam failure, be designated as a Generic Issue in NRC Generic Issues Program. In the opinion of the reviewers, the issue meets the criteria specified in Management Directive 6.4. The following summary statements address those criteria one by one:

- **The issue affects public health and safety, the common defense and security, or the environment**. Failure of one or more dams upstream from a nuclear power plant may result in flood levels at a site that render essential safety systems inoperable. For example, high floodwaters may fail all available power sources (e.g., offsite, emergency diesel, auxiliary), hinder operations, and damage other infrastructure resulting in station blackout and higher than acceptable risk. Moreover, safety-related components may be collocated and simultaneously inundated when floodwaters reach a critical elevation. This correlation in demands on collocated components results in a reduction in redundancy and an elevated risk of system failure. The totality of information analyzed in this report suggests that external flooding due to upstream dam failure poses a larger than expected risk to plants and public safety with a probability and consequence sufficient to warrant a Generic Issue evaluation.

- **The issue applies to two or more facilities and/or licensees/certificate holders, or holders of other regulatory approvals.** This scenario is plausible at multiple nuclear power plant sites, as discussed.

- **The issue cannot be readily addressed through other regulatory programs and processes; existing regulations, policies, or guidance; or voluntary industry initiatives.** NRC regulatory/staff guidance and requirements related to upstream dam failure have evolved since the earlier licensing of U.S. nuclear power plants. A review of the old and new guidance against the plant data covered in this report suggests that additional analysis of external flooding caused or exacerbated by upstream dam failure is warranted and likely to be beneficial. It is important to note that ongoing regulatory actions regarding Fort Calhoun Station do not consider any flood contribution from upstream dam failure(s). In general, this issue is not addressed by any regulatory program or process; existing regulation, policy, or guidance; or voluntary industry initiative.

- **The issue can be resolved by new or revised regulation, policy, or guidance.** It is possible to develop regulations, policy, or guidance that require appropriate analysis of hazard due to upstream dam failure (particularly coincident with large precipitation events) and, if required, mitigation of the associated risks.

- **The issue's risk or safety significance can be adequately determined.** Flooding from upstream dam failure(s) can be analyzed and modeled. The impact of potential flooding scenarios can be analyzed and risk significance can be determined. The issue does not involve phenomena or other uncertainties that would require long-term studies or experimental research to establish the risk or safety significance.

- **The issue is well defined, discrete, and involves a radiological safety, security, or environmental matter.** The issue proposes a specific event and a logical and plausible condition of increased risk. The risk involves a plausible consequence of an uncontrolled release of radiologic material at levels hazardous to the public due to loss of safety-related equipment because of inundation by floodwaters.

- **The resolution of the issue may potentially involve review, analysis, or action by the affected licensees, certificate holders or holders of other regulatory approvals.** If further analysis results in a conclusion of higher than acceptable risk due to external flooding as a result of upstream dam failure, it may be necessary to require licensees to reevaluate flood risk using refined analysis methods or to take action to mitigate flood risk through the installation of cost-justified backfits.

A significant contributing factor to the screening analysis recommendation is the fact that the initial regulatory approach to this specific issue has evolved considerably and in a manner that addresses weaknesses in the previous approach. The prescribed standard review process is now more comprehensive and rigorous with regard to consideration of upstream dam failures than it was at the time of the issuance of the original licenses for many nuclear power plants. This reflects a deliberate desire to improve the evaluation of the issue as it applies to safety. Moreover, a capability to make more accurate flood projections and risk-informed determinations is readily available. It is the opinion of the review group that reevaluation of a subset of currently operating nuclear power plants using modern review processes and techniques is warranted and is likely to be beneficial.

Active investigations at the Oconee and Fort Calhoun sites have resulted in a much better understanding of the issue as it applies to those sites. NRC's perception of relevant factors and associated potential risks has significantly improved over what it was prior to the investigations. As a result, further analysis and action addressing flooding is underway with regulatory or procedural changes likely. It is significant that the need for these actions was not obvious until after the prior investigation was performed. Based on the analysis documented in this report, the screening analysis group concludes that a similar evaluation of a subset of U.S. nuclear power plant sites is warranted because these sites may have similar deficiencies not likely to be identified and characterized until an appropriate evaluation is conducted. It is the analysis group's opinion that the likelihood of significant and beneficial discovery justifies the formal evaluation that would be performed if this issue were classified as a Generic Issue under the program defined in NRC Management Directive 6.4.

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