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

November 14, 2016

Mr. Randall K. Edington
Executive Vice President
Nuclear/CNO
Arizona Public Service Company
P.O. Box 52034, MS 7602
Phoenix, AZ 85072-2034

SUBJECT: PALO VERDE NUCLEAR GENERATING STATION, UNITS 1, 2, AND 3 – STAFF ASSESSMENT OF RESPONSE TO 10 CFR 50.54(f) INFORMATION REQUEST – FLOOD-CAUSING MECHANISM REEVALUATION (CAC NOS. MF5546, MF5547 AND MF5548)

Dear Mr. Edington:

By letter dated March 12, 2012, the U.S. Nuclear Regulatory Commission (NRC) issued a request for information pursuant to Title 10 of the *Code of Federal Regulations*, Section 50.54(f) (hereafter referred to as the 50.54(f) letter). The request was issued as part of implementing lessons learned from the accident at the Fukushima Dai-ichi nuclear power plant. Enclosure 2 to the 50.54(f) letter requested that licensees reevaluate flood-causing mechanisms using present-day methodologies and guidance. By letter dated December 12, 2014 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML14350A466), Arizona Public Service Company (APS, the licensee) responded to this request for Palo Verde Nuclear Generating Station, Units 1, 2, and 3.

By letter dated September 28, 2015 (ADAMS Accession No. ML15268A413), the NRC staff sent APS a summary of the staff's review of the licensee's reevaluated flood-causing mechanisms. The enclosed staff assessment provides the documentation supporting the NRC staff's conclusions summarized in the letter. As stated in the letter, the reevaluated flood hazard result for local intense precipitation was not bounded by the current design-basis flood hazard. Therefore, the NRC staff anticipates that the licensee will complete an evaluation of this unbounded flood mechanism, through a focused evaluation as discussed in COMSECY-15-0019, "Closure Plan for the Reevaluation of Flooding Hazard for Operating Nuclear Power Plants," and Japan Lessons-Learned Division (JLD) Interim Staff Guidance (ISG) JLD-ISG-2016-01, "Guidance for Activities Related to Near-Term Task Force Recommendation 2.1, Flooding Hazard Reevaluation; Focused Evaluation and Integrated Assessment."
This closes out the NRC's efforts associated with CAC Nos. MF5546, MF5547 and MF5548.

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

Sincerely,

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

Docket Nos. 50-528, 50-529 and 50-530

Enclosure:
Staff Assessment of Flood Hazard
Reevaluation Report

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STAFF ASSESSMENT BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO FLOODING HAZARD REEVALUATION REPORT

NEAR-TERM TASK FORCE RECOMMENDATION 2.1

PALO VERDE NUCLEAR GENERATING STATION, UNITS 1, 2, AND 3

DOCKET NOS. 50-528, 50-529, AND 50-530

1.0 INTRODUCTION

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

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

By letter dated December 12, 2014, Arizona Public Service Company (APS, the licensee) provided its FHRR for Palo Verde Nuclear Generating Station (PVNGS, Palo Verde), Units 1, 2, and 3 (APS, 2014).

On September 28, 2015, the NRC issued an interim staff response (ISR) letter to the licensee (NRC, 2015b). The purpose of the ISR letter is to provide the flood hazard information suitable for the assessment of mitigating strategies developed in response to Order EA-12-049, "Requirements for Mitigation Strategies for Beyond-Design-Basis External Events" (NRC, 2012b), and the additional assessments associated with Recommendation 2.1: Flooding. That ISR letter also made reference to this staff assessment, which documents the NRC staff's basis and conclusions. The flood hazard mechanism values presented in the letter's enclosures match the values in this staff assessment without change or alteration.

As mentioned in the ISR letter and discussed below, the reevaluated flood hazard results for the local intense precipitation (LIP) flood-causing mechanism is not bounded by the plant's current design basis (CDB). Consistent with the 50.54(f) letter and amended by the process outlined in

COMSECY-15-0019 and Japan Lessons-Learned Division (JLD) Interim Staff Guidance (ISG) JLD-ISG-2016-01, Revision 0 (NRC, 2015a and NRC, 2016c), the staff anticipates that the licensee will perform and document a focused evaluation for LIP and associated site drainage that assesses the impact of the LIP hazard on the site, and evaluate and implement any necessary programmatic, procedural, or plant modifications to address this hazard exceedance.

Additionally the licensee is expected to develop flood event duration (FED) parameters and flood-related associated effects (AE) to conduct the mitigating strategies assessment (MSA) and focused evaluation of the LIP flood mechanism.

2.0 REGULATORY BACKGROUND

2.1 Applicable Regulatory Requirements

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

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

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

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

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

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

2.2 Enclosure 2 to the 50.54(f) Letter

Section 50.54(f) of 10 CFR states that a licensee shall at any time before expiration of its license, upon request of the Commission, submit written statements, signed under oath or affirmation, to enable the Commission to determine whether or not the license should be modified, suspended, or revoked. The 50.54(f) letter requested, in part, that all power reactor licensees and construction permit holders reevaluate all external flooding-causing mechanisms at each site (NRC, 2012a). This includes applying current techniques, software, and methods used in present-day standard engineering practice.

2.2.1 Flood-Causing Mechanisms

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

2.2.2 Associated Effects

The licensee should incorporate and report associated effects per JLD-ISG-2012-05, "Guidance for Performing the Integrated Assessment for External Flooding" (NRC, 2012d), in addition to the maximum water level associated with each flood-causing mechanism. Guidance document JLD-ISG-2012-05 (NRC, 2012d) defines "flood height and associated effects" as the maximum stillwater surface elevation plus:

- wind waves and run-up effects
- hydrodynamic loading, including debris
- effects caused by sediment deposition and erosion
- concurrent site conditions, including adverse weather conditions
- groundwater ingress
- other pertinent factors

2.2.3 Combined Effects Flood

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

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

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

2.2.4 Flood Event Duration

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

2.2.5 Actions Following the FHRR

For the sites where the reevaluated probable maximum flood elevation is not bounded by the CDB probable maximum flood elevation for any flood-causing mechanisms, the 50.54(f) letter requests licensees and construction permit holders to:

- Submit an interim action(s) plan with the FHRR documenting actions planned or already taken to address the reevaluated hazard.

- Perform an integrated assessment to (a) evaluate the effectiveness of the CDB (i.e., flood protection and mitigation systems); (b) identify plant-specific vulnerabilities; and (c) assess the effectiveness of existing or planned systems and procedures for protecting against and mitigating consequences of flooding for the flood event duration.

If the reevaluated flood hazard is bounded by the CDB flood hazard for all flood-causing mechanisms at the site, licensees are not required to perform an integrated assessment. COMSECY-15-0019 (NRC, 2015a) and JLD-ISG-2016-01, Revision 0 (NRC, 2016c) outline a revised process for addressing cases in which the reevaluated flood hazard is not bounded by the plant's CDB. The revised process describes an approach in which licensees with LIP hazards exceeding their CDB flood will not be required to complete an integrated assessment, but instead will perform a focused evaluation that will assess the impact of the LIP hazard on their sites and then evaluate and implement any necessary programmatic, procedural or plant modifications to address the hazard exceedance. For other flood hazard mechanisms that exceed the CDB, licensees can assess the impact of these reevaluated hazards on their site by performing either a focused evaluation or a revised integrated assessment (NRC, 2015a and NRC, 2016c).

3.0 TECHNICAL EVALUATION

The NRC staff reviewed the information provided in the PVNGS, Units 1, 2, and 3 FHRR (APS, 2014). The licensee conducted the flood hazard reevaluation using present-day methodologies and regulatory guidance used by the NRC staff in connection with ESP and COL reviews.

In connection with the staff's FHRR review, electronic copies of the computer input/output files used in the numerical modeling were provided to the staff and cited as part of the "NRC Report for the Audit of APS's Flood Hazard Revaluation Report Submittals Relating to the Near-Term Task Force Recommendation 2.1-Flooding for Palo Verde" (NRC, 2016a). The staff's review and evaluation is provided below.

3.1 Site Information

3.1.1 Detailed Site Information

The 50.54(f) letter (NRC, 2012a) included the SSCs important to safety in the scope of the hazard reevaluation. Per the 50.54(f) letter, Enclosure 2, "Requested Information, Hazard Reevaluation Report," Item a, the licensee included this pertinent data concerning the SSCs in the PVNGS Units 1, 2, and 3 FHRR (APS, 2014). Enclosure 2 (Recommendation 2.1: Flooding), "Requested Information, Hazard Reevaluation Report," Item a, describes site information to be contained in the FHRR.

The FHRR (APS, 2014) stated that the nominal grade for the PVNGS site is elevation 951 ft (289.9 m) National Geodetic Vertical Datum of 1929 (NGVD29). Unless otherwise stated, all elevations in this staff assessment are given with respect to NGVD29. Ground surface elevations at the site generally dip south from a high of nearly 1,030 ft (313.9 m) at the northern site boundary, to about 890 ft (271.3 m) at the southern boundary (APS, 2014). The elevations of Units 1, 2, and 3 are 957.5 ft (291.9 m), 954.5 ft (290.9 m), and 951.5 ft (290.0 m) NGVD29, respectively. Table 3.0-1 provides a summary of the controlling reevaluated flood-causing mechanisms, including associated effects, that the licensee computed to be higher than the respective powerblock elevations. Figure 3.1-1 depicts key hydrologic features of the PVNGS site described in this report.

The PVNGS site is located on a gently, south-dipping plain within the Sonoran high desert. Surface drainage at the site is controlled by the natural topography that works in concert with a system of ephemeral streams or washes[1]; this intermittent drainage system ultimately feeds into either the distal Gila River to the south or the Hassayampa River to the east-southeast. The site is bounded on the north and east by the East Wash and on the north and west by the Winters Wash, and the Centennial Wash to the south; all of these water features are ephemeral. The natural drainage system has been complimented by a man-made drainage network that includes ditches and culverts. The licensee reported that the onsite drainage system is designed to minimize the potential for surface water ponding within the powerblock area. At some locations within the site, the licensee reported that compacted fill has been introduced to raise the elevations in those areas adjacent to structures above projected elevation flood levels; the addition of fill has also been locally used to modify site grades from 0.5 to 1 percent locally to improve the efficiency of the existing drainage network. That surface drainage network is also enhanced by the geology of the site; the PVNGS site is generally underlain by permeable soils which permit the infiltration of surface water. Any surface water ponding that might take place would be considered by the licensee to be transient.

Groundwater intrusion was not a design issue as no groundwater was encountered during original construction at the PVNGS site. Limited perched water occurs at depths 30 to 60 ft (9.1 to 18.3 m) below the ground surface. A regional groundwater system is also present but its depth is about 200 ft (61.0 m) below the ground surface.

Each reactor has two identical essential spray ponds that serve as the ultimate heat sink for the respective reactor units. The maximum operating surface water elevation for the essential spray ponds is 937 ft (285.6 m) NGVD29. The licensee reported modifications to the PVNGS site that have led to the construction of other hydrologic features of interest. There are two reservoirs on-site immediately to the east of the reactor block, but within the confines of the East Wash containment berm. They provide cooling water makeup to the site and are referred to as the "45-Acre Reservoir" and the "85-Acre Reservoir," in reference to their respective surface areas. The water surface elevation (WSE) of the two reservoirs is normally maintained at 951 ft (289.9 m) NGVD29. Finally, there are three evaporation ponds near the southern boundary of the site operated in connection with the Water Reclamation Facility Sewage Treatment plant that supports the cooling water needs for the PVNGS. The elevation of the containment berm surrounding the three ponds is 942 ft (287.1 m) NGVD29; and the maximum operating WSE for all of the evaporation ponds is 937 ft (285.6 m) NGVD29.

3.1.2 Design-Basis Flood Hazards

The CDB flood levels are summarized by flood hazard mechanism in Table 3.1-1. The CDB flood hazard elevations are 955.5 ft (291.2 m), 952.5 ft (290.3 m), and 949.5 ft (289.4 m) NGVD29 for PVNGS Units 1, 2, and 3, respectively. The licensee reported that the design-basis flood hazard for the PVNGS site is a probable maximum flood (PMF) of the Winters Wash drainage basin in combination with site-wide inundation as a result of a LIP event.

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[1] By definition, a wash is a natural fluvial drainage feature that temporarily or seasonally fills and flows with meteoric water after a precipitation event occurs such as a thunderstorm. Consistent with its morphology, the licensee reports in the FHRR that there is measureable flow in each of the two washes of interest about once a year.

The licensee noted that the PVNGS site is not considered to be susceptible to flooding by rivers, intermittently-flowing tributaries (washes), dam failures, ice flooding, or channel migration. The site is also not adjacent to any coastal area and, therefore, not vulnerable to flooding by tsunami, tidal surge, or seiche by virtue of its geographic isolation. As a consequence, these flooding scenarios were not considered as part of the original licensing basis for the site. As such, the PVNGS site is considered to be a "dry site" (APS, 2014). The NRC staff reviewed the information provided in the FHRR and determined that sufficient information was provided to be responsive to Enclosure 2 of the 50.54(f) letter.

3.1.3 Flood-Related Changes to the Licensing Basis

The licensee reported in its FHRR (APS, 2014) that there was no information to suggest that anthropogenic factors have had an impact on the watersheds encompassing the PVNGS site. However, the licensee reported that construction of the roadbed associated with the Interstate 10 (or I-10) highway took place across portions of the Winters Wash and East Wash drainage basins approximately 6 miles (9.6 km) north of the PVNGS site in 1990. In connection with that construction, culverts and drainage ditches were installed resulting in modification of the local topography and associated drainage patterns.

The licensee also reported that in 2012 the natural flow alignment of the East Wash channel was modified and re-routed around the powerblock yard. This realignment included the construction of a containment berm intended to protect the powerblock from any intermittent flood waters associated with the wash. The berm elevation varies from 983.1 ft (299.6 m) NGVD29 at its northern-most extent to 948.4 ft (289.1 m) NGVD29 at a point along its eastern flank.

The licensee noted that these changes were accounted for in the hydrologic models used in the FHRR though the use of improved, higher-resolution topographic data for the region and site. The staff reviewed the flood hazard information provided and determined that sufficient information on the flood-related changes to the licensing basis was provided to be responsive to Enclosure 2 of the 50.54(f) letter (NRC, 2012a).

3.1.4 Changes to the Watershed and Local Area

Watershed changes reported by the licensee included replacement of the Waddell Dam (on the Gila River) in 1994. The licensee also reported that the storage capacities of the Theodore Roosevelt Dam (on the Salt River) and the Bartlett Dams (on the Verde River) were expanded through augmentation of those containment structures. These changes were accounted for in the applicable PVNGS FHRR analyses performed by the licensee (APS, 2014).

The licensee also reported other changes that were accounted for in the hydrologic models used in the FHRR though the use of improved, higher-resolution topographic data for the region and site. They included:

- Construction of I-10 (as described above) to the north of the PVNGS site.

- Construction of the so-called 45-Acre Reservoir and a vehicle barrier system (VBS) within the powerblock footprint. Additional new construction included expanding the size of other non-safety-related buildings outside of the power plant's protected area. Lastly, construction of Evaporation Ponds Nos. 2 and 3 was reported to have occurred in 1988 and 2009, respectively. The evaporation ponds are to the south and down-gradient of the powerblock yard.

- Paving of the Elliot Road, to the south of the site.

The staff reviewed the flood hazard information provided and determined that sufficient information on changes to the watershed and local area was provided to be responsive to Enclosure 2 of the 50.54(f) letter (NRC, 2012a).

3.1.5 Current Licensing Basis Flood Protection and Pertinent Flood Mitigation Features

There are many different types of flood protection features credited in the PVNGS CLB. Those features include: the East Wash embankment (including its riprap); the Winters Wash embankment; all designated Seismic Category I building exterior walls, basemats, roof drainage systems; the containment berms for the 45-Acre and 85-Acre Reservoirs; drainage ditches; the use of compacted fill; and existing site grading.

The licensee also reported that fill had been added to multiple powerblock locations and existing physical plant structures that was intended to improve the passive drainage capability of the site (APS, 2014). The staff reviewed the flood hazard information provided and determined that sufficient information on CLB flood protection and pertinent flood mitigation features was provided to be responsive to Enclosure 2 of the 50.54(f) letter (NRC, 2012a).

3.1.6 Additional Site Details to Assess the Flood Hazard

To provide additional information in support of the summaries and conclusions in the FHRR, the licensee made certain calculation packages available to the staff via an electronic reading room. The staff did not rely directly on the calculation packages in its review; they were found only to expand upon and clarify the information already provided in the FHRR and docketed, and so those calculation packages were not docketed or cited.

3.1.7 Results of Plant Walkdown Activities

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

By letter dated November 27, 2012, APS provided the flood Walkdown Report for the PVNGS site (APS, 2012). By letter dated January 31, 2014 (APS, 2014), APS provided a response to the NRC staff's request for additional information dated December 23, 2013 (NRC, 2013c), for completeness of information. The staff issued a staff assessment report on May 20, 2014 (NRC, 2014), which documented its review of the Walkdown Report. The NRC staff concluded that the licensee's implementation of the flooding walkdown methodology met the intent of the walkdown guidance.

3.2 Local Intense Precipitation and Associated Site Drainage

The licensee reported that the reevaluated flood hazard, including associated effects, for LIP and associated site drainage is based on stillwater surface elevations of 957.7 ft (291.9 m), 955.0 ft (291.1 m), and 952.4 ft (290.3 m) NGVD29, respectively, at Units 1, 2, and 3 (NRC, 2016b). The licensee reevaluated the potential impact of wind waves and run-up and determined they would have no effect on the LIP flood elevations (APS, 2014).

This flood-causing mechanism is discussed in the licensee's CDB. The CDB PMF elevations for LIP and associated site drainage are based on stillwater surface elevations of 955.5 ft (291.2 m), 952.5 ft (290.3 m), and 949.5 ft (289.4 m) NGVD29, respectively, at Units 1, 2, and 3 (APS, 2013). Wind waves and run-up were not considered in the CDB for LIP; for the purposes of the 50.54(f) analysis, the licensee considered these effects inconsequential owing to the low water depths estimated.

3.2.1 Site Drainage and Elevations

The licensee reevaluated the flood hazard resulting from LIP due to a thunderstorm over a drainage area (corresponding to the FHRR modelling domain) of about 4 mi^2 (10 km^2) that included the footprint of the PVNGS powerblock, the site's VBS, and all contiguous natural drainage areas. For the purposes of the FHRR, updated ground-surface elevations were obtained from aerial photography. However, the licensee reported that due to shadowing effects, the topographic elevations obtained from that aerial survey were in error at certain locations within the PVNGS powerblock. Those areas included the area between the Diesel Generator and Operations Support Buildings for Units 2 and 3 and the Unit 2 breezeway between the Auxiliary and Turbine Buildings (NRC, 2016b). Consequently, the licensee reported that it conducted a manual GPS survey of the areas in question to provide more-accurate ground-surface elevations where the aerial data were believed to be in error (APS, 2014). In connection with the August 2015 audit, the licensee provided the locations and topographic elevation data obtained from the manual ground survey (NRC, 2016b). Using those newly-acquired topographic data, a new digital elevation model grid was constructed by the licensee for subsequent use in the LIP analysis. That grid had a 3 ft-by-3 ft (0.91 m-by-0.91 m) resolution mesh. During the August 2015 audit, the licensee stated that the accuracy of the data obtained from the aerial photographic survey was ±0.237 ft (0.0722 m); (NRC, 2016b) compared to 0.001 in. (0.003 mm) for measurements made as part of the manual survey.

3.2.2 Local Intense Precipitation

For ESPs and COLs, current NRC guidance for LIP evaluation is to select the appropriate probable maximum precipitation (PMP) event reported in the National Weather Service's Hydrometeorological Report (or HMRs) applicable to the site. For the PVNGS site, the PMP parameter value obtained from the applicable HMR – HMR 49 National Oceanic and Atmospheric Administration ((NOAA), 1977) – is 15.5 in. (39.4 cm) for a 6-h, 1-mi^2 (3-km^2) event. Alternatively, the PMP value used by the licensee was obtained from an up-to-date site-specific PMP (ssPMP) study completed by Applied Weather Associates (AWA) for the State of

Arizona (AWA, 2013). As reported in the FHRR (APS, 2014), the AWA study relied on a 6-h, 1-mi^2 (3-km^2) LIP event; according to that study, based on both updated meteorological record as well as numerical processing techniques, the site-specific PMP event was found to produce a lower cumulative rainfall depth of 12.8 in. (32.5 cm) over 6 hours. In deriving the LIP event used in the FHRR, the licensee assumed that peak rainfall intensity occurred at the midpoint of the thunderstorm event, as shown in Figure 3.2-1, with a maximum 10-min incremental rainfall depth of about 2.7 in. (6.9 cm), and a maximum 1-h rainfall depth of 10.7 in. (27.2 cm) (APS, 2014).

In evaluating the site drainage resulting from the LIP event, the licensee evaluated flood stages at 55 flow path locations common to each reactor unit (NRC, 2016b; see Figure 3.2-2) and reported the maximum estimated flood elevation corresponding to each location for each reactor unit (i.e., a total of 115 locations). Because of local topographic variations at each of the three units as built, local maxima of inundation depths were reported at different flow path locations for each of the three reactors.

3.2.3 ssPMP Sensitivity Analysis

To evaluate the licensee's use of a LIP event based on an ssPMP value, the staff used information from HMR 49 (NOAA, 1977) to derive an alternative LIP event with a peak rainfall intensity at the midpoint of the event, and a 6-h, 1-mi^2 (3-km^2) cumulative PMP depth of 15.5 in (39.4 cm) from HMR 49. This HMR-based event had a maximum 15-min incremental rainfall depth of about 8 in. (20.3 cm), and a maximum 1-h rainfall depth of 11.8 in. (30.0 cm) which were comparable to the event described in the updated final safety analysis report (UFSAR) evaluation of the effects of LIP (APS, 2013). Both maximum depth and peak rainfall intensity for the HMR-based LIP event exceed similar values for the ssPMP event used by the licensee. To evaluate the effects of the licensee's use of a ssPMP-based LIP event, the staff performed an independent calculation to compare the flood modeling results for peak WSE using the licensee's runoff analysis model, FLO-2D (see Section 3.2.4 below), to WSE results obtained by the staff using the licensee's model with a LIP event based on the HMR 49 PMP value.[2]

The results of staff's sensitivity analysis show that the WSEs estimated using the HMR-based event were only slightly higher than the WSEs estimated using the licensee's ssPMP-based event. Differences in the respective WSE estimates did vary from location-to-location within the powerblock, however, the maximum differences were on the order of +0.2 ft, (+0.6 m) at each reactor unit – e.g., +0.25 ft (+7.6 cm) for Unit 1, +0.20 ft (+6 cm) for Unit 2, and +0.17 ft (+5.2 cm) for Unit 3. As a result of the small differences, the staff determined that it was not necessary to further review the licensee's methodology for determining ssPMP estimates. Therefore, the staff concluded that the licensee's ssPMP values were reasonable to use in the LIP runoff analysis discussed below.

[2] For this calculation, the staff relied on a more-recent version of the computer code – version (build) 15.09.09 versus version 13.02.04 used by the licensee.

3.2.4 Runoff Analysis

The licensee reevaluated the flood elevation from a LIP event using the FLO-2D Pro (Build No. 13.02.04) computer code (FLO-2D Software, Inc., 2012) to compute flows and water-surface elevations on a two-dimensional gridded domain. Due to the number of variables and complexity of the LIP model, the staff requested that the licensee provide the FLO-2D input files used to support development of the FHRR. The staff used those files to evaluate the configuration of the licensee's FLO-2D model including the engineering judgement used to select for the values of the hydraulic parameters being executed by the computer code.

The licensee described five simulation cases in its FHRR (APS, 2014), completed as part of a hierarchical hazard assessment that generally followed the example in Appendix B of NUREG/CR-7046 (2011e). Case 1 consisted of a constant rainfall rate equal to the peak intensity of the LIP described in Section 3.2.2. Upon review, the staff agrees with the licensee and concluded that this extreme rainfall scenario was unrealistic. Cases 2 through 4 relied on the LIP hyetograph described in Section 3.2.2 and shown in Figure 3.2-1. Cases 2 and 3 were identical except for the size of the FLO-2D computational grid, which was 25 ft-by-25 ft (7.6 m-by-7.6 m) for Case 2 and 15 ft-by-15 ft (4.6 m-by-4.6 m) for Cases 3 and 4. The staff determined that the higher-grid resolution modeling domain (15 ft-by-15 ft) was judged to represent flow around and near buildings, flow obstructions, and other areas of variable topography. Differences between Cases 3 and 4 included lower Manning's n roughness coefficient values for Case 4 and a more realistic representation of roof slopes for Case 4. As described below, the staff determined that the lower Manning's n values were reasonable. The staff also determined that the licensee's representation of building roofs were reasonable, as described below. The licensee's Case 5 was identical to Case 3 except for the time distribution of rainfall. Case 4 was ultimately selected by the licensee to assess the reevaluated flood hazard and was the primary focus of the staff's FHRR review.

The licensee defined outflow cells along all boundaries of the FLO-2D modelling domain to allow surface water reaching any boundary location to flow out of the modelling domain. Most of the southern boundary of the computer model was located along the containment berm constituting the northern edge of the on-site evaporation ponds. The higher elevation of the berm, reported to extend 14 ft (4.3 m) above grade, limited the amount of outflow from those particular grid cell locations. Based on the topographic information provided by the licensee, the staff found the licensee's use of the outflow boundary conditions for the FLO-2D model appropriate. The FLO-2D model, which was reviewed by the NRC, had boundary and other key model features as shown in Figure 3.2-3.

To simplify the computer simulation, the licensee assumed that storm water-conveyance structures were assumed to be completely blocked. The licensee assumed that gaps in individual sections of the VBS were also blocked during the LIP event, and represented this structure in the FLO-2D computer model as a levee of uniform elevation of 3.5 ft (1.1 m) above the ground surface elevation (APS, 2014). The licensee also represented the essential spray ponds in the computer model topographically as levees. The staff determined that the location of the VBS was appropriately represented in the model and that the representation of that feature with blocked (obstructed) openings as a levee, was a conservative assumption and is one modeling option choice consistent with NUREG/CR-7046 (NRC, 2011e).

The FHRR Case 4 simulation selected by the licensee considered infiltration losses in the LIP analysis (APS, 2014). The staff evaluated the effect of the infiltration losses on WSE estimates by conducting an independent simulation that assumed no infiltration losses. Based on that independent simulation, it was found that the influence of infiltration losses on the maximum flood depths produced less than 0.5 in. (1.3 cm) effect on the at the flow path locations identified by the licensee; the staff therefore concluded that the licensee's modeling assumption in this regard was reasonable.

The staff evaluated the Manning's n values used in the FHRR Case 4 simulation and determined that the values were near the upper end of the ranges recommended in the FLO-2D reference manual, except for the value assigned to the locations of the powerblock, buildings, and pavement, which were at the lower end of the recommended range. The licensee stated that the lower Manning's n value selected for the locations of buildings within the powerblock and paved areas were more representative of surface conditions on-site than a higher value (from the upper-end of the recommended range described in the FLO-2D reference manual) for this particular parameter (APS, 2014). The staff reviewed the recommended Manning's n values for concrete and paved surfaces described in Chow et al. (1988) and concluded that the lower value used by the licensee was reasonable. The staff also evaluated the effect of the Manning's n value on estimated water depths by completing a sensitivity simulation that used a Manning's n value that was at the upper end of the range recommended in the FLO-2D reference manual for locations including the powerblock, buildings, and paved areas. The staff determined that the higher Manning's n value increased the maximum flood depths by about 0.2 ft (0.06 m) or less at the flow path locations identified by the licensee.

The licensee assigned area reduction factors (ARF) and width reduction factors (WRF) of 0.93 to grid cells corresponding to building locations. In addition, the elevation of these grid cells was raised 1 to 2 ft (0.3 to 0.6 m) above the surrounding cells for the purposes of the computer simulations, and the elevations of cells corresponding to building locations were adjusted to reflect the relative elevations of the roofs, as well as the actual slopes of those roofs. The staff determined that the locations of buildings were properly implemented in the computer model and that the representation of the buildings with higher grid cell elevations would both promote flow from these cells as well as prevent flow to the cells. The staff evaluated the effect of the ARF and WRF parameter values used by the licensee to represent buildings by completing a parametric sensitivity simulation in which the values of those parameters were set to zero. The staff determined that the use of zero values for the ARF and WRF parameters resulted in small (<0.1 ft (0.3 m)) differences in water depths at the flow path locations identified by the licensee, and that the licensee's approach resulted in higher peak flood elevations. The staff concluded that the licensee's use of non-zero ARF and WRF values was therefore reasonable and consistent with staff guidance.

3.2.5 Water Level Determination

The licensee identified 55 potential flow path locations around each reactor unit by which flood water could potentially affect plant safety, and reported maximum flood elevation, maximum flood depth, flooding duration, maximum velocity, and maximum hydrostatic and hydrodynamic forces (NRC, 2016b). Flow path locations for Unit 1 are shown in Figure 3.2-2 using that reactor's layout as an example. The licensee stated that two of the pathways at each reactor unit location were excluded as special cases, specifically a low-grade area in the North Yard and the tendon gallery shaft location (pathway 55) because it is an isolated open space (NRC, 2016b). The licensee also stated that the pathways along the Unit 2 breezeway were excluded because of measurement errors in estimating the elevations of the model grid cells, as discussed above (NRC, 2016b). The licensee compared the estimated flood depth to the inlet height of doors and hatches at each of the potential pathway locations. The licensee reported that maximum flood depths were greater than some door/hatch inlet heights for safety-related structures (APS, 2014). In Table 4-3 of the FHRR, the licensee reported the reevaluated flood hazard as a maximum flood depth ranging from 0.2 to 0.6 ft (0.06 to 0.2 m) for these features. The licensee also acknowledged that there was a temporal aspect to those flood depths that varied by location when the drainage characteristics and geometry of the powerblock were taken into account.

The staff verified the results reported in the FHRR using the computer input files provided by the licensee. The staff reviewed the resulting model output and determined that (a) mass balance errors were small, (b) flow pathways and areas of inundation appeared reasonable, and (c) flow velocities were reasonable with no indication of numerical instabilities and no unexpected supercritical flow conditions were identified near potential flooding pathways. Based on these results, the staff finds the licensee's FLO-2D model to be an appropriate basis for evaluating water elevations from LIP and associated site drainage.

Using results from the FLO-2D computer model, the staff determined that maximum flood depth above the inlet height of each potential flooding pathway varied across the site, with maximum depths of 0.6 ft (0.2 m), 0.6 ft (0.2 m), and 0.34 ft (0.1 m), respectively, at Units 1, 2, and 3. The reported WSEs and flood water depths for each reactor unit and flow path location are shown in Table 3.2-1. The staff determined that flood depth exceeded the inlet heights at about half the potential flooding pathways. The staff confirmed that flood depths were greater than 0.6 ft (0.2 m) for some of the excluded pathways identified by the licensee. Flood depths along the breezeway between the Unit 2 Auxiliary and Turbine Buildings were about 0.8 ft (0.2 m) higher than the corresponding areas for Units 1 and 3. Based on a review of the topographic data and the model grid cell elevations (described above), the staff determined that the FLO-2D model results for the Case 4 simulation overestimated the flood depths along the Unit 2 breezeway and underestimated the flood depths at some potential flooding pathway locations of Unit 3. The staff reviewed the simulated flow paths around the three reactor units and determined that flooding around the safety-related structures of each unit is substantially independent of flow conditions at the other units. Given the similarity in site layout of the three units, the staff concluded that flood depth along the breezeways for Unit 2 and Unit 3 was best represented by the Case 4 simulation results. The staff further concluded that the licensee's estimate of maximum flood depth above the inlet height of 0.6 ft (0.2m) is appropriate for each of the three reactor units.

Using the results from the Case 4 LIP simulation, the staff evaluated the maximum water-surface elevation at each unit for the non-excluded, potential flooding pathways identified by the licensee. The staff confirmed the licensee's maximum WSEs reported in the FHRR of 957.7 ft (291.9 m), 955.0 ft (291.1 m), and 952.4 ft (290.3 m) NGVD29, respectively, for Units 1, 2, and 3.

3.2.6 Conclusion

The staff confirmed the licensee's conclusion that the reevaluated flood hazard for LIP and associated site drainage is not bounded by the CDB flood hazard. Therefore, the staff expects that the licensee will submit a focused evaluation for LIP and associated site drainage consistent with the process and guidance discussed in COMSECY-15-0019 (NRC, 2015a) and JLD-ISG-2016-01, Revision 0 (NRC, 2016c).

3.3 Streams and Rivers

This flood-causing mechanism is discussed in the licensee's CDB. The licensee reported in its FHRR that the reevaluated flood hazard, including associated effects for streams and rivers, is based on stillwater WSEs in the East Wash of 979.5 ft (298.6 m) NGVD29 at the north-facing embankment location (floodplain cross-section 'X1'), and at three other locations (floodplain cross-sections 'A1', 'B', and 'C') along the east-facing embankment (APS, 2014): 963.4 ft (293.6 m), 955.2 ft (291.1 m), and 946.2 ft (288.4 m) NGVD29, respectively. The locations of the floodplain cross-sections described are depicted in Figure 3.1-1. When wind waves and run-up effects were included, the corresponding elevations for the four floodplain cross-section locations described were 981.0 ft (299.0 m), 964.8 ft (294.1 m), 956.6 ft (291.6 m), and 947.6 ft (288.8 m) NGVD29. The licensee also reported in its FHRR, that the maximum reevaluated flood hazard estimated for the Winters Wash drainage basin (at the longitudinal extension of the cross-section 'B' floodplain location at the East Wash – hereafter 'B extended'), is based on a stillwater WSE of 940.0 ft (286.5 m) NGVD29. By including wind waves and run-up, this results in an estimated WSE of 940.4 ft (286.6 m) NGVD29 (APS, 2014). The licensee's reevaluation of flooding on streams and rivers described in the FHRR included three components: (a) developing PMP events, (b) simulating the PMFs associated with these precipitation events, and (c) evaluating the effect of combined flooding events. The licensee's reevaluation included the 281 mi^2 (728 km^2) Winters Wash drainage basin and about 17 mi^2 (44 km^2) of the 28 mi^2 (73 km^2) East Wash drainage basin. The licensee also used a screening analysis to evaluate the flooding potential at the PVNGS site from certain distal riverine systems (Centennial Wash, the Hassayampa River, and the Gila River). The extent of the Winters Wash and East Wash drainage basins are shown in Figure 3.3-1 along with portions of the river systems that were the subject of the screening analysis. The licensee stated in its FHRR (APS, 2014) that the methods used in reevaluating flooding on streams and rivers followed guidance in ANSI/ANS-2.8 (ANSI/ANS,1992) and NUREG/CR-7046 (NRC, 2011e), and guidance from the Flood Control District of Maricopa County (FCDMC, 2011).

3.3.1 Screening Analysis

There are five streams and rivers of interest that could potentially flood the PVNGS site. The licensee evaluated flooding on the Centennial Wash drainage basin, the Hassayampa River, and the Gila River using a screening analysis that is described in more detail in this section. The licensee estimated PMF discharge from a regression model based on existing PMF studies from the surrounding region and estimated watershed areas (APS, 2014). The licensee used a U.S. Army Corps of Engineers (USACE) computer code – the Hydrologic Engineering Center River Analysis System (HEC-RAS) (USACE, 2010a) – to evaluate the peak WSEs resulting from the PMF discharge for each of the respective watersheds (NRC, 2016b). The results of the licensee's screening analysis is summarized in Table 3.3-1. In the screening analysis, the licensee evaluated the potential for flooding in nearby rivers where the PMF would have to cross a watershed divide in order to inundate the site. The licensee's screening approach was consistent with NUREG/CR-7046 in that the licensee considered alternative conceptual models for the streams and rivers flooding. The screening analysis involved using a regression model based on available data from nearby watersheds to estimate the PMF discharge in two of the alternative watersheds, and using an existing PMF discharge estimate for the third. The staff determined this was a reasonable approach because the regression was a good fit to the data and because the licensee's screening analysis resulted in flood elevations significantly below the elevation at which the reactor site would be affected. The licensee stated that flooding on the Centennial Wash drainage basin, the Hassayampa River, and the Gila River would not affect the PVNGS site. The licensee concluded that the most likely flooding scenarios involving streams and rivers at the PVNGS site is from the Winters Wash and East Wash watersheds.

The staff reviewed the hydrography of the area, the PMF regression model used by the licensee, the configuration of the respective HEC-RAS models, and the licensee's model results. The staff also confirmed that the PVNGS site is isolated from the Gila River, the Hassayampa River, and Centennial Wash. The staff determined that there are multiple factors supporting the licensee's screening decision-making. Those factors included combinations of distance, elevation, and geographic/topographic isolation. In order to inundate the PVNGS site, the potential for flooding in those nearby rivers would require that the PMF cross a watershed divide. As a consequence, that staff confirmed that a PMF on either the Centennial Wash drainage basin, the Hassayampa River, or the Gila River would not affect the PVNGS site. The staff concluded that the licensee's screening approach was consistent with staff guidance, and that the licensee's conclusion that the most likely scenarios for streams and rivers flooding at the PVNGS site are from the Winters Wash and East Wash watersheds, was reasonable.

3.3.2 Probable Maximum Precipitation

The licensee elected to use a basin-wide site-specific PMP estimate for the purposes of the streams and rivers hazard reevaluations in lieu of selecting a precipitation value from the applicable National Weather Service HMR used for the purposes of the CDB (NOAA, 1977). For the Winters Wash drainage area, the HMR-derived PMP value is 14.6 in. (37.1 cm), corresponding to a 24-h rainfall event. For the East Wash drainage area, the HMR-derived value is 14.4 in. (36.6 cm) for a 6-h PMP rainfall event.

For the purposes of the FHRR, two separate PMP events were considered corresponding to the two respective drainage basins based on a study completed for the State of Arizona (AWA, 2013). For the Winters Wash drainage basin, the licensee used a 72-h duration tropical storm with a cumulative rainfall depth of 11.2 in. (28.5 cm) (APS, 2014). Peak rainfall intensity occurred 42 hours after the start of the event, with a maximum intensity of 4.2 in. (10.6 cm) over a 6-h period, as shown in Figure 3.3-2. For the smaller area of the East Wash drainage basin, the licensee used a 6-h duration local storm with a cumulative rainfall depth of 10.1 in. (25.6 cm) with a peak intensity of 2.1 in. (5.3 cm) over 10 min occurring 3-h after the start of the event, as also shown in Figure 3.3-2.

3.3.3 Probable Maximum Flood

The licensee estimated the PMF discharge for the Winters Wash and the East Wash drainage basins using the USACE Hydrologic Engineering Center - Hydrologic Modeling System (HEC-HMS) computer code (USACE, 2010b), to calculate runoff from the PMP event (APS, 2014). The discharge estimated by the HEC-HMS computer model was subsequently used as an upstream boundary condition in the FLO-2D computer code used to model the PMF in both washes.

3.3.3.1 Winters Wash PMF

The licensee used the FLO-2D computer code (Build No. 13.02.04) to model and evaluate the depth and duration of flooding in Winters Wash. The licensee represented the Winters Wash drainage basin by dividing it into 13 sub-basins; those sub-basins ranged in size from about 2 to 50 mi^2 (5 to 129 km^2). The model domain was based on a 50-ft (15.2-m) square grid and encompassed about 32 mi^2 (83 km^2) that included portions of both the Winters Wash and East Wash drainage basins from locations about 2.5 mi (4 km) north of the powerblock to about 2.5 mi (4 km) south. The licensee stated that the site was not inundated by the PMF occurring on Winters Wash, the reevaluated flood hazard elevation associated with the PMF was estimated to be 940 ft (286.5 m) NGVD29 at a location adjacent to the PVNGS site (specifically, at a location corresponding to the cross-section B extended location illustrated in Figure 3.1-1). The licensee also evaluated the effects of wind wave activity in the Winters Wash drainage basin during the PMF based on the 2-yr return period maximum sustained wind (estimated for the LIP evaluation) and maximum fetch length using procedures taken from USACE (2008). The wave run-up calculated by the licensee was 0.4 ft (0.1 m).

Due to the complexity of the licensee's PMF flood analysis for Winters Wash, as well as the number of engineering judgments used to construct the PMF model, the staff requested that the licensee provide the HEC-HMS and FLO-2D input files used in obtaining the results described in the FHRR for the purposes of review. The files provided constituted a series of simulation cases, with initial cases using conservative assumptions and other cases modifying these assumptions based on site-specific information (NRC, 2016b). The staff evaluated the licensee's basis for the infiltration loss model, the unit hydrograph approach, and the channel routing in the calculation of PMF discharge using the HEC-HMS model. Using the input files from the licensee's FLO-2D model, the staff evaluated the configuration of the FLO-2D models used in the licensee's evaluation of flood depth and duration. The staff confirmed that the licensee's analysis was consistent with the description in the FHRR. The staff also confirmed that the licensee's approach was consistent with and supported by the available information, and was consistent with the hierarchical hazard assessment approach described in NUREG/CR-7046 (NRC, 2011e). Lastly, using the FLO-2D model input files, the staff confirmed the reevaluated flood hazard elevation for the Winters Wash drainage system. The maximum predicted flood elevation for a PMF on the Winters Wash drainage basin was estimated to be well-below the grade elevation for all three reactor units.

3.3.3.2 East Wash PMF

The licensee estimated the PMF discharge and flood depths in the East Wash drainage basin using a pair of FLO-2D computer models (Build No. 14.03.07). The licensee used a 100-ft (30.5-m) square grid for the FLO-2D model of the East Wash watershed to evaluate discharge resulting from the East Wash PMP event. This model extended from the upper end of the East Wash watershed to the northern boundary of the evaporation ponds located within the powerblock yard. The licensee used results from the 100-ft (30.5-m) square grid model to provide inflows to a more detailed, 25-ft (7.6-m) square grid FLO-2D model that was then used to estimate flood elevations. The smaller grid model encompassed the PVNGS site and a portion of East Wash drainage basin from about 2.5 mi (4.0 km) north of the powerblock to the northern boundary of the evaporation ponds. In Table 4-3 of the FHRR, the licensee reported maximum WSEs at four cross-sections along the north- and east-facing embankment locations along the East Wash flow path (i.e., cross-section locations 'X1', 'A1', 'B', and 'C' depicted in Figure 3.1-1). The WSEs calculated ranged from 979.5 ft (298.6 m) to 946.2 ft (288.4 m) NGVD29 and all were at least 2 ft (0.6 m) below the embankment elevations at the locations described above. The licensee calculated wave run-up of 1.5 ft (0.5 m) along the north-facing portion of the embankment and 1.4 ft (0.4 m) for the east-facing portion of the embankment along the East Wash (APS, 2014).

Due to the complexity of the licensee's PMF flood analysis for East Wash, as well as the number of engineering judgments used to construct the PMF model, the staff requested that the licensee provide the FLO-2D input files used in obtaining the results described in the FHRR for the purposes of review. Using both the FLO-2D computer code input files provided by the licensee (APS, 2015) and a detailed description of the model analysis (URS, 2014), the staff evaluated the configuration of both the 100-ft (30.5-m) and 25-ft (7.6-m) square grid models used in the evaluation of the East Wash PMF. The staff confirmed that the licensee's analysis was consistent with the description in the FHRR. The staff also confirmed that the licensee's approach was consistent with and supported by the available information, and was consistent with the hierarchical hazard assessment approach described in NUREG/CR-7046 (NRC, 2011e). Using the FLO-2D input files, the staff confirmed the reevaluated flood hazard elevations provided by the licensee in the FHRR for the East Wash drainage basin.

The staff also performed an independent FLO-2D analysis of PMF for the East Wash drainage basin using the PMP value reported in HMR 49 (NOAA, 1977). The staff's independent simulation demonstrated that the HMR-based estimated WSE did not exceed the embankment elevation for the East Wash containment berm.

3.3.4 Combined Events

The licensee followed ANSI/ANS-2.8 (ANSI/ANS, 1992) when evaluating the potential effects on the reevaluated flood hazard from combined events (APS, 2014). Because of the arid climatic conditions of the area, the licensee screened-out combined events involving snowpack and snowmelt. The licensee stated that the snowpack/snowmelt combined effects alternatives were screened out because snowmelt contributions to large floods occurs at elevations above approximately 7,000 ft (or about 2,100 m) NAVD29, and because historical temperatures near the PVNGS site are high enough that snow is expected to melt quickly, thereby reducing the possibility of snowmelt contributing to precipitation-induced flooding. The staff noted that maximum elevations in the Winters Wash watershed are about 3,000 ft (or about 900 m) NAVD29, and significantly lower in the East Wash watershed. The staff evaluated the licensee's basis for screening out snowpack/snowmelt combined effects and determined that it was reasonable.

The licensee evaluated the combined effects of the PMP, an antecedent rain equal to 40 percent of the PMP, and wave effects from the 2-yr wind applied in the critical wind direction. The licensee stated that the antecedent storm occurred 3 days prior to the PMP on Winters Wash and 1 day prior to the PMP on East Wash (APS, 2014). Flood elevations adjacent to the site were evaluated using a collection of FLO-2D models. Based on results obtained from those models, the licensee concluded that the flood hazard from the combined events was bounded by the PMF analysis for Winters Wash and that flood elevations in East Wash would not overtop the containment berm isolating that drainage feature from the PVNGS powerblock.

The staff reviewed the combined events information provided in the FHRR and determined that the licensee's analysis was consistent with the available information and with the guidance described in ANSI/ANS-2.8 (ANSI/ANS, 1992). Based on the small size of the watersheds, the soil characteristics of those watersheds, the duration of the hydrographs resulting from the PMF modeling, and the time between the antecedent storm and the PMP, the staff also determined that the antecedent rainfall events evaluated by the licensee are unlikely to have a significant impact on the PMF results.

3.3.5 Conclusion

In summary, the staff confirmed the licensee's conclusion that the reevaluated hazard for flooding from streams and rivers is bounded by the CDB flood hazard at the PVNGS site. Therefore, the NRC staff determined that flooding from streams and rivers does not need to be analyzed in a focused evaluation or a revised integrated assessment consistent with the process and guidance discussed in COMSECY-15-0019 (NRC, 2015a) and JLD-ISG-2016-01, Revision 0 (NRC, 2016c).

3.4 Failure of Dams and Onsite Water Control/Storage Structures

The licensee reported in its FHRR that the reevaluated flood hazard, including associated effects, for failure of dams is based on a stillwater-surface elevation of 900.5 ft (274.5 m) NGVD29 on the Gila River. Wind waves and run-up effects had been previously evaluated for the purposes of the UFSAR; those effects had been determined to be inconsequential by the licensee by virtue of the site's geographic isolation from the river and consequently where not reported in the FHRR.

This flood-causing mechanism is discussed in the licensee's CDB. The CDB probable maximum flood elevation for failure of dams is based on a stillwater WSE of 900 ft (274.3 m) NGVD29 on the Gila River. There are no dams or onsite water control/storage structures reported to be associated with the Hassayampa River, the East Wash, or Winters Wash. Several small detention dams are reported along the flow path of the Centennial Wash, the largest being a low earthfill dam about 45 mi (72.4 km) upstream from the site. As the capacity of this reservoir is only about 100 acre-feet (123,000 cubic meters), the flooding hazard posed by this particular storage feature is considered inconsequential for the purposes of the PVNGS FHRR as the estimated WSE generated at the site would be bounded by the CDB.

In conducting its FHRR review, the staff confirmed that there are no water control/storage structures present within the East Wash or the Winters Wash drainage areas. The staff also confirmed that the PVNGS site is isolated from the Gila River, the Hassayampa River, and Centennial Wash. The staff determined that there are multiple factors supporting the licensee's screening process. Those factors included combinations of distance, elevation, and geographic/topographic isolation. In order to inundate the PVNGS site, the potential for flooding in those nearby rivers would require that the PMF cross a watershed divide. As a result, that staff concluded that failure of a water control/storage structures on any of those drainage features would not flood the reactor site. The summary of the licensee's reasoning for screening certain rivers from the FHRR is summarized in Table 3.4-1. The staff reviewed the information (including drainage features) and concluded that the licensee's reasoning for screening streams and rivers from the flood hazard reevaluation was equally valid for the dam failure analysis, and was reasonable based on the arguments presented.

In the matter of potential flood hazards associated with onsite water storage structures within the powerblock proper, the licensee evaluated the flooding potential that might exist if there were a loss of containment from any of the 11 water storage structures located within the PVNGS site. Based on engineering judgement, the licensee concluded that the storage structures, should they fail, would not exceed the CDB. The licensee's onsite water storage structure failure assessment and screening rationale is discussed in Table 3.4-1.

In conducting its review, the staff evaluated the information provided by the licensee including the detailed topographic map for the PVNGS site and environs as well as available aerial photography showing the water storage structures of interest. While reviewing that information, the staff was also reminded that the FHRR made reference to the slope of the PVNGS powerblock; that slope was reported to dip one percent to the south resulting in a minimum drop of 5 to 7 ft (1.5 to 2.1 m) at the peripheral edge of the site. This design detail, acting in concert with the existing surface water drainage system, is relied on to preferentially remove transient meteoric water away from the powerblock to locations down-gradient of the site (APS, 2014).

The licensee also evaluated the potential for wind-generated overtopping of the applicable onsite water bodies such as the 45-Acre and 85-Acre Reservoirs, the evaporation ponds, and the essential spray ponds based on the 2-yr return period maximum sustained winds and maximum fetch lengths. The licensee estimated the 2-yr wind (47.3 mph (76.1 km/h)) using frequency analysis on available data from a representative weather station chosen for proximity to the PVNGS site and at least 30 years of wind speed data. The staff determined that the licensee's 2-yr wind estimate was consistent with ANSI/ANS-2.8 (ANSI/ANS, 1992). The licensee concluded that wind-generated waves would not contribute to the flood elevations adjacent to safety-related structures. The staff reviewed the licensee's wind wave evaluation and determined that the licensee followed appropriate procedures (USACE, 2008). Given the proximity of the onsite water bodies from the powerblock areas, the general drainage patterns on the site, and the flow paths during flooding as determined from the Case 4 FLO-2D model simulations, the staff concluded that wind waves and run-up during LIP flooding would not significantly contribute to the flood hazard at the PVNGS site.

The staff reviewed the information presented by the licensee concerning the flooding risk posed by the failure of onsite water storage structures. The staff agrees with the licensee's conclusion that it is highly unlikely for any of these water storage structures to flood the PVNGS powerblock to a depth that exceeds the CDB. The staff found that the site's topography, the powerblock grading, the on-site drainage system, and the orientation of important powerblock structures would be expected to act in unison to passively divert flood waters away from key reactor structures. Staff review comments concerning the potential failure of each onsite water storage structure can also be found in Table 3.4-1. The staff determined that the licensee's conclusion that the identified onsite water storage storages do not pose a flooding risk to the PVNGS site was reasonable.

The NRC staff reviewed the licensee's methodology for the PMF analysis, including the dam screening process, sensitivity runs for Manning's n values, and dam breach parameters and concludes that the methods are appropriate for the purposes of the 50.54(f) letter. The NRC staff confirms the licensee's conclusion that the reevaluated flood hazard for failure of dams and onsite water control or storage structures at a stillwater-surface elevation of 900.5 ft (274.5 m) NGVD29 on the Gila River is bounded by the CDB flood hazard at the PVNGS site. Therefore, the NRC staff determined that flooding from failure of dams or onsite water control or storage structures does not need to be analyzed in a focused evaluation or a revised integrated assessment consistent with the process and guidance discussed in COMSECY-15-0019 (NRC, 2015a) and JLD-ISG-2016-01, Revision 0 (NRC, 2016c).

3.5 Storm Surge

The licensee reported in its FHRR (APS, 2014) that the reevaluated hazard and associated effects for storm surge-related flooding, does not affect the plant site since this flood mechanism does not inundate the plant site, and thus did not report a storm surge-caused flood elevation for the PVNGS site. This flood-causing mechanism is discussed in the licensee's CDB, but was not considered to be physically plausible due to the PVNGS site location approximately 260 mi (418 km) inland from the Pacific Ocean and 1,000 mi (1,600 km) inland from the Gulf of Mexico. Consequently, the licensee reported that this flood-causing mechanism was not considered in the CDB for the PVNGS site.

In connection with the FHRR review, the staff reviewed the flooding hazard from surge-related flooding, including associated effects, against the relevant regulatory criteria based on present-day methodologies and regulatory guidance. Based on geographic evidence in the site region, the staff concluded that there is no potential for storm-surge like phenomena to affect the PVNGS. This is due primarily to the absence of a large body of standing water (ocean, bay, estuary, lake, etc.) over which meteorological forces can act to raise the elevation of the particular water body in question; in the absence of such water bodies, storm-related surges cannot form (Fairbridge, 1966).

The NRC staff reviewed the information provided by the licensee and agrees that storm surge will not impact the site, based primarily on geographic evidence. Therefore, the NRC staff determined that flooding from storm surge does not need to be analyzed in a focused evaluation or a revised integrated assessment consistent with the process and guidance discussed in COMSECY-15-0019 (NRC, 2015a) and JLD-ISG-2016-01, Revision 0 (NRC, 2016c).

3.6 Seiche

The licensee reported in its FHRR, that the reevaluated hazard (including associated effects) for seiche-related flooding effects does not affect the plant site since this flood mechanism does not inundate the plant site. As a result, the licensee did not report a seiche-caused flood elevation. This flood-causing mechanism is discussed in the licensee's CDB, but was generally considered to be not physically plausible. Seiche-like phenomena occurs in connection with enclosed or semi-enclosed water basins such as lakes and bays (Fairbridge, 1966). These types of geographic features are not present at, or adjacent to, the PVNGS site. Consequently, the licensee reported that this flood-causing mechanism was not considered in the CDB for the PVNGS site.

In connection with the FHRR review, the staff reviewed the flooding hazard from seiche-related flooding, including associated effects, against the relevant regulatory criteria based on present-day methodologies and regulatory guidance. Based on geographic/topographic evidence of the site region, the staff concluded that there are no large water bodies present to allow for the formation of seiches. Other water bodies with a theoretical potential for seiche-induced flooding at the PVNGS site include the aforementioned make-up water reservoirs, the essential spray ponds, and the evaporation ponds. These features are discussed, including the staff's review comments, in Table 3.4-1 of this staff assessment.

The staff reviewed the flooding hazard from seiche-related flooding (including associated effects) for the aforementioned surface water impoundments against the relevant regulatory criteria, which is based on present-day methodologies and regulatory guidance. Based on the shallow depth of the surface water impoundments found to be on-site, the staff concluded that if seiche-related flooding phenomena were to occur, that the effects would be inconsequential and bounded by the LIP flooding scenario.

In summary, the NRC staff reviewed the information provided by the licensee and agrees that a seiche will not impact the site. The staff confirmed the licensee's conclusion that the reevaluated hazard for flooding from seiche-related flooding effects is not applicable to the PVNGS site. Therefore, the NRC staff determined that flooding from seiche does not need to be analyzed in a focused evaluation or a revised integrated assessment consistent with the process and guidance discussed in COMSECY-15-0019 (NRC, 2015a) and JLD-ISG-2016-01, Revision 0 (NRC, 2016c).

3.7 Tsunami

The licensee reported in its FHRR that the reevaluated hazard analysis for tsunami does not impact the site since this flood mechanism does not inundate the plant site, and thus did not report a tsunami-caused flood elevation. This flood-causing mechanism is discussed in the licensee's CDB, but was not considered to be physically plausible since the PVNGS site is not at a geographic setting that might be susceptible to tsunami-related flooding. The site is inland and not located on or near the coast where tsunami-like waves can make land after forming along the ocean floor. The PVNGS site is approximately 260 miles (418 km) from the Pacific Ocean and 1,000 miles (1,600 km) from the Gulf of Mexico. Consequently, the licensee reported that this flood-causing mechanism was not considered in the CDB for the PVNGS site.

In connection with the FHRR review, the staff reviewed the flooding hazard from tsunami-related flooding, including associated effects, against the relevant regulatory criteria based on present-day methodologies and regulatory guidance. Based on geographic evidence in the site region, the staff concluded that there is no potential for tsunami-like phenomena to affect the PVNGS site. The in-land location of PVNGS is well-away from the influence of recognized tsunamogenic sources (Gutenberg, 1939).

The NRC staff reviewed the information provided by the licensee and confirms the licensee's conclusion that the PMF from tsunami-induced flooding does not impact the site. The staff also confirmed the licensee's conclusion that the reevaluated hazard for tsunami-induced flooding of the PVNGS site is bounded by the CDB flood hazard. Therefore, the NRC staff determined that flooding from tsunami does not need to be analyzed in a focused evaluation or a revised integrated assessment consistent with the process and guidance discussed in COMSECY-15-0019 (NRC, 2015a) and JLD-ISG-2016-01, Revision 0 (NRC, 2016c).

3.8 Ice-Induced Flooding

The licensee reported in the FHRR that the reevaluated hazard (including associated effects) for ice-induced flooding effects does not impact the site and therefore, did not report a PMF elevation. This flood-causing mechanism is discussed in the licensee's CDB, but was not considered to be physically plausible since the climate at the PVNGS site is generally considered to be "arid," with mean daily temperatures ranging from 53 degrees Fahrenheit (°F) to 90°F (12° to 32° Celsius). These temperatures are well-above the freezing point of water and consequently, water bodies in and around the PVNGS site are not subject to freezing.

The staff reviewed the flooding hazard potential from ice-induced flooding against the relevant regulatory criteria, which is based on present-day methodologies and regulatory guidance. The staff queried the Cold Regions Research and Engineering Laboratory (CRREL) ice jam database maintained by USACE (USACE, 2015) to perform an independent review. Based on that brief confirmatory review, the NRC staff concluded that there were no reports of ice jam formation or ice dams on either the Gila or Hassayampa Rivers. The staff's review also found no reports of ice jam/dam formations on any of the dry drainage washes of interest.

In summary, the staff confirmed the licensee's conclusion that the PMF from ice-induced flooding alone could not inundate the site. The staff also confirmed the licensee's conclusion that the reevaluated hazard for ice-induced flooding of the site is bounded by the CDB flood hazard. Therefore, the NRC staff determined that ice-induced flooding does not need to be analyzed in a focused evaluation or a revised integrated assessment consistent with the process and guidance discussed in COMSECY-15-0019 (NRC, 2015a) and JLD-ISG-2016-01, Revision 0 (NRC, 2016c).

3.9 Channel Migrations or Diversions

The licensee reported in its FHRR that the reevaluated hazard (including associated effects) for channel migrations or diversions does not impact the site and therefore, did not report a PMF elevation. This flood-causing mechanism is discussed in the licensee's CDB, but was not considered likely to occur at the PVNGS site based on a qualitative assessment of geologic, topographic, and land-use information. In both the UFSAR and the FHRR, the licensee noted that the only hydrologic sources of flooding risk were the intermittent drainage basins defined by the Winters Wash and the East Wash.

At its closest point, the Winters Wash is approximately 0.5 miles (0.8 km) from the PVNGS owner-controlled area. In the UFSAR (APS, 2007), the licensee reported that about 10 ft (3.0 m) of compacted fill had been added to the western margin of the powerblock site to provide additional margin (i.e., grade height) against potential flooding along that particular water course. The engineering adequacy of this enhancement had been previously evaluated in an earlier staff review of an update to the PVNGS UFSAR. The East Wash is immediately adjacent to the PVNGS site. An armored containment berm was constructed in connection with the realignment of the East Wash in 2012. The engineering adequacy of this particular enhancement had been previously evaluated in an earlier staff review of an update to the PVNGS UFSAR. Both the licensee's analysis was well as the staff's independent review of flooding within the East Wash drainage basin confirmed that the elevation of the protective berm constructed along the wash, provides sufficient margin against the PMF event. Lastly, the Centennial Wash drainage basin, the Hassayampa River, and the Gila River were screened from consideration by virtue of their physical isolation from the PVNGS site.

The staff reviewed the flooding hazard potential from channel migrations or diversions (including associated effects) against the relevant regulatory criteria, which is based on present-day methodologies and regulatory guidance as described below. The NRC staff guidance described in NUREG/CR-7046 (NRC, 2011e) acknowledges that there are no well-established predictive models for estimating the potential for channel diversion in a riverine environment. However, the potential for channel migrations or diversions to take place at a particular location can be assessed by reviewing certain types of information such as topographic maps that are generally recognized to reflect evidence of the horizontal movement (meandering) of rivers and streams. The staff's review involved searching the U.S. Geological Survey (USGS) historic topographic map digital data base (USGS, 2015). First, staff identified the earliest maps published for the area subsequently reviewed those maps for geomorphic evidence of channel diversion (including river meandering). After completing this initial step, the staff reviewed more recently-developed maps of the reactor site to see if there had been changes in the topography in the intervening years. The staff's review of the USGS's historic data base of topographic maps of the PVNGS site and environs did not reveal any evidence of river or stream meandering. Based on this review, the staff concludes that there is no physical evidence of river meandering and/or channel diversion for at least the last century.

In summary, the staff confirmed the licensee's conclusion that the flood hazard from channel migrations or diversions is not a plausible flooding mechanism at the PVNGS site. The staff also confirmed the licensee's conclusion that the reevaluated hazard for channel migration- or diversion-induced flooding of the PVNGS site is bounded by the CDB flood hazard. Therefore, the NRC staff determined that flooding from channel migration or diversions does not need to be analyzed in a focused evaluation or a revised integrated assessment consistent with the process and guidance discussed in COMSECY-15-0019 (NRC, 2015a) and JLD-ISG-2016-01, Revision 0 (NRC, 2016c).

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

4.1 Reevaluated Flood Height for Hazards Not Bounded by the CDB

Section 3 of this staff assessment documents the staff review of the licensee's flood hazard water height results. Table 4.1-1 contains the maximum results, including waves and runup, for reevaluated flood mechanisms not bounded by the CDB presented in Table 3.1.1. The staff agrees with the licensee's conclusion that LIP is the only hazard mechanism not bounded by the CDB.

Consistent with the process and guidance discussed in COMSECY-15-0019 (NRC, 2015a), the NRC staff anticipates the licensee will submit a focused evaluation for LIP and associated site drainage.

4.2 Flood Event Duration for Hazards Not Bounded by the CDB

The staff reviewed information provided in the APS's FHRR (APS, 2015) regarding the FED parameters needed to perform the additional assessment of plant response for flood hazards not bounded by the CDB. The FED parameters for the flood-causing mechanisms not bounded by the CDB are summarized in Table 4.2-1. The staff considers the values reported to be reasonable based on the magnitude of the estimated LIP flooding hazard. Using results from the FHRR Case 4 FLO-2D model simulation (see Section 3.2.4), the staff determined that the period of inundation in the licensee's computer simulation was sufficient to capture the peak (maximum) flood elevations at all powerblock locations of interest. However, the total FED at the potential flooding pathways identified by the licensee in Figure 3.2-2 (including the period of recession as shown on Figure 2.2-1) exceeded the simulation time of 7-h.

The licensee did not provide FED values for recession of water from the site during the LIP event. The licensee is expected to develop FED parameters for these flood-causing mechanisms as part of the MSA or focused evaluation. The NRC staff will review these FED parameters as part of future additional assessments of plant response from PVNGS.

4.3 Associated Effects for Hazards Not Bounded by the CDB

The staff reviewed information provided in the APS's FHRR (APS, 2015, NRC, 2016b) regarding AE parameters needed to perform future additional assessments of plant response for flood hazards not bounded by the CDB. The AE parameters directly related with maximum total water height, such as waves and run-up, are summarized in Section 4.1 of this staff assessment. The AE parameters not directly associated with total water height are listed in Table 4.3-1.

The staff determined that the maximum water velocity at the potential flooding pathways identified by the licensee was 2.7 fps (0.8 m/s). The licensee concluded that erosion, sedimentation, and debris loading could be screened-out due to low flow velocities at this site (APS, 2014). Based on the relatively low flood depths and velocities of the Case 4 simulation results, the staff agreed that these AE are minimal and the results reported in Table 4.3-1 are reasonable.

The licensee is expected to develop AE parameters for factors listed as "not provided" in Table 4.3-1 as part of the MSA or focused evaluation.

The staff concludes that the licensee's methods were appropriate and the AE parameter results provided are reasonable for use in additional assessments associated with the MSA and the focused evaluation.

4.4 Conclusion

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

The licensee is expected to develop FED parameters and applicable flood AEs to conduct future additional assessments as discussed in the NEI 12-06 (Revision 2), Appendix G (NEI, 2015). The staff will evaluate the flood event duration parameters (including warning time and period of inundation) and flood-related AE marked as "not provided" in these tables as part of future assessments of plant response, if applicable to the assessment and hazard mechanism.

5.0 CONCLUSION

The NRC staff has reviewed the information provided for the reevaluated flood-causing mechanisms at PVNGS. Based on its review of the available information provided in APS's 50.54(f) response (APS, 2014), the staff concludes that the licensee conducted the hazard reevaluation using present-day methodologies and regulatory guidance used by the NRC staff in connection with ESP and COL reviews.

Based upon the preceding analysis, the NRC staff confirmed that the licensee responded appropriately to Enclosure 2 of the 50.54(f) letter, dated March 12, 2012. In reaching this determination, staff confirmed the licensee's conclusions that (a) the reevaluated flood hazard results for LIP are not bounded by the CDB flood hazard, (b) an additional assessment of plant response will be performed for the LIP mechanism, and (c) the reevaluated flood-causing mechanism information is appropriate input to the additional assessments of plant response.

6.0 REFERENCES

Notes: ADAMS Accession Nos. refers to documents available through NRC's Agencywide Documents Access and Management System (ADAMS).

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

FLOOD-CAUSING MECHANISM	SRP SECTION(S) AND JLD-ISG
Local Intense Precipitation and Associated Drainage	SRP 2.4.2 SRP 2.4.3
Streams and Rivers	SRP 2.4.2 SRP 2.4.3
Failure of Dams and Onsite Water Control/Storage Structures	SRP 2.4.4 JLD-ISG-2013-01
Storm Surge	SRP 2.4.5 JLD-ISG-2012-06
Seiche	SRP 2.4.5 JLD-ISG-2012-06
Tsunami	SRP 2.4.6 JLD-ISG-2012-06
Ice-Induced	SRP 2.4.7
Channel Migrations or Diversions	SRP 2.4.9
SRP refers to the Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition (NRC, 2007). JLD-ISG-2012-06 refers to the "Guidance for Performing a Tsunami, Surge, or Seiche Hazard Assessment" (NRC, 2013a). JLD-ISFG-2013-01 refers to the "Guidance for Assessment of Flooding Hazards Due to Dam Failure" (NRC, 2013b).	

Table 3.0-1. Summary of Controlling Flood-Causing Mechanisms at the PVNGS Site

REEVALUATED FLOOD-CAUSING MECHANISMS AND ASSOCIATED EFFECTS THAT MAY EXCEED THE POWERBLOCK ELEVATION		ELEVATION [NGVD29]
Local Intense Precipitation and Associated Drainage	Unit 1 (957.5 ft (291.9 m) NGVD29) *	957.7 ft (291.9 m)
	Unit 2 (954.5 ft (290.9 m) NGVD29) *	955.0 ft (291.1 m)
	Unit 3 (951.5 ft (290.0 m) NGVD29) *	952.4 ft (290.3 m)
*Powerblock elevation.		

Table 3.1-1. Current Design Basis (CDB) Flood Hazard Elevations at the PVNGS Site [NGVD29]

FLOODING MECHANISM		STILLWATER ELEVATION	ASSOCIATED EFFECTS	CDB FLOOD ELEVATION	FHRR REFERENCE
Local Intense Precipitation and Associated Drainage	Unit 1	955.5 ft (291.2 m)	Minimal	955.5 ft (291.2 m)	Section 2.2.1
	Unit 2	952.5 ft (290.3 m)	Minimal	952.5 ft (290.3 m)	
	Unit 3	949.5 ft (289.4 m)	Minimal	949.5 ft (289.4 m)	
Streams and Rivers	Winters Wash (@ Cross Section 'AA')	956.4 ft (291.5 m)	5.6 ft (1.7 m)	962.0 ft (293.2 m)	Section 2.2.2 Table 2-2
	East Wash (@ Cross Section 'G2')	978.8 ft (298.3 m)	4.0 ft (1.2 m)	982.2 ft (299.4 m)	Section 2.2.2 Table 2-2
	Gila River	776 ft (237 m)	Not Applicable (N/A)	776 ft (237 m)	Section 2.2.2
	Centennial Wash	888 ft (271 m)	N/A	888 ft (271 m)	Section 2.2.2
	Hassayampa River	942 ft (287 m)	N/A	942 ft (287 m)	Email from Michael Dilorenzo, APS to Juan Uribe, NRC, Subject: "Palo Verde Flood Hazard Reevaluation Report"(ADAMS Accession No. ML15266A226)
Failure of Dams and Onsite Water Control/ Storage Structures		900 ft (274.3 m)	N/A	900 ft (274.3 m)	Section 2.2.3
Storm Surge		No impact on the site identified	No impact on the site identified	No impact on the site identified	Section 2.2.4
Seiche	45-Acre Reservoir	951.0 ft (289.9 m)	Minimal	951.0 ft (289.9 m)	Section 2.2.6
	85-Acre Reservoir	951.0 ft (289.9 m)	Minimal	951.0 ft (289.9 m)	Section 2.2.6
	Evaporation Ponds	937.0 ft (285.6 m)	Minimal	937.0 ft (285.6 m)	Section 2.2.6
Tsunami		No impact on the site identified	No impact on the site identified	No impact on the site identified	Section 2.2.4
Ice-Induced		No impact on site identified	No impact on the site identified	No impact on the site identified	Section 2.2.4

Channel Migrations or Diversions	No impact on site identified	No impact on site identified	No impact on site identified	Section 2.2.5

Table 3.2-1. FHRR-Reported Maximum Water Surface Elevations and Inundation Depths Reported for the PVNGS, in feet NAVD29 (NRC, 2016b).

FLOW PATH LOCATION	PVNGS UNIT 1		PVNGS UNIT 2		PVNGS UNIT 3	
	ssPMP-BASED WSE	INUNDATION DEPTH	ssPMP-BASED WSE	INUNDATION DEPTH	ssPMP-BASED WSE	INUNDATION DEPTH
1	957.08	0.03	953.52	0.07	951.65	0.03
2	956.94	0.03	953.40	0.04	951.72	0.15
3	957.44	0.03	954.05	0.05	951.43	0.07
4	957.49	0.1	954.41	0.18	951.53	0.11
5	957.33	0.2	954.07	0.03	951.44	0.03
6	957.20	0.03	954.04	0.03	951.53	0.03
7	957.23	0.03	953.98	0.03	951.54	0.03
8	957.38	0.05	953.95	0.21	951.74	0.16
9	957.55	0.13	954.43	0.11	951.81	0.18
10	957.55	0.27	954.41	0.13	951.81	0.19
11	957.53	0.1	954.40	0.03	951.75	0.16
12	957.53	0.13	954.45	0.08	951.76	0.11
13	957.45	0.04	954.35	0.03	951.89	0.03
14	957.62	0.03	954.31	0.03	951.86	0.03
15	957.44	0.03	954.34	0.03	951.80	0.03
16	957.36	0.03	954.26	0.03	951.61	0.03
17	957.07	0.03	954.21	0.47	951.66	0.03
18	957.12	0.16	954.30	0.72	951.24	0.33
19	957.20	0.27	954.31	0.86	951.30	0.33
20	957.28	0.35	954.35	1.05	951.67	0.45
21	957.65	0.51	954.47	1.49	951.84	0.79
22	957.70	0.48	954.52	1.2	951.90	0.19
23	957.71	0.47	954.53	1.22	952.28	0.4
24	957.71	0.47	954.53	1.22	952.17	0.23
25	957.71	0.47	954.53	1.22	952.17	0.23
26	957.59	0.57	955.00	0.03	952.37	0.04
27	957.60	0.45	954.80	0.3	952.28	0.06
28	957.59	0.38	954.80	0.6	952.14	0.07
29	957.59	0.31	954.80	0.28	952.09	0.04
30	957.59	0.14	954.80	0.37	951.96	0.35

FLOW PATH LOCATION	PVNGS UNIT 1		PVNGS UNIT 2		PVNGS UNIT 3	
	ssPMP-BASED WSE	INUNDATION DEPTH	ssPMP-BASED WSE	INUNDATION DEPTH	ssPMP-BASED WSE	INUNDATION DEPTH
31	957.43	0.8	954.90	1.19	952.09	0.03
32	957.57	0.23	955.04	0.03	952.31	0.03
33	957.72	0.09	954.79	0.21	951.95	0.44
34	957.11	0.06	954.21	0.09	952.10	0.16
35	957.20	0.07	954.39	0.05	952.17	0.16
36	956.94	0.17	954.28	0.05	951.42	0.21
37	956.89	0.19	954.02	0.26	951.50	0.03
38	957.04	0.16	954.18	0.24	951.77	0.04
39	957.05	0.03	954.32	0.04	951.32	0.11
40	957.02	0.31	954.73	0.03	952.10	0.03
41	957.12	0.11	954.66	0.3	951.95	0.13
42	957.73	0.04	954.68	0.24	951.99	0.6
43	956.89	0.02	954.01	0.16	951.48	0.03
44	956.88	0.25	954.01	0.16	951.44	0.03
45	957.06	0.11	954.28	0.07	951.51	0.12
46	957.06	0.11	954.36	0.07	951.47	0.27
47	957.04	0.13	954.35	0.07	951.47	0.28
48	957.08	0.04	954.74	0.05	952.08	0.13
49	957.10	0.05	954.75	0.03	952.08	0.13
50	956.94	0.03	953.37	0.1	950.85	0.03
51	956.63	0.4	953.22	0.11	950.58	0.03
52	957.50	0.3	954.37	0.03	951.43	0.09
53	957.52	0.41	954.48	0.04	951.60	0.22
54	957.52	0.43	954.19	0.05	951.61	0.05
55	957.69	3.56	955.10	3.5	951.63	0.03

Note: Flow path locations are depicted in Figure 3.2-4.

Table 3.3-1. Summary of Streams and Rivers Screening Analysis for the PVNGS Site

POTENTIAL FLOODING FEATURE	HYDROLOGIC DESCRIPTION	FLOOD ELEVATION(S)♦ [NGVD29]	FHRR SCREENING DISPOSITION (ELEVATIONS NGVD29)
Gila River	The Gila River is a 649-mile (1,044 km) tributary of the Colorado River flowing from New Mexico into central Arizona. The river is located about six miles to the southeast at its nearest point to the PVNGS site.	776 ft (237 m)	The licensee screened-out this river as a potential flood hazard source for the purposes of the FHRR by virtue of its estimated maximum flood elevation – approximately 51 ft (15.5 m) below the grade of PVNGS Unit 3 at elevation 951.5 ft (290.0 m)).
Hassayampa River	The Hassayampa River is 100-mile (161 km) tributary of the Gila River. The ephemeral tributary is located about 5 miles (8.0 km) to the south of the PVNGS site.	942 ft (287 m)	The licensee screened-out this river as a potential flood hazard source for the purposes of the FHRR by virtue of its physical isolation from the PVNGS site; a topographic ridge whose elevation is 975-ft (297.2-m) runs between the river and the reactor site and thus acts as a natural flood protection barrier.
Centennial Wash	The Centennial Wash is an intermittent (dry) wash located about 5 miles (8.0 km) south of the PVNGS site. This wash forms the final watershed of the Gila River in central Arizona.	888 ft (271 m)	The licensee screened-out this river as a potential flood hazard source for the purposes of the FHRR by virtue of its estimated maximum flood elevation – approximately 63 ft (19.2 m) below the grade of PVNGS Unit 3 at elevation 951.5 ft (290.0 m)).
Winters Wash	The Winters Wash is an intermittent wash located to the west of the PVNGS site. The licensee reports that the drainage area for the wash extends over 250 mi^2 (647.5 km^2). Winter's Wash was not previously used to estimate the design basis flood hazard for the PVNGS site as the East Wash, by virtue of location adjacent to the reactor site but on the other side of the powerblock, had an unobstructed flow path directly into the powerblock.	929.5 ft (283.3 m) – 956.4 ft (291.5 m) *935.1 ft (285.0 m) – 962 ft (293.2 m)* ♦♦	See Section 3.3.3.1 of staff assessment text.

POTENTIAL FLOODING FEATURE	HYDROLOGIC DESCRIPTION	FLOOD ELEVATION(S)♦ [NGVD29]	FHRR SCREENING DISPOSITION (ELEVATIONS NGVD29)
East Wash	The East Wash is an intermittent wash located immediately to the east of the PVNGS site. The licensee reports that the drainage area for the wash extends over 5.8 mi^2 (15.0 km^2). As the wash's natural drainage path is, at some locations, adjacent to the PVNG site, the licensee constructed a containment berm in 2012 to provide additional flood protection to the site against this particular hydrologic feature. At its highest point, the berm's elevation is 983 ft (299.6 m).	940 ft (286.5 m) – 979 ft (298.4 m) *945.8 ft (288.3 m) – 980 ft (298.7 m)* ♦♦	See Section 3.3.3.2 of staff assessment text.

♦ Elevations can vary depending upon location.
♦♦ Elevations reported in *italics* reflect consideration of wind-wave/run-up effects.

Table 3.4-1. Summary of On-Site Storage Screening Analysis for the PVNGS Site

FEATURE	DESCRIPTION	FHRR SCREENING DISPOSITION	STAFF REVIEW COMMENTS
Essential Spray Ponds	There are six essential spray ponds within the PVNGS powerblock site that serve as the ultimate heat sinks for the reactors; there are two contiguous ponds for each reactor unit. The dimensions reported for the rectangular, reinforced concrete structures are approximately 172 ft by 345 ft (or 52.4 m by 105.2 m); the essential spray pond walls are approximately 17.5 ft (5.3 m) high. The UFSAR (PSEG, 2007) notes that the ESPs were constructed of reinforced concrete that is 2 ft (0.6 m) thick; the ESPs were also designed as Seismic Category 1 structures.	The licensee noted that any flood water originating from the ESPs would drain away from the powerblock yard following existing site gradients. The licensee also noted that flooding attributed to the ESPs was, at minimum, is bounded by the LIP analysis.	Upon inspection of the PVNGS site map, loss of containment or overtopping of the Unit 3 ESP would be directed down-gradient following the existing topography away from the powerblock. Based on the capacity of the Unit 1 and 2 ESPs (26,000 cubic meters each) as well as the location of the breach, the flooding consequences would be bounded by the CDB given the volume of water in question.
45-Acre Reservoir	Makeup water for the PVNGS site is stored onsite in two, independent below-grade impoundments east of the powerblock area. The 45-Acre Reservoir is reported by the licensee to have an "active minimum storage capacity" of 1,140 acre-feet (1.4 million m^3). The normal operating water elevation for the rectangular-shaped reservoir is 951 ft (289.9 m) NGVD29, which is about 0.5 ft (0.2 m) below the nominal grade of Unit 3 – the topographically-lowest reactor unit. There also is a 961-ft (292.9-m) NGVD29 berm that separates this reservoir from the powerblock yard. The containment berm for this reservoir was designed as Seismic Category 1 structures	Based on the site's topography and grading, the licensee noted that any flood water attributed to the 45-Acre Reservoir as the result of some type of breaching scenario would drain to the south, away from the powerblock following existing site gradients.	This surface water impoundment is situated substantially between the 960-ft (293-m) NGVD29 and 950-ft (290-m) NGVD29 topographic contours; a small portion of the reservoir extends above the 950-ft (290-m) NGVD29 topographic contour. Should there be any breach of containment or overtopping, flood waters would be expected to flow down-gradient following the existing topography.
85-Acre Reservoir	The 85-Acre Reservoir is the second independent, below-grade impoundment east of the powerblock area providing makeup water to the PVNGS site. The licensee reported that this reservoir has an "active minimum storage capacity" of approximately 1,950 acre-feet (2.4 million cubic meters). The normal operating water elevation for the circular-shaped reservoir is 951 ft (289.9 m) NGVD29, which is 0.5 ft (0.2 m) below the nominal grade of Unit 3. There also is a containment berm – whose maximum elevation is 955-ft	Based on the site's topography and grading, the licensee noted that any flood water attributed to the 85-Acre Reservoir as the result of some type of breaching scenario would drain to the south, away from the powerblock following existing site gradients.	This surface water impoundment is situated substantially between the 950-ft (290-m) NGVD29 and 940-ft (287-m) NGVD29 topographic contours; a small portion of the reservoir extends above the 950-ft (290-m) NGVD29 topographic contour. Should there be any breach of containment or overtopping, flood waters would be expected to flow down-gradient

	(291.1-m) NGVD29 – that separates this reservoir from the greater powerblock yard. The berm for this reservoir was designed as Seismic Category 1 structures		following the existing topography.
Evaporation Ponds	There is a complex of three evaporation ponds to the south of the PVNGS powerblock. Whose total surface area is 812 acres (329 hectare). The evaporation ponds are south and down-gradient of the powerblock yard, and are used to receive blow-down waste water from the reactors. The pond complex is surrounded with an embankment whose minimum elevation is 942 ft (287.1 m) NGVD29, surrounds the pond complex. The maximum operating WSE for all of the evaporation ponds is 937 ft (285.6 m) NGVD29, which is 14 ft (4.3 m) below the nominal grade of the Unit 3 reactor.	Based on the site's topography, the licensee noted that any flood water attributed to breaching of the evaporation ponds would drain to the south, away from the powerblock, following existing site gradients and would be conveyed to the Gila River (or its tributaries) following existing topography.	The three evaporation ponds are situated at the southern end of the PVNGS site, down-gradient from the powerblock. Should any or all of the evaporation ponds lose containment, flood waters would be expected to flow down-gradient following the existing topography.
NOTE: Some descriptive information on the PVNGS water storage structures was taken from the 2007 UFSAR (APS, 2007) for the site.			

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

FLOOD-CAUSING MECHANISM		REEVALUATED FLOOD HAZARD [NGVD29]			REFERENCE
		STILLWATER WSE	WAVE/RUN-UP HEIGHT	TOTAL MAXIMUM WSE	
Local Intense Precipitation and Associated Drainage	Unit 1	957.7 ft (291.9 m)	Minimal	957.7 ft (291.9 m)	NRC (2016b)
	Unit 2	955.0 ft (291.1 m)	Minimal	955.0 ft (291.1 m)	NRC (2016b)
	Unit 3	952.4 ft (290.3 m)	Minimal	952.4 ft (290.3 m)	NRC (2016b)

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

FLOOD-CAUSING MECHANISM	TIME AVAILABLE FOR PREPARATION FOR FLOOD EVENT	DURATION OF INUNDATION OF SITE	TIME FOR WATER TO RECEDE FROM SITE
Local Intense Precipitation and Associated Drainage	Not Provided	2 – 5 h	Not Provided
Note: The licensee has the option to use NEI guideline 15-05 (NEI, 2015) to estimate the warning time necessary for flood preparation.			

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

ASSOCIATED EFFECTS FACTOR	FLOOD-CAUSING MECHANISM
	Local Intense Precipitation and Associated Drainage
Hydrodynamic Loading at Plant Grade	3.2 lb/ft^2 (153.2 N/m^2)
Debris Loading at Plant Grade	Minimal
Sediment Loading at Plant Grade	Minimal
Sediment Deposition and erosion	Minimal
Concurrent Conditions, Including Adverse Weather	Not provided
Other Pertinent Factors (e.g., Waterborne Projectiles)	Not provided

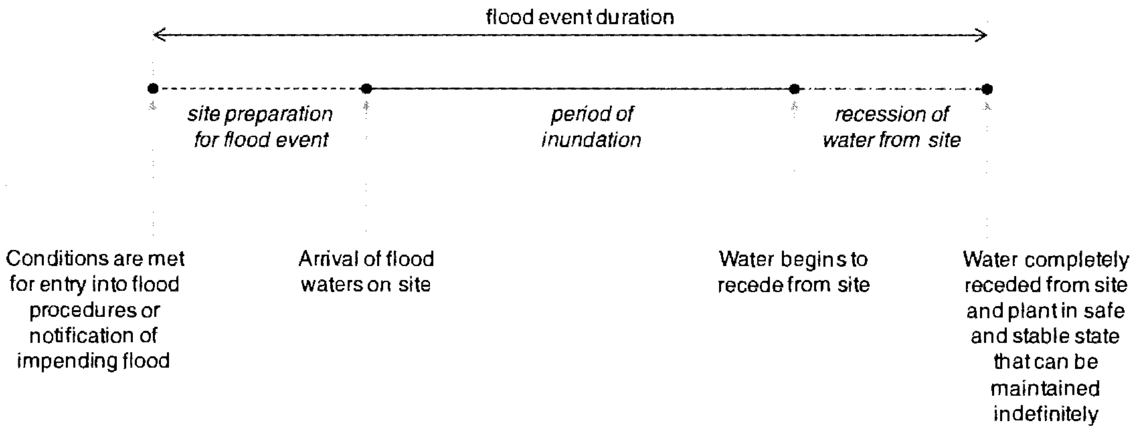


Figure 2.2-1 Flood Event Duration

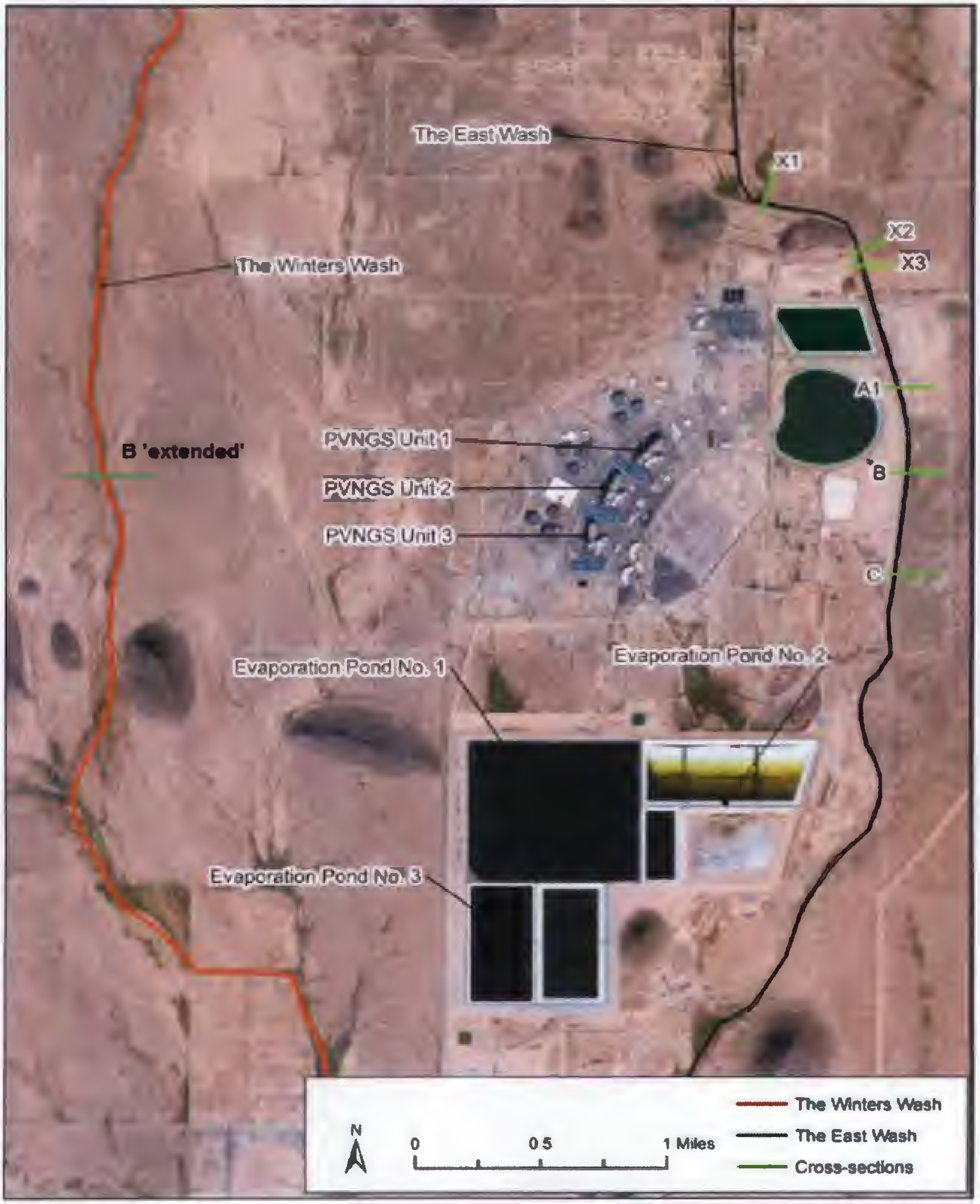
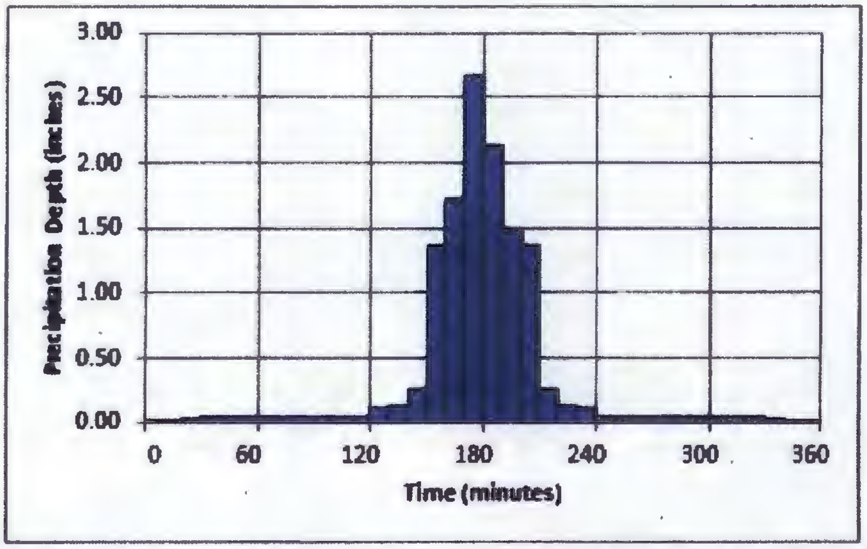
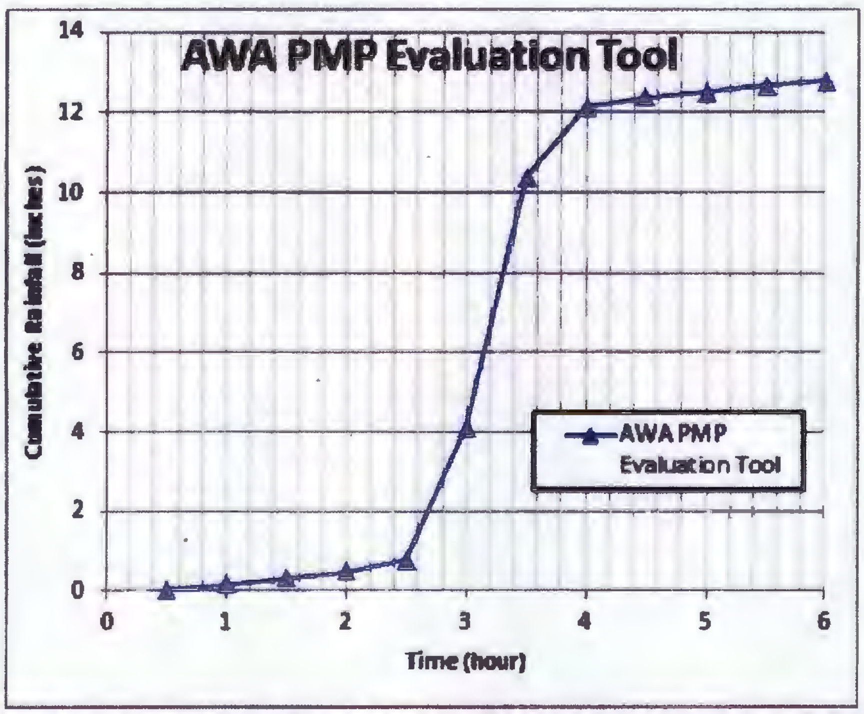


Figure 3.1-1. Generalized Layout of the PVNGS Site (APS, 2014, FHRR Figure 1-2)



INCREMENTAL RAINFALL DISTRIBUTION FOR THE 6-HR DURATION LIP FOR REEVALUATION ANALYSIS



CUMULATIVE REEVALUATION LIP HYETOGRAPHS

Figure 3.2-1. LIP Hyetograph for the PVNGS Site (APS, 2014, FHRR Figure 3-2)

Figure 3.2-2. Flow Path Locations for Unit 1. Locations for Units 2 and 3 are similar.

Figure 3.2-3. FLO-2D Model Domain (in blue) for the LIP Flooding Evaluation. VBS shown in red, buildings in orange.

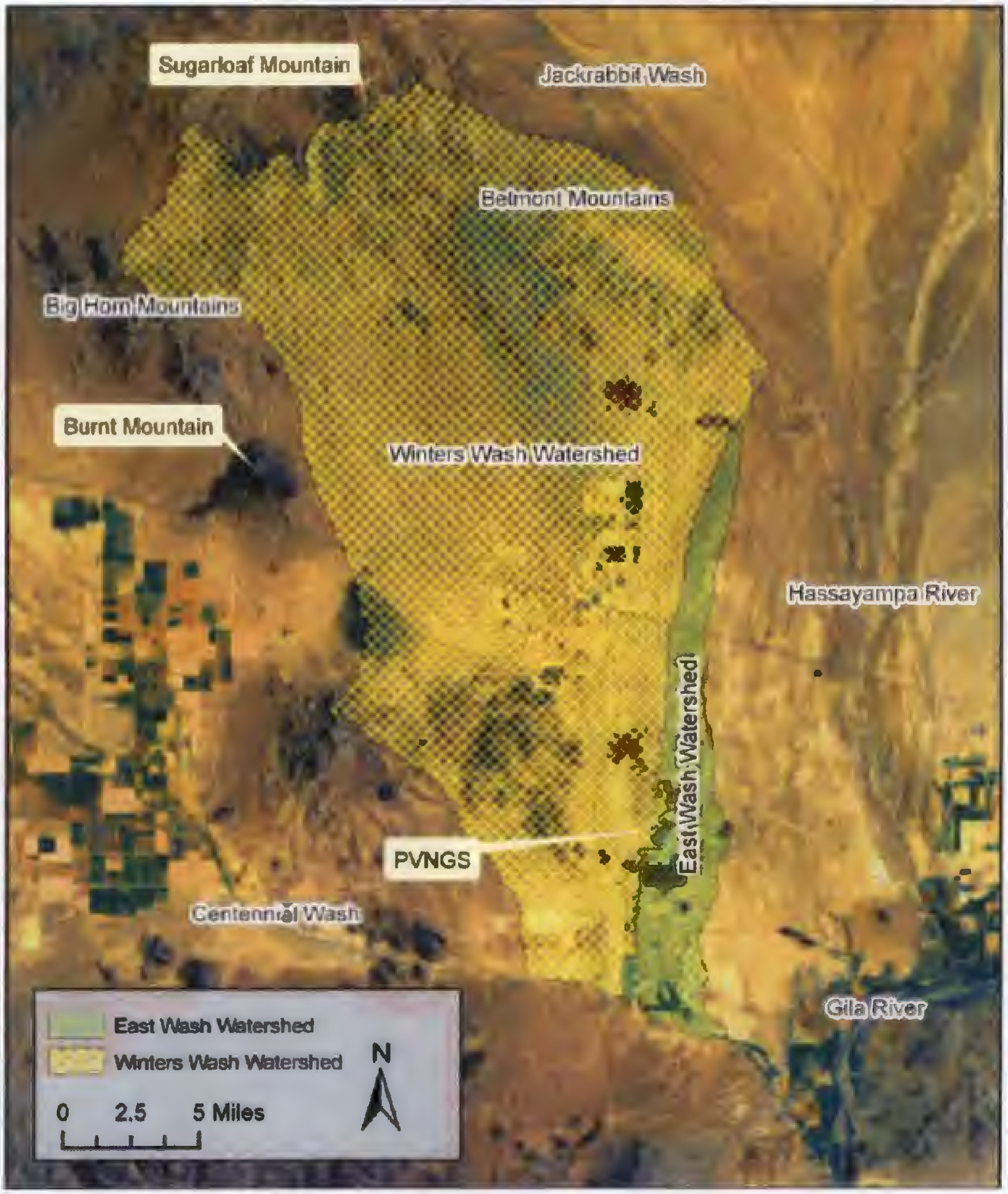


Figure 3.3-1. Winters Wash and East Wash Watersheds (APS, 2014, FHRR Figure 2-4)

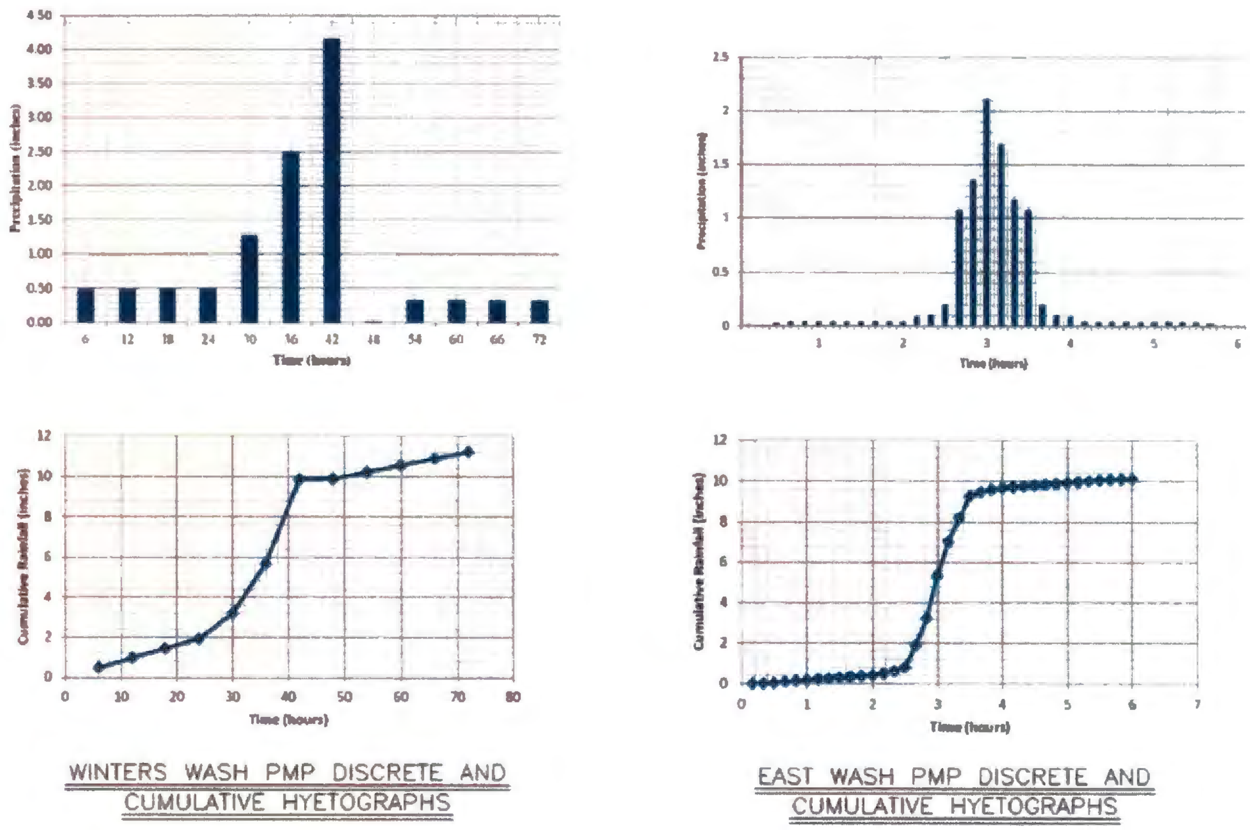


Figure 3.3-2. PMP Hyetographs for Winters Wash and East Wash Watersheds (APS, 2014, FHRR Figure 3-6)

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

Sincerely,

/RA/

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

Docket Nos. 50-528, 50-529 and 50-530

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