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

July 5, 2017

Mr. Adam C. Heflin
President, Chief Executive Officer,
and Chief Nuclear Officer
Wolf Creek Nuclear Operating Corporation
P.O. Box 411
Burlington, KS 66839

SUBJECT: WOLF CREEK GENERATING STATION – STAFF ASSESSMENT OF RESPONSE TO 10 CFR 50.54(f) INFORMATION REQUEST – FLOOD-CAUSING MECHANISM REEVALUATION (CAC NO. MF3648)

Dear Mr. Heflin:

By letter dated March 12, 2012, the U.S. Nuclear Regulatory Commission (NRC) issued a request for information pursuant to Title 10 of the *Code of Federal Regulations*, Section 50.54(f) (hereafter referred to as the 50.54(f) letter). The request was issued as part of implementing lessons learned from the accident at the Fukushima Dai-ichi nuclear power plant. Enclosure 2 to the 50.54(f) letter requested licensees to reevaluate flood-causing mechanisms using present-day methodologies and guidance. By letters dated February 10, 2014, and October 21, 2015 (Agencywide Documents Access and Management System (ADAMS) Accession Nos. ML14077A281 and ML16032A191, respectively), Wolf Creek Nuclear Operating Corporation (WCNOC, the licensee) responded to this request for Wolf Creek Generating Station (Wolf Creek).

By letter dated December 24, 2015 (ADAMS Accession No. ML15357A180), the NRC staff sent the licensee a summary of its review of Wolf Creek's reevaluated flood-causing mechanisms. The enclosed staff assessment provides the documentation supporting the NRC staff's conclusions summarized in the letter. As stated in the letter, because local intense precipitation and failure of dams and onsite water control/storage structures flood-causing mechanisms are not bounded by the plant's current design basis, additional assessments of the flood hazard mechanism are necessary.

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

This staff assessment closes out the NRC's efforts associated with CAC No. MF3648

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

A. Heflin

If you have any questions, please contact me at (301) 415-1617 or e-mail at Frankie.Vega@nrc.gov.

Sincerely,

Frankie Vega, Project Manager
Hazards Management Branch
Japan Lessons-Learned Division
Office of Nuclear Reactor Regulation

Docket No. 50-482

Enclosures:
1. Staff Assessment of Flood Hazard Reevaluation Report (Non-public)
2. Staff Assessment of Flood Hazard Reevaluation Report (public)

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STAFF ASSESSMENT BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO FLOODING HAZARD REEVALUATION REPORT

NEAR-TERM TASK FORCE RECOMMENDATION 2.1

WOLF CREEK GENERATING STATION

DOCKET NO 50-482

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* (CFR), Section 50.54(f), (hereafter referred to as the "50.54(f) letter"). The request was issued in connection with implementing lessons learned from the 2011 accident at the Fukushima Dai ichi nuclear power plant as documented in the Near-Term Task Force (NTFF) 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 NRC staff would provide a prioritization plan indicating Flooding Hazard Reevaluation Report (FHRR) deadlines for each plant On May 11 2012 the NRC staff issued its prioritization of the FHRRs (NRC 2012b)

By letter dated March 10 2014 (WCNOC 2014a), Wolf Creek Nuclear Operating Company (WCNOC or the licensee) provided the FHRR for Wolf Creek Generating Station (Wolf Creek) The NRC staff issued Requests for Information (RAIs) to the licensee by letter dated March 23 2015 (NRC, 2015a) The licensee responded to the RAI by letter dated May 20, 2015 (WCNOC 2015a) In response to further questions from NRC staff that were communicated with the licensee via electronic mail (NRC, 2015c) the licensee provided revised RAI responses dated February 23, 2016 (WCNOC 2016a)

The NRC staff conducted a regulatory audit on November 10, 2015, and December 16, 2015 The NRC staff issued an Audit Summary Report summarizing additional information obtained during this audit (NRC 2016c)

On December 24, 2015, the NRC issued an interim staff response (ISR) letter to the licensee (NRC, 2015d) 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 "Issuance of Order to Modify Licenses with Regard to Requirements for Mitigation Strategies for

Enclosure 2

assessment, which documents NRC staff's basis and conclusions. The flood hazard mechanism values presented in the letter's enclosures match the values in this staff assessment without change or alteration.

As mentioned in the ISR letter (NRC, 2015d), the reevaluated flood hazard result for local intense precipitation (LIP),failure of dams and onsite water control/storage structures flood-causing mechanisms are not bounded by the plant's current design basis (CDB). Consistent with the 50.54(f) letter and amended by the process outlined in COMSECY-15-0019 (NRC, 2015b), Japan Lessons-Learned Division (JLD) Interim Staff Guidance (ISG) JLD-ISG-2012-01, Revision 1 (NRC, 2016a) and JLD-ISG-2016-01, Revision 0 (NRC, 2016b), the NRC staff anticipates that the licensee will perform and document a focused evaluation for LIP that assesses the impact of the LIP hazard on the site, and evaluates and implements any necessary programmatic, procedural, or plant modifications to address this hazard exceedance.

Additionally, for the failure of dams and onsite water control/structure flood-causing mechanism, the NRC staff anticipates that the licensee will submit either (a) a revised integrated assessment of (b) a focused evaluation confirming the capability of existing flood protection or implementing new flood protection consistent with the process outlined in COMSECY-15-0019 (NRC, 2015b) and JLD-ISG-2016-01, Revision 0 (NRC, 2016c).

For any reevaluated flood hazards that are not bounded by the plant's CDB hazard, the licensee is expected to develop flood event duration (FED) parameters and associated effects (AE) parameters. These parameters will be used to conduct the mitigating strategies assessment (MSA) and focused evaluation or integrated assessment.

2.0 <u>REGULATORY BACKGROUND</u>

2.1 <u>Applicable Regulatory Requirements</u>

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.

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

General Design Criterion 2 in Appendix A of 10 CFR Part 50 states that structures, systems, and components (SSCs) important to safety at nuclear power plants must be designed to withstand the effects of natural phenomena such as earthquakes, tornados, hurricanes, floods, tsunamis, and seiches without loss of capability to perform their intended safety functions. The design bases for these SSCs are to reflect appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area. The design bases are also to have sufficient margin to account for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

Section 50.2 of 10 CFR defines the design-basis as the information that identifies the specific functions that an SSC of a facility must perform, and the specific values or ranges of values chosen for controlling parameters as reference bounds for design which each licensee is required to develop and maintain. These values may be (a) restraints derived from generally accepted "state of the art" practices for achieving functional goals, or (b) requirements derived from 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 updated final safety analysis report (UFSAR). The licensee's commitments made in docketed licensing correspondence that remains in effect are also considered part of the CLB.

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

2.2 Enclosure 2 to the 50.54(f) Letter

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

2.2.1 Flood-Causing Mechanisms

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

2.2.2 Associated Effects

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

- Wind waves and runup effects;

- Hydrodynamic loading, including debris;
- Effects caused by sediment deposition and erosion;
- Concurrent site conditions, including adverse weather conditions;
- Groundwater ingress; and
- Other pertinent factors.

2.2.3 Combined Effects Flood

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

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

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

2.2.4 Flood Event Duration

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

2.2.5 Actions Following the FHRR

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

- Submit an interim action plan with the FHRR documenting actions planned or already taken to address the reevaluated hazard; and

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

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

3.0 TECHNICAL EVALUATION

The NRC staff reviewed the information provided for the flood hazard reevaluation of the Wolf Creek site (WCNOC, 2014a, 2015, 2016). 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.

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

3.1 Site Information

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

3.1.1 Detailed Site Information

The Wolf Creek site is located on a small peninsula on the northeastern side of Wolf Creek Lake, which is a reservoir created by impounding Wolf Creek behind an earthen dam (WCNOC, 2014a). Wolf Creek Lake is the source of cooling water for the Wolf Creek site. The location of the Wolf Creek site is near the top of a low hill with a grade elevation of 1,099.5 ft. main sea level (MSL) adjacent to buildings in the powerblock area. The floor elevation of safety-related buildings is 1,100 ft. MSL (WCNOC, 2014a). The ground surface slopes gently down to the Wolf Creek Lake on the western, southern, and eastern sides of the powerblock, resulting in an elevation drop of approximately 12.5 ft. when the lake is at its normal operating level of 1,087 ft. MSL (WCNOC, 2014a).

The licensee stated in its FHRR that the dam retaining Wolf Creek is not a Seismic Category I dam and is not safety-related. The ultimate heat sink (UHS) of Wolf Creek is located within Wolf

Creek Lake and is created by constructing a submerged Seismic Category I dam. The UHS provides water to the Essential Service Water System (ESWS). The bottom elevation of the intake channel in the UHS is at 1,065 ft. MSL and slopes down towards the ESWS Pumphouse where the elevation is 1,064 ft. MSL (WCNOC, 2014a).

3.1.2 Design-Basis Flood Hazards

The licensee stated in the Wolf Creek FHRR (WCNOC: 2014a, 2015c) that the CDB, as presented in the UFSAR of Wolf Creek (WCNOC, 2015b), indicates that the site is not affected by flooding. The plant grade elevation of the WCGS site is 1099.5 ft. MSL and the floor elevation is 1,100 ft. MSL (WCNOC, 2014a). The maximum calculated water levels due to the LIP event near the safety-related buildings range from 1,099.5 ft. to 1,099.8 ft. MSL (WCNOC, 2014a). During the LIP event, the design-basis assumption is that the site drainage system is not functional. The maximum water level due to the LIP event is below the plant floor elevation of 1,100 ft. MSL (WCNOC, 2014a). The 1-hour (h), 1 mi^2 LIP rainfall depth is 19 inches and is part of the cumulative 6-h rainfall of 28.8 inches used in the design-basis. The LIP rainfall is determined using Hydrometeorological Report Number 52 (HMR 52) (WCNOC, 2014a).

Flooding from probable maximum precipitation (PMP) on the Wolf Creek Watershed and Wolf Creek Lake using a PMP distribution,was applied over the design watershed of 27.4 mi^2 using Hydrometeorological Report No. 33 (HMR 33). The cumulative 48-h duration PMP was estimated to be 32.8 inches with a peak occurring at approximately 34 hours (WCNOC, 2014a).

The coincident wave activity of the PMF resulted in a maximum run-up of 0.8 ft. at the plant site shore. The resulting run-up elevation was 1,095.8 ft. MSL when added to the PMF pool elevation. Backwater caused by the PMF in the Neosho River or Long Creek does not affect the site due to the topographic ridges between the site and the Long Creek and Neosho River valley.

As stated in the FHRR, failure of dams located above John Redmond Reservoir will not adversely affect any safety-related facilities at the Wolf Creek site. What the licensee identified as the most critical case postulates the domino-type failure of John Redmond, Marion, Cedar Point, and Council Grove reservoirs. For the postulated failure, the maximum flood stage of the Neosho River was estimated to be [redacted] at a distance of about five miles downstream from the John Redmond Dam (WCNOC, 2014a). The licensee also stated in its FHRR that the topographic ridge between the Neosho River and Wolf Creek valleys below John Redmond Dam will separate the postulated flood levels in the Neosho River from any facilities at the site, with the exception of the cooling lake main dam. The estimated maximum flood level on the downstream slope of the Wolf Creek Lake Dam, caused by the postulated events in the Neosho River, is 1,049.6 ft. MSL. This flood level is below the surface grades of any Seismic Category I facilities at the site and is about 50 ft. below the plant grade elevation of 1099.5 ft. MSL (WCNOC, 2014a).

The licensee also stated in its FHRR that flooding hazards from storm surge and seiche, tsunami, and ice-induced flooding were screened out in the CDB (WCNOC, 2014a). The licensee presented a summary of CDB flood elevations due to all flood-causing mechanisms in Table 2-3 of the FHRR. These flood-causing mechanisms are presented in Table 3.1-3 of this staff assessment.

3.1.3 Flood-Related Changes to the Licensing Basis

The licensee summarized applicable flood-causing mechanisms at the Wolf Creek site in Table 2-3 of the FHRR. The Wolf Creek FHRR also states that the LIP flooding hazard was recently updated in 2013 using HMR 52 with a 6-h distribution (WCNOC, 2014a); the previous LIP analysis used HMR 33. The LIP flooding depth using HMR 52 was estimated to be 1,099.8 ft. MSL at Seismic Category I buildings, whereas the HMR 33 flooding depth estimate is 1,099.9 ft. MSL around the powerblock (WCNOC, 2014a).

The licensee reported that on the basis of the flooding walkdown activities and the flooding walkdown report (WCNOC, 2012) that there is reasonable assurance the flood protection features are available, functional, and capable of performing their specified functions as set forth in the CLB. Furthermore, the Wolf Creek external flood protection features are effective and able to perform their intended flood protection function when subject to a design-basis external flooding hazard (WCNOC, 2014a). Also, no changes since license issuance and no comments regarding adverse site conditions affecting flooding protection were noted in the walkdown report (WCNOC, 2012).

3.1.4 Changes to the Watershed and Local Area

The licensee reported in its FHRR that changes to the Wolf Creek site layout and SSCs related to flooding protection were evaluated as part of the WCGS flooding walkdown report.

The licensee did not report significant changes to the watershed. The local area change reported in the FHRR is the construction of a vehicle barrier system (VBS). Also, the shoreline slope of the Wolf Creek Lake reported for the design-basis was 30:1 (horizontal to vertical). However, the current topographic data used for the flood hazard reevaluation indicates that the average shoreline slope is to be 46:1. The licensee attributed the difference in slope to be most likely the result of differences in the methods employed to compute average slope, not due to significant change in the shoreline topography (WCNOC, 2014a).

3.1.5 Current Licensing Basis Flood Protection and Pertinent Flood Mitigation Features

The licensee stated in its FHRR that safety-related facilities are not affected as a result of flooding from LIP or PMF in the cooling lake; therefore, no flooding protection requirements are necessary (WCNOC, 2014a). The Wolf Creek FHRR also reports that the flooding walkdown report (WCNOC, 2012) identified the credited flood protection and mitigation features that are considered in the Wolf Creek CLB to protect against the ingress of water to safety- elated SSCs. These include topography, structures, floors, walls, penetrations, vaults, the forebay, doors, sump pumps, and sump pump motors. The ESWS Pumphouse has pressure doors that are located at elevation 1,100.0 ft. MSL. These pressure doors are flood protection doors and are normally closed and under administrative control (WCNOC, 2014a).

3.1.6 Additional Site Details to Assess the Flood Hazard

The licensee provided model input and output files and associated hydrologic and bathymetric data for NRC staff's review.

3.1.7 Plant Walkdown Activities

The 50.54(f) letter (NRC, 2012a) requested that licensees plan and perform plant walkdown activities to verify that current flood protection systems were available, functional, and implementable. Other requests described in 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, WCNOC submitted the Flooding Walkdown Report as requested in Enclosure 4 of the 50.54(f) letter for the Wolf Creek site (WCNOC, 2012). The walkdown report was supplemented by letter dated January 28, 2014 (WCNOC, 2014b), which also included RAI responses. On May 30, 2014 (NRC, 2014), the NRC staff issued its assessment of the Walkdown Report, which documented its review of that licensee action and concluded that the licensee's implementation of the flooding walkdown methodology met the intent of the walkdown guidance.

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

The licensee reported in the Wolf Creek FHRR (WCNOC, 2014a) that the reevaluated onsite flood water-surface elevations for LIP ranged from approximately 1,100 ft. MSL up to a maximum of 1,100.5 ft. MSL. This flood-causing mechanism is discussed in the licensee's CDB. The CDB flood elevation for the LIP flood causing mechanism is 1,099.9 ft. MSL (WCNOC, 2015b).

3.2.1 Model Input

3.2.1.1 <u>LIP Intensity and Distribution</u>

The licensee estimated the LIP depth using National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) Hydrometeorological Report HMR 52 (NOAA, 1982) and determined that the 1-h, 1-mi^2 precipitation depth was 19 in., with a cumulative 6-h depth of 28.8 in. (WCNOC, 2015c). The hyetograph has a duration of 6 hours and is subdivided into 5-minute intervals, with the most intense rainfall of 19 inches occurring in the first hour (WCNOC, 2015c).

The NRC staff reviewed the licensee's LIP estimates from HMR 52 and agreed that the estimates are appropriate for the Wolf Creek site.

3.2.1.2 <u>Runoff Model Development</u>

The licensee analyzed flooding resulting from LIP at the Wolf Creek site and evaluated flood water surface elevations and depths using the PMP at the site and the modeling software FLO-2D. The PMP input was the cumulative 6-hr rainfall as stated earlier. The licensee revised its LIP flooding analysis after submitting its original FHRR (WCNOC, 2014a) and provided the updated analysis in Revision 1 to the FHRR (WCNOC, 2015c). The updated analysis was necessary to account for changes in the site layout since the original analysis. The original analysis used FLO-2D Build No. 13.02.04; the revised analysis used Build No. 14.03.07 to simulate the runoff and resulting water-surface elevations.

The revised FHRR documented changes to the site layout that included addition of new buildings, changes to the VBS configuration, and changes in elevation from regrading in several locations. The licensee submitted a revised FHRR describing these changes and the updated LIP flood analysis (WCNOC, 2015c). For areas around the powerblock, the updated reevaluated maximum water-surface elevation for LIP flood was 1,100.5 ft. MSL adjacent to the Turbine Building.

The reevaluated flood water-surface elevations at the safety-related SSCs are shown in Table 3.2-1 of this assessment. The reevaluated flood-water surface elevation values exceed the plant grade of 1,099.5 ft. MSL and plant floor elevation of 1,100 ft. MSL for most SSCs (WCNOC, 2016a). Specifically, the greatest water-surface elevation near safety-related buildings (1,100.4 ft. MSL) occurs next to the Auxiliary Building and the Reactor Building. The highest water-surface elevation of 1,100.5 ft. MSL occurs near the non-safety-related Turbine Building.

The remainder of this section describes the NRC staff's evaluation of the licensee's revised LIP flood model.

As stated in Section 3.2 of the revised Wolf Creek FHRR (WCNOC, 2015c), a two-dimensional (2D) flood-routing model, FLO-2D (Build 14.03.07), was used for the LIP flood analysis. The licensee stated that this FLO-2D Pro (FLO-2D, 2014) model represented all the topographical and manmade features (i.e., buildings, tanks, and structures) that significantly affect runoff at the Wolf Creek site (Figure 3.2-1).

In its revised LIP flood model, the licensee used a grid cell size of 15 ft. by 15 ft. (WCNOC, 2016a). The licensee collected additional topographic data in two regraded locations situated west of the Control Building and near the Essential Service Water System (ESWS) Pumphouse (Figure 3.2-2 of this assessment). The surface elevations in the area west of the Control Building were raised 0.5 to 1 ft. The maximum local change in surface elevations near the ESWS Pumphouse was a raising or lowering of approximately 1 ft. The licensee stated that the overall slope and drainage in this area remained unchanged. The licensee stated that the analysis domain extends far enough from the powerblock to prevent boundary conditions from influencing hydraulic conditions during the simulation (WCNOC, 2015c) (Figure 3.2-3 of this assessment). Roads were identified by the licensee as defining the southern and western boundaries for the LIP analysis (WCNOC, 2015c). The eastern boundary was defined by the edge of Wolf Creek Lake, and the northern boundary was located to include additional areas that could contribute runoff toward the powerblock area (WCNOC, 2015c). The NRC staff reviewed the licensee's LIP flood model and agreed that the model used appropriate site-specific data and was consistent with standard engineering practice.

To represent the flow around buildings and off of the roofs of buildings, the licensee raised the FLO-2D grid cells approximately 2 ft. higher than the surrounding area while preserving runoff from one roof onto another, where appropriate (WCNOC, 2016a). Some of the safety-related buildings in the powerblock area have 2-in. high nailer strips along roof perimeters (WCNOC 2015a). The licensee credited the water storage on the roofs provided by the nailer strips (WCNOC, 2016a). The NRC staff's review of runoff from building roofs determined that the licensee used site-specific data appropriately and that the licensee's approach was reasonable.

The licensee used an up-to-date land-use map for the revised LIP flood model (Figure 3.2-4 of this assessment). The licensee used the curve number method for delineating soil types and a land-use map to specify infiltration loss rates in the model (SCS, 1986). The curve numbers varied from 61 for grass to 99 for water. Most of the powerblock area consisted of gravel, pavement, and buildings that were assigned curve numbers from 85 to 98. The NRC staff reviewed the licensee's approach to specifying infiltration loss rates in the FLO-2D model and determined that the approach followed standard engineering practice and was reasonable. The NRC staff performed a sensitivity analysis to determine the sensitivity of maximum flood water-surface elevation to the infiltration rate. The NRC staff's analysis determined that the maximum increase in predicted maximum flood water-surface elevations for safety-related buildings in the powerblock area when the infiltration losses were ignored (set to zero loss), was less than 1 inch. Therefore, the NRC staff determined that the LIP flood maximum water-surface elevations are not sensitive to selected infiltration loss rates and concluded that the licensee's FLO-2D model is reasonable.

The licensee specified Manning's roughness coefficients for different surfaces using the land-use categories—grass, gravel, pavement and buildings, and water. The licensee stated that it was necessary to assign a Manning's roughness coefficient to water to ensure model stability. In its review, the NRC staff noted that the Manning's roughness coefficient values used in the model were at the lower end of the recommended range of values of the land-use categories. Because higher values of Manning's roughness coefficient can result in increased depth of flow, the staff requested additional information from the licensee for a justification for using lower values (WCNOC, 2015a). The licensee stated that its chosen Manning's roughness coefficient values, based on a number of technical literature sources, were most representative for the Wolf Creek site (WCNOC, 2015a). The NRC staff reviewed the licensee's justification and agreed that the licensee's choice for Manning's roughness coefficient values were reasonable.

Based on its revised FLO-2D simulation, the licensee provided the maximum water-surface elevation at critical locations within the powerblock area and outside the powerblock area (WCNOC, 2015c). Table 3.2-1 of this assessment lists the reevaluated LIP flood water-surface elevations that exceed the floor elevations of safety-related buildings. Table 3.2-2 of this assessment lists the simulated maximum LIP flood water-surface elevation, maximum flood depths, flood durations, maximum velocities, maximum hydrostatic forces, and maximum hydrodynamic forces at doors of safety-related buildings within the powerblock area. At 10 doors, the reevaluated LIP flood maximum water-surface elevation exceeded the corresponding floor elevations. Table 3.2-3 of this assessment lists the simulated maximum LIP flood water-surface elevation, maximum flood depths, flood durations, maximum velocities, maximum hydrostatic forces, and maximum hydrodynamic forces at other Wolf Creek safety-related access points outside of the powerblock. At 11 of these access points, the reevaluated LIP flood maximum water-surface elevations exceeded the corresponding critical elevations.

The NRC staff reviewed information provided in the ERR, as well as the responses to staff requests for additional information. The NRC staff performed confirmatory analyses and calculations to determine whether the licensee's representation is reasonable and conforms to the current practice and site configuration. The NRC staff also performed sensitivity analysis of the FLO-2D model to determine the sensitivity of the model parameters to changes in model input values. The NRC staff also examined the model output files and flow maps to determine the fundamental physical requirements of a simulation model are met. The NRC staff also examined the resulting inundation map to determine the topographical accuracy of inundation depths and physical locations of SSCs.

The NRC staff determined that the general methods described in the licensee's FHRR and the calculation package are consistent with present-day methods. Based on staff's review, there were 10 locations within the powerblock area and 11 locations outside the powerblock area where the reevaluated LIP flood water-surface elevations exceeded critical elevations.

The NRC staff confirmed the licensee's conclusion that the reevaluated flood hazard for the LIP and associated site drainage is not bounded by the CDB flood hazard. Therefore, the NRC staff expects that the licensee will submit a focused evaluation for the LIP and associated site drainage for the Wolf Creek site.

3.3 Streams and Rivers

The licensee reported in its FHRR that the reevaluated flood hazard for streams and rivers is based on a stillwater-surface elevation of 1,093.5 ft. MSL. Including wind waves and runup results in an elevation of 1,094.4 ft. MSL. These elevations did not change as a result of the site layout changes described in the revised FHRR (WCNOC, 2015c)

This flood-causing mechanism is discussed in the licensee's CDB. The CDB probable maximum flood (PMF) elevation for streams and rivers is based on a combination of stillwater-surface elevation and wave run-up of 1,100.2 ft. MSL and 1,095.8 ft. MSL at the ESWS Pumphouse and Wolf Creek shoreline, respectively.

The NRC staff reviewed the flooding hazard from streams and rivers against the relevant regulatory criteria based on present-day methodologies and regulatory guidance.

The licensee stated that it evaluated flooding in rivers and streams at the Wolf Creek site following the Hierarchical Hazard Assessment method (NRC, 2011) in its FHRR (WCNOC, 2015c). In this analysis, the licensee determined that the maximum flood discharges in the Neosho River and Long Creek (watersheds neighboring the Wolf Creek watershed) due to the PMF would be contained within their respective river channels, and therefore, floods in the two watersheds would not pose a hazard to the Wolf Creek site. The Wolf Creek watershed (31.1 mi^2) was divided into five subbasins (Figure 3.3-1 of this assessment): subbasins 1 through 3 represented subbasins upstream of the Wolf Creek Lake; part of subbasin 4 represented the land from which runoff reaches Wolf Creek Lake directly; and subbasin 5 represented the southern portion of the watershed that drains directly into Wolf Creek downstream of the Wolf Creek Lake Dam (Figure 3.3-1). The licensee estimated the PMP for the Wolf Creek watershed using the U.S. Army Corps of Engineers' (USACE) HMR 52 software (USACE, 1987). The 72-h duration of the PMP has a cumulative precipitation depth of 36.70 in. The licensee used USACE's Hydrologic Modeling System (HEC-HMS) software (USACE, 2010a) to implement a hydrologic model for the Wolf Creek watershed and the River Analysis System (HEC-RAS) software (USACE, 2010b) to implement a hydraulic model for the stream reaches and Wolf Creek Lake. The HEC-HMS model was used to estimate the runoff hydrographs and volumes resulting from the PMP event, and the HEC-RAS model was used to estimate the flood water surface elevations at representative points. After reviewing the FHRR, calculation packages, and model files provided by the licensee, the NRC staff performed sensitivity runs to evaluate the licensee's assessment of PMF discharges and maximum water surface elevations. The NRC staff's review is discussed below in the Runoff and PMF Analyses subsection.

3.3.1 PMP Estimation

The HMR 52 computer program was used to estimate the PMP for two cases: Wolf Creek watershed including the portion downstream of Wolf Creek Lake dam (31.1 mi^2) (Case 1) and Wolf Creek watershed upstream of Wolf Creek Lake dam (27.7 mi^2) (Case 2). The licensee estimated precipitation depths at 6-h intervals for increasing areas for both Cases 1 and 2. The 72-h duration cumulative rainfall depth for Case 1 is 36.7 in., peaking at about 39-h into the storm. Similarly, for Case 2, the 72-h cumulative rainfall is 37.4 in., peaking at about 39-h into the storm. The total rainfall depths estimated in this analysis are higher than those reported in the UFSAR (WCNOC, 2015b). The NRC staff concurs that the licensee's approach for estimating the PMP for the Wolf Creek watershed is consistent with present-day methods.

3.3.2 Runoff and PMF Analyses

The licensee applied the HEC-HMS model to the Wolf Creek watershed (Figure 3.3-2 of this assessment) including the portion downstream of Wolf Creek Lake dam. The watershed includes five subbasins, two river reaches, and Wolf Creek Lake. The HEC-HMS model was calibrated against the 100-yr peak discharge estimated using the U.S. Geological Survey (USGS) regression equation for ungaged sites with unregulated streams, using average mean annual precipitation obtained from Figure 3 of the USGS (USGS, 2000). Because Kansas is in the Type II rainfall category for the Soil Conservation Service (SCS) rainfall distribution (SCS, 1986), the SCS Type II 100-yr/24-h rainfall depths from the NOAA Atlas 14, Volume 8, Version 2, are used as input to the HEC-HMS model as an SCS Storm. The licensee calibrated the HEC-HMS model by adjusting the curve number, lag time, and Manning's roughness coefficients.

The HEC-HMS model was set up for five different scenarios with refinement increasing from the most conservative Case 1 to the most refined Case 5. For Cases 3 through 5, the licensee considered the nonlinearity effect during a PMP event by reducing the lag time by 33 percent and increasing the resulting discharge by 5 percent. In Case 5, the licensee used rainfall losses based on SCS Curve Number, SCS Unit Hydrograph for runoff transformation, and instantaneous channel routing. The licensee used discharges computed for HEC-HMS Case 5 as input values in the HEC-RAS model.

To examine the licensee's assessment of the maximum water surface elevation resulting from the PMF at Wolf Creek Lake, the NRC staff ran HEC-HMS PMF simulations for nine sensitivity scenarios. These scenarios included three precipitation loadings (front, center, and end loadings), use of SCS unit hydrographs adjusted for nonlinearity effects, and Muskingum channel routing (Table 3.3-1 of this assessment). The NRC staff's scenarios used no precipitation losses. The 9-day storm used in the staff's scenarios consisted of a 40 percent PMP event used as an antecedent precipitation event during the first 3 days, followed by 3 days with no precipitation, and then followed by the full 3-day PMP storm (Figure 3.3-3). The center-loaded precipitation scenario (Case 1C, Table 3.3-1) PMF simulation is similar to that of the licensee's Case 1 except that the staff's simulation included an antecedent precipitation event. Compared to the licensee's Case 1 peak water surface elevation estimate of 1,095.3 ft MSL, the NRC staff's center-and end-loaded precipitation cases (Cases 1C and 1E) resulted in slightly higher peak water surface elevation at the lake (1,095.9 and 1,096.8 ft. MSL, respectively) while the front-loaded precipitation case (Case 1F) resulted in lower peak water surface elevation at the lake (1,094.6 ft MSL). Cases 2F, 2C, and 2E that used SCS Unit Hydrograph runoff transformation resulted in maximum flood water surface elevations of 1,094.6, 1,095.9, and

1,096.4 ft. MSL, respectively. The NRC staff's Cases 3F1, 3C1, and 3E1 that used Muskingum routing resulted in peak water-surface elevations of 1,094.6, 1,095.8, and 1,096.2 ft. MSL at the lake, respectively. The NRC staff used Cases 3-F2, C2, and E2 to evaluate sensitivity of PMF simulation results to a Manning's roughness coefficient of 0.03, which is 50 percent larger than the licensee's chosen value of 0.02. Peak water-surface elevations at the lake resulting from using a larger Manning's roughness coefficient show that model sensitivity is minimal (Table 3.3-1).

The licensee used the HEC-HMS discharges estimated for each subbasin as input to the HEC-RAS model (Figure 3.3-4 of this assessment) to produce a more refined estimate of peak water-surface elevation in Wolf Creek Lake during the PMF event and to evaluate potential effects on the flood water surface elevations in the lake if the spillway of Wolf Creek Lake Dam was partially blocked by debris. The HEC-RAS model included a reach representing Wolf Creek upstream of the lake (Upper Reach), Wolf Creek Lake, Wolf Creek Lake Dam, and a reach representing Wolf Creek downstream of the lake (i.e., Lower Reach). The licensee stated that HEC-RAS was calibrated by adjusting the Wolf Creek Dam weir coefficients against water level above the crest elevation obtained from the existing spillway rating curve for Wolf Creek Lake.

The licensee conducted 10 HEC-RAS simulations: Cases 1 through 5 were steady-state flow simulations using the peak discharges from licensee's HEC-HMS Cases 1 through 5; Case 6 was unsteady-state flow simulation using discharges from licensee's HEC-HMS Case 5; Cases 7 through 9 were the same as Case 6 with varying levels of blockages of the spillways; and Case 10 was a model run to evaluate the effect of sedimentation in Wolf Creek Lake. The licensee used results from Case 6 as the most refined and realistic scenario, and it showed that flooding did not exceed the capacity of the spillways. The licensee reported a Wolf Creek Lake maximum flood water surface elevation of 1,093.6 ft. MSL. The NRC staff considers the methods used by the licensee consistent with present-day methods.

The licensee also evaluated wind waves and runup coincident with the PMF at Wolf Creek Lake Dam, the Wolf Creek Lake shoreline, and intake structure of the ESWS Pumphouse (Figure 3.3-5 of this assessment). The licensee used the peak PMF water surface elevation obtained from HEC-RAS Case 6 as the stillwater surface elevation for wind wave estimation. The licensee estimated the wind wave effects to be 7.0 ft., 0.8 ft., and 4.9 ft. at the Wolf Creek Lake Dam, Wolf Creek Lake shoreline, and the ESWS Pumphouse, respectively. The combined maximum flood water surface elevations were 1,100.6, 1,094.4, and 1,098.4 ft. MSL at the three locations, respectively. The NRC staff consider that the licensee's approach is consistent with present-day methods.

As stated above, the NRC staff's sensitivity analyses resulted in peak stillwater surface elevation values ranging from 1,094.5 to 1,096.8 ft. MSL at the lake (Table 3.3-1). Adding the licensee-estimated wind-wave effects to the stillwater surface elevations from the NRC staff's sensitivity analyses[1] would result in a maximum combined peak flood water surface elevations of 1,097.6 and 1,101.7 ft. MSL at the lake shoreline and ESWS Pumphouse, respectively. The

[1] Although the fetch lengths for the stillwater surface elevations from staff's sensitivity analyses are longer than those estimated by the licensee, the NRC staff found the difference results in only minor variations of final water level at the site. Therefore, the NRC staff found that the licensee-estimated wind-wave activity is a reasonable estimate based on staff's sensitivity analyses.

CDB for the ESWS intake structure is 1,102.5 ft. MSL. The plant grade and plant floor elevations are 1,099.5 and 1,100.0 ft. MSL, respectively.

The licensee also evaluated effects of spillway blockage on maximum water level at the Wolf Creek Lake using 50, 20, and 10 percent blockages and effects of sedimentation in Wolf Creek Lake. The licensee stated that the estimated stillwater surface elevation from its most realistic HEC-RAS case (Case 9) with 10 percent spillway blockage did not exceed 1,095.0 ft. MSL.

The licensee stated that the estimated stillwater elevation for the sedimentation scenario, its HEC-RAS Case 10, was 1,093.5 ft. MSL. To evaluate the licensee's conclusions, the NRC staff performed two sensitivity analyses by running the licensee's HEC-RAS Cases 7 and 10 by using discharges estimated by staff's HEC-HMS Case-2E (Table 3.3-1). The NRC staff's two HEC-RAS sensitivity analyses resulted in estimated maximum flood water surface elevations of 1,095.9 and 1,094.7 ft. MSL, respectively. Adding the licensee-estimated wind-wave effects to the stillwater surface elevations from the staff's sensitivity analyses would result in a maximum combined peak flood water surface elevations of 1,096.8 and 1,100.8 ft. MSL at the lake shoreline and ESWS Pumphouse, respectively. Because these maximum flood water surface elevations are lower than the current design bases at the lake shoreline and the ESWS Pumphouse, the NRC staff concluded that the PMF in Wolf Creek watershed would not exceed the CDB.

In summary, the NRC staff confirmed the licensee's conclusion that the reevaluated flood hazard for streams and rivers is bounded by the CDB flood hazard. Therefore, the NRC staff determined that flooding due to streams and rivers does not need to be analyzed in a focused evaluation or integrated assessment.

3.4 Failure of Dams and Onsite Water Control/Storage Structures

The licensee reported in the Wolf Creek FHRR that the reevaluated flood hazard using the volume method as described in JLD-ISG-2013-01 (NRC, 2013a), including associated effects, for failure of dams and onsite water control or storage structures is based on a stillwater-surface elevation of [redacted] MSL. This flood-causing mechanism is discussed in the licensee's CDB. The CDB PMF elevation for failure of dams and onsite water control or storage structures is based on a stillwater-surface elevation of [redacted] MSL.

The licensee stated in its FHRR (WCNOC, 2015c) that except for the Wolf Creek Lake Dam, no other dams were listed in the USACE National Inventory of Dams (NID) database for the Wolf Creek watershed. However, 322 dams are located within the Neosho River watershed adjoining the Wolf Creek watershed (Figure 3.4-1 of this assessment). The licensee's assessment included the following steps:

- Obtain a list of dams from the USACE NID database;
- Identify "inconsequential" or downstream dams using watershed boundaries; and
- Apply the Volume Method (NRC, 2013b) combined with a 500-yr return period flood flow to identify "noncritical" and "potentially critical" dams and determine the potential for flooding above the Wolf Creek plant grade elevation of 1,099.5 ft MSL (WCNOC, 2015c).

The licensee stated that flooding above the plant grade of Wolf Creek would require that backwater from flooding on the Neosho River would need to exceed the Wolf Creek Lake dam service spillway crest elevation of 1,088.0 ft MSL. After screening out the downstream dams in the Neosho River watershed, the licensee identified 231 dams to be evaluated. A steady-state HEC-RAS model representing the Neosho River from 334.4 to 343.3 river miles upstream of the Neosho River mouth was calibrated against 100-yr and 500-yr flood discharges. The HEC-RAS model was run using appropriate antecedent flow conditions to compute flood levels and the remaining available storage volumes below the plant grade of 1,099.5 ft. MSL. The licensee determined that the flood water surface elevation resulting from the 500-yr flood discharge ranged from 1,022.5 to 1,026.3 ft. MSL along the reach. Adding the volume of water stored in the 231 dams raised the licensee's reevaluated stillwater surface elevation to [redacted] MSL, which is [redacted]. below the plant grade elevation and [redacted] below the Wolf Creek Lake Dam service spillway.

During review of the Neosho River watershed upstream of its confluence with Wolf Creek, the NRC staff discovered that the licensee did not include 25 dams that are located within the level-8 hydrologic unit code (HUC) 11070202, which is part of the Neosho River Watershed, in its analysis (Figure 3.4-2 of this assessment). Also, the licensee included 14 dams located in two level-12 HUCs, 110702040102 and 110702040103. These two level-12 HUCs are part of the Long Creek drainage that discharges to the Neosho River downstream of its confluence with Wolf Creek. Therefore, the NRC staff removed the 14 dams located in the Long Creek drainage. Including the 25 dams located in level-8 HUC 11070202 and excluding the 14 dams located in the Long Creek drainage, the NRC staff determined that 242 dams exist in the Neosho River watershed upstream of the confluence of the Neosho River with Wolf Creek. The NRC staff applied the Volume Method and estimated that the stillwater surface elevation would be [redacted] MSL, which is slightly higher than the licensee's estimate of [redacted] MSL (Table 3.4-1 of this assessment). From an inspection of the elevations along the ridge separating the Neosho River and Wolf Creek watersheds, the NRC staff determined that the increased stillwater surface elevation would not result in lateral overflow from the Neosho River watershed into Wolf Creek Lake. The NRC staff estimated the stillwater surface elevation also would be lower than the Wolf Creek Dam Main spillway crest elevation of 1,088.0 ft. MSL.

The NRC staff evaluated the Peak Outflow without Attenuation Method described in NRC JLD-ISG-2013-01 (NRC, 2013) as a sensitivity study compared to the licensee's Volume Method. For the dams used in the staff's evaluation of the licensee's Volume Method, the peak discharges following the breach of each of the dams were estimated using U.S. Bureau of Reclamation (USBR) (USBR, 1982) and Froehlich (Froehlich, 1995) equations, each with two different dam heights, hydraulic height, and NID height, obtained from the USACE NID. Hydraulic height refers to the vertical difference between the maximum design water level and the lowest point in the original streambed, and NID height is the greatest of dam height, structural height, and hydraulic height. The NRC staff summed the peak discharges estimated for all dams and the 500-yr flood discharge estimated by the licensee for the Neosho River below John Redmond dam to estimate the discharge near the Wolf Creek site as recommended by JLD-ISG-2013-01 (NRC, 2013). This discharge was conservatively specified as a steady-state discharge in HEC-RAS of the Neosho River reach below John Redmond Dam to determine the flood water surface elevation. The NRC staff simulated four steady-state scenarios listed in Table 3.4-2 of this assessment. The estimated flood water surface elevation just below the John Redmond Dam ranged from 1,078.3 to 1,107.2 ft. MSL. Because these flood water surface elevations are likely to exceed the drainage divide between the Neosho River and the Wolf Creek watersheds, the NRC staff also evaluated the dam breach flood water surface elevations using the Peak Outflow with Attenuation Method, which is the third method recommended in JLD-ISG-2013-01 (NRC, 2013).

Guidance document JLD-ISG-2013-01 recommends that attenuation of peak discharges following dam breaches should be estimated using the USBR equation (USBR, 1982). The USBR attenuation equation requires the distance of each upstream dam from the John Redmond Reservoir. The NRC staff estimated these distances using the National Hydrography Dataset. The NRC staff estimated the attenuated peak discharges for each dam using the USBR equation and added them to the 500-yr flood discharge estimated by the licensee for the Neosho River. The NRC staff's evaluation resulted in two attenuated peak discharges at John Redmond Dam corresponding to dam breach peak discharges estimated using the USBR peak discharge equation input with hydraulic and NID heights (Table 3.4-3 of this assessment). The NRC staff used the two peak discharges to perform steady-state simulations using the licensee's HEC-RAS model for the Neosho River below John Redmond Dam. The resulting conservative water surface elevation values at the John Redmond Dam were 1,058.0 and 1,060.5 ft MSL for hydraulic and NID heights, respectively (Table 3.4-3). Using the Peak Flow with Attenuation Method resulted in flood water surface elevations that were much lower (by at least 27 ft., which is the difference between the crest elevation of Wolf Creek Dam main spillway and the higher of the two estimated flood water surface elevations in Table 3.4-3) than the elevation of the drainage divide between the Neosho River and Wolf Creek watersheds and the crest elevation of the Wolf Creek Lake Dam main spillway. Based on these results, the NRC staff concluded that a flood resulting from dam breaches in the Neosho River watershed would not cause a flood hazard at the Wolf Creek site. While coincident wind waves could result in an increase in the dam breach flood water surface elevation, the NRC staff determined that the margin (at least 27 ft.) is sufficient to account for coincident wind-wave effects.

The NRC staff reviewed the information provided by the licensee in the ERR and responses to staff's request for additional information. The NRC staff performed confirmatory analyses to determine whether the volume method used by the licensee has been implemented properly and confirm the reasonableness of the data and method used in the analysis.

The NRC staff confirmed the licensee's conclusion that the reevaluated flood hazard for failure of dams and onsite water control or storage structures is not bounded by the CDB. Therefore, the NRC staff expects that the licensee will submit a focused evaluation or revised integrated assessment for failure of dams or onsite water control or storage structures for the Wolf Creek site.

3.5 Storm Surge

The licensee reported in its FHRR that the reevaluated hazard for storm surge does not inundate the plant site, but did not report a maximum flood elevation. The licensee reported in its FHRR that storm surge was screened out as a potential flooding mechanism in the CDB. The NRC staff reviewed the flooding hazard from storm surge against the relevant regulatory criteria based on present-day methodologies and regulatory guidance.

The licensee stated that the Wolf Creek site is located more than 1,000 miles from the Pacific Ocean, approximately 935 miles inland from the Atlantic Coast, and approximately 600 miles inland from the Gulf of Mexico (USGS, 2013). The licensee also stated that the site is located adequately inland such that hurricanes and a Probable Maximum Hurricane (PMH) will not be a source of a potential flood hazard. Therefore, further consideration of storm surge flooding outlined in NUREG/CR-7134 and JLD-ISG-2012-06 (NRC, 2012b; 2013c) was not applicable to the Wolf Creek site.

The licensee also stated that storm surge due to Probable Maximum Wind Storms (PMWS) and squall lines was also not applicable to the Wolf Creek site, because the site is not located on the Great Lakes, as is discussed in ANSI/ANS-2.8 (ANS, 1992) and NRC JLD-ISG-2012-06 (NRC, 2013c).

The NRC staff confirmed the licensee's conclusion that the reevaluated hazard for flooding from storm surge is bounded by the CDB. The NRC staff also confirmed the licensee's conclusion that the flood hazard from storm surge alone would not inundate the site. Therefore, flooding from storm surge does not need to be analyzed in a focused evaluation or integrated assessment.

3.6 Seiche

The licensee reported in its FHRR that the reevaluated hazard for seiche does not inundate the plant site, but did not report a maximum flood elevation. The licensee reported in its FHRR that seiche was screened out as a potential flooding event in the CDB, as stated in the UFSAR. Therefore, this flood-causing mechanism is not included in the licensee's CDB. The licensee reported assessments performed to determine the feasibility of meteorological and seismically induced seiche on Wolf Creek Lake.

In order to account for the potential of seiche induced by meteorological effects, the licensee used the Dean and Dalrymple method (Dean and Dalrymple, 1991) by assuming the lake to be a rectangular basin with an average depth. Using the Dean and Dalrymple methodology for seiche periods for Wolf Creek Lake, the licensee estimated seiche periods were 6.5 minutes for the lake's length and 38.7 minutes for the width of the lake. Seiching at these periods could only occur if an oscillatory force (pressure or wind) excited lake oscillations at one of the seiche periods. The periods calculated for lake oscillation could not be continuously forced by changes in overall weather conditions because these conditions typically fluctuate at time scales of 1 hour or more (Peinke et al., 2004). The licensee concluded that meteorologically-induced seiche could therefore be screened from consideration as a source of flooding at the Wolf Creek site.

The licensee also reported assessments performed to determine the feasibility of seismically-induced seiche. The licensee reported that the Wolf Creek site is situated in an area of low seismic hazard (USGS, 2012). The occurrence of landslides in the area adjacent to Wolf Creek Lake is not considered possible due to the low relief of topographic features in the vicinity of the Wolf Creek site. Therefore, potential seismic events and landslide were not expected to cause seiches on Wolf Creek Lake and, therefore, cause flooding at the Wolf Creek site.

The NRC staff confirmed the licensee's conclusion that the flood hazard from seiche alone would not inundate the site. Therefore, the NRC staff determined that flooding due to seiche does not need to be analyzed in a focused evaluation or integrated assessment.

3.7 Tsunami

The licensee reported in its FHRR that the reevaluated hazard for tsunami does not inundate the plant site, but did not report a PMF elevation. The licensee reported in its FHRR that tsunami was screened out as a potential flooding event in the CDB, as stated in the UFSAR. This flood-causing mechanism is not included in the licensee's CDB.

The licensee reported in its FHRR that it reviewed the NOAA historic tsunami records that impacted the east coast of the United States and the Gulf of Mexico following the guidance in NRC NUREG/CR-6966 (NRC, 2009) and NRC JLD-ISG-2012-06 (NRC, 2012c). The licensee reported that the maximum historic water levels due to historic tsunami run-up recorded along the east cost of the United States and the Gulf of Mexico was 19.7 ft., which occurred at Daytona Beach, Florida, in 1992 (NOAA, 2013). Since Daytona Beach is approximately 1,050 miles from the Wolf Creek site, and the closest shoreline that could be subjected to tsunami flooding is approximately 600 miles away, the licensee determined that the Wolf Creek site region is not subject to tsunamis. Therefore, no further analysis for tsunami hazards is required.

The NRC staff confirmed the licensee's conclusion that the flood hazard from tsunami alone would not inundate the site. Therefore, the NRC staff determined that flooding due to tsunami does not need to be analyzed in a focused evaluation or integrated assessment.

3.8 Ice-Induced Flooding

The licensee reported in its FHRR that ice-induced flooding was screened out as a potential flooding event in the CDB as stated in the UFSAR. This flood-causing mechanism is not included in the licensee's CDB.

The licensee reported in its FHRR that the analysis for ice-induced flooding included assessment of ice jams, frazil ice, and ice thickness. The licensee reviewed the ice jams database (USACE, 2013) and determined that there was only one ice jam recorded on the Neosho River Basin dating back to February 1949, near the city of Council Grove, Kansas, which is about 50 miles northwest of the Wolf Creek site upstream of the John Redmond Reservoir. The licensee also reported that potential ice jams upstream of the John Redmond Reservoir would not adversely affect the Wolf Creek site because any potential floodwaters occurring due to release from the ice jam would be mitigated or dissipated before entering, or within, the John Redmond Reservoir or one of the other flood control facilities on the Neosho River. The Wolf Creek FHRR also reported that no historical ice jams have been recorded in the Wolf Creek watershed.

The Wolf Creek FHRR states that in January 1996, the ESWS intake trash racks of Train A became completely blocked by frazil ice and the frazil ice blockage was cleared by sparging the trash racks with air (NRC, 1996). When the trash racks were blocked by frazil ice in January 1996, the ESWS warming flow was insufficient to prevent frazil ice from forming at the Train A trash racks. The licensee reported that the current version of the UFSAR states that there is a system in place to mitigate future potential frazil ice formation by diffusing warm water in front of the ESWS intake trash racks. The licensee reported that mixing warmed water with supercooled water is effective near water intakes, where the required quantity of warm water can be modest (USACE, 2002).

The licensee estimated freezing degree days, which is defined as the difference between 32 degrees Fahrenheit and the daily average air temperature. The maximum estimated ice thickness on Wolf Creek Lake, was estimated to be approximately 20.6 in using the data from the Emporia Municipal Airport weather station, and approximately 19.14 in using data from the

John Redmond Lake weather station. The licensee used the methodology reported in the Meteorological Data Report (USACE, 2004).

The licensee reported that the bottom of the intake channel to the ESWS Pumphouse is at elevation 1,065 ft, which is 22 ft below the normal operating level of Wolf Creek Lake. Thus, the bottom of the estimated ice thickness of 20.6 in would still be approximately 20.28 ft. above the bottom of the intake channel to the ESWS Pumphouse. Therefore, the licensee concluded that the reevaluation analysis and the design basis screened out ice formation as a potential flood hazard.

The NRC staff reviewed the flooding hazard from ice-induced flooding against the relevant regulatory criteria based on present-day methodologies and regulatory guidance. The NRC staff reviewed the information provided by the licensee in the ERR and responses to staff's request for additional information. The NRC staff reviewed available ice related information from the ice jam database (USACE, 2013) to confirm whether there were records of significance with regard to the potential of flooding from this flood-causing mechanism.

The NRC staff confirmed the licensee's conclusion that the flood hazard from ice-induced flooding alone would not inundate the site. Therefore, the NRC staff determined that ice-induced flooding does not need to be included in a focused evaluation or integrated assessment.

3.9 Channel Migrations or Diversions

The licensee reported in the Wolf Creek FHRR that the reevaluated hazard for channel migrations or diversions does not inundate the plant site, but did not report a PMF elevation.

The licensee reported in its FHRR that flooding from channel diversion was screened out as a potential flooding event in the CDB as stated in the UFSAR. This flood-causing mechanism is not discussed in the licensee's CDB.

The licensee reported in its FHRR that the rivers and creeks in the vicinity of the Wolf Creek site are the Neosho River, Wolf Creek, and Long Creek. The licensee performed a qualitative assessment of the streams and rivers in the vicinity of the Wolf Creek site, in conjunction with the information presented in the UFSAR and determined that safety-related SSCs at the Wolf Creek site would not be affected by diversion of flows from the Neosho River, Wolf Creek, or Long Creek.

The NRC staff confirmed the licensee's conclusion that the flood hazard from channel migrations or diversions could not inundate the Wolf Creek site. Therefore, the NRC staff determined that ice-induced flooding does not need to be analyzed in a focused evaluation or integrated assessment.

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

4.1 Reevaluated Flood Elevation for Hazards Not Bounded by the CDB

Section 3 of this staff assessment documents the NRC staff review of the licensee's flood hazard water height results. Table 4.1-1 of this assessment contains the maximum flood height results, including waves and runup, for flood mechanisms not bounded by the CDB. The NRC staff agrees with the licensee's conclusion that LIP and failure of dams and onsite water control structures flood-causing mechanisms are not bounded by the CDB. The NRC staff anticipates that the licensee will submit a focused evaluation for LIP. For the failure of dams and onsite water control structures flood-causing mechanism, the NRC staff anticipates the licensee will perform additional assessments of plant response, either a focused evaluation or integrated assessment.

4.2 Flood Event Duration for Hazards Not Bounded by the CDB

The NRC staff reviewed the information provided in WCNOC's 50.54(f) response (WCNOC; 2014a, 2015c, 2016b) 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 flood-causing mechanisms not bounded by the CDB are summarized in Table 4.2-1 of this assessment. The NRC staff considers the values reported to be reasonable.

The licensee provided FED parameter values for the LIP flood-causing mechanism (WCNOC; 2014a, 2015c, 2016b). The licensee provided flood warning time of 1 hour. The licensee also provided estimates for duration of inundation of the site and time of recession for the LIP flood water to be 1.23 hours and 8.76 hours, respectively. The licensee used results from a 2D numerical modeling method, as described in the FHRR and reviewed in Section 3.2 of this staff assessment, to determine the inundation duration and period of recession parameters. The staff reviewed the LIP model and associated documents and confirmed that the licensee's reevaluation of the inundation periods for LIP and associated drainage uses present-day methodologies and regulatory guidance. The NRC staff found these parameter values to be reasonable based on staff's review of numerical model results discussed in Section 3.2 above.

For the failure of dams and onsite water control/storage structures flood-causing mechanisms the licensee stated that the reevaluated flood level is [redacted] below the plant grade and [redacted] below the service spillway invert. As a result this flood-causing mechanism does not inundate the site. Therefore, the licensee concluded that there was no need for further consideration of FED parameters for this flood-causing mechanism (WCNOC, 2015c). The NRC staff agrees with this conclusion, and parameter values are reported as 'not applicable' in Table 4.2-1.

The NRC staff reviewed the licensee's response regarding FED parameters for all flood-causing mechanisms not bounded by the CDB (WCNOC; 2014a, 2015c, 2016b) and determined that the parameters are reasonable for use in future assessments of plant response.

4.3 Associated Effects for Hazards Not Bounded by the CDB

The NRC staff reviewed information provided in WCNOC's 50.54(f) response (WCNOC; 2014a, 2015c, 2016b) regarding AE parameters needed to perform future additional assessments of plant response for flood hazards not bounded by the CDB. The AE parameters not directly associated with a maximum WSE are listed in Table 4.3-1 of this assessment.

The licensee provided estimates of hydrostatic and hydrodynamic loads for the LIP event. The hydrostatic loads were computed based on the modeled water surface elevation. The hydrodynamic loads were estimated from the modeled velocity time series results of the FLO-2D model. The total waterborne load was estimated as the summation of the two loads. As stated in the FHRR, the reevaluated combined hydrostatic and hydrodynamic loads at the points of interest were bounded by the maximum tornado impact pressure by a significant margin for all Class I structures. The NRC staff reviewed the simulated water surface elevations and velocities and determined that the information provided by the licensee is appropriate and reasonable for the FHRR review.

In order to estimate the debris load the licensee used the guidance provided in ASCE 7-10 (ASCE, 2010). The analysis included a debris object weighing 2,000 lbs to determine the maximum impact load. To account for the larger weight, a slightly larger diameter of 1.25 ft. was used to calculate the resulting pressure. The resulting estimates are a maximum waterborne projectile impact force of 121,761 lbs and pressure of 99,220 pounds per square foot, which occurred with estimated maximum potential flow velocity of 20 ft./s. The reevaluated waterborne projectile impact pressures were compared to the CLB/CDB tornado missiles, and found that sufficient margin existed for Class I structures, even at the highest range of expected flood velocities. The NRC staff reviewed the maximum velocities from the model outputs, consistent with the guidance provided in ASCE 7-10 (ASCE, 2010) and determined that the approach is acceptable for the purpose of the FHRR review.

The licensee stated that the failure of dams and onsite water control/storage flood-causing mechanism does not inundate the site since the maximum water surface elevation is below grade level. The NRC staff agrees with this conclusion based on the review discussed in Section 3.4 above, and parameter values are reported as 'not applicable' in Table 4.3-1 of this assessment.

The NRC staff reviewed the AE parameters provided by the licensee and the NRC staff confirms the licensee's AE parameter results are reasonable for use in future assessments of plant response.

4.4 Conclusion

Based on the preceding analysis, NRC staff confirmed that the reevaluated flood hazard information discussed in Section 4 is an appropriate input to the additional assessments of plant response as described in the 50.54(f) letter (NRC, 2012a), COMSECY-15-0019 (NRC, 2015b) and associated guidance.

5.0 CONCLUSION

The NRC staff has reviewed the information provided for the reevaluated flood-causing mechanisms of Wolf Creek. Based on its review of available information provided in WCNOC's 50.54(f) response (WCNOC; 2014a, 2015c, 2016b), the NRC staff concludes that the licensee conducted the hazard reevaluation using present-day methodologies and regulatory guidance used by the NRC staff in connection with ESP and COL reviews.

Based upon the preceding analysis, the NRC staff confirmed that the licensee responded appropriately to Enclosure 2, Required Response 2, of the 50.54(f) letter, dated March 12, 2012. In reaching this determination, NRC staff confirmed the licensee's conclusions that: (1) the reevaluated flood hazard results for LIP and failure of dams and water control/storage structures are not bounded by the CDB flood hazard; (2) additional assessments of plant response will be performed for the LIP and failure of dams and water control/storage structures flood-causing mechanisms; and (3) the reevaluated flood-causing mechanism information is appropriate input to the additional assessments of plant response as described in the 50.54(f) letter and COMSECY-15-0019 (NRC, 2015b) and associated guidance.

The NRC staff has no additional information needs with respect to WCNOC's 50.54(f) response related to the FHRR.

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Licenses with Regard to Requirements for Mitigation Strategies for Beyond-Design-Basis External Events," Order EA-12-049, March 12, 2012, ADAMS Accession No. ML12054A736.
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Table 2.2-1. Flood-Causing Mechanisms and Corresponding Guidance

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

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

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

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

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

Reevaluated Flood-Causing Mechanisms and Associated Effects that May Exceed the Powerblock Elevation (1099.5 ft)*	ELEVATION [MSL]
Local Intense Precipitation and Associated Drainage	1,099.9 ft. [Areas Away from the Powerblock FHRR (ESW Manhole MHE1B)] 1,100.5 ft. [Areas Around the Powerblock FHRR (Turbine Building)]

*Flood Height and Associated Effects as defined in JLD-ISG-2012-05.

Table 3.1-1 List of Powerblock Structures and their Elevations

Structure	Safety-Related	Elevation (ft.)
Auxiliary Building	Yes	1,100.0
Communication Corridor	No	1,100.0
Condensate Storage Tank, Pipe House Door	No/No	1,100.0
Control Building	Yes	1,100.0
Diesel Generator Building	Yes	1,100.0
Emergency Fuel Oil Tanks and Access Vaults	Yes	1,099.8
ESWS Access Vaults (4)	Yes	1,098.8
ESWS Manholes (10)	Yes	1,097.1 – 1,099.7
ESWS Pumphouse Pressure Doors	Yes	1,100.0
ESWS Valve House	Yes	1,100.3
Fuel Building	Yes	1,100.0
Hot Machine Shop	No	1,100.0
Radwaste Building	No	1,100.0
Reactor Building, Tendon Gallery Access Shaft	No/Yes	1,100.3
Reactor Make-Up Water Storage Tank, Valve House Door	No/Yes	1,100.0
Refueling Water Storage Tank, Valve House Door	Yes/Yes	1,100.0
Turbine Building	No	1,100.0

Table 3.1-2 Existing Wolf Creek Design Parameters

Design Parameter	Value
Plant Grade Elevation	1,099.5 ft.
Top of Slab Elevation for Safety-Related Structures	1,100.0 ft.
Top of Wolf Creek Darn Elevation	1,100.0 ft.
Crest Elevation of Wolf Creek Dam Main Spillway	1,088.0 ft.
Lowest Elevation of Exterior Entrances to any Safety-Related Structure (ESWS manholes)	1,097.2 ft.
Elevation of Service Water Intake Structure	1,058.0 ft.
Top of UHS Baffle Dike	1,094.0 ft.
Top of Submerged UHS dam	1,070.0 ft.
Local Intense Precipitation	28.8 in (6-hr cumulative rainfall)
Probable Maximum Precipitation (for the watershed)	32.8 in (48-hr PMP)
Design Precipitation Rate for Roof Drainage	19 in (in 1 hour)
Maximum Water Level at the Site, Including Wave Run-up	1,095.8 ft.
Maximum Water Level at the ESWS Pumphouse	1,100.2 ft.
Wind Speed for Wave Run-up	40 mph (overland)

Table 3.1-3. Current Design Basis Flood Hazards

Flooding Mechanism	Stillwater Level (MSL)	Waves/Runup	Design Basis Hazard Elevation (MSL)	Reference
Local Intense Precipitation and Associated Drainage **Powerblock Area**	1,099.9 ft.	Minimal	1,099.9 ft.	FHRR Section 2.2 and Table 4-3
Streams and Rivers				
Wolf Creek site Shoreline	1,095.0 ft.	0.8 ft.	1,095.8 ft.	FHRR Table 4-3
ESWS Pumphouse	1,095.0 ft.	5.2 ft.	1,100.2 ft.	FHRR Table 4-3
Dam failure Flooding on the Neosho River	[redacted] ft.	Not applicable	[redacted] ft.	FHRR Table 4-3
Storm Surge	Not included in DB	Not included in DB	Not included in DB	FHRR Section 3.5
Seiche	Not included in DB	Not included in DB	Not included in DB	FHRR Table 4-3
Tsunami	Not included in DB	Not included in DB	Not included in DB	FHRR Table 4-3
Ice-Induced	Not included in DB	Not included in DB	Not included in DB	FHRR Table 4-3
Channel Migrations or Diversions	Not included in DB	Not included in DB	Not included in DB	FHRR Table 4-3

Note 1: Reported values are rounded to the nearest one-tenth of a foot.
Note 2: The licensee indicated in their revised FHRR that the CDB site elevation changed due to regrading. The new site elevation is 1,099.9 ft. This change was captured in Wolf Creek's UFSAR Rev. 28.

Table 3.2-1. Reevaluated Local Intense Precipitation Flood Water-Surface Elevations Exceeding Building Floor Elevations at Safety-Related Buildings

Locations	Flood Water-Surface Elevation, ft. MSL	Floor Elevation of Safety-Related Buildings, ft. MSL
Auxiliary Building	1,100.4	1,100
Control Building	1,100.4	1,100
Diesel Generator Building	1,100.0	1,100
Fuel Building	1,100.4	1,100
Reactor Building	1,100.4	1,100
Refueling Water Storage Tank	1,100.1	1,100

Table 3.2-2. LIP Flood Hazards at Exterior Doors of Powerblock Buildings

Structure Description	Ground Elevation (ft MSL)	Critical (floor) Elevation (ft MSL)	Maximum Flood Elevation (ft MSL)	Maximum Flood Depth (ft.)	Flood Duration (h)[a]	Maximum Velocity (ft/s)	Maximum Hydrostatic Force (lb/ft.)[b]	Maximum Hydrodynamic Force (lb/ft.)[b]
Auxiliary Building Door (Pressure Door/Alcove Door)	1,099.3	1,100.0	1,100.4	1.0	0.5	1.2	32	3
Auxiliary Building Door (Missile Door)	1,099.4	1,100.0	1,100	0.5	<0.05	1.5	8	3
Auxiliary Building Door (Pressure Door/Alcove Door)	1,099.4	1,100.0	1,100.0	0.6	0.2	2.6	11	10
Communication Corridor (Double Door/Hollow Core Door)	1,099	1,100.0	1,100.0	0.9	1.0	0.7	25	1
Communication Corridor (Roll Up Door)	1,099.3	1,100.0	1,100.1	0.8	0.7	0.7	19	1
Communication Corridor (Hollow Core Door)	1,099.3	1,100.0	1,100.1	0.9	0.9	0.9	22	1
Control Building (Pressure Door/Alcove Door)	1,099.6	1,100.0	1,100.0	0.4	0.0	1.8	4	3
Diesel Generator Building (Missile Door)	1,099.4	1,100.0	1,099.9	0.6	0.1	2.8	10	10
Diesel Generator Building (Missile Door)	1,099.2	1,100.0	1,100	0.6	0.5	1.6	13	4
Fuel Building (Hollow Core Door)	1,099.1	1,100.0	1,099.8	0.7	1.0	1.7	15	5
Fuel Building (Hollow Core Door)	1,099.4	1,100.0	1,099.9	0.5	0.1	1.2	8	2
Fuel Building (Roll Up Door)	1,099.6	1,100.0	1,100.1	0.4	0.0	0.9	5	1
Hot Machine Shop (Hollow Core Door)	1,099.3	1,100.0	1,100.2	0.9	0.6	2.3	26	11
Hot Machine Shop (Hollow Core Door)	1,099.3	1,100.0	1,099.9	0.6	0.4	0.9	12	1
Hot Machine Shop (Roll Up Door)	1,099.3	1,100.0	1,099.9	0.6	0.1	1.2	12	2
Stair T-2 (Hollow Core Door)	1,099.4	1,100.0	1,100.1	0.7	0.5	1.0	15	1
Stair T-3 (Hollow Core Door)	1,099.4	1,100.0	1,100 1	0.7	0.5	1.0	16	1

a. Flood duration was computed based on a threshold depth of 0.5 ft. (duration is time that flood depth is greater than 0.5 ft.)
b. Hydrostatic and hydrodynamic forces are reported in force per unit width. Multiplying the reported forces by the width of a structure or wall provides the total force exerted on the wall. Hydrodynamic forces act in the direction of flow velocity. Consequently, the reported hydrodynamic forces should be interpreted as a conservative estimate. In cases where flow velocity is directed away from the building or tank (i.e., off the roof and away from the building or tank), the hydrodynamic force acting on the door is zero.
Source: WCNOC, 2015c (FHRR Table 3-2)

Table 3.2-3. LIP Flooding At Other Wolf Creek Safety-Related Access Points

Structure Description	Ground Elevation (ft MSL)	Critical (floor) Elevation (ft MSL)	Maximum Flood Elevation (ft.)	Maximum Flood Depth (ft.)	Flood Duration (h)[a]	Maximum Velocity (ft./s)	Maximum Hydrostatic Force (lb/ft.)[b]	Maximum Hydrodynamic Force (lb/ft.)[b]
Condensate Storage Tank Pipe House Door	1,099.3	1,100.0	1,100.4	1.1	1.8	1.0	35	1
Emergency Fuel Oil Tanks and Access Vaults	1,099.5	1,099.8	1,099.8	0.3	0.0	0.5	3	<1
ESWS Manhole[c] MHE1A	1,099.5	1,099.5	1,099.9	0.5	0.0	0.5	7	<1
ESWS Manhole[c] MHE1B	1,099.6	1,099.5	1,099.9	0.4	0.0	0.5	4	<1
ESWS Manhole[c] MHE2A	1,097.5	1,098.0	1,097.7	0.2	0.0	0.7	1	<1
ESWS Manhole[c] MHE2B	1,097.8	1,098.0	1,097.8	0.1	0.0	0.3	<1	<1
ESWS Manhole[c] MHE3A	1,097.0	1,097.0	1,097.5	0.2	0.0	0.4	1	<1
ESWS Manhole[c] MHE3B	1,097.1	1,097.0	1,097.5	0.2	0.0	0.4	1	<1
ESWS Manhole[c] MHE4A	1,096.8	1,097.0	1,097.7	0.8	1.4	2.2	22	9
ESWS Manhole[c] MHE4B	1,096.9	1,097.0	1,097.7	0.8	1.4	2.2	22	9
ESWS Manhole[c] MHE5A	1,097.2	1,097.8	1,098.3	1.4	10.0	0.6	64	<1
ESWS Manhole[c] MHE5B	1,097.3	1,097.8	1,098.3	1.4	10.0	0.6	64	<1
ESWS Pumphouse Pressure Door A	1,099.3	1,100.0	1,099.5	0.1	0.0	0.8	<1	<1
ESWS Pumphouse Pressure Door B	1,099.5	1,100.0	1,099.8	0.2	0.0	0.4	<1	<1
Reactor Building Tendon Gallery Access Shaft	1,099.2	1,100.3	1,100.2	1.1	6.4	0.7	37	<1
Reactor Makeup Water Storage Tank Valve House Door	1,099.3	1,100.0	1,099.9	0.5	<0.1	1.7	9	3
Refueling Water Storage Tank Valve House Door	1,099.2	1,100.0	1,099.9	0.7	0.9	3.4	17	20
ESW Vertical Loop Chase	1,099.6	1,100.5	1,100.3	0.9	1.1	0.8	28	<1
ESW Access Vault AV1	1,098.6	1,100.0	1,099.4	1.0	5.8	1.3	31	2
ESW Access Vault AV2	1,096.6	1,098.0	1,097.3	0.7	1.1	4.0	13	25
ESW Access Vault AV3	1,098.9	1,099.5	1,099.6	0.4	0.0	1.2	6	1
ESW Access Vault AV4	1,097.9	1,098.5	1,098.3	0.7	1.9	2.5	17	8
ESW Access Vault AV5	1,098.1	1,098.5	1,099.2	0.4	0.0	1.2	6	1

a. Flood duration was computed based on a threshold depth of 0.5 ft (duration is time that flood depth is greater than 0.5 ft.).
b. Hydrostatic and hydrodynamic forces are reported in force per unit width. Multiplying the reported forces by the width of a structure or wall provides the total force exerted on the wall. Hydrodynamic forces act in the direction of flow velocity. Consequently, the reported hydrodynamic forces should be interpreted as a conservative estimate. In cases where flow velocity is directed away from the building or tank (i.e., off the roof and away from the building or tank), the hydrodynamic force acting on the door is zero.
c. The ESWS manholes are designed to be watertight.
Source: WCNOC, 2015c (FHRR Table 3-3)

Table 3.3-1. Summary of Licensee and NRC Staff HEC-HMS Case Configurations and Peak Water-Surface Elevation of Wolf Creek Lake

Cases	HEC-HMS Model Configuration	Peak Wolf Creek Lake Water-Surface Elevation (ft. MSL)
Configurations by the licensee (WCNOC, 2014a (FHRR, Table 3-5)		
Case-1	No rainfall loss, No runoff transformation, No routing	1,095.3
Case-2	No rainfall loss, SCS UH transformation, Muskingum routing	1,095.1
Case-3	No rainfall loss, SCS UH transformation, including nonlinearity effect during PMP event, Muskingum routing	1,095.1
Case-4	SCS CN rainfall loss, SCS UH transformation, including nonlinearity during PMP event, Muskingum routing	1,095.0
Case-5	SCS CN rainfall loss, SCS UH transformation, including nonlinearity effect during PMP event, No routing	1,095.1
Configurations by NRC staff		
Case-1F	Antecedent storm before PMP, Front PMP Loading, No rainfall loss, No runoff transformation, No routing	1,094.6
Case-1C	Antecedent storm before PMP, Center PMP Loading, No rainfall loss, No runoff transformation, No routing	1,095.9
Case-1E	Antecedent storm before PMP, End PMP Loading, No rainfall loss, No runoff transformation, No routing	1,096.8
Case-2F	Antecedent storm before PMP, Front PMP Loading, No rainfall loss, SCS UH runoff transformation, No routing	1,094.6
Case-2C	Antecedent storm before PMP, Center PMP Loading, No rainfall loss, SCS UH runoff transformation, No routing	1,095.9
Case-2E	Antecedent storm before PMP, End PMP Loading, No rainfall loss, SCS UH runoff transformation, No routing	1,096.4
Case-3F1	Antecedent storm before PMP, Front PMP Loading, No rainfall loss, SCS UH runoff transformation, Muskingum routing (Manning's = 0.02)	1,094.6
Case-3C1	Antecedent storm before PMP, Center PMP Loading, No rainfall loss, SCS UH runoff transformation, Muskingum routing (Manning's = 0.02)	1,095.8
Case-3E1	Antecedent storm before PMP, End PMP Loading, No rainfall loss, SCS UH runoff transformation, Muskingum routing (Manning's = 0.02)	1,096.2
Case-3F2	Antecedent storm before PMP, Front PMP Loading, No rainfall loss, SCS UH runoff transformation, Muskingum routing (Manning's = 0.03)	1,094.5
Case-3C2	Antecedent storm before PMP, Center PMP Loading, No rainfall loss, SCS UH runoff transformation, Muskingum routing (Manning's = 0.03)	1,095.7
Case-3E2	Antecedent storm before PMP, End PMP Loading, No rainfall loss, SCS UH runoff transformation, Muskingum routing (Manning's = 0.03)	1,096.1

Table 3.4-1. Comparison of Water-Surface Elevations Related to Dam Failure Flooding

Dam Failure Flooding Analysis	Water-Surface Elevation at the Confluence of Wolf Creek and the Neosho River (ft. MSL)
Current Design-Basis[a], based on dynamic modeling	[redacted]
Flooding Hazard Reevaluation[a], based on volume method	[redacted]
NRC Staff Calculation, based on volume method	[redacted]

a. Source: WCNOC, 2014a.

Table 3.4-2. Peak Flow Method Without Attenuation Using Different Empirical Equations

Equations	Dam Height Used	Discharge (cfs)	500-year Return Flow (cfs)	Total Discharge (cfs)	HEC-RAS Water-Surface Elevation (ft. MSL)
Froehlich	Hydraulic Height	4,243,600	290,000	4,533,600	1,078.3
	NID Height	4,720,900	290,000	5,010,900	1,081.4
USBR	Hydraulic Height	8,232,200	290,000	8,522,200	1,100.6
	NID Height	9,634,400	290,000	9,924,400	1,107.2

Table 3.4-3. Peak Flow Method With Attenuation With Grid-Based Distance

Dam Height Used	Discharge (cfs)	500-year Return Flow (cfs)	Total Discharge (cfs)	HEC-RAS Water-Surface Elevation (ft. MSL)
Hydraulic Height	1,663,160	290,000	1,953,160	1,058.0
NID Height	1,932,290	290,000	2,222,290	1,060.5

Table 4.1-1: Reevaluated Flood Hazard Elevations for Flood-Causing Mechanisms Not Bounded by the Wolf Creek CDB

Flood-Causing Mechanism	Stillwater Elevation, [MSL]	Associated Effects [MSL]	Reevaluated Flood Hazard [MSL]	Reference
Local Intense Precipitation and Associated Drainage				
Areas Away from the Powerblock (ESW Manhole MHE1B)	1,099.9 ft.	Minimal	1,099.9 ft.	FHRR Table 3-3
Areas Around the Powerblock (Turbine Building)	1,100.5 ft.	Minimal	1,100.5 ft.	FHRR Table 3-1
Failure of Dams and Onsite Water Control/Storage Structures				
Upstream Dam Failure – Neosho River	[redacted] ft.	Not Applicable	[redacted] ft.	FHRR Section 3.3.3 & Table 4-3

Table 4.2-1: Flood Event Duration for Flood-Causing Mechanisms Not Bounded by the Wolf Creek CDB

Flood-Causing Mechanism	Time for Preparation for Flood Event	Duration of Site Inundation	Time for Water to Recede from Site
Local Intense Precipitation and Associated Drainage	1 hour	1.23 hours	8.76 hours
Failure of Dams and Onsite Water Control/Storage Structures	Not Applicable	Not Applicable	Not Applicable

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

	Flooding Mechanism	
Associated Effects Factor	**Local Intense Precipitation**	**Failure of Dams and Onsite Water Control/Storage Structures(1)**
Hydrodynamic loading at plant grade	64 lb/ft. for hydrostatic 25 lb/ft. for hydrodynamic	Not Applicable
Debris loading at plant grade	Minimal	Not Applicable
Sediment loading at plant grade	Minimal	Not Applicable
Sediment deposition and erosion	Minimal	Not Applicable
Concurrent conditions, including adverse weather (winds)	38.7 mph	Not Applicable
Groundwater ingress	Minimal	Not Applicable
Other pertinent factors (e.g., waterborne projectiles)	Minimal	Not Applicable

Source: (WCNOC, 2016b) and (WCNOC, 2015c)

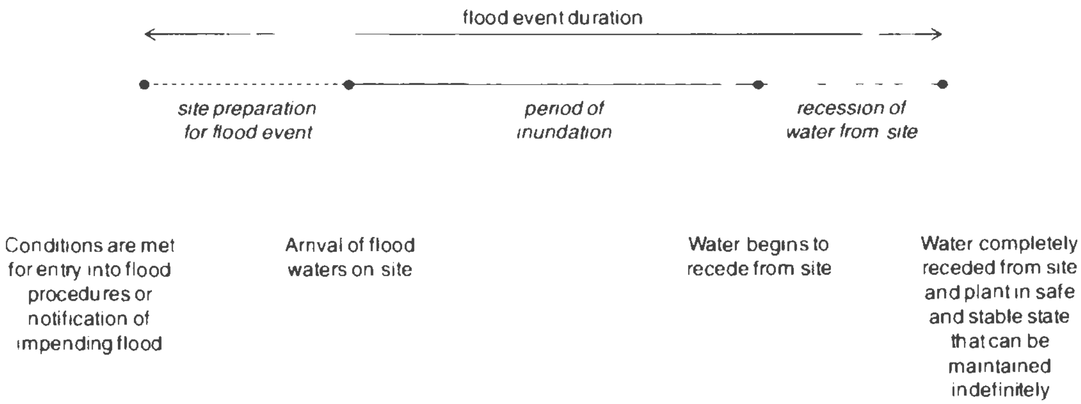

Figure 2.2-1. Flood Event Duration
Source: JLD-ISG-2012-05 (NRC, 2012c), Figure 6

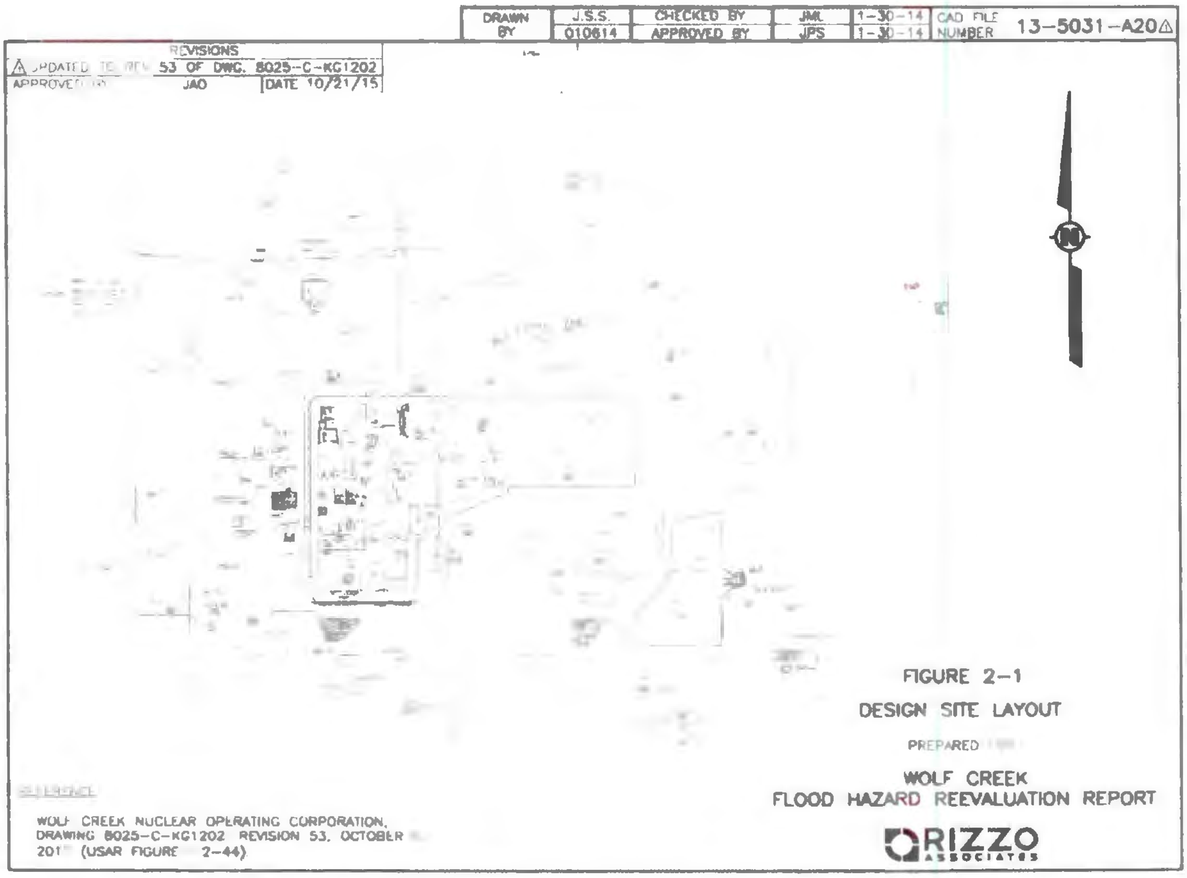

Figure 3.1-1. Wolf Creek Site Layout (adapted from Figure 2-1 of the FHRR)

Figure 3.2-1. Locations of Buildings, Structures, and Obstructions on the Wolf Creek Site (adapted from Figure 2-2 of the licensee's Calculation No. 14-5262-F-02).

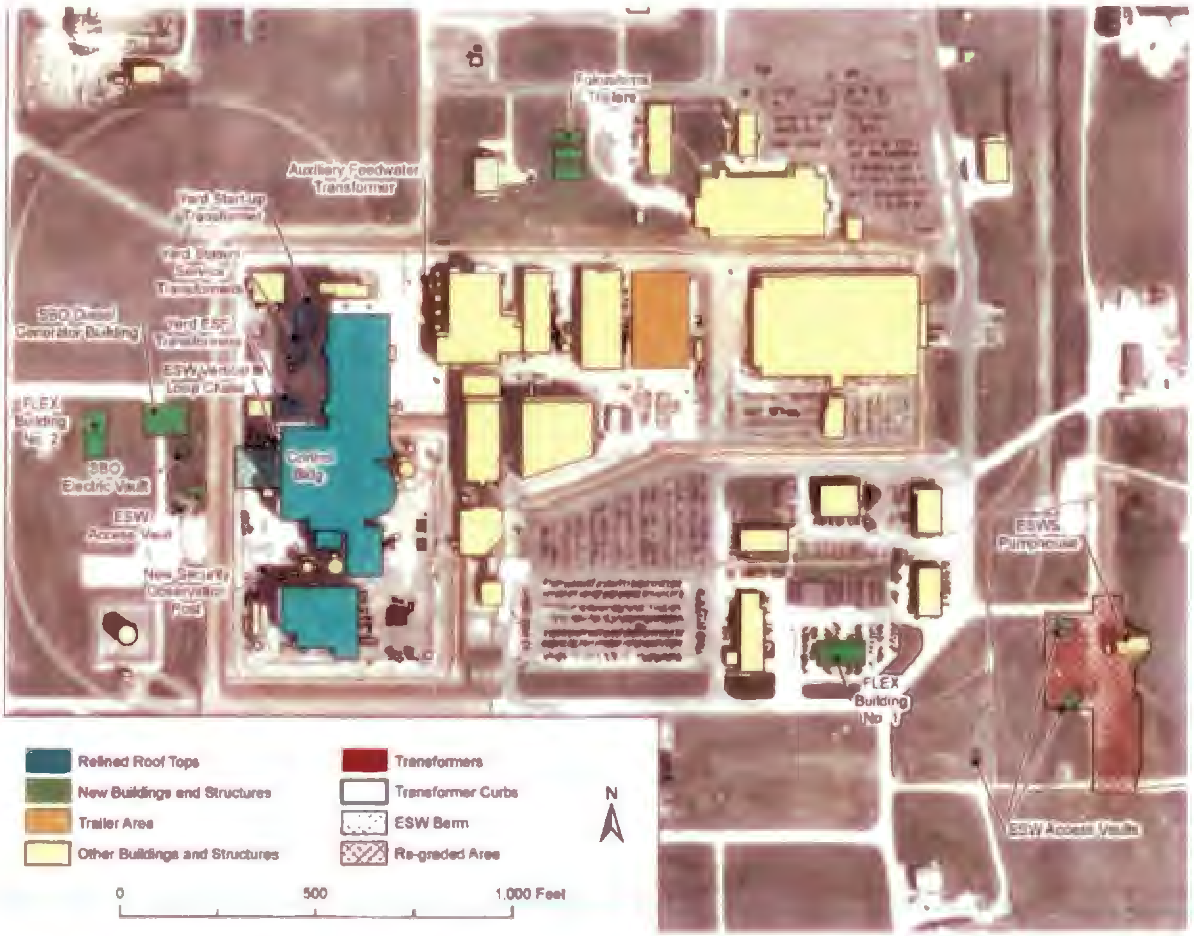

Figure 3.2-2. Wolf Creek Site Layout (adapted from Figure 2-1 of the licensee's Calculation No. 14-5262-F-02).

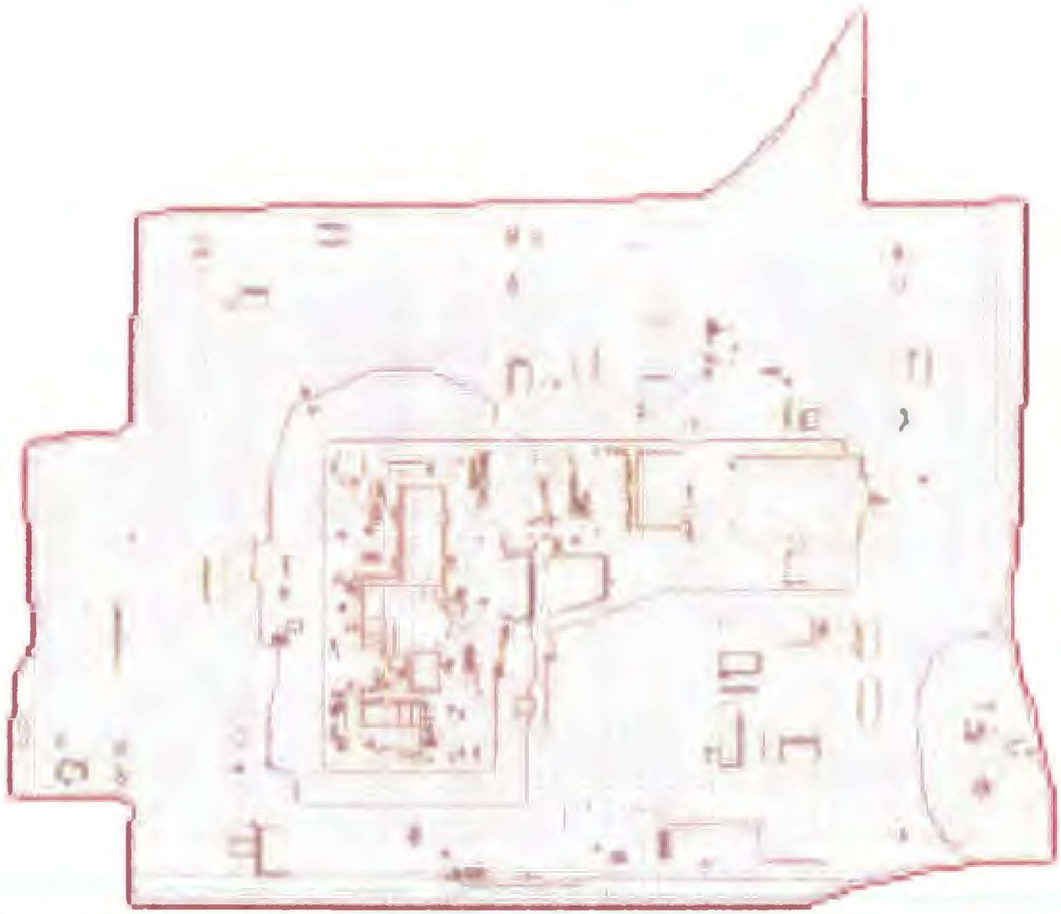

Figure 3.2-3. FLO-2D Model Domain for the Wolf Creek Site Used for Local Intense Precipitation Flood Analysis

Figure 3.2-4. Land-use Map for the Wolf Creek Site Used for Local Intense Precipitation Flood Analysis.

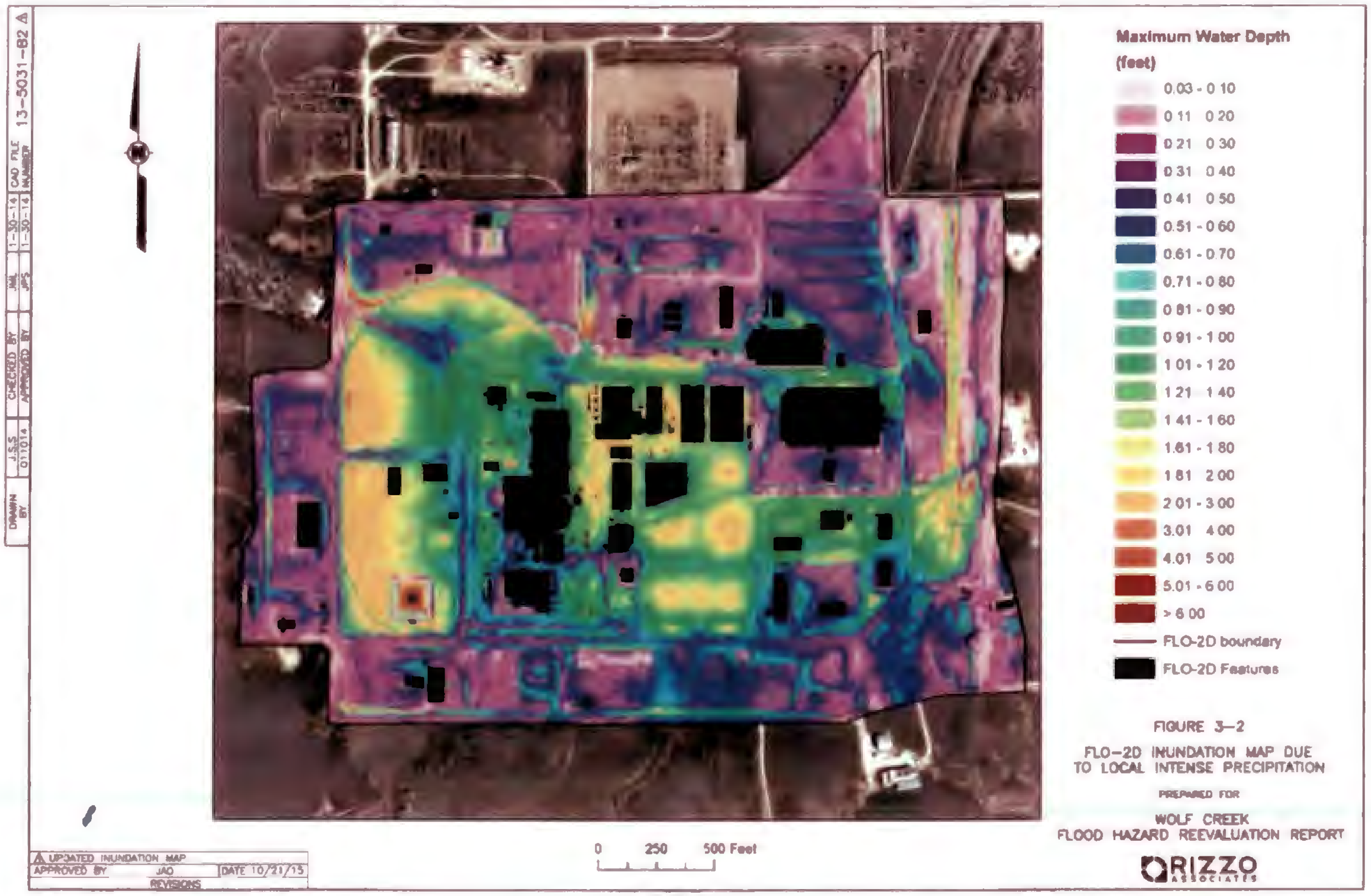

Figure 3.2-5. FLO-2D-predicted Maximum Water Depth Distribution Within the FLO-2D Model Domain Based on Case 7 Simulation Results (adapted from Figure 3-2 of FHRR Revision 1 [WCNOC, 2015c]).

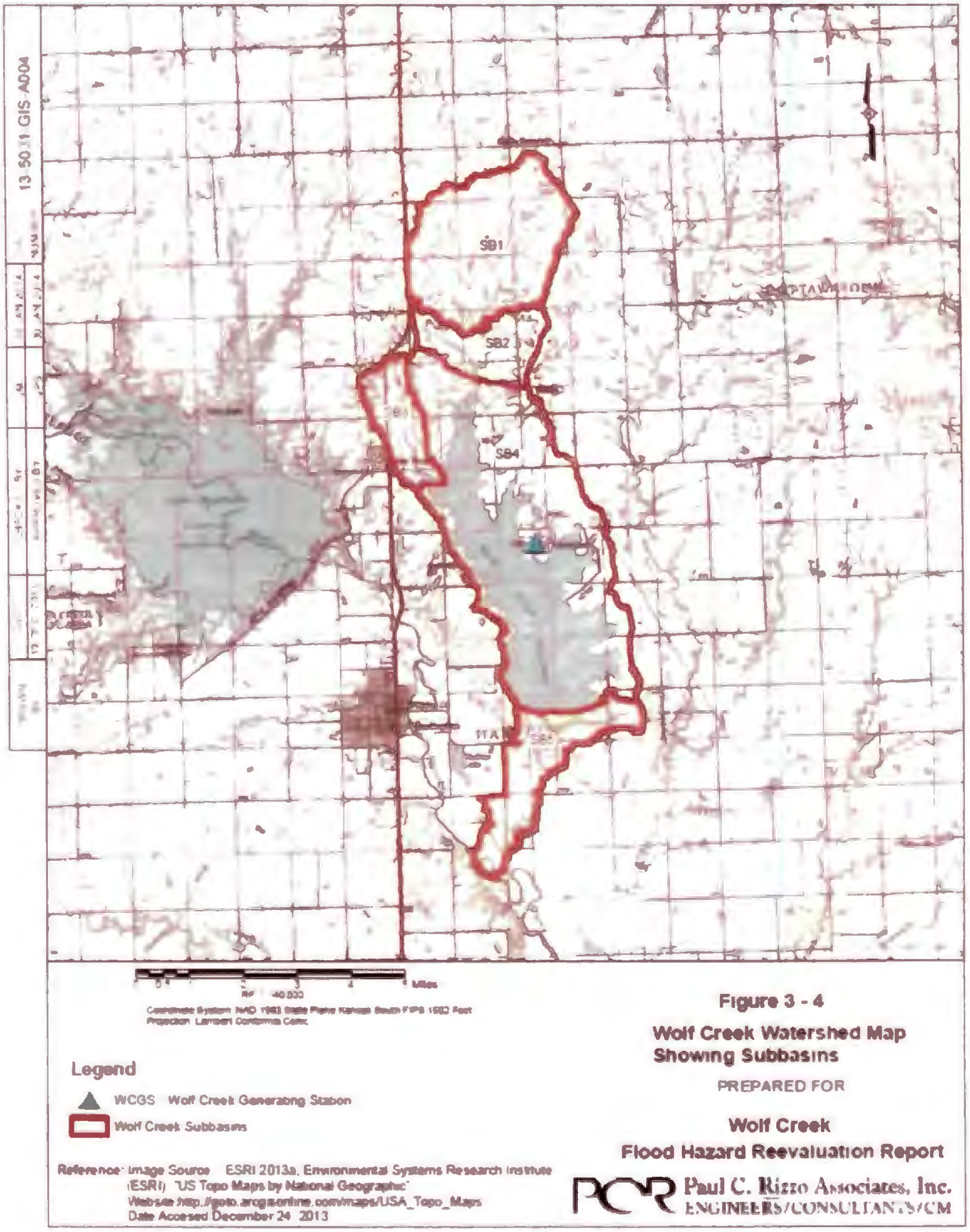

Figure 3.3-1. Locations of Wolf Creek Lake, Wolf Creek Lake Dam, and Wolf Creek site in the Wolf Creek Drainage, Including Subbasins Used for the Runoff Analyses During the Regional PMP (WCNOC, 2014a, Figure 3-4).

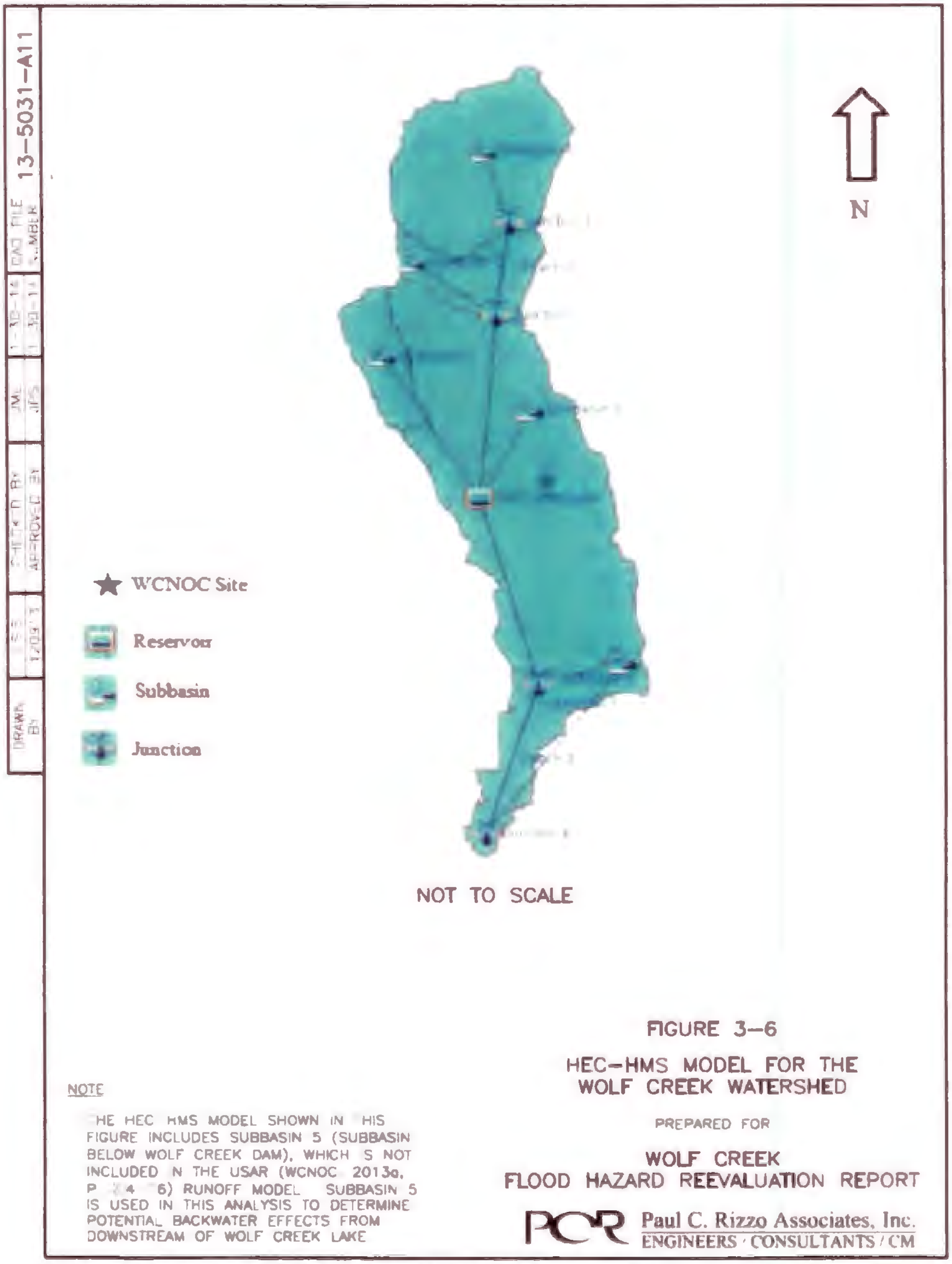

Figure 3.3-2. Schematic of HEC-HMS Subbasin Connectivity of the Wolf Creek Watershed for Computation of Runoff During the PMP Event (WCNOC, 2014a, Figure 3-6).

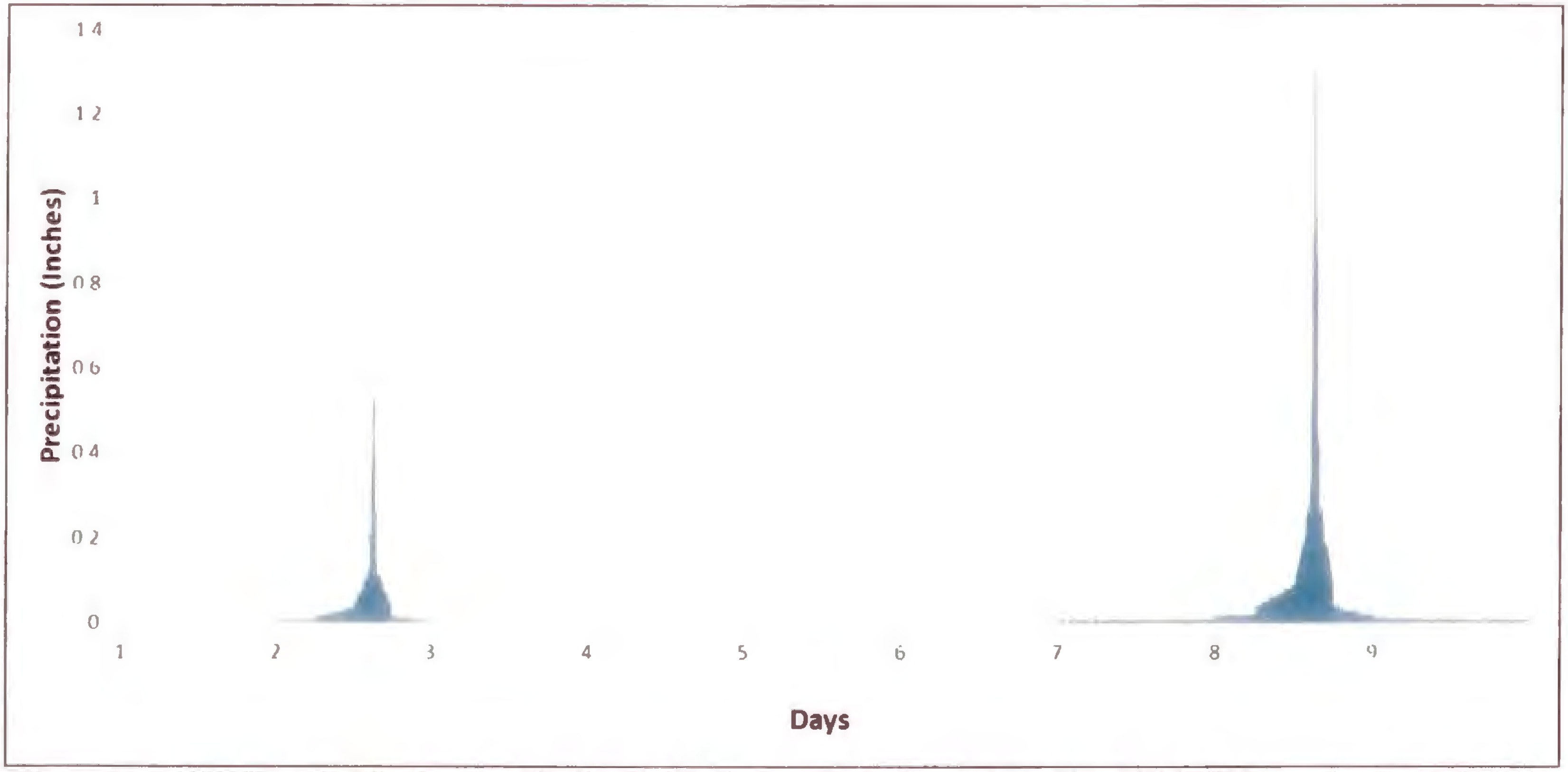

Figure 3.3-3. PMP Time Distribution Used by the Staff in its Sensitivity Scenarios with a 40% PMP Preceding the Full PMP

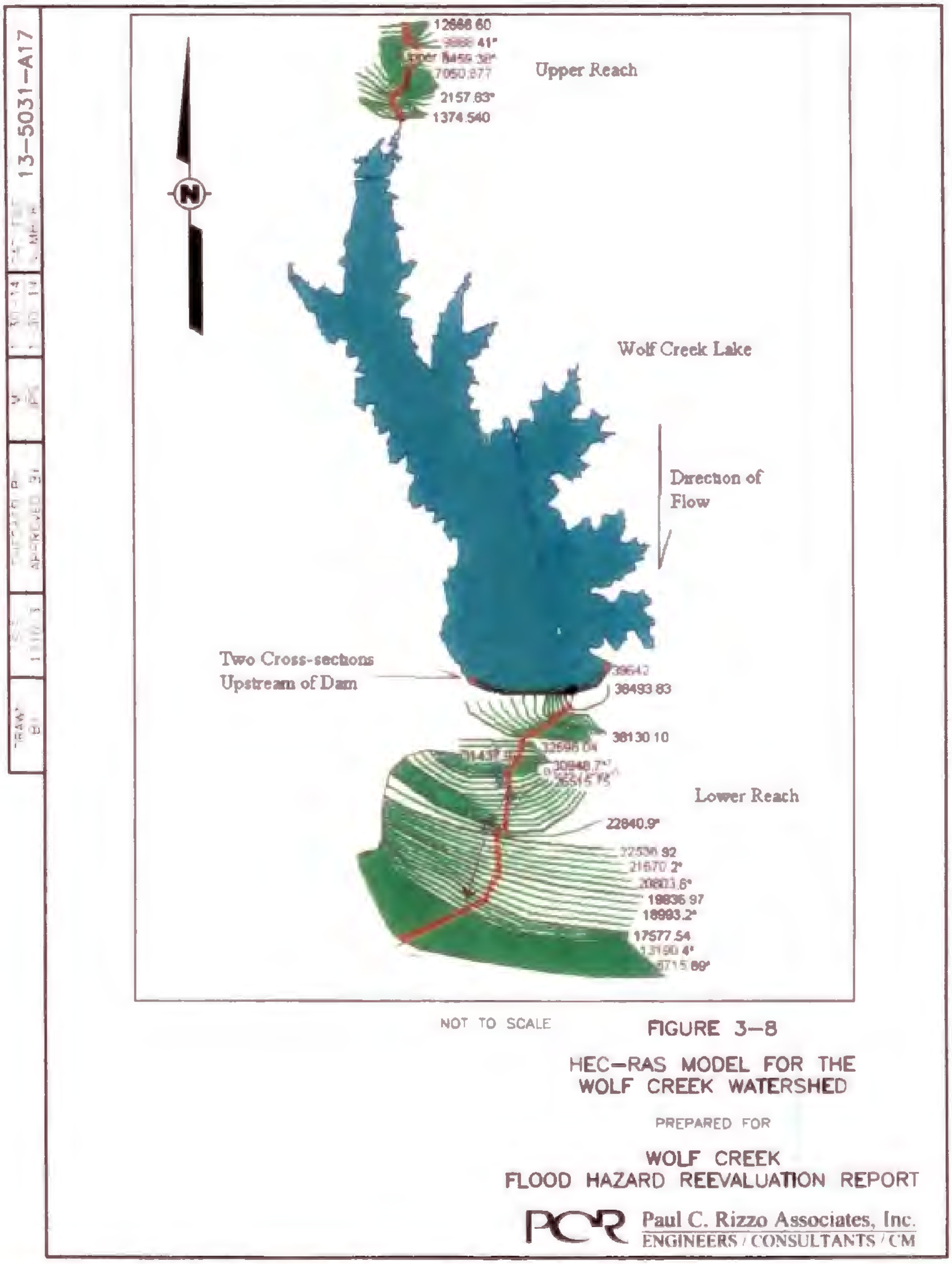

Figure 3.3-4. Layout of Cross Sections from HEC-RAS of the Wolf Creek Watershed for Computation of Hydraulic Characteristics of the PMF event (WCNOC, 2014a, Figure 3-8)

NOTES:

1. IMAGE SOURCE: USGS, 2013, UNITED STATES GEOLOGICAL SURVEY (USGS), "NATIONAL MAP VIEWER," WEBSITE <http://viewer.nationalmap.gov/viewer/>, DATE ACCESSED: JUNE 27, 2013
2. THE SHORELINE OF THE WOLF CREEK LAKE CORRESPONDS TO A LAKE LEVEL OF 1093.54 FEET

FIGURE 3–9

FETCH LOCATIONS OVER WOLF CREEK LAKE

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WOLF CREEK FLOOD HAZARD REEVALUATION REPORT

Paul C. Rizzo Associates, Inc.
ENGINEERS / CONSULTANTS / CM

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Figure 3.3-5. Fetch Determination in Wolf Creek Lake for Computation of Wind Wave Activity for the PMF Event (WCNOC, 2014a, Figure 3-8).

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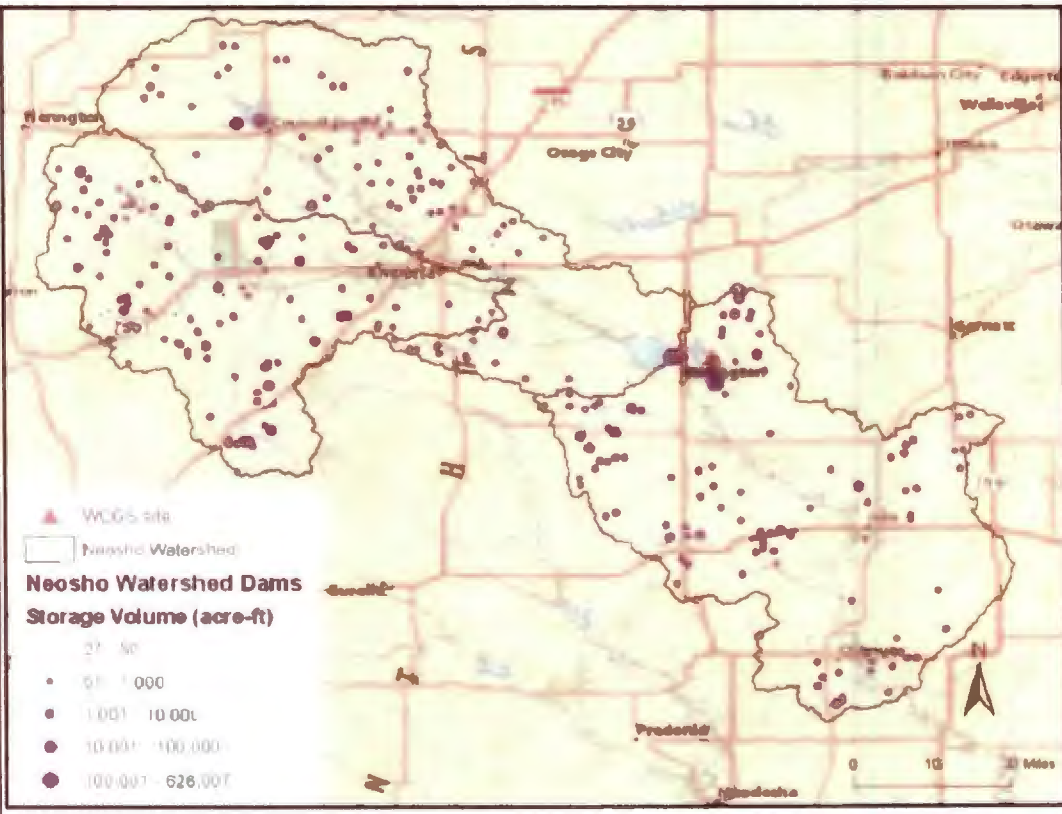

LEGEND

WCGS – WOLF CREEK GENERATING STATION

REFERENCES

1. IMAGE SOURCE: ESRI, 2013c, ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE (ESRI), "ARCGIS IMAGERY." WEBSITE: <http://www.arcgis.com/home/item.html?id=a5fef63517cd4a099b437e55713d3d54>, DATE ACCESSED: OCTOBER 18, 2013.
2. HUC BASIN SOURCE: USGS, 2013, UNITED STATES GEOLOGICAL SURVEY (USGS), "NATIONAL MAP VIEWER AND DOWNLOAD PLATFORM." WEBSITE: <http://viewer.nationalmap.gov/viewer/>, DATE ACCESSED: JUNE 27, 2013.
3. USACE, 2013a, UNITED STATES ARMY CORPS OF ENGINEERS (USACE), NATIONAL INVENTORY OF DAMS, WEBSITE: <http//geo.usace.army.mil/pgis/f?p=397:1:112429380233301::::>, DATE ACCESSED: NOVEMBER 4, 2013.

FIGURE 3–12

LOCATION OF DAMS NEAR THE SITE

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Figure 3.4-1. Locations of Dams Upstream of the Wolf Creek Site on the Neosho River Identified by the Licensee (WCNOC, 2014a, Figure 3-12)

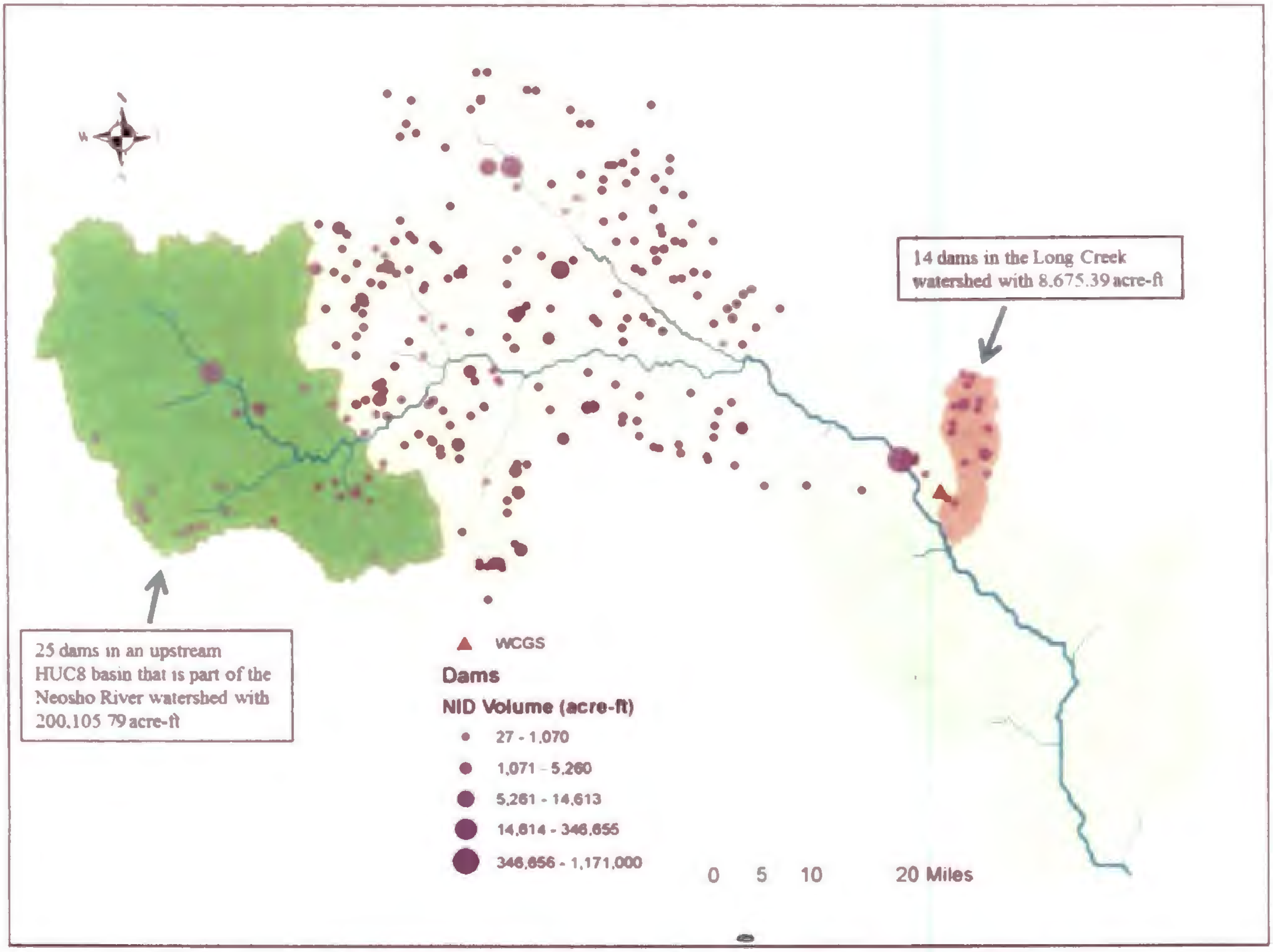

Figure 3.4-2. The Neosho River Watershed and Dams Identified by the NRC Staff.

SUBJECT: WOLF CREEK GENERATING STATION – STAFF ASSESSMENT OF RESPONSE TO 10 CFR 50.54(f) INFORMATION REQUEST – FLOOD-CAUSING MECHANISM REEVALUATION DATED JULY 5, 2017

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