MEMORANDUM TO: Mark A. Cunningham, Director
Division of Risk Assessment
Office of Nuclear Reactor Regulation

FROM: Scott C. Flanders, Director
Division of Site and Environmental Reviews
Office of New Reactors

SUBJECT: TRANSMITTAL OF NRO STAFF TECHNICAL EVALUATION OF DUKE POWER COMPANY'S ASSESSMENT OF POSTULATED JOCASSEE DAM FAILURE IMPACTS ON OCONEE NUCLEAR STATION

In response to NRR's request for NRO staff to assist in the hydrologic/hydraulic evaluation associated with the assessment of external flooding at the Oconee Nuclear Station (ONS) due to a postulated failure of the Jocassee Dam, NRO has completed its technical evaluation of the licensee's flooding assessment. Our assessment is based on a review of the licensee's 1992 inundation study, multiple technical discussions with the licensee and industry experts, and an independent analysis using current methods. Based on this assessment, we conclude that the licensee's analysis does not fully address uncertainties in external flooding of the ONS units due to a postulated breach of the Jocassee Dam. NRO has reached this conclusion based upon the following:

1) The licensee assessment is neither a bounding scenario nor does it provide a technical basis for the assumptions and approach;
2) The licensee's selected parameter values are non-conservative compared to the values independently developed by NRO staff using current accepted methods from peer-reviewed literature;
3) The licensee's analysis has not adequately demonstrated that overtopping of the dam will not occur;
4) The licensee analysis relies on a one dimensional model which is inadequate for representing the true flow field on the ONS site and therefore may not adequately estimating the flood depth at the SSF;
5) The licensee analysis did not incorporate the effects of wind generated waves into their flood height calculation and provided no basis for excluding it.

In order to address uncertainties, the following should be considered in the analysis.

1) Determine the most severe flooding scenario by conducting sensitivity analysis across the parameters using current methods (see Table 1 of Attachment);
2) Include in the analysis an antecedent storm prior to the PMP;

CONTACT: Kenneth R. See, NRO\DSER
301-415-1508

3) Evaluate the impacts of a PMP event on Jocassee reservoir and dam by adjusting the curve number to reflect the saturated soil conditions during a PMP/PMF event;
4) Consider using a two-dimensional model to estimate the flow and flood depth at the ONS site;
5) Incorporate the effects of wind generated waves into their flood height calculation.

The detailed discussion of our evaluation is attached. This essentially completes our activities associated with this evaluation and assistance.

Enclosure:
As stated.

CC: M. Johnson, NRO
G. Holahan, NRO
P. Hiland, NRR

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FROM: Scott C. Flanders, Director
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Division of Risk Assessment
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Patrick L. Hiland, Director
Division of Engineering
Office of Nuclear Reactor Regulation

FROM: Scott C. Flanders, Director
Division of Site and Environmental Reviews
Office of New Reactors

SUBJECT: TRANSMITTAL OF NRO STAFF TECHNICAL EVALUATION OF DUKE POWER COMPANY'S ASSESSMENT OF POSTULATED JOCASSEE DAM FAILURE IMPACTS ON OCONEE NUCLEAR STATION

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2) The licensee's selected parameter values are non-conservative compared to the values independently developed by NRO staff using current accepted methods from industry peer-reviewed literature;
3) The licensee's analysis has not adequately demonstrated that overtopping of the dam will not occur; and,

In order to address the adequate protection issue, the staff recommends that the licensee

1) Determine the most severe flooding scenario by conducting sensitivity analysis across the parameters determined by the staff using current industry practice, and
2) Include in the analysis an antecedent storm prior to the PMP in accordance with current industry practice, and
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(6) Evaluate the impacts of a PMP event on Jocassee reservoir and dam by adjusting the curve number to reflect the saturated soil conditions during a PMP/PMF event.

The detailed discussion of our evaluation is attached.

**ADAMS Accession Number:**

| OFFICE | NRO/DSER/RHEB | NRO/DSER/RHEB | NRO/DSER | NRO/DSER |
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| DATE | 02/ /2009 | 02/ /2009 | 02/ /2009 | 02/ /2009 |

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<u>Technical Review of Duke Power Company's Analysis of External Flooding of the Oconee Nuclear Station from Failure of the Jocassee Dam for NRR</u>

## 1.0 Purpose of Technical Review

The purpose of this review is to conduct a technical evaluation of the external flooding analysis for the Oconee Nuclear Station. The analysis was performed by the licensee, Duke Energy Carolinas, LLC (Duke). NRO performed this review at the request of NRR to provide analysis support to the NRR team reviewing Dukes response to the information request by the NRC pursuant to 10 CFR 50.54(f) regarding external flooding at the Oconee Nuclear Station.

## 2.0 Overview of Issue.

The technical issue regarding external flooding at the Oconee Nuclear Station, currently under review by the NRR, involves the analysis of potential consequences at the site due to failure of the upstream Jocassee Dam. Current studies indicate that the flood waters at the Oconee site following a breach of the dam will inundate the Standby Shutdown Facility (SSF), which provides backup emergency electrical power to all three Oconee units.

## 3.0 <u>Regulatory Background</u>

NRO relied on the following regulatory information to guide its approach in performing the technical review.

The design bases for external flooding issues stem from the General Design Criterion 2 (GDC 2), "Design Bases for Protection Against Natural Phenomena," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50. In GDC 2, flooding is listed as an example of natural phenomena against which the structures, systems, and components (SSC) important to safety must be designed in order to withstand its effects without loss of capability to perform their safety functions. GDC 2 requires appropriate consideration for the most severe natural phenomena with sufficient margins, along with the importance of the function to be performed by the SSC.

The requirements in GDC 2 are reflected in the applicable regulatory guidance contained in the Standard Review Plans (SRP) and Regulatory Guides (RG). The SRPs discuss acceptance criteria acceptable to meet regulatory requirements. They include consideration of "floods produced due to dam failures" (SRP 2.4.2, "Floods"), flood waves due to dam failure "and the resulting highest water surface elevation that may result in flooding of SSC important to safety" (SRP 2.4.4, "Potential Dam Failures"), and the consideration of "any potential hazard to the safety-related facilities due to the failure of onsite, upstream, and downstream water control structures in plant design" (SRP 2.4.10, "Flooding Protection Requirements"). RG 1.59, "Design Basis Floods for Nuclear Power Plants," provides supporting guidance on acceptable methods of determining design basis floods (i.e., those resulting from the "worst site-related flood probable") that nuclear power plants should be designed to withstand without loss of capability to achieve and maintain cold shutdown.

The aspects of this technical issue that affect the ongoing regulatory decision-making process involve the analysis of the credible range of dam failure modes and the determination of resulting flood levels at the Oconee site. The existing regulatory framework requires the evaluation to include a bounding-case flooding at the site. Therefore, the NRC expects that the

failure analysis of the Jocassee Dam should reflect the most severe flood possible at the site, that is, the highest water surface elevation affecting the SSF. Two parameters that were varied in the analysis are dam breach width and the time of breach development. Both parameters affect the calculation of the water surface elevation at the SSF and include significant uncertainties in terms of failure mode of the dam, breach evolution (e.g., shape and size), and meteorological and hydrological conditions.

## 4.0 Summary of Licensee Evaluation

In 1992, in response to a FERC request, the Duke Power Company's Hydro Support Services Engineering Section initiated a flooding study to evaluate a postulated failure of the Jocassee dam. The purpose of the calculation was to assess flooding effects to support the development of emergency action plan maps for Jocassee Dam failure as required by FERC. Two cases were evaluated, a "sunny day" case involving a sudden failure of the dam, and a probable maximum flooding (PMF) case which evaluates a postulated significant precipitation event which results in high water levels and consequential dam failure. In each case, the maximum water level calculated upstream of the Keowee Dam exceeds eight feet above the crest of the dam, so a dam breach was assumed to occur over a two-hour period.

In the sunny day case, the study used initial reservoir levels for the Jocassee and Keowee impoundments two feet below full pond, and assumed a trapezoidal breach with a base 250 feet wide. The sides of the trapezoid were sloped 1:1 to the crest with an average breach width of 575 feet. The failure time was four hours. The Keowee dam was assumed to fail in this event due to the resultant overtopping. The sunny day case results in a calculated flood level 12.5 ft above the SSF elevation.

The PMF case used an initial Jocassee reservoir level four feet below full pond, and a Keowee reservoir level two feet below full pond as assumed in the sunny day case. The assumed precipitation event produced a Jocassee reservoir elevation of three feet below the crest of the Jocassee dam. Failure of the dam was assumed to occur with this elevated water level, using the same 575 feet breach size and four-hour failure time. The PMF case results in a calculated flood level 16.8 ft above the SSF elevation. Note that in both cases evaluated, the licensee did not use full pond level as specified in NRC guidance[1].

In its September 26, 2008, response to the NRC's 50.54(f) letter, the licensee performed additional calculations using the original FERC analyses as its basis. All input parameters from the 1992 FERC calculations were maintained constant (i.e., breach width and failure times) except that the Jocassee reservoir level was lowered to reflect its current drought level of 25 feet below full pond and then varied the level to 20 feet below full pond level for the calculations. The results of these calculations with lower initial water levels in the reservoir are lower than the 1992 results, with the SSF flood height calculated as 6.7 feet – 11.2 feet.

During a December 4, 2008, technical meeting, the licensee presented slides to explain its hydrologic and hydraulic analysis performed in support of the Jocassee Dam failure analysis. During this presentation, the licensee stated that it used the curve number method, which was developed by the Natural Resource Conservation Service (NRCS), (formerly the Soil Conservation Service), U.S. Department of Agriculture to estimate the precipitation runoff into the Jocassee watershed and reservoir. This method requires the user to assign a curve number to represent the potential for runoff from a particular watershed or basin. The curve number is affected by the soil type, land use, existing moisture condition (antecedent runoff condition) and the depth below grade to an impermeable soil layer. Curve number values can be found in

documents produced by the NRCS and in most hydrology textbooks. Curve numbers can range in value from zero to one-hundred. A curve number of zero would indicate no runoff would occur from precipitation and a curve number of 100 would indicate that all the precipitation would be converted to runoff. The licensee used a curve number of 55 to estimate the precipitation runoff into the Jocassee watershed and reservoir. NRO reviewed the licensee's documents supporting its 1992 inundation study obtained from FERC which show that the licensee, in addition to using the curve number of 55, assumed average moisture conditions existed throughout the entire watershed during the probable maximum precipitation (PMP) and PMF.

## 5.0 Technical Evaluation

### 5.1 Evaluation Approach

In order to determine if a more rigorous evaluation could potentially result in substantial variation from the licensee's results, NRO researched and identified industry peer-reviewed literature related to currently accepted methods for estimating dam breach parameters:

- Wahl, T.L. (1998), "Prediction of embankment dam breach parameters – A literature review and needs assessment." Dam Safety Report No. DSO-98-004, U.S. Dept. of the Interior, Bureau of Reclamation, Denver.
- Wahl, T.L. (2004), "Uncertainty of Predictions of Embankment Dam Breach Parameters." Journal of Hydraulic Engineering, 130(5) 389-397.
- Gee, D. M., and Brunner, G.W. "Comparison of Breach Predictors." Association of State Dam Safety Officials (ASDSO) Conference 2007.
- U.S. Geological Survey (in cooperation with the California Dept. of Water Resources) (1968). "Flood Surge on the Rubicon River, California – Hydrology, Hydraulics and Boulder Transport." Geological Survey Professional Paper 422-M.
- FERC (1988), USA Federal Energy Regulatory Commission – Notice of Revised Emergency Action Plan Guidelines, February 22, 1988.
- U. S. Army Corps of Engineer, Hydrologic Engineering Center, "H&H for Dam Safety Studies (Prospect Course Manual 2006) U.S. Army Corps of Engineers, Davis, CA.

NRO did not conduct an analysis to predict flood levels at the site, but focused on evaluating critical parameters and their values used in the flooding analysis.

### 5.2 Evaluation

After consultation with two of the authors of the above papers who are recognized as experts in the field (Dr. Gee, U.S. Army Corps of Engineers and Tony Wahl, Bureau of Reclamation), the NRC generated its own estimates of the breach parameters using the literature as guidance (see Attachment for detailed calculations). NRO determined median breach widths ranging from 928 – 1200 feet (compared with 575 feet used by the licensee), and breach times ranging from less than 1 hour up to 6 hours (compared with 4 hours used by the licensee). (Refer to Attachment 1 for details.)

The literature[4] compares the predicted values of these parameters with actual dam failure data, and while there is good correlation, there is also significant uncertainty and variance (see Figures 1 and 2 in the Attachment). Because of the potential uncertainties in the predicted

values, a sensitivity analysis should be performed to fully investigate the downstream impacts of a range of credible dam breach scenarios, since different combinations of breach width and failure times may result in significant variation in the predicted maximum flooding level.

The licensee's analysis used median values based on a single data point, and did not provide any sensitivity analyses to investigate the uncertainties, The licensee's use of a breach width of 575 feet and 4-hour time of failure is not consistent the results of the NRO analyses. The results of the NRC analyses, using currently accepted methods, are summarized in Table 1 of the attachment; they represent an appropriate range over which the licensee should perform sensitivity analysis to determine the most severe flooding at the ONS site.

As noted, the licensee stated that it used a curve number of 55 to estimate the precipitation runoff into the Jocassee watershed and reservoir, and NRO's review determined that the licensee also assumed average moisture conditions existed throughout the entire watershed. NRO has concluded that the licensee has not demonstrated why these assumptions are valid. Also, the licensee has not followed the current practice of including an antecedent storm in its analysis and its effect on the soil moisture conditions just prior to the PMP in the watershed as described in NRC guidance[1,2]. This analysis will impact the possibility of overtopping the dam and subsequent dam failure from overtopping during a PMF. Specifically, overtopping will occur at 1125 feet. The licensee's current analysis using a curve number of 55 calculates a reservoir level of 1122 feet, providing only 3 feet of margin to overtopping. NRO's review indicates that a curve number of 74 appears more appropriate to account for the increased runoff due to saturated soil during the PMP event and thus cannot conclude that the licensee's analyses are appropriately conservative with regard to the effects of soil saturation and runoff. Given the small margin available to overtopping and the precipitation and saturated soil conditions that the licensee has not demonstrated are appropriately accounted for, the staff is unable to conclude that overtopping of the dam is not possible.

In evaluating the downstream flooding effects, the licensee has used a one-dimensional code (HEC-RAS) which may be non-conservative for evaluating flood effects around the complex topography and submerged structures of the plant site. While the use of a more accurate, two-dimensional code is the preferred method of evaluation, a one-dimensional code may be acceptable provided the inputs are demonstrated to be consistently conservative; this has not been adequately demonstrated by the licensee. The licensee has also failed to account for potential wind-generated waves during the event. Given the inherent uncertainties in flood effects, more rigor and conservatism is required to assure the licensee's calculations bound the range of potential flood impacts due to the range of credible dam failure scenarios.

## 6.0 Conclusions and Recommendations

NRO finds the licensee's analysis inadequate because it does not consider a range of credible dam failure parameters and resultant plant flood scenarios consistent with currently accepted technical methods, it did not consider appropriate soil saturation and runoff conditions which may exist prior to the PMP/PMF event, and therefore does not assure a reasonably conservative treatment of downstream flooding effects.

The licensee evaluated only a single breach width (575 feet) and failure time (4 hours) which had previously been applied in its 1992 FERC evaluation, which are apparently based on a single data point of the 1964 Hell Hole Dam failure. While the licensee characterized the values as conservative to the actual failure parameters (100 feet and 18 hours), selecting a single data point while not considering any other data or analytical methods does not address the inherent

uncertainties in the data, and is inconsistent with accepted methods for calculating dam breach parameters (discussed below). In addition, NRO is aware of alternative interpretations of the Hell Hole Dam failure which indicate an actual failure time of one hour[3]. These two parameters, breach width and failure time, can significantly vary the expected flood height downstream at the plant site, and therefore a more thorough evaluation of the possible range of these parameters should have been made, consistent with currently accepted methods.

Based on this assessment, we conclude that the licensee's analysis does not fully address uncertainties in external flooding of the ONS units due to a postulated breach of the Jocassee Dam. NRO has reached this conclusion because:

1) The licensee assessment is neither a bounding scenario nor does it provide a technical basis for the assumptions and approach;
2) The licensee's selected parameter values are non-conservative compared to the values independently developed by NRO staff using current accepted methods from peer-reviewed literature;
3) The licensee's analysis has not adequately demonstrated that overtopping of the dam will not occur;
4) The licensee analysis relies on a one dimensional model which is inadequate for representing the true flow field on the ONS site and therefore may not adequately estimating the flood depth at the SSF;
5) The licensee analysis did not incorporate the effects of wind generated waves into their flood height calculation and provided no basis for excluding it.

In order to address uncertainties, the following should be considered in the analysis.

(1) Determine the most severe flooding scenario by conducting sensitivity analysis across the parameters using current methods (see staff evaluation);
(2) Include in the analysis an antecedent storm prior to the PMP;
(3) Evaluate the impacts of a PMP event on Jocassee reservoir and dam by adjusting the curve number to reflect the saturated soil conditions during a PMP/PMF event;
(4) Consider using a two-dimensional model to estimate the flow and flood depth at the ONS site;
(5) Incorporate the effects of wind generated waves into their flood height calculation.

1 NUREG-0800 U.S. Nuclear Regulatory Commission Standard Review Plan, Section 2.4.3 "Probable Maximum Flood (PMF) on Streams and Rivers" and Section 2.4.4 "Potential Dam Failures."

2 ANSI/ANS-2.8-1992, "Determining Design Basis Flooding at Power Reactor Sites.

3 U.S. Geological Survey (in cooperation with the California Dept. of Water Resources) (1968). "Flood Surge on the Rubicon River, California – Hydrology, Hydraulics and Boulder Transport." Geological Survey Professional Paper 422-M.

4 Wahl, T.L. (1998), "Prediction of embankment dam breach parameters – A literature review and needs assessment." Dam Safety Report No. DSO-98-004, U.S. Dept. of the Interior, Bureau of Reclamation, Denver.

The literature identifies uncertainties in the predictive correlations of the dam breach width and failure time, as shown in Figures 1 and 2, below.

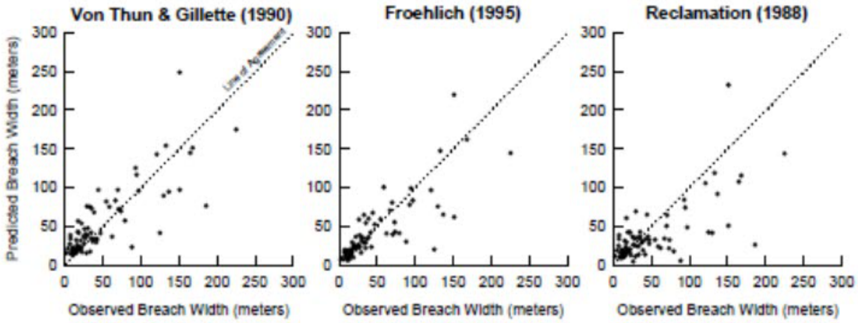


Figure 1. Comparison of Predicted and Observed Breach Widths for Various Regression Equations.

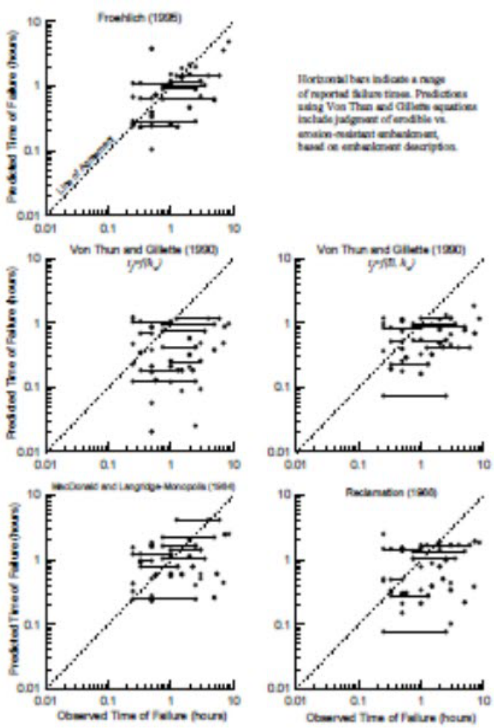


Figure 2. Comparison of Predicted and Observed Time of Failure for Various Regression Equations.

The following calculations show the predicted parameter values using the methods detailed in the journal papers referenced in the Technical Evaluation.

List of Symbols

| | |
|---|---|
| $B_{avg}$ | Average Breach Width |
| $h_b$ | Height of Breach |
| $h_w$ | Height of Water Above Breach Bottom |
| $t_f$ | Time of Failure |
| $V_{er}$ | Volume of Dam Eroded Away |
| $V_w$ | Volume of Reservoir Above Breach Bottom |

1. Failure Times

MacDonald and Langridge -Monopolis (1984)

$V_{er} := 0.00348 \cdot (V_w \cdot h_w)^{0.852}$ (Rockfill)

$V_{er} = 1.1 \times 10^7$

$t_f := 0.0179 \cdot V_{er}^{0.364}$   $t_f = 6.5$   hrs

Von Thune and Gillette (1990)

$t_f := 0.015 \cdot h_w$ (Highly Erodible)   $t_f = 1.4$   hrs

Froehlich (1995a)

$t_f := 0.00254 \cdot (V_w)^{0.53} \cdot h_b^{-0.9}$

$t_f = 3$   hrs

Von Thune and Gillette (1990)

$B_{avg} := 295.321$ (See Breach Width Calculation)

$t_f := \dfrac{B_{avg}}{(4 \cdot h_w + 61)}$   $t_f = 0.7$   hrs   (Highly Erodible)

$t_f := \dfrac{B_{avg}}{(4 \cdot h_w)}$   $t_f = 0.8$   hrs   (Erosion Resistant)

Bureau of Reclamation (1988)

$t_f := 0.011 \cdot B_{avg}$   $B_{avg} := 283.5$ m   (See Breach Width Calculation)

$t_f = 3.2$   hrs

There is a significant range of failure times depending upon the methodology used. For highly erodible dams, which would not typically include rockfill dams, the range of failure times is 0.7 to 1.4 hours. For erosion-resistant and rockfill dams, the range of failure times is 0.8 hours to 6.5 hours. An additional method for any dam type yields a 3.2-hour time to failure. Thus, the minimum time of failure was 0.7 hours, and the maximum was 6.5 hours with an average of 2.6 hours.

Based on these multiple assessments, NRO concludes that the licensee assessment should include sensitivity studies that include a time to failure as low as one hour.  This value is consistent with current best industry practices.

2. Breach Width

Bureau of Reclamation (1988)

$$B_{avg} := 3 \cdot h_w \qquad B_{avg} = 283.5 \qquad 283m = 928.5\,ft$$

Von Thun and Gillette (1990)

$$B_{avg} := 2.5 \cdot h_w + 59.1 \qquad B_{avg} = 295.3 \qquad 295m = 967.8\,ft$$

Froehlich (1995a)

$$K := 1$$

$$B_{avg} := 0.1803 \cdot K \cdot V_w^{\,0.32} \cdot h_b^{\,0.19} \qquad B_{avg} = 364 \quad m \qquad 364m = 1.2 \times 10^3\,ft$$

The minimum average breach width was 928.5 feet and the maximum was 1200 feet with an average of 1,030 feet.

Dam breaches typically are trapezoidal in shape.  To determine whether the dimensions predicted by the regression equations above are physically possible for the Jocassee Dam, the dimensions of the actual dam were taken from FERC Drawing 2503, Keowee – Toxaway Project, Exhibit L, Sheet 4 (See Figure 3).

(b)(3):16 U.S.C. § 824o-1(d), (b)(7)(F)

Figure 3. FERC Drawing 2503 Showing Jocassee Dam Elevation.

The drawing was scanned and the dam elevation figure was digitized to scale using computer software. Figures 4 and 5 show the results of this work.

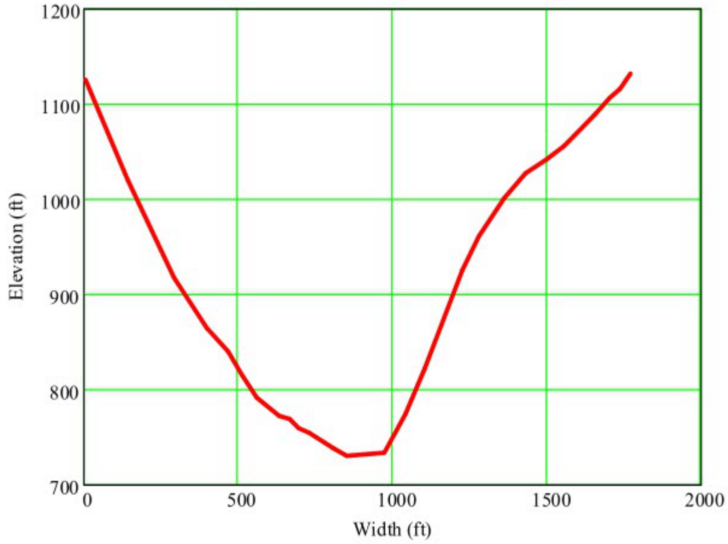


Figure 4. Jocassee Dam Elevation (Looking Downstream).

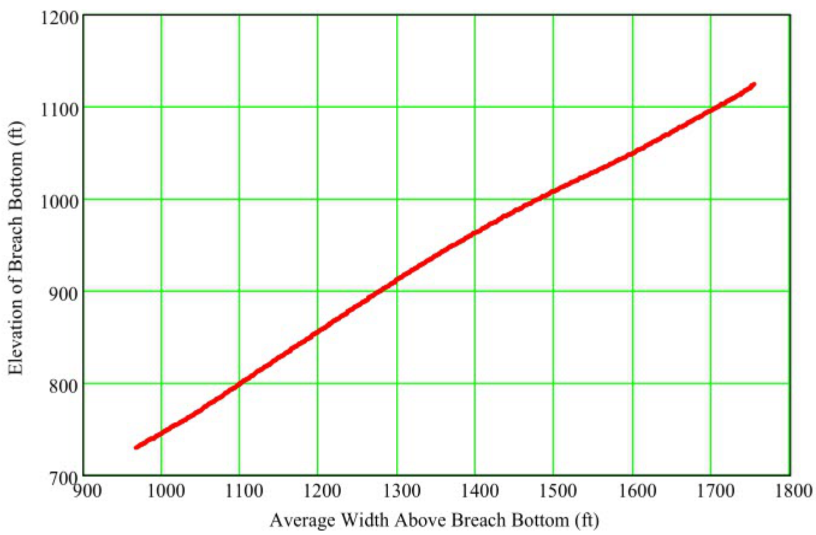


Figure 5. Average Width of Dam Above Breach Bottom (feet).

Based on Figure 5, the average width of the entire dam (above elevation 730 feet) is approximately 967 feet and is 1100 feet above the elevation of 800 feet.

The dimensions of the trapezoidal breach were determined two different ways. First, the dimensions of the breach were chosen to match the average breach width of 900 feet as found from the regression equations. The second was to match the average width of the trapezoidal breach to the average width of the dam above the specified bottom breach elevation. Figures 6 through 9 shows the trapezoidal breach imposed on the dam elevation profile.

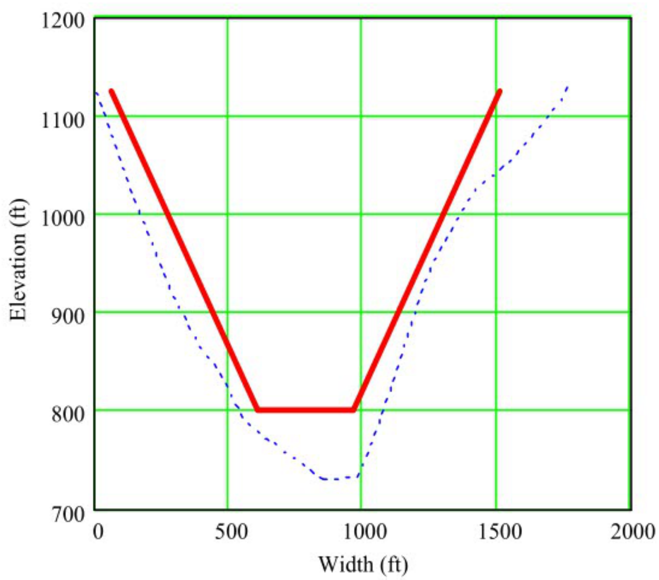


Figure 6. Trapezoidal Breach with an Average Width of 900 feet and a Bottom Elevation of 800 feet.

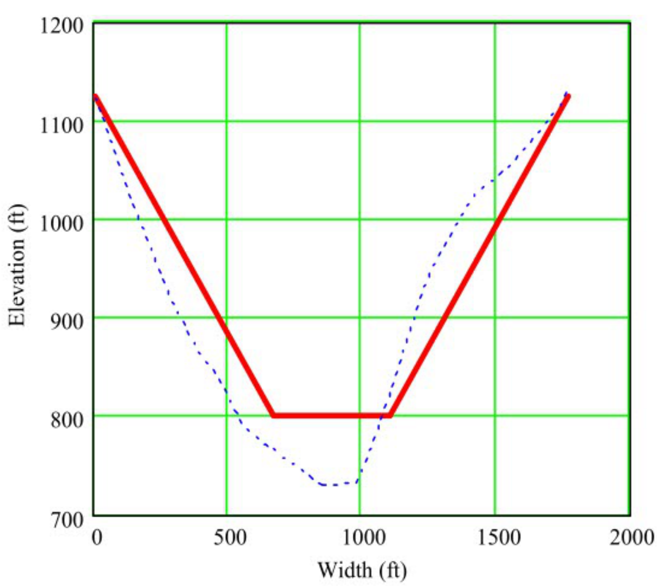


Figure 7. Trapezoidal Breach with an Average Width of 1100 feet and a Bottom Elevation of 800 feet. (Total failure Above Elevation 800 feet.)

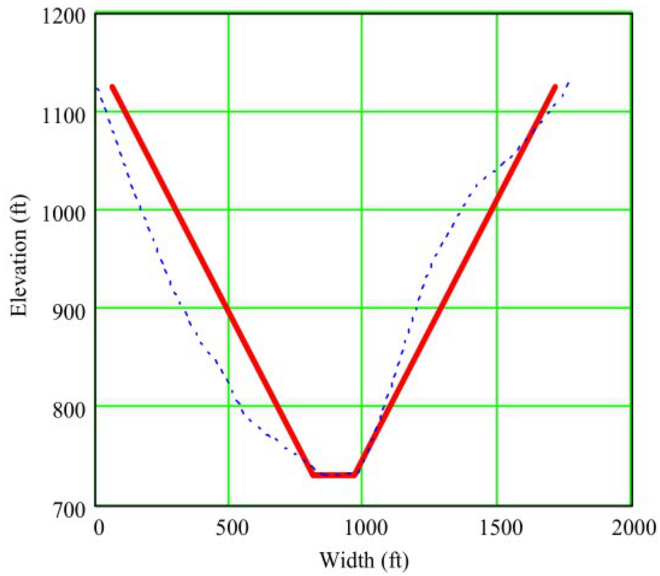


Figure 8. Trapezoidal Breach with an Average Width of 900 feet and a Bottom Elevation of 730 feet.

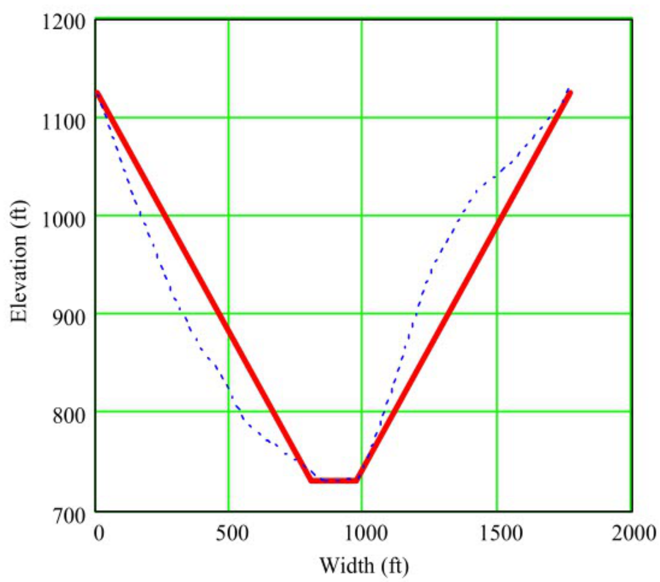


Figure 9. Trapezoidal Breach with an Average Width of 967 feet and a Bottom Elevation of 730 feet. (Total Failure Above Elevation 730 feet)

Based on these figures, NRO concludes that its postulated breach widths are physically consistent with the Jocassee Dam configuration.

Table 1 Model Parameters to Vary in HEC-RAS Model

| Parameter | Minimum Value | Maximum Value |
|---|---|---|
| Jocassee Dam base breach width (ft.) | 150 | 430 |
| Jocassee Dam top breach width (ft.) | 1445 | 1770 |
| Jocassee Dam bottom breach elevation (ft. MSL) | 730 | 800 |
| Jocassee Dam time to failure (hrs.) | 1 | 4 |
| Jocassee Reservoir level (ft. MSL) | 1105 | 1125 |
| Keowee Reservoir level | 730 | 815 |
| NRCS Curve number | 55 | 80 |

MSL = mean sea level

Parameters should be varied at appropriate intervals across each range identified.