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August 2, 2010

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, D.C., 20555-001

Subject: Duke Energy Carolinas, LLC
Oconee Nuclear Station, Units 1, 2, and 3
Renewed Facility Operating License, DPR-38, DPR-47, and DPR-55
Docket Numbers 50-269, 50-270, and 50-287
Oconee Response to Confirmatory Action Letter (CAL) 2-10-003

References:

1. Nuclear Regulatory Commission (NRC) Letter From Luis A. Reyes to Dave Baxter, "Confirmatory Action Letter - Oconee Nuclear Station, Units 1, 2, and 3 Commitments to Address External Flooding Concerns (TAC Nos. ME3065, ME3066 and ME3067)," dated June 22, 2010
2. NRC Letter From Joseph G. Giitter to Dave Baxter, "Evaluation of Duke Energy Carolinas, LLC (Duke Energy), November 30, 2009, Response to NRC Letter dated April 30, 2009, Related to External Flooding at Oconee Nuclear Station, Units 1, 2, and 3 (Oconee) (TAC Nos. ME3065, ME3066, and ME3067)," dated January 29, 2010
3. Duke Energy Letter From Dave Baxter to NRC Document Control Desk, "Oconee External Flood, Response to Request for Additional Information (RAI)," dated March 5, 2010
4. Duke Energy Letter From Dave Baxter to Nuclear Regulatory Commission (NRC) Document Control Desk, "Oconee External Flood, Revised Response to Request for Additional Information (RAI)," dated June 24, 2010

This letter responds to the NRC's request for information by August 2, 2010, as noted in the Confirmatory Action Letter (CAL) dated June 22, 2010, (Reference 1), and completes the Duke Energy Carolinas, LLC (Duke Energy) response to the NRC's request for additional information, dated January 29, 2010, (Reference 2).

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The NRC submitted a request for additional information (RAI) by letter dated January 29, 2010, (Reference 2). By letter dated March 5, 2010, (Reference 3) Duke Energy provided a complete response to five of the eight RAIs, and a partial response to three of the eight RAIs requested in Reference 2. By letter dated June 24, 2010, (Reference 4) Duke Energy notified the NRC of its plan to provide the additional information pursuant to the CAL (Reference 1).

The attached RAI responses complete Duke Energy's response to Reference 2 and are considered appropriate to satisfy the August 2, 2010, request for information in Reference 1.

This letter and its attachment contain security sensitive information. As such, Duke Energy hereby requests the NRC withhold this letter and its attachment from public disclosure pursuant to 10 CFR 2.390 (d)(1), "Public inspections, exemptions, requests for withholding."

There are no new regulatory commitments contained in this letter or its attachment. If you have any questions on this matter, please contact Jeff Thomas, Fleet Regulatory Compliance Manager, (704) 382-3438, or Bob Meixell, Oconee Regulatory Compliance, (864) 873-3279.

Sincerely,

Dave Baxter, Vice President
Oconee Nuclear Station

Attachment:

Attachment 1; RAI Responses

Dave Baxter affirms that he is the person who subscribed his name to the foregoing statement, and that all the matters and facts set forth herein are true and correct to the best of his knowledge.

Dave Baxter
[Executive Name]

Subscribed and sworn to me: 8/2/2010
Date

Ruth H Joyner
Notary Public

My Commission Expires: 6/15/2016
Date

SEAL

bc w/attachment 1:

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1. Question:

Justify the assumptions used for parameters (breach dimension, breach time, and breach location) associated with the Jocassee Dam, Keowee Main Dam, Keowee West Saddle Dam, Intake Dike, and the Little River Dam. Also include the assumptions associated with the operation and capacity of the turbines and discharge gates for the Jocassee Dam. Specifically, describe how the values selected for each parameter represent a conservative value.

Response:

Duke Energy Carolinas, LLC (Duke Energy) letter dated March 5, 2010, had an interim response to RAI Question 1. In an effort to manage the exchange of these numerous details and maintain focus, a review of that interim response confirmed that all portions of that interim response remain valid. The interim response will not be duplicated here, allowing more focus on the additional information being provided to this RAI. This additional information complements the interim response. Therefore, the complete response for RAI Question 1 is composed of the interim response found in the March 5, 2010, letter and the additional information provided in this response.

The interim response presented the parameters for three sets of dam failure scenarios, commonly referred to as Cases 1, 2, and 3. The difference between the three cases was limited to the breach parameters characterizing the postulated failures for the Jocassee Dam only (the failure parameters for the downstream earthen structures were the same for all three cases). As stated in our interim response, "...Case 2 breach size was adopted as the conservative case" due to the substantial margin found in the results of Case 2 when comparing estimated peak flows per the various computational methods.

Although Case 2 is the conservative case, it was acknowledged in Duke Energy's interim response, additional efforts were underway to assess the sensitivity of the failure times for the Keowee impoundment structures to further substantiate the conservatism regarding those specific parameters used within Case 2. It was this additional scope of investigation that warranted the March 5, 2010, interim response.

The determination of the expected failure time for the Keowee Main Dam due to normal overtopping could be supported by existing research. However, in this case, much less research and documentation exists for the postulated consequential failure of one dam (Keowee Main Dam) due to rapidly rising overtopping as the result of the failure of an upstream dam (Jocassee Dam). The sequential failures of Keowee dams due to the Jocassee Dam failure is commonly referred to as a cascading dam failure. Due to the lack of solid technical information regarding cascading dam failures and for consistency, the same methodology and approach used to characterize the Jocassee Dam failure was used for the Keowee impoundment structure failures.

Duke Energy investigated the Keowee impoundment structures failure times from two perspectives (as planned per our interim response), a technical basis and sensitivity assessment. The technical basis approach was investigated, but very limited information was available, and what was available from a published literature search (1975 Chinese Dam failures) did not provide the level of detail to support the development of a solid technical basis. Therefore, the sensitivity approach was pursued to confirm the parameters selected for Case 2 represented conservative values.

The failure time sensitivity assessment started with Case 2 as the basis. Six variations of Case 2 were developed using different failure times and failure combinations of Keowee impoundment structures. The evaluation was a two-step process using both the 1-dimensional (1-D) and 2-dimensional (2-D) tools. All six variations were assessed within the 1-D tool. Based on the results of the 1-D modeling, two of the sensitivity cases were further assessed using the more detailed 2-D tool.

The details of the sensitivity assessment are documented in RAI Question 4 response since the scope of RAI Question 4 is common to this assessment. As shown and concluded by the information presented in RAI Question 4 response, faster breach times for the Keowee Main Dam do not produce higher water levels for the Oconee site. This applies to both the first peak and the second peak water heights. In addition, a more rapid failure time for the Oconee Nuclear Station (ONS) Intake Canal Dike does not control maximum ONS Yard water heights and tends to remove the second peak effect. This sensitivity assessment demonstrated a failure of the north side of the ONS Intake Canal Dike in combination with the east side failure for the dike did not control local water heights. Therefore, faster failure times for Keowee impoundment structures did not produce higher water heights for the Oconee site and the failure times originally computed for these structures are conservative.

In conclusion, the combination of the interim response found in Duke Energy's March 5, 2010, letter, along with the time sensitivity results presented in this response, support the conservative selection of the parameters used to define Case 2.

4. Question:

The 2-dimensional (2-D) model shows a second surge of water at the Oconee site due to a backup of water from the Keowee Tailrace. Describe the effect of the overall water level at the Oconee site, following a faster breach time of the Keowee Main Dam.

Response:

The RAI Question 4 interim response provided in Duke Energy's letter dated March 5, 2010, shall be considered superseded by the information contained within this response. All pertinent information from the interim response relative to this final response will be repeated below for completeness.

The 2-D assessment for Case 2, as presented to the NRC on October 28, 2009, revealed two distinct peak water heights occurring in the ONS Yard and around the Standby Shutdown Facility (SSF). The first peak is primarily due to water flowing over the ONS Intake Canal Dike crest and collecting in and around the SSF due to current plant structures controlling the draining capability of the ONS Yard. As a result, water is temporarily detained in and around the SSF while the flood waters are both collected and released by the Oconee site.

The second peak water height in the 2-D assessment is due to the flood waters collecting in the Keowee Tailrace area and flooding the site. The second peak water height is less than the first peak. Essentially, the Keowee Tailrace is the ultimate collection point for waters from the Keowee Main Dam, Keowee West Saddle Dam, the swale at the World of Energy, and the Oconee Intake Canal Dike.

The first and second peak water heights at the SSF are only calculated in the 2-D assessments since they are not determined in the 1-D Hydrologic Engineering Center-River Analysis System (HEC-RAS) assessments. However, all 2-D assessments start with the 1-D results to determine the global inputs to the 2-D assessments (the inflow and outflow boundary conditions). Once these input parameters are determined the additional 2-D assessments can be completed.

The failure time sensitivity assessment is based on Case 2 overall parameters. Six variations of Case 2 were developed for the 1-D modeling effort using different failure times and failure combinations of Keowee impoundment structures as defined below.

- **Model Run 100A** - Rapid failure (0.5hrs) for Keowee Main Dam
- **Model Run 100B** - Median failure (1.65hrs) for Keowee Main Dam
- **Model Run 100C** - Rapid failure (0.5hrs) for ONS Intake Canal east dike
- **Model Run 100D** - Rapid failure(0.5hrs) of additional breach (bottom width of 400 ft.) at ONS Intake Canal north dike
- **Model Run 100E** - Rapid failure(0.5hrs) of both east and north portions at ONS Intake Canal Dike
- **Model Run 100F** - Rapid failure (0.5hrs) for all Keowee structures: Keowee Main and West Saddle Dams, ONS Intake Canal Dike (east and north), and Little River Dam

1-D (HEC-RAS) Results

Table 1

	Keowee Dam						Oconee Intake Canal Dike			
Model Count	Headwater Elevation (ft msl)	Time (Hrs)	Discharge (mcfs)	Time (Hrs)	Tailrace Elevation (ft msl)	Time (Hrs)	Headwater Elevation (ft msl)	Time (Hrs)	Discharge (mcfs)	Time (Hrs)
100	835.3	0330	2.34	0420	776.7	0500	822.7	0320	0.79	0400
100A	828.9	0300	2.79	0300	777.7	0410	821.0	0320	0.74	0400
100B	834.2	0300	2.81	0350	780.5	0350	822.7	0320	0.78	0400
100C	834.9	0330	2.31	0430	776.5	0500	820.0	0310	0.79	0400
100D	835.2	0330	2.34	0420	777.1	0500	821.8	0320	0.84	0400
100E	834.9	0330	2.32	0430	776.7	0500	819.5	0310	0.81	0400
100F	828.9	0300	2.79	0300	777.4	0330	818.8	0310	0.65	0330

Based on the results of the 1-D modeling in Table 1, Model runs 100B and 100F were selected for the more detailed 2-D assessment. Primary consideration was given to the magnitude of Keowee Dam peak discharge flows. Secondary consideration was given to relative tailrace elevations. Tertiary consideration was given to Oconee Intake Dike peak discharge flows.

The appropriate output information from the two 1-D models (model runs 100B and 100F) and the original model run 100 was used as input to the three 2-D model runs (boundary conditions). The results of the three 2-D model runs are shown in Table 2.

2-D Results

The 2-D 2009 Case 2 model used the output from the 2009 1-D model scenario (run) 100 as its input boundary conditions. Therefore, the relationship of Case 2 (as referenced for 2-D assessments) and model run 100 (as referenced for 1-D assessments) was established. Due to sensitivity assessments with the 2-D model inputs and general refinements of the 2-D model itself, the 2-D model nomenclature needed to expand. A '2-D' prefix was added to differentiate the 2-D assessments from the 1-D assessments and still use the '100' series identifier to relate the two evaluations.

The original 2-D model (known as 2-D 2009) was used for the original Case 2 evaluation. This model was improved in late 2009/early 2010 with refined mesh elements that include enhanced building location and size data in the Oconee Yard around the SSF. The term 'Input scenario' was used to denote the 1-D model scenario runs 100, 100B, and 100F.

Due to the additional 2-D modeling performed in 2010 to investigate the sensitivity of failures of Keowee structures and incorporate Duke Energy's independent review, the cases are defined as follows:

- Case 2 - Original 1-D model run 100 and 2-D model based on the same parameters.
- Case 2-D 100M - Case 2 with updated computational mesh, ONS Yard topography, and boundary conditions. The breach parameters are identical to the original 1-D model run 100.
- Case 2-D 100B - Case 2 with updated computational mesh, ONS Yard topography, and boundary conditions. The breach parameters were modified using the 1-D model run 100B parameters per Table 2.

- Case 2-D 100F - Case 2 with updated computational mesh, ONS Yard topography, and boundary conditions. The breach parameters were modified using the 1-D model run 100F parameters per Table 2.
- Case 2-D 100W - Using Case 2-D 100M with additional outputs from improved June 2010 1-D model run utilizing Case 2 parameters. (Addressed in RAI Question 7)

Table 2

Scenario	Breaching							
	Keowee Dam				Intake Dike			
	HEC-RAS		2D		HEC-RAS		2D	
	Elevation	Decimal Time	Elevation	Decimal Time	Elevation	Decimal Time	Elevation	Decimal Time
Case 100M	817	2.25	817	2.12	817	2.93	817	2.93
Case 100B	817	2.25	817	2.12	817	2.93	817	2.95
Case 100F	817	2.25	817	2.13	817	2.98	817	3.02
Scenario	Maximum Water Surfaces							
	Keowee Dam				Intake Dike			
	HEC-RAS		2D		HEC-RAS		2D	
	Elevation	Decimal Time	Elevation	Decimal Time	Elevation	Decimal Time	Elevation	Decimal Time
Case 100M	835.3	3.50	838.7	3.50	822.7	3.33	823.2	3.43
Case 100B	834.2	3.00	836.2	3.25	822.7	3.33	822.6	3.40
Case 100F	828.9	3.00	828.0	3.2	818.8	3.17	819.6	3.25
Scenario	Maximum Water Surfaces							
	Swale				Tailwater (2nd Peak)			
	HEC-RAS		2D		HEC-RAS		2D	
	Elevation	Decimal Time	Elevation	Decimal Time	Elevation	Decimal Time	Elevation	Decimal Time
Case 100M	828.6	4.00	829.0	4.13	776.7	5.00	804.30	4.8
Case 100B	826.2	4.00	827.6	4.00	780.5	3.83	801.24	4.4
Case 100F	821.0	3.33	822.7	3.35	777.4	3.50	802.02	4.5
Scenario	Maximum Water Surfaces							
	SSF							
	HEC-RAS		2D					
	Depth	Decimal Time	Depth	Decimal Time				
Case 100M	N/A	N/A	19.5	3.45				
Case 100B	N/A	N/A	18.6	3.58				
Case 100F	N/A	N/A	13.4	3.40				

As shown in Table 2, the faster breach times for the Keowee Main Dam represented by the 2-D Cases 100B and 100F do not produce higher water levels for the Oconee site than 2-D Case 100M. This applies to both the first peak and the second peak water heights. In addition, a more rapid failure time for the ONS Intake Canal Dike does not control maximum ONS Yard water heights. This sensitivity assessment demonstrated a failure of the north side of the ONS Intake Dike in combination with the east side failure for the dike did not control local ONS Yard water heights. Therefore, faster failure times for Keowee impoundment structures did not produce higher ONS Yard water heights for the Oconee site and the failure times (Case 2) originally computed for these structures are conservative.

As shown in Table 2, the failure time sensitivity assessment for the Keowee Main Dam and other Keowee impoundment structures demonstrated that the Case 2 breach failure parameters are indeed conservative values in determining the maximum water heights in the Oconee Yard. In conclusion, faster breach times for the Keowee Main Dam (and other Lake Keowee impoundment structures) do not produce higher water levels for the Oconee site and the failure parameters for Case 2 are conservative values for investigating the flooding impacts at the site.

7. Question:

Provide a copy of the final HEC-RAS models and 2D models that were used for the runs to justify the proposed modifications that will be made to protect the Oconee site from external flooding.

Response:

This RAI response completely supersedes the March 5, 2010, interim response for RAI Question 7. In lieu of the actual electronic models (both 1-D and 2-D), Duke Energy is submitting, after discussions with the Nuclear Regulatory Commission Staff, the following detailed summary of the models with all key inputs pertinent to the creation of the runs used to justify potential modifications to protect the site from the external flood.

Overall approach

For dam breach modeling, the hydraulic characteristics of the channels and reservoirs are dependent on the experience of the modeler and references from published studies. It is usually not possible to use historic flood levels to verify or calibrate the model due to the significant depth of flooding. This is the case for the Jocassee-Keowee models where the two reservoirs have never experienced a natural flood that raised the elevations above the full pond levels.

Model development is a multi-step process that evolves from a generalized channel representation to a refined physical and hydraulic set of cross sections that form the basis of the computer simulated hydraulic model. This flood assessment was done using 1-D and 2-D separate models. The 1-D model was used to characterize the system of complex hydraulic reaches (branches) from Jocassee Dam to Hartwell Dam and determine key inputs to the more site specific 2-D model. The 2-D model, using the outputs of the 1-D model, further determined the depth of flood for the Oconee site. The density of the computer mesh representing the hydraulic reaches within proximity of the Oconee site are at their practical limit to facilitate the use of the 2-D model as a tool for this project.

Initial conditions

Jocassee Lake level:	1110 ft.msl (Full pond)
Keowee Lake level:	800 ft.msl (Full pond)
Hartwell Lake level:	660 ft.msl (Full pond)

Breach Parameters

Table 1

CASE 2 BREACH PARAMETERS

Case	Bottom Breach Elevation (ft msl)	Bottom Breach Width (ft)	Side Slopes (ft per ft)	Failure Time (hrs)	Initial Piping Elevation (ft msl)	Overtopping Breach Initiation Elevation (ft msl)
			Jocassee Dam			
2	800	425	1.55:1 & 0.7:1	2.8	1020	NA
			Keowee Dam			
2	670	500	1:1	2.8	NA	817
			ONS Intake Canal Dike			
2	715.5	200	1:1	0.9	NA	817
			Little River Dam			
2	670	290	1:1	1.9	NA	817

Models of Record

1-D Model info

The model of record for the 1-D work is Case 2, or run 100 (using the most recent HEC-RAS model called June 2010 model), as described in OSC-10029, "Expected ONS Yard Flood Heights due to Postulated Jocassee Dam Break, 1-D Model Work (HEC-RAS)." More specifically this model is found in detail in Report entitled "Oconee Nuclear Station Jocassee-Keowee Dam Breach Study March 2009 Report Addendum 2 Breach Scenarios 100A through 100F HEC-RAS Model Results July 2010." An electronic version of this model is found in OSC-10029.

Subsequent to the Independent Review of the models (both 1-D and 2-D), the 1-D HEC-RAS model had suggestions from the Independent Review incorporated into the working model. This updated model is now referred to as the June 2010 model. All the input parameters remained the same as the previous working model for Case 2. The primary difference is the response of the model now more closely aligns with the results of the 2-D model.

2-D Model info

The model of record for the 2-D work is Case 2-D 100W, as described in OSC-10030, "Expected ONS Yard Flood Heights due to Postulated Jocassee Dam Break, 2-D Model Work". More specifically this model is found in detail in Report entitled "Oconee Nuclear Station Jocassee 2-D Hydraulic Model Study Hydraulic Modeling Report Breach Scenarios 2-D 100B and 2-D 100F Addendum to Technical Report July 2010" found within that calculation. An electronic version of this model is found in OSC-10030.

As a result of the update for the 1-D HEC-RAS model per the Independent Review (referred to as the June 2010 model), the 2-D model needed to be executed with the new boundary conditions determined from the June 2010 1-D work. The associated new 2-D run is labeled Case 2-D 100W. All the input parameters remained the same as the previous working model for Case 2. This updated 2-D run incorporates the updated boundary conditions taken from the most recent 1-D model.

Results (both 1-D and 2-D models for the record model run)

Table 2

Breaching							
Keowee Dam				Intake Dike			
1-D		2-D		1-D		2-D	
Elevation	Decimal Time	Elevation	Decimal Time	Elevation	Decimal Time	Elevation	Decimal Time
817	2.23	817	2.1	817	2.88	817	2.87
Maximum Water Surfaces							
Keowee Dam				Intake Dike			
1-D		2-D		1-D		2-D	
Elevation	Decimal Time	Elevation	Decimal Time	Elevation	Decimal Time	Elevation	Decimal Time
834.8	3.33	839.6	3.43	821.8	3.33	823	3.35
Maximum Water Surfaces							
Swale				Tailwater (2nd peak)			
1-D		2-D		1-D		2-D	
Elevation	Decimal Time	Elevation	Decimal Time	Elevation	Decimal Time	Elevation	Decimal Time
827.8	3.67	828.5	4.13	791.5	5	805.3	4.78
Maximum Water Surfaces							
SSF							
1-D		2-D					
Elevation	Decimal Time	Elevation	Decimal Time				
n/a	n/a	815	3.71				

1-D model specifics:

1-D, HEC-RAS (U. S. Army Corps of Engineers (USACE) HEC-RAS Version 4.0)

The HEC-RAS model is a one-dimensional (1-D) dynamic flow model with unsteady flow model components used in estimating inundation due to hypothetical dam failures, such as Jocassee Dam, or to study historic dam failure events. HEC-RAS is a graphical, input-based software program that has an available geographic information systems (GIS) interface and post processing tools to support input and review output. HEC-GeoRAS was employed to develop model geometry independent of HEC-RAS using available GIS data from the State of South Carolina (with some overlap into Georgia) to create Digital Elevation Model (DEM) electronic files for Jocassee, Keowee, and Hartwell reservoir systems. A small portion of the lower southwestern corner of Lake Hartwell was not included in the GIS data and the U.S. Geological Survey (USGS) National Elevation Data Set (NED) was used to supplement the model.

The Jocassee-Keowee Dam Breach Model consists of the Jocassee, Keowee, and Hartwell reservoir systems with an approximate length of 44 miles. The hydraulic response of three reservoirs comprised of 17 rivers/tributaries is incorporated in the model.

The model consists of 1,397 primary cross sections that were established in HEC-GeoRAS along with 6,689 interpolated cross sections to bring the model total cross section count to 8,086. There are 10 storage areas identified and 14 reach section junctions. The physical size characteristics of Jocassee Dam, Keowee Dam, ONS Intake Canal Dike, Little River Dam, and Hartwell Dam are incorporated in the model. Breach failure parameters were established for all dams with the exception of Hartwell Dam. Hartwell Dam is not failed in the model and serves as a downstream control section.

The unsteady flow requirements in HEC-RAS require detailed inputs that describe boundary conditions and initial conditions at the first upstream cross sections and model endpoint. The flow hydrograph boundary conditions are introduced at the first cross section in each upstream tributary to Lake Keowee and Lake Hartwell, respectively. Low flow constant discharge hydrographs in one-hour increments have been established at each tributary for the duration of the model.

Keowee Dam is approximately 3,400 feet long and is comprised of the Main Dam and West Saddle Dam (WSD). The WSD is exposed to the same overtopping characteristics as the Main Dam. HEC-RAS is limited to a single breach designation at any given model structure. The Main Dam was selected as the designated breach due to the greatest overall height and breach discharge capacity. To overcome the single breach model limitation, a breach of the WSD was simulated using a 1,680-foot-by-20-foot crest gate. The WSD breach height and cross-sectional area provide a representative section that would breach and add to the flow discharging from the reservoir. The WSD is assigned a full crest gate opening time frame of 30 minutes to simulate the WSD breach development. The crest gate does not begin to open until the reservoir elevation exceeds 817 feet mean sea level (msl).

The Manning's *n* values for a majority of the cross sections are limited to three designations:

1. The Left over-Bank (LOB) and Right over-Bank (ROB) *n* values (0.08) define a floodplain consisting of trees and tree stumps with sprouts.
2. The main channel *n* value (0.025) describes a deep water channel.
3. A 60-foot threshold was chosen by the modelers to identify the change from stream to deep reservoir flow conditions (based on research descriptions for modified roughness values).

Modeled reservoir tributaries were considered streams; therefore, those *n* values remained at 0.035 (value for natural stream that contains stones and weeds).

The Manning's *n* values of 0.07 were used in the respective tailrace reaches below Jocassee Dam, Keowee Dam, ONS Intake Canal Dike, and Little River Dam to account for roughness associated with displaced dam breach material (suspended material and bed load). The affected reach lengths below each dam where the higher roughness value was assigned was assumed as the base length (upstream-downstream) dimension of each dam, followed by a second base length dimension to allow transition from 0.07 to the reservoir roughness coefficients of 0.025 in a linear fashion.

HEC-RAS allows the modeler to select which energy loss calculation methodology will be used at a given junction. In a majority of junctions, the energy equation application is sufficient in determining energy losses across the junction with angled tributary flow as the loss is not significant. However, there are junction situations where the tributary angle could cause significant energy loss. Under these conditions, the modeler specified the momentum equation to calculate energy losses. The momentum equation option was used at six of 14 junctions.

HEC-RAS storage areas were used to account for reservoir storage capacity not associated with the defined primary river reach cross sections. This allows water diversion from/to the main stem reservoirs at Lake Keowee and Lake Hartwell. The storage area editor allows the modeler to select the methodology to be used in calculating storage volume. The elevation/volume method was selected since it represents the more accurate and realistic reservoir performance as it relates to natural topography.

Ineffective flow areas identify portions of any given cross section that are used for storage but do not contribute to the overall water conveyance through the cross section. HEC-RAS allows the modeler to denote portions of a given cross section as ineffective flow areas. The model incorporates this feature where applicable.

Two key model areas were selected to assess mass volume conservation. The first area was at the connecting canal confluence (junction) with the Keowee River arm of the reservoir. The second area of interest is the combined outflows from Keowee Main Dam, Keowee West Saddle Dam, Little River Dam, and the ONS Intake Canal Dike. Mass volume conservation is calculated by integrating the respective discharge hydrographs (cfs-hrs) at the two areas of interest. The discharge hydrographs are different for the various model simulations and are dependent on the selected breach parameters at the respective dam sites. The summation of the integrated hydrographs for Keowee Dam and the Connecting Canal should approximately equal the Jocassee Dam breach hydrograph upstream of the junction to preserve mass volume conservation. Confidence in the HEC-RAS model performance was confirmed by calculating mass volume conservation at key points in the model.

Another model validation was the reservoir storage capacity assessment for Lake Keowee. The comparison is based on the nominal reservoir elevation of 798 ft msl. The existing documented Lake Keowee storage capacity at elevation 798 ft. is approximately 910,400 acre-ft. The calculated reservoir capacity for this 1-D model at 798 ft. is approximately 886,600 acre-ft, representing a conservative variance of approximately -2.6%. A similar reservoir capacity calculation was performed for Lake Hartwell. The existing documented reservoir storage volume for Lake Hartwell at elevation 660 ft. msl is approximately 2,555,200 acre-ft. The calculated reservoir volume from the model is approximately 2,659,300 acre-ft, representing a variance of approximately 4.1%. The modeling target variance was ±5% was satisfied

<u>2-D model specifics:</u>

2-D model info

The 2-D analysis was performed to add detail to the HEC-RAS analysis and model the potential inundation of the Standby Shutdown Facility (SSF) in the ONS Yard. In this project, the US Department of the Interior Bureau of Reclamation developed the 2-D computational hydraulic model SRH-2-D (LAI 2006) that was utilized. This model allows for solution of open channel flow equations on unstructured hybrid meshes. SRH-2-D applies a finite-volume discretization to the 2-D, depth averaged St. Venant equations, and mass conservation is satisfied both locally and globally. The code can process wetting and drying of elements, steady and unsteady flows, sub-critical and super-critical flows, and complex channel geometries.

A 2-D computational model was constructed of the area immediately surrounding the station with a 2-D mesh. The mesh size was selected to model the desired area while keeping the computational array to a manageable size. The final computational mesh has approximately 57,500 unstructured elements. The mesh is coarser in areas that are farther away from ONS

and finer in areas where more detail was required, both by the goals of this analysis and by characteristics of the flow. The results of the HEC-RAS analysis were extracted and utilized as boundary conditions for the 2-D analysis. The upstream boundary condition consisted of an inflow hydrograph, while the downstream boundary conditions consisted of stage hydrographs. For reference, the inflow boundary condition section is approximately 6,200 feet wide.

Breaching of Keowee Dam, the Keowee WSD, and the ONS Intake Canal Dike was implemented updating the elevations assigned to the computational mesh during the simulation. Each structure was updated five times during its failure; according to the breach parameters assigned during the HEC-RAS analysis. The stepped breach approach in the 2-D model is different than the sine wave breach progression used in the HEC-RAS model. Dam failure happens continuously over the breach interval in HEC-RAS, while the 2-D model breach occurs in five stepped increments over the failure interval. The use of five increments in the 2-D model represents a balance between modeling efficiency and representing the breach accurately. Once the trigger elevation was reached (817 feet), five breach intervals were established for the breached structures.

In the 2-D model, the breaching of the WSD was simulated as a physical alteration of the dam embankment. Due to the HEC-RAS limitation, the WSD was modeled as a gate.

The boundary conditions for the model include an inflow boundary and two outflow boundaries. Conditions for the boundaries were extracted from the simulated HEC-RAS case results. The 2-D model inflow is represented by the discharge hydrograph from the appropriate HEC-RAS cross section. Two outflow boundary conditions are represented by stage hydrographs extracted from the simulated HEC-RAS model.

The surface roughness applied to the 2-D model used a Manning's Roughness Coefficient. The selection of values for Manning's Roughness Coefficient was based on the HEC-RAS modeling effort. For areas that can be considered main channel, the same coefficient was selected as in the HEC-RAS study (n = 0.025). For areas considered overbank, the same coefficient was selected as in the HECRAS study (n = 0.080). In the ONS Yard, the buildings were modeled as voids in the mesh, allowing an accurate calculation of flow velocities and depths during the inundation of the ONS Yard. The ONS Yard also has a Manning's coefficient of 0.08 due to roughness associated with infrastructure, blocked flow, and turbulent conditions.

Independent Review Summary

An extensive independent Technical Review of both models was undertaken at the request of Duke Energy. This was a much more detailed review than what was conducted on earlier work regarding these models. This scope of work included, but was not limited to:

- Geometry
- Density of Cross-Sections and Mesh
- Boundary Conditions
- Roughness Parameters
- Breach Parameters
- Mass Conservation
- 1-D Summary
- Relationship between the models
- Appropriateness of inputs
- Tool (software) limitations

The conclusions of this detailed review are:

- Model development reflects a high level of diligence
- Both models represent the hydraulic system well
- Work performed in accordance with accepted engineering practice
- Unbiased appraisal of wide range of breach scenarios
- Boundary assignments for 2-D work are reasonable
- Density of mesh in 2-D applied practically

Notable recommendations from the Independent Review were:

- The cross section modifications below Keowee Dam in the 1-D model
- The corresponding sensitivity check in the 2-D model

Prior 1-D model tailrace elevations below Keowee Dam had been significantly lower (27 ft) than 2-D model results. Keowee Dam Tailrace and Keowee River channel cross sections were modified to more appropriately represent the changes in topography and hydraulic channeling between the Keowee Tailrace, SC-183 bridge below the Keowee Tailrace, and the "oxbow" section of the Keowee River near 4 Mile Creek. This updated 1-D model is now referred to as the June 2010 model. All the input parameters remained the same as the previous working model for Case 2.

As a result of the update for the 1-D HEC-RAS model, the 2010 2-D model was used to re-run Case 2 with the new boundary conditions determined using the June 2010 1-D model. The associated new 2-D run is labeled Case 2-D 100W. No changes were made to the Case 2 scenario input parameters.

The primary difference in the 1-D modeling between the previous results and results after implementing the model refinements noted in the independent review is the tailwater estimates more closely align with the results of the 2-D model. Modified cross sections resulted in peak tailrace elevation differences between the 1-D and 2-D models of less than 14 ft.

Overall, modifying the 1-D model (June 2010) and executing an equivalent 2-D case with revised boundary conditions based on the 1-D model (Case 100W) does not produce significant changes in results when compared to the previous model. The timing of the maximum water surface elevations at the Keowee Dam, ONS Intake Canal Dike, and Keowee Tailwater agree more closely between the 1-D model (June 2010) and Case 2-D 100W.