October 26, 2010

MEMORANDUM TO: Drew Persinko, Acting Deputy Director
Division of Operating Reactor Licensing
Office of Nuclear Reactor Regulation

FROM: George A. Wilson, Acting Deputy Director ***/RA/***
Division of Engineering
Office of Nuclear Reactor Regulation

SUBJECT: NRC STAFF ASSESSMENT OF DUKE ENERGY CAROLINAS, LLC., OCONEE EXTERNAL FLOODING ISSUE (TAC NOS. ME4441, ME4442, AND ME4443)

The Division of Engineering has reviewed the information provided by Duke Energy Carolinas, LLC., with regards to the Oconee external flooding issue. DE's technical assessment is attached. This technical assessment officially closes line item (2) associated with the CAL which states, "The licensee to submit to the NRC all documentation necessary to demonstrate that the inundation of the Oconee site from the failure of the Jocassee Dam has been bounded," which was provided to the staff on August 2 and October 12, 2010. If you have any questions, please contact Meena Khanna or myself.

Enclosure:
As stated

CONTACT: Meena Khanna, NRR/DE/EMCB
(301) 415-2150

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NRC Assessment of Oconee External Flooding Issue

Background

Duke Energy Carolinas, LLC (the licensee) performed an inundation study[1] in 1992 to meet a Federal Energy Regulatory Commission (FERC) requirement for formulating an emergency action plan in the event that the Jocassee Dam failed. This study showed that approximately 16.5 ft. of water would inundate the site.

In April 2006, while performing a Reactor Oversight Process (ROP) evaluation, the NRC staff questioned the licensee's maintenance of the SSF flood protection barrier. During the subsequent ROP Significance Determination Process (SDP), the NRC identified that the licensee had incorrectly calculated the Jocassee Dam failure frequency and had not adequately addressed the potential consequences of flood heights predicted at the Oconee Nuclear Station (ONS) site, based on the 1992 inundation study. The NRC staff also recognized that the licensee's 1992 inundation study did not follow the guidelines for the probable maximum flood (PMF) evaluation, as described in Regulatory Guides 1.59[2] and 1.102[3].

The NRC sent a 10 CFR 50.54 (f) request for information on August 15, 2008[4,5]. In response to this letter, in 2009, the licensee conducted additional inundation analyses[6] consisting of one- and two-dimensional studies. These studies indicated that the resultant flood, which results in approximately 18.5 feet of water on the site, would cause the site to be inundated with flood waters. The licensee, in its response to the 10 CFR 50.54 (f) letter, stated that the inundation will lead to core damage, containment failure, and the loss of spent fuel pool cooling at all three units. Thus, if a flooding event from a Jocassee Dam failure occurred at the ONS site, all three units have no defense-in-depth to prevent core damage. The remaining intact element of defense-in-depth of containment integrity will be severely challenged, if unmitigated, resulting in the potential for radionuclide release to be highly probable. These results have led the NRC to conclude that the licensee lacks defense-in-depth to ensure that there is adequate protection at the ONS site against such floods.

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[1] "Jocassee Hydro Project, Dam Failure Inundation Study," Federal Energy Regulatory Commission (FERC) Projects No. 2503, December 1992.
[2] Regulatory Guide 1.59, "Design Basis Floods for Nuclear Power Plants," U.S. Nuclear Regulatory Commission, (Rev. 2) August 1977.
[3] Regulatory Guide 1.102, "Flood Protection for Nuclear Power Plants," U.S. Nuclear Regulatory Commission, (Rev. 1) September 1976.
[4] Letter to D. Baxter of Duke Energy Carolinas, LLC, dated August 15, 2008, Information Request Pursuant to 10 CFR 50.54(f) related to External Flooding, Including Failure of the Jocassee Dam at ONS, (ML0816402440).
[5] Letter from D. Baxter of Duke Energy Carolinas, LLC, to US NRC, dated September 26, 2008.
[6] See Duke's presentation to NRC dated October 28, 2009.

As a result, the NRC expressed, via the aforementioned 10 CFR 50.54(f) letter, a concern that the licensee has not demonstrated "…overall adequacy of the flood protection of Oconee given the Jocassee Hydro Project…Specifically, the NRC is seeking information … whether Oconee lacks appropriate and adequate compensating engineering safeguards for such an event."

Subsequent to the licensee's response to the 10 CFR 50.54(f) letter, the NRC, in its April 20, 2009, letter[7] stated, in part, "the NRC staff remains concerned that the licensee has not demonstrated that Oconee will be adequately protected in the long term from external flooding events."

By letter dated January 15, 2010[8], the licensee submitted a letter to the NRC which provided its compensatory measures (CMs) to ensure that ONS will be adequately protected from external flooding events until the final mitigating strategies have been implemented and all site modifications have been completed. The NRC staff plans to perform a further review of the CMs and will perform a future inspection.

Then, by letter dated January 29, 2010[9], the staff issued its response to the licensee regarding its November 30, 2009 response to the NRC letter dated April 30, 2009, related to external flooding at ONS. The staff indicated that although the licensee provided a more accurate estimate of the flooding caused by a failure of the Jocassee Dam, the staff found that additional information was needed. The information was needed for the staff to determine if the analyses performed to date will demonstrate, for the entire Jocassee earthen works, that the ONS site will be adequately protected from external flooding events. The licensee submitted a preliminary set of responses to the staff's questions by letter dated March 5, 2010[10].

On June 22, 2010[11], the staff issued a Confirmatory Action Letter (CAL) to the licensee, requesting the following: (1) that the compensatory measures remain in place until final resolution has been agreed upon between the licensee and the NRC staff, (2) the licensee to submit to the NRC all documentation necessary to demonstrate that the inundation of the Oconee site from the failure of the Jocassee Dam has been bounded, (3) licensee to submit a

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[7] Letter to D. Baxter, Evaluation of Duke Energy Carolinas, LLC, September 26, 2008 Response to NRC Letter Dated August 15, 2008 Related to External Flooding at ONS (ML0905707791).
[8] Letter from D. Baxter of Duke Energy Corolinas, LLC, to US NRC, dated January 15, 2010 that addresses the Interim Compensatory Measures at ONS.
[9] Letter to D. Baxter of Duke Energy Carolinas, LLC, dated January 29, 2010, Evaluation of Duke's Response to NRC Letter Dated April 30, 2009 Related to External Flooding at ONS (ML100271591).
[10] Letter from D. Baxter of Duke Energy Carolinas, LLC, to US NRC, dated March 5, 2010, Partial Response to NRC RAI dated February 3, 2010, Related to External Flooding at ONS.
[11] Confirmatory Action Letter from L. Reyes (NRC) to D. Baxter (Duke), dated June 22, 2010 (ML101730329)

list of all necessary modifications to mitigate the inundation by November 30, 2010, and (4) licensee to make all necessary modifications by November 30, 2011.

To date, the licensee has committed to keep the CMs in place until final resolution has been agreed upon between the licensee and the NRC staff and the licensee has adequately submitted to the NRC all documentation necessary to demonstrate that the inundation of the Oconee site from the failure of the Jocassee Dam has been bounded.

Purpose

The purpose of this assessment is to verify that the licensee's Case 2 random sunny day failure scenario for the Jocassee Dam and the ONS site provides reasonable assurance for water levels that the site would see if there was a random sunny day failure of the Jocassee Dam. This Case 2 scenario will be the new flooding bases for the site. Results of the hypothetical dam failures provide inputs to surface water flow models used to simulate floodwater levels at the ONS site, specifically the water levels at locations that could have an effect on emergency shutdown capability, particularly, the Safe Shutdown Facility (SSF). The SSF is a partially flood protected structure which houses control systems to shut down the plant. Ground elevation at the base of the SSF is 796.0 ft. msl.

The breach parameters were evaluated to ensure that they provided reasonable assurance for the flooding levels that the ONS site would see with a random sunny day failure of the Jocassee Dam. The probable failure mode analysis (PFMA)[12] stated that the most likely failure of the Jocassee Dam would be a piping failure through the left (east) or right (west) abutment. The last flooding inundation study performed had the starting reservoir level of the Jocassee Dam at 1110 feet, which is the maximum power pool level during the hurricane season (1108 ft.). Those two initial parameters provide reasonable assurance and were used to start the hypothetical failure scenario associated with the Jocassee Dam. The other parameters evaluated were breach dimensions, breach position, breach time, peak discharge flow rates, and Manning's n-values. The evaluation for these values will be discussed later. The main structures that were evaluated in the flooding scenario were the Jocassee Dam, Hartwell reservoir, and the structures around the ONS. The structures around the ONS include the Keowee Dam, Little River Dam, ONS Intake Canal Dike, and the West Saddle Dam.

[12] Potential Failure Modes Analysis – Jocassee Development Keowee-Toxaway Project (FERC Project No. 2503-SC), Dec. 2004

HEC-RAS Modeling

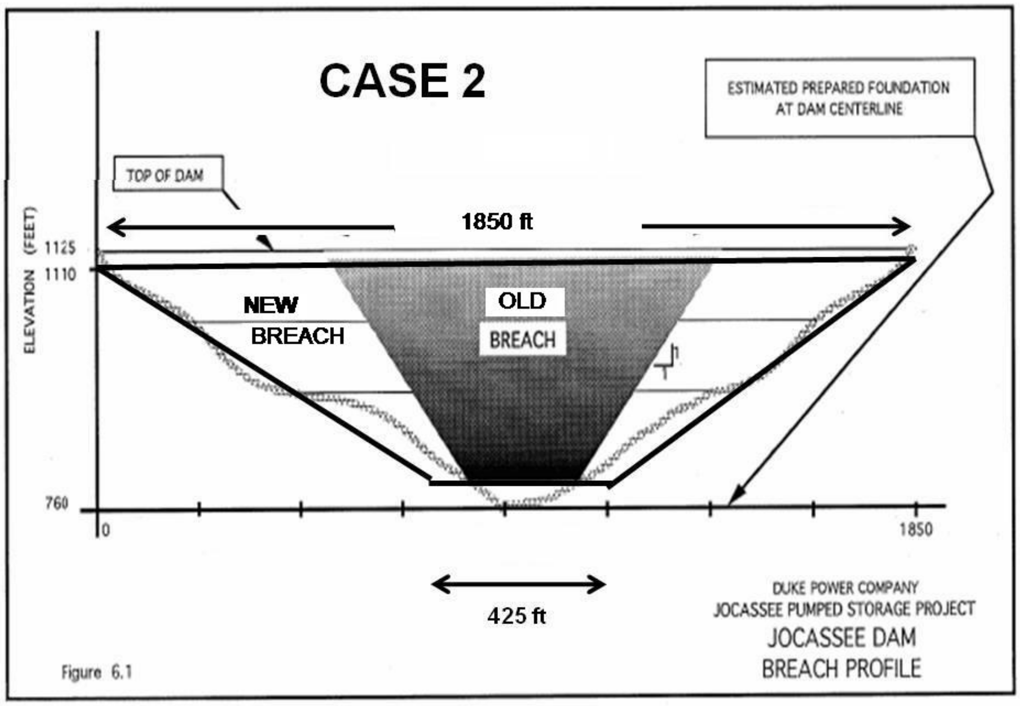
To accurately determine water levels over the ONS site resulting from the random sunny day failure of the Jocassee Dam, unsteady (time varying) flow over approximately 44 miles of river system has to be simulated. The simulation model has to include Jocassee, Keowee, and Hartwell reservoir systems and incorporate the failure of Jocassee, Keowee, and Little River

Dams. Hartwell Dam, which could also fail, may be conservatively used as a downstream control and limit the size of the model. The model also needs to be able to incorporate flow bifurcation around the ONS site to the north and reunification of flows below Little River Dam. To perform this river system modeling, the licensee chose the HEC-RAS program for this purpose. The HEC-RAS program was developed by the U.S. Army Hydrologic Engineering Center.

The HEC-RAS simulations allowed the efficient calculation of flow hydrographs and water elevations at various points of interest around the plant under various conditions of failure of the Jocassee Dam, as well as the failure of downstream structures such as Keowee Dam, West Saddle Dam, Little River Dam, and the intake canal dike. Also included in the sensitivity studies was the effect of Manning's n-value variation for both the main channel and overbank for various reaches. Once the failure parameters for the Jocassee Dam were established, more sensitivity studies were performed for additional failure modes for Keowee Dam. These cases included evaluation of beach geometries for the various earthen works (widths, bottom elevation, side slopes) and failure progression characteristics of the breaches (time to failure, linear or sine wave progression).

Jocassee Dam, Oconee Site Dams, and Dike Breach Parameters and HEC-RAS Modeling

The HEC-RAS computation used to assess flooding at the Oconee site was identified as Case 2. Case 2 was selected as representing sufficient conservatism out of 3 cases that were evaluated by the licensee. The licensee's following parameter values represent Case 2 for a "random sunny day" failure of the Jocassee Dam and provide reasonable assurance:



The Jocassee Dam failure parameters for Case 2 include:

Reservoir Elevation: 1110 ft. msl
Bottom Breach Elevation: 800 ft. msl
Bottom Breach Width: 425 ft.
Side Slopes, West Slope: (1.55:1); East Slope: (0.7:1)
Time to Failure: 2.8 hrs.
Piping Elevation: 1020 ft. msl
Failure Progression: Sine Wave

The Jocassee Dam starting reservoir level of 1110 ft is above is above the maximum power pool level during the hurricane season (1108 ft.), providing reasonable assurance of adequate conservatism.

The Jocassee Dam breach outflow was computed using the HEC-RAS model. The peak outflow was determined to be 5,440,000 cubic feet per second (cfs) which was greater than the empirically determined peak using several available models, including:

MacDonald & Langridge-Monopolis, 1984	1,656,000 ft^3/s
MacDonald & Langridge-Monopolis, 1984	5,385,000 ft^3/s (upper envelope)
Costa, 1985	1,730100 ft^3/s
Bureau of Reclamation, 1982	3,324,000 ft^3/s
Evans, 1986	1,889,600 ft^3/s

Therefore, the HEC-RAS model result is conservative and provides reasonable assurance.

The Jocassee Dam breach dimension assumes the entire loss of the dam embankment and massive erosion of bedrock at the dam base. The biotite gneiss which comprises the bedrock type at the base of the dam would be extremely resistant to erosion, so a large degree of conservatism is added in the breach size and reasonable assurance is provided. The average width of the assumed dam breach (~1137 ft) is larger than the average width estimated using Froehlich's (2008) methods (i.e., ~928 ft).

The Jocassee Dam breach hypothetical failure time of 2.8 hrs. is very short for a dam with the quality of construction, basal rock type, and degree of monitoring of Jocassee Dam, so conservatism is added in the breach size and reasonable assurance is provided. The breach dimension and times are related and were estimated using the Froehlich (2008) methods.

As part of the model verification process, the licensee compared the volume of the outflow hydrograph from the Jocassee Dam failure with the total volumes of the flow hydrographs through the connecting canal and over Keowee Dam. This demonstrated that volume was properly being conserved in the flow routing by the model. The ability of the HEC-RAS geometric input to model the volumes of Lake Keowee and Lake Hartwell was also verified by comparing the volumes at normal pool level as calculated by the model with the known volumes. Both lake volumes agreed within 5%.

Failure parameters for the downstream dams were:

Parameter	Keowee Dam	West Saddle Dam	ONS Intake Canal Dike	Little River Dam
Breach Bottom el	670 ft. msl	795 ft.	715.5 ft. msl	670 ft. msl
Breach Bottom width	500 ft.	1680 ft.	200 ft.	290 ft.
Side slopes	1:1	1:0	1:1	1:1
Overtopping	817 ft. msl	817 ft. msl	817 ft. msl	817 ft. msl

trigger				
Main dam failure time	2.8 hrs.	0.5 hrs.	0.9 hrs.	1.9 hrs.

Dam failure parameters for the above dams and structures were developed based on Froehlich's (2008) methods. The bottom breach width for Keowee using Froehlich's (2008) methods was determined to be 1028 ft. with a failure time of 5 hrs. The physical size of the dam however, limits the bottom breach width to 500 ft. Because the breach size and failure time are related, the failure time was reduced to 2.8 hrs., based on proportions. The breach widths and failure times of the Oconee Intake Dike, West Saddle Dam, and Little River Dam were determined in a similar manner. The staff concludes that the dam failure parameters for the other structures listed above are conservative based on the physical constraints of the structures and provide reasonable assurance. Also see the discussions in Attachment 1 to Baxter (2010c).

The overtopping trigger of two feet over the crest of the dam was considered conservative based on the assumption that the slower (and/or later) the breach of Keowee and West Saddle Dam, the greater the flow through the intake canal dike canal dike breach, which is the major contributor to the water level at the SSF.

At a water elevation of 2 ft over the crest, the water velocities are about 2 to 4 times the velocity required to initiate erosion on a grassed slope.

Manning's n-values assumed for the record run (100) were:

Jocassee Tailrace	- 0.07
Keowee reservoir and Little River channels	- 0.025
Keowee Reservoir and Little River overbank	- 0.08
Keowee Reservoir tributaries	- 0.035
Keowee, Intake and Little River tailraces	- 0.07
Hartwell Reservoir Channel	- 0.025
Hartwell Reservoir overbank	- 0.08

A 60-foot threshold was chosen by the licensee to identify the change from stream to deep reservoir flow conditions. A deep water flow condition was modeled with a Manning's n-value of 0.025. Modeled reservoir tributaries were considered streams and their n-values remained at 0.035.

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 the 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 values were 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.

The NRC staff considers the n-values chosen by the licensee to be appropriate. Table 5-6 of Open Channel Hydraulics (Chow, 1959) tabulates the n-values for various conditions. A range of 0.025 to 0.060 corresponds to a main channel that has no bolders or brush bracketing the values of 0.025 and 0.035 used by the licensee. Figure 5-4 in Chow (1959) shows a definite decrease in n-value with increasing stage for 3 different rivers. This supports the reduction of n-value with depth assumed by the licensee. Also according to Chow (1959), a value of 0.08 corresponds to flood plains of cleared land as might be expected after being swept with high velocity water from the tailrace of a breached dam. Comparison of the reaches with pictures and n-values in USGS Water Supply Paper 1849 also helped narrow the acceptable range of n-values by the staff. Sensitivity studies performed by the licensee tend to show a decrease in sensitivity to downstream main channel n-value at higher flows.

Preliminary results from the licensee presented in October 2009 showed a double peaked elevation hydrograph occurring at the SSF. From the timing of the peaks, it was determined that the first peak was primarily due to overtopping and breaching of the ONS intake canal dike. The second peak appeared to be primarily from the Keowee tailrace with flow from the Keowee Dam failure combined with flow over the site from the West Saddle Dam and the ONS intake dike failure.

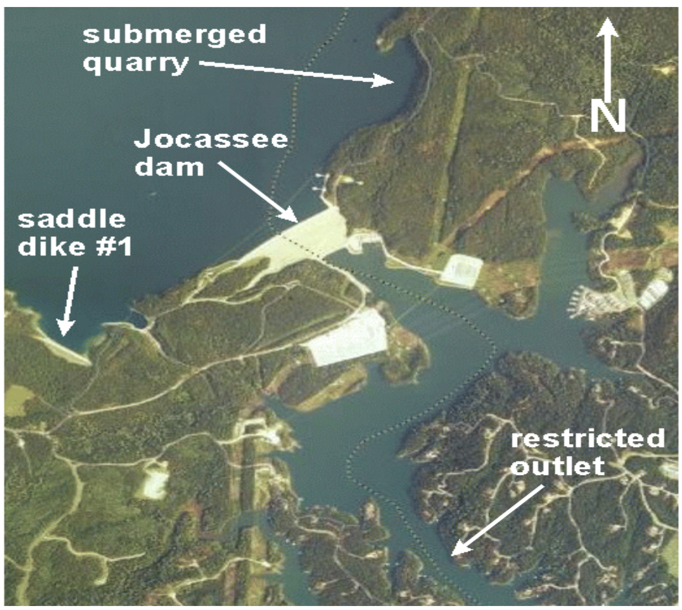
At the request of the staff, the licensee further investigated the effects of a more rapid failure of Keowee Dam to produce a greater Keowee tailrace contribution to site flooding. The licensee added 6 more HEC-RAS runs and selected two of the runs (100B and 100F) for more detailed 2-D modeling. HEC-RAS run 100 was used to set the 2-D boundary conditions. The additional HEC-RAS runs evaluated were:

100A Rapid failure (0.5 hrs) for Keowee Main dam
100B Median failure (1.65 hrs) for Keowee Main Dam
100C Rapid failure (0.5 hrs) for ONS Intake Canal east dike
100D Rapid failure (0.5 hrs) of additional breach (bottom width 400ft.) at ONS Intake Canal Dike
100E Rapid failure (0.5 hrs) of both east and north portions at ONS Intake Canal Dike

100F Rapid failure (0.5 hrs) for all Keowee structures, ONS Intake Canal Dike, and Little River Dam

Additional Conservatisms in the HEC-RAS for Jocassee Breach Modeling

The tailwater effect of the convoluted flood pathway below Jocassee Dam was not considered. A limit on the depth of hypothetical breach cutting at Jocassee (and therefore on the peak discharge) is provided by the tailwater elevation of 800 ft, which represents the Keowee normal pool level. This is the base elevation that is assumed for the hypothetical breach at Jocassee. It is conservative to not include the tailwater effect of the convoluted flow pathway below Jocassee Dam because this would shorten the time required to empty the reservoir.



Satellite image of Jocassee Dam showing submerged quarry site and embayment area below the dam which has a restricted outlet connection to the rest of Keowee Lake

The scouring effects of the flood waters were not considered. The effect of this scour would be to enlarge the channel system (compared to its present width and depth) and accelerate the transport of floodwaters southward away from the site, so conservatisms were added at the water levels at the site. Mapping of flood scouring effects has been documented by various authors, including the recent work of Krizanich (2010) downstream from the Taum Sauk reservoir. See the scoured flood path in the figure below.

Flood path from the Taum Sauk dam breach.

2 - Dimensional Modeling

Early in the review, there was concern about the ability of a 1-dimensional model to effectively simulate the flow regime immediately upstream of the canal to the north of the plant (connecting the Keowee River Basin to the Little River Basin) where the downstream velocity vector makes a 90 degree change in direction. Also, the potential for inundation of the site comes from many potential sources and is likely to flow in different directions without channelization. Such overland flow may involve eddy patterns, flow recirculation, and spill over barriers. Alternate wetting and drying of area elements may also be required depending on the overland flow patterns. For these reasons, a two-dimensional model was coupled to the HEC-1 simulations at boundaries, sufficiently remote, where the hydraulic parameters of flow and depth would be relatively unaffected by flow over the site.

The 2-D model chosen was one developed by the U.S. Department of Interior Bureau of Reclamation entitled Sedimentation and River Hydraulics – Two Dimensional River Flow Modeling (SRH-2D). For the modeling effort, a 2-D Mesh of triangular and quadrilateral elements was constructed of the area surrounding the station. 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 were more detail is required. As shown in the above figure, the upstream boundary is about 6,200 feet wide and the upstream boundary

condition consists of an inflow hydrograph. The downstream boundary conditions consist of stage hydrographs.

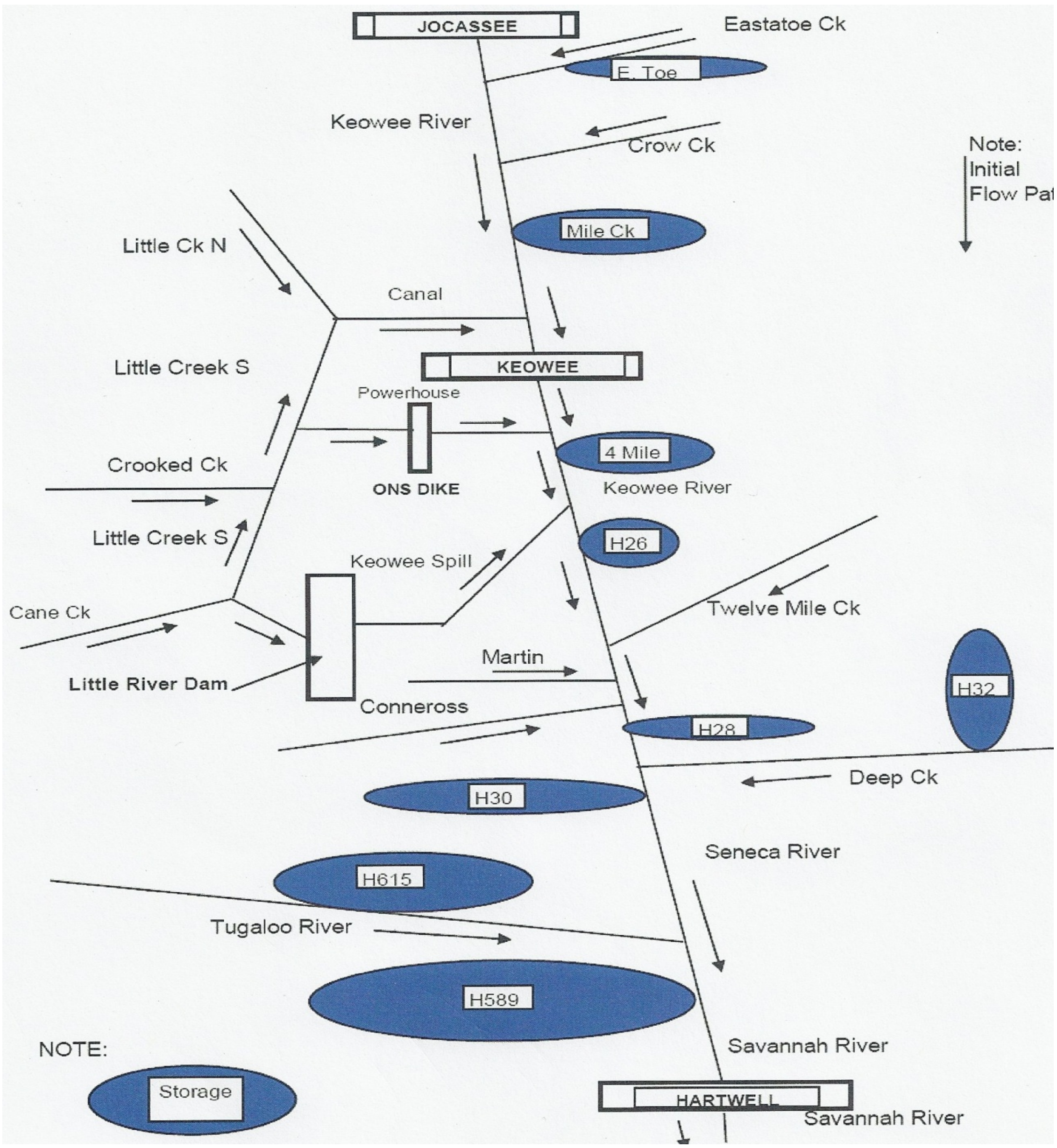


Figure 1: FLOW MODEL SCHEMATIC (Duke, 2009)

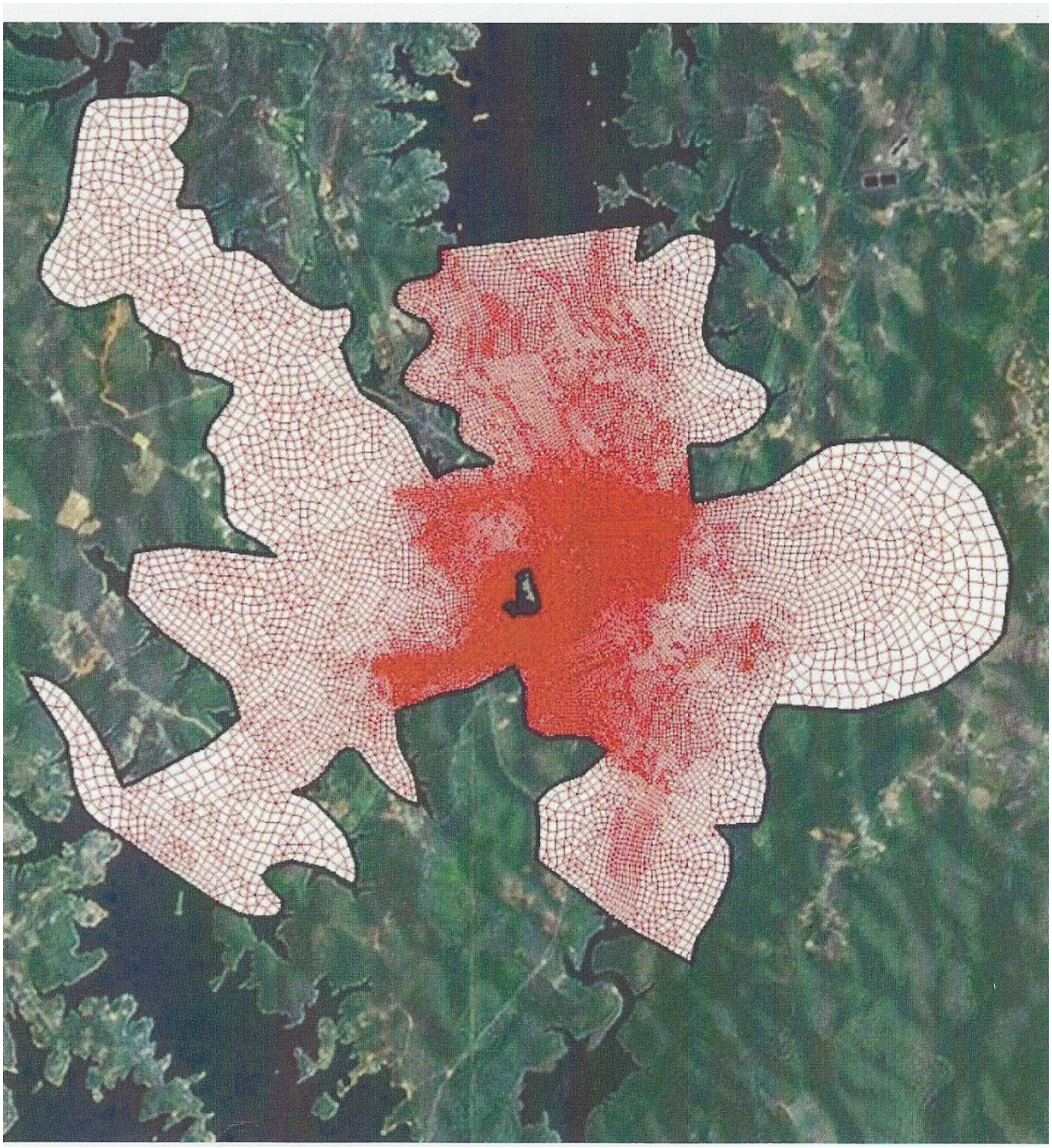


Figure 2: TWO-DIMENSIONAL MODEL BOUNDARY DEFINITIONS (Duke, 2010)

2 -D Model Computations

The one dimensional HEC-RAS and two-dimensional SRH-2D models are not dynamically Coupled; and mass and momentum between the two models cannot be conserved. Hence, the potential backflow between the inflow and outflow boundaries cannot be incorporated into the

model. Also, the simulations represent an extreme and unobserved scenario and parameters, such as, roughness coefficients over the site cannot be calibrated, requiring the selection of conservative values. The lack of coupling resulted in higher water levels from the 2-D simulations at the upstream boundaries than from the HEC-RAS runs (Wilson, 2010 and Young, 2009). The peak of the higher values at the upstream boundary after a short dip, as plotted by

Wilson, appeared about 20 minutes later than the peak at Keowee. This indicated a possible reflection of the flood wave at Keowee Dam intensified by the rigid (no backflow) upstream boundary condition. This intensified reflection may have resulted in greater flow through the Keowee tailrace. The ONS peak appeared occur earlier and was probably unaffected, although it was still about a foot higher than the HEC-RAS simulation.

Model runs100B and 100F were selected for the more detailed 2-D assessment. Evaluation of these runs showed that faster failure times did not increase water depths at the SSF and that the original set of parameters with an updated computational mesh results in the greatest depth at the SSF of 19.5 ft.

When it was confirmed that case 100M (original case) resulted in the highest 2-D water levels, case 100W was formulated to incorporate improvements utilizing new boundary conditions and became the record model run.

The final maximum water surface levels, determined from this updated computational mesh and the parameters as listed earlier are:

	2-D water levels	1-D water level
Keowee Dam (upstream)	839.6 ft msl	834.8 ft. msl
Keowee Dam (tailwater)	805.3 ft msl	791.5 ft. msl
Intake Dike	823.0 ft msl	821.8 ft. msl
Swale	828.5 ft msl	827.8 ft.msl
SSF	815.0 ft msl	n/a

The model showed that there are key points that control the water level at the Oconee site and are discussed below.

Keowee Dam (upstream) is the primary control on the water level upstream of the canal which allows flow from the Keowee River Basin into the Little River Basin and eventually into the intake canal. The crest elevation of Keowee Dam is 815 ft msl. The water level above Keowee Dam also controls the amount of water, which could flow through the swale near the World of Energy. Upstream of Keowee Dam is a convenient location to compare water levels computed with HEC-RAS with those computed by the 2-D model showing the relative adequacy of boundary conditions.

The Keowee Dam tailwater is a possible source of flooding from the east side of the plant site across the switchyard. Flooding from the Keowee Dam tailrace resulted in a second (lower) flood peak at the SSF. It was noted that the 2-D simulation resulted in a higher second peak than the 1-D simulation at the tailwater. This was caused by retention of flow from the Oconee Intake canal in the plant yard and delayed release into the tailrace, a result of simultaneous forward and lateral flow which could not be modeled in the 1-D simulation.

The intake dike, which has a top elevation of 815 ft. msl, will allow flooding of the plant upon overtopping, independent of the breach location(s). Breaching to the east, however, will result in flow to the south east of the power block and eventually flow to the Keowee Dam tailrace. Breaching to the north does not appear to result in higher water levels at the SSF.

The “swale” is a low lying pathway from the north of the plant to the World of Energy. Flooding from the swale would have an impact on the inundation levels at the ONS site. The swale has an invert or bottom elevation of 827 ft. msl. Only flood water from the Case 2 and Case 3 Jocassee Dam failure simulations will flow through the swale.

<u>Conclusion</u>

The flooding models provided by the licensee Energy for the ONS site demonstrated that the licensee has included conservatisms and has provided reasonable assurance of the new flooding levels at the site, based on a random sunny day failure of the Jocassee Dam. This Case 2 scenario will be the new flooding basis for the site. The licensee concluded that the greatest depth of water during the Case 2 flooding scenario at the SSF was 19.5 ft.

This technical assessment officially closes line item (2) associated with the CAL which states, “The licensee to submit to the NRC all documentation necessary to demonstrate that the inundation of the Oconee site from the failure of the Jocassee Dam has been bounded,” which was provided to the staff on August 2 and October 12, 2010.

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