OCONEE NUCLEAR STATION
JOCASSEE-KEOWEE DAM BREACH MODEL REPORT

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REPORT VERIFICATION

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This document has been reviewed for accuracy and quality commensurate with the intended application.

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Corporate Seal: Professional Engineer Seal:

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Executive Summary

The Keowee Hydroelectric Development is owned and operated by Duke Energy Carolinas, LLC (Duke Energy), and is part of the Keowee-Toxaway Project (Project) licensed by the Federal Energy Regulatory Commission (FERC) as Project No. 2503-SC. The FERC regulates the Project, which includes the oversight of all water retaining structures at Jocassee Pumped Storage Development and the Keowee Development. The Keowee Development includes Lake Keowee and Keowee Dam. The Oconee Nuclear Station (ONS) is located on Lake Keowee and is adjacent to the right abutment of Keowee Dam and tailrace.

HDR|DTA, a business unit of HDR Engineering, Inc. of the Carolinas, has been retained by Duke Energy to develop a dam breach model using the U.S. Army Corps of Engineers (USACE) HEC_RAS, v4, unsteady flow program to determine flooding impacts at ONS associated with a simulated "sunny day" failure of Jocassee Dam. Initial HEC_RAS results were developed in December 2008 using the 8 Jocassee dam failure scenarios developed in September 2008 based on the 1992 Jocassee Emergency Action Plan (EAP) dam failure model. The eight September dam failure scenarios were modeled using the National Weather Service DAMBRK program. Based on the 2008 HEC_RAS results and recommendations from HDR|DTA, Duke Energy requested additional HEC_RAS model refinements in January 2009 to include additional cross sections, and incorporating the ONS Intake Canal Dike and potential dike failure.

The March 2009 HEC_RAS results are based on a complex and detailed model with simulated dam failures occurring at Jocassee, Keowee, and Little River dams along with the ONS Intake Canal Dike. Results indicate that Keowee Dam is overtopped during all eight dam failure scenarios with the maximum overtopping depth at 15.7 ft. The maximum overtopping at ONS Intake Canal Dike is approximately 4.5 ft for the assumed dam breach parameters used in all 8 scenarios. All eight modeled dam failure scenarios indicate that the simulated cross sectional water surface elevation below Keowee Dam does not exceed the ONS yard elevation of 796 ft mean sea level (msl). Additional model development details and results are included in the following report.

Section 1

Project Understanding and Approach

The Keowee Hydroelectric Development is owned and operated by Duke Energy Carolinas, LLC (Duke Energy), and is part of the Keowee-Toxaway Project licensed by the Federal Energy Regulatory Commission (FERC) as Project No. 2503-SC. The Keowee-Toxaway Project (Project) includes the Jocassee Pumped Storage Development and the Keowee Development. The FERC regulates the Project and their role includes regulatory oversight of all water retaining structures at both developments. The Oconee Nuclear Station (ONS) is located on Lake Keowee adjacent to the Keowee Dam and tailrace.

Based on a request for additional information concerning flooding impacts at ONS from a hypothetical failure of the Jocassee Dam, HDR|DTA was commissioned by Duke Energy to develop a dam breach failure model using the U.S. Army Corps of Engineers (USACE) HEC_RAS v4 unsteady flow program and compare the output from the HEC_RAS model to results from the September 2008 Jocassee Dam failure simulations using the National Weather Service (NWS) DAMBRK model. The September 25, 2008 letter report titled, "Oconee Nuclear Station, Model Simulation Results for Jocassee Dam Failure Report", presented in Appendix A. The emergency action plan (EAP) model was previously developed by Duke Energy and results were submitted to FERC in 1992. HDR|DTA was selected to perform this work based on experience with the HEC_RAS and DAMBRK models and development of the 1992 Jocassee EAP dam failure scenarios. Initial model simulation results were submitted on December 31, 2008 in a letter report also titled, "Oconee Nuclear Station, Model Simulation Results for Jocassee Dam Failure", presented in Appendix B.

HDR|DTA was asked to refine the December 31, 2008 dam breach analysis based on a postulated failure of Jocassee Dam in accordance with the following January 7, 2009 scope of work.

- Resolve the storage-volume issue on the Keowee Reservoir, both arms of the lake.
- Re-examine the Manning's n values for all cross-sections of the model, upstream and downstream of ONS.

- Review current cross sections for the entire model to determine that area that should be 'inactive flow areas'.
- Assure flows over Keowee Dam are routed to the tailrace for summation into tailrace volumes and elevations.
- Include a branch line off of Little River branch up to Oconee Intake structure for volume and elevation determination.
- Use all current breach assumptions for Keowee and Jocassee dams.
- Add a breach for ONS Intake Canal Dike if overtopped for more than 30 minutes with at least 0.5 ft of water.
- Route water from ONS Intake Canal Dike to tailrace.

Section 2
Project Site Description

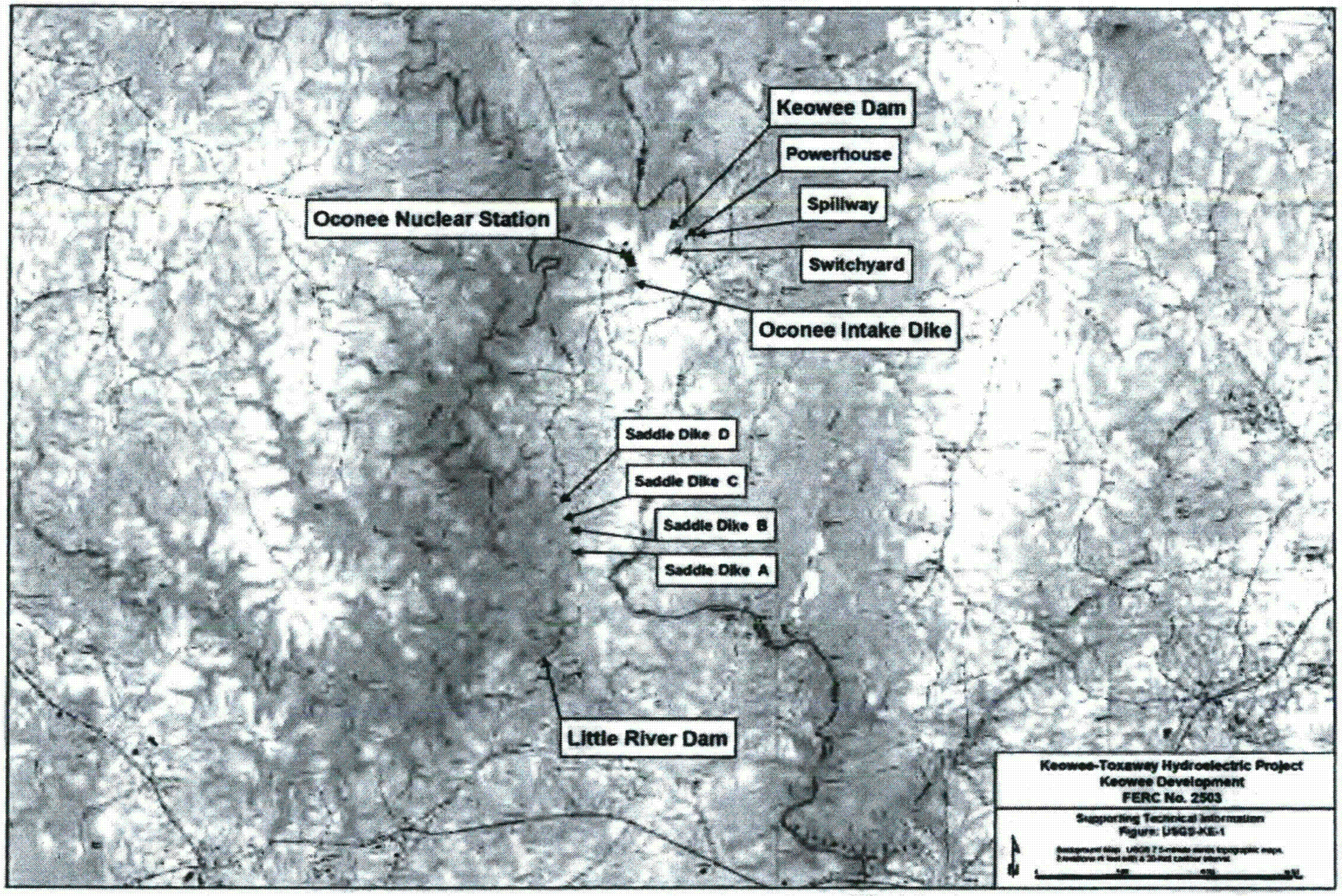
The Keowee Development is owned and operated by Duke Energy and is part of the Keowee-Toxaway Project licensed by the FERC as Project No. 2503-SC. The Project includes the Jocassee Pumped Storage Development and the Keowee Development. The U. S. Army Corps of Engineers (USACE) owns and operates Hartwell Dam, which forms the third development site of the Jocassee-Keowee Dam Breach Study. Hartwell Dam is located downstream of Keowee Dam. The tailrace below Keowee Dam forms the upper reach of Lake Hartwell.

2.1 Keowee Development

The Keowee Development is located on the Keowee River and consists of Keowee Dam; Little River Dam; Saddle Dikes A, B, C, and D; Oconee Intake Dike; gated concrete ogee spillway; powerhouse; and intake structure. ONS lies just beyond the right abutment of Keowee Dam with property bordering the right side of the Keowee tailrace.

The Keowee reservoir (Lake Keowee) if formed by two parallel watersheds connected together through an excavated 6,000-foot-long canal. The connecting canal is located approximately ½-mile north of ONS. The left side watershed (Keowee River) is impounded by Keowee Dam while the right watershed (Little River) is impounded by Little River Dam. The ONS Intake Canal Dike, which impounds cooling and service water at the intake structure for ONS, is located on the south side of the nuclear plant and is approximately ¾-mile southwest of the Keowee powerhouse. The ONS Intake Canal Dike is located at the end of an excavated canal leading from the Little River side of Lake Keowee. There are a series of four saddle dikes located between Little River Dam and ONS Intake Canal Dike. An overview of the Keowee Development is shown in Figure 1.

FIGURE 1
KEOWEE DEVELOPMENT OVERVIEW



The seven dams/dikes that comprise the Keowee Development are homogeneous earthfill embankments and share a common crest elevation of approximately 815 ft mean sea level (ft msl). The respective crest lengths and maximum heights are:

- Keowee Dam: crest length (3,500 ft) and height (165 ft);
- Little River Dam: crest length (1,800 ft) and height (165 ft);
- ONS Intake Canal Dike: crest length (1,200 ft) and height (80 ft);
- Saddle Dike A: crest length (1,900 ft) and height (50 ft);
- Saddle Dike B: crest length (225 ft) and height (15 ft);
- Saddle Dike C: crest length (350 ft) and height (15 ft); and
- Saddle Dike D: crest length (650 ft) and height (40 ft).

Saddle Dikes B and C are located above the normal reservoir elevation of 800 ft msl and serve as flood control barriers. Saddle Dikes A, B, C, and D were not included in the dam breach model study.

The Keowee Development discharge capacity consists of two hydroelectric generating units located in the powerhouse and four Tainter gates at the spillway section located near the left abutment of Keowee Dam. The spillway crest elevation is 765 ft msl. Normal reservoir elevation is approximately 800 ft msl with a corresponding tailrace elevation of approximately 672 ft msl. The maximum available discharge capacity at reservoir elevation 800 ft msl is approximately 115,000 cfs and includes the combined capacity of four Tainter gates fully raised and one hydroelectric generating unit.

2.2 Jocassee Development

The Jocassee Development is located approximately 12 miles upstream of Keowee Dam and is a zoned rockfill embankment with an earthen core. Jocassee Dam is approximately 385 ft tall and has a crest length of approximately 1,825 ft. The dam crest elevation is 1,125 ft msl. Two radial spillway gates and four reversible pump-turbines provide the development discharge capacity. The reservoir fluctuation varies between 1,080 ft msl and 1,110 ft msl.

2.3 Hartwell Development

Hartwell Dam is located approximately 30 miles downstream of Keowee Dam. The top of dam elevation is approximately 679 ft msl with a dam length of approximately 18,000 ft. Hartwell Dam is approximately 204 ft tall. The Keowee Dam tailrace forms the upper reach of Lake Hartwell. The normal reservoir elevation at the Hartwell Dam is approximately 600 ft msl. The spillway consists of 12 gates measuring 40 ft wide by 35.5 ft tall each, with a spillway crest elevation of 630 ft msl. The maximum spillway discharge capacity at reservoir elevation 600 ft msl is approximately 280,000 cfs. The USACE has installed hydroelectric generation capabilities at Hartwell with a total discharge capacity of approximately 26,800 cfs.

Section 3

Model Development

In follow-up to the January 7, 2009 scope of work items HDR|DTA developed an unsteady flow model of the Jocassee/Keowee/Hartwell reservoir system using the USACE HEC_RAS (Version 4.0) program. 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.

The HEC_RAS Jocassee-Keowee Dam Breach Model of March 2009 (Model) was developed to include additional Lake Hartwell detail and additional cross section refinement of Lake Keowee, including the Keowee River, Little River, and the connecting canal sections of the reservoir. The Model refinement was necessary to address the following 2009 scope criteria:

- Reservoir storage volume;
- Manning's n value sensitivity;
- Ineffective flow area development;
- Routing of water flow at Keowee Dam (breach and overtopping) to the Keowee tailrace;
- Increased tributary and storage area flood routing;
- Additional dam failures (ONS Intake Canal Dike, Little River Dam); and
- River routing to tie the ONS Intake Canal Dike and Little River Dam outflow back into Keowee River.

HDR|DTA employed HEC-GeoRAS 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 HDR|DTA reverted to using the U.S. Geological Survey (USGS) National Elevation Data Set (NED) to develop the storage volume for H589 Storage Area. The

completed electronic geometry files were then imported to HEC_RAS. Geometry inputs and details are provided in Section 3.1, Model Geometry.

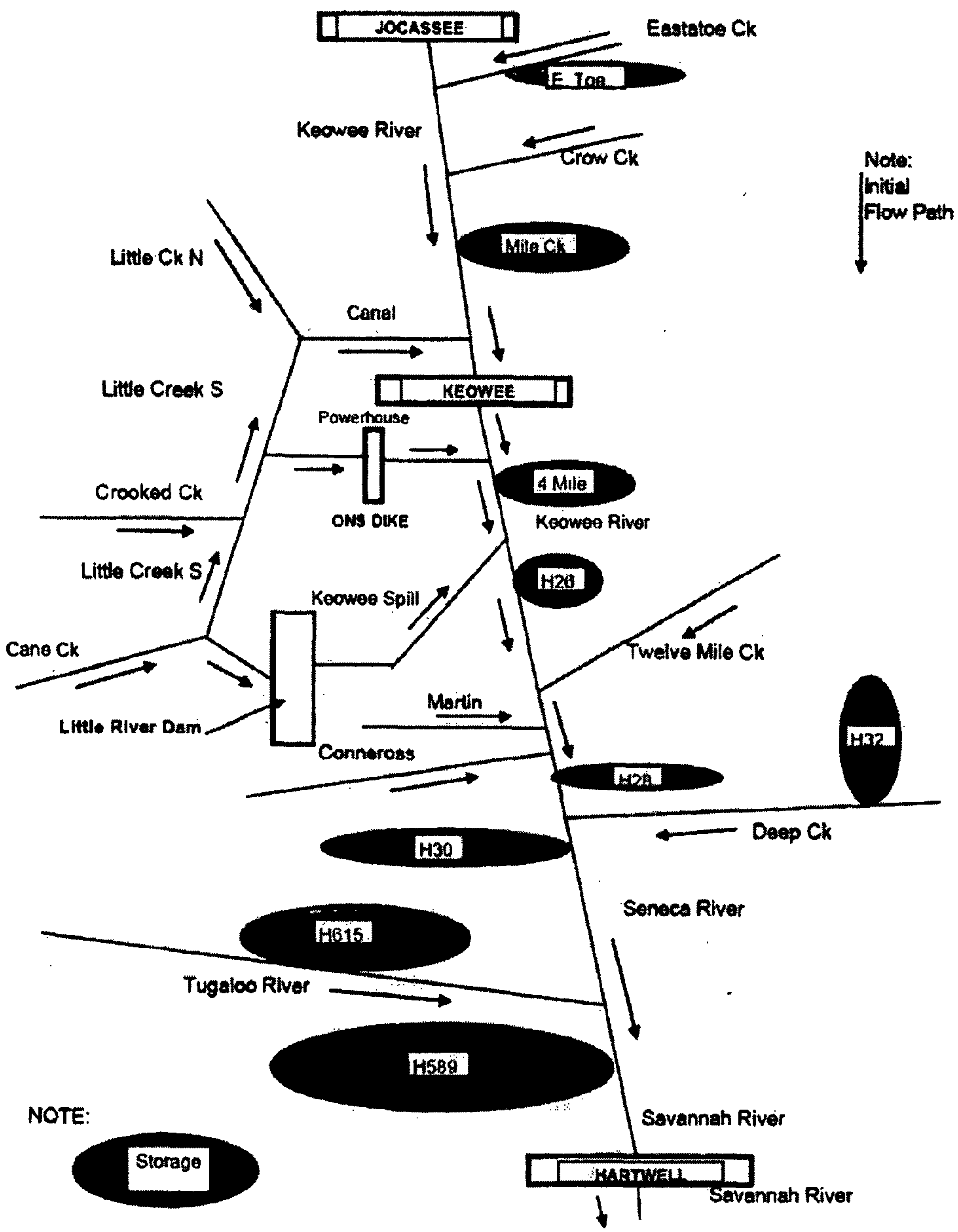
Additional flow parameters are required with the addition of Hartwell Dam in the dam breach model. Unsteady flow, boundary conditions, and initial discharge and reservoir elevation condition details are provided in Section 3.3, Unsteady Flow.

3.1 Model Geometry

The Jocassee-Keowee Dam Breach Model (Model) consists of the Jocassee, Keowee, and Hartwell reservoir systems with an approximate length of 44 miles. The hydraulic response of three reservoirs comprising 17 river/tributaries are incorporated in the Model. The one-line Model schematic is presented in Figure 2. The one-line schematic identifies the named river/tributary reaches, dams/dikes, storage areas-connecting tributary, and projected flow paths associated with the respective dam failures at Jocassee Dam, Keowee Dam, ONS Intake Canal Dike, and Little River Dam.

FIGURE 2
MODEL SCHEMATIC

Jocassee-Keowee Dam Breach Study
Dam Breach Model Schematic



The named reaches and storage areas that form Lake Keowee and Lake Hartwell are identified as:

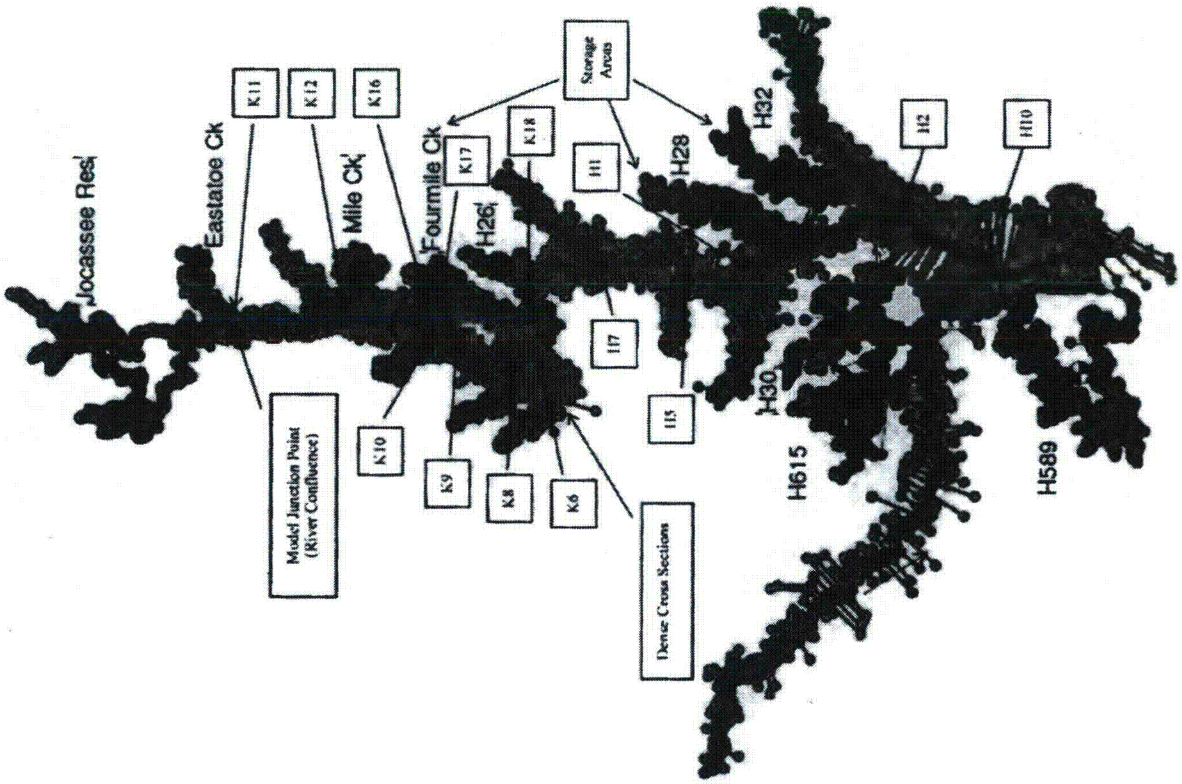
- Lake Keowee
  - Jocassee Reservoir Storage Area
  - Eastatoe Creek
  - Eastatoe Storage Area
  - Crow Creek
  - Mile Creek Storage Area
  - Keowee River (upstream of Keowee Dam, Sections 1-4)
  - Canal
  - Little Creek N
  - Crooked Creek
  - Cane Creek
  - Keowee Spill (upper portion located upstream of Little River Dam)
  - Little Creek S (Sections 1-3)
  - Powerhouse (upper portion located upstream of ONS Intake Canal Dike)

- Lake Hartwell
  - Keowee River (downstream of Keowee Dam, Sections 4-6)
  - Powerhouse (lower portion to Keowee River confluence)
  - Fourmile Creek Storage Area
  - Keowee Spill (lower portion to Keowee River confluence)
  - H26 Storage Area
  - Twelve Mile Creek
  - Seneca River (Sections 1-4)
  - Martin Creek
  - Conneross Creek
  - H28 Storage Area
  - Deep Creek
  - H32 Storage Area

- H30 Storage Area
- Tugaloo River
- H615 Storage Area
- Savannah River
- H589 Storage Area

The Model consists of 1,411 primary cross sections that were established in HEC-GeoRAS along with 5,762 interpolated cross sections to bring the Model total cross section count to 7,173. As a comparison to reference the previous analysis, the December 2008 HEC_RAS model had 617 cross sections (149 primary and 468 interpolated). There are 10 storage areas identified and 14 reach section junctions. The physical size characteristics of Jocassee Dam, Keowee Dam, ONS Intake Canal Dike, and Hartwell Dam were incorporated in the Model. Breach failure parameters were established for all dams with the exception of Hartwell Dam. Additional cross section, storage area, reach junction, and dam structure details are provided in Section 3.2, Geometry Details. The overall HEC_RAS model graphic is shown in Figure 3. Additional and more detailed Model graphics are located in Appendix C1.

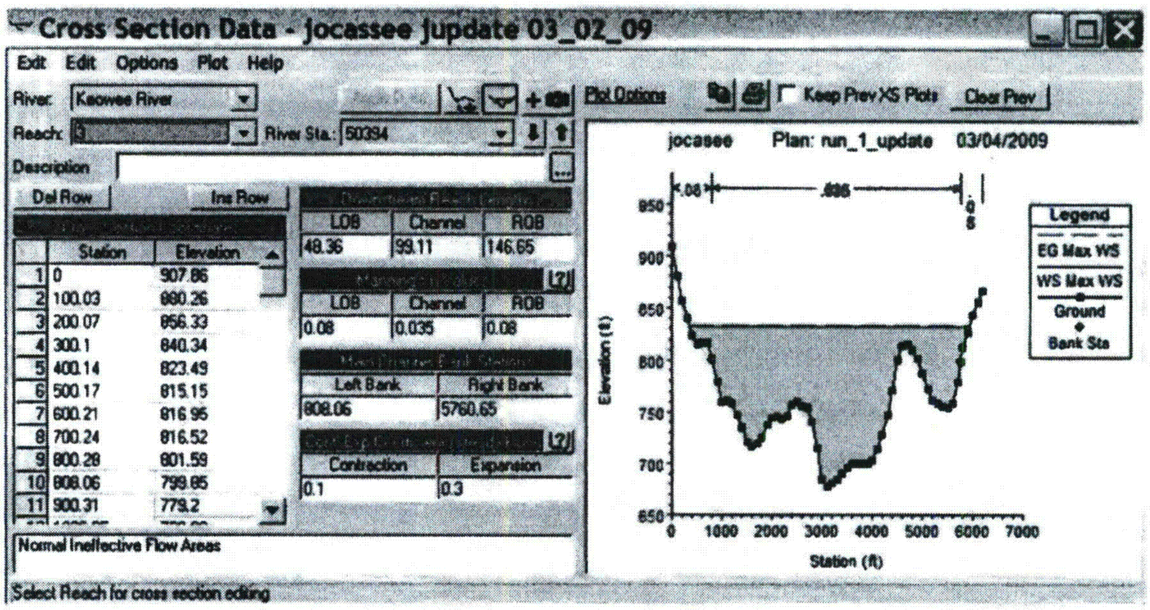
FIGURE 3
HEC_RAS DAM BREACH MODEL



3.2 Geometry Details

A typical cross section is shown in Figure 4 and depicts Lake Keowee below the confluence of Keowee River and Crow Creek.

FIGURE 4
TYPICAL CROSS SECTION



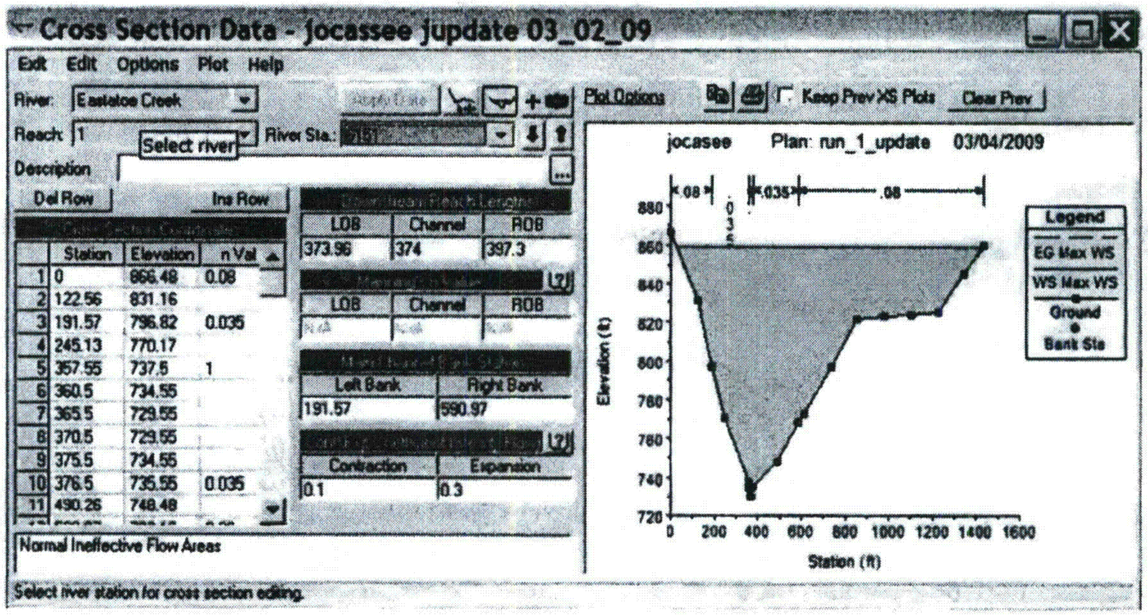
The cross section is identified by River (Keowee River), Reach (3), and River Station (50394). Cross section 50394 is defined by the station and elevation coordinates as pulled from the South Carolina GIS maps through HEC-GeoRAS. The Manning's n values are listed as 0.08 (Left Overflow Bank [LOB]), 0.035 (Channel), and 0.08 (Right Overflow Bank [ROB]). The next downstream cross section is located 99.11 ft away (reach length).

The Manning's n values and reach lengths for the Model's primary cross sections are provided in Appendices C2 and C3, respectively. The Manning's N values for a majority of the cross sections are limited to three designations as shown in Figure 4. The LOB and ROB n values (0.08) define a floodplain consisting of trees and tree stumps with sprouts. The main channel n value (0.035) describes a natural stream that contains stones and weeds. The n value range is:

- Trees, tree stumps with heavy sprouts: Minimum – 0.05, Normal – 0.06, Maximum – 0.08;
- Heavy stand of timber, few down trees, little undergrowth: Minimum – 0.08, Normal – 0.10, Maximum – 0.12; and
- Clean, straight, full channel with stones and weeds: Minimum – 0.03, Normal – 0.035, Maximum – 0.04.

There are several river reach sections where HDR|DTA employed up to six Manning's n values. Cross section 6151 on Eastatoe Creek utilizes five n values and is shown in Figure 5.

FIGURE 5
MULTIPLE MANNING'S N APPLICATION



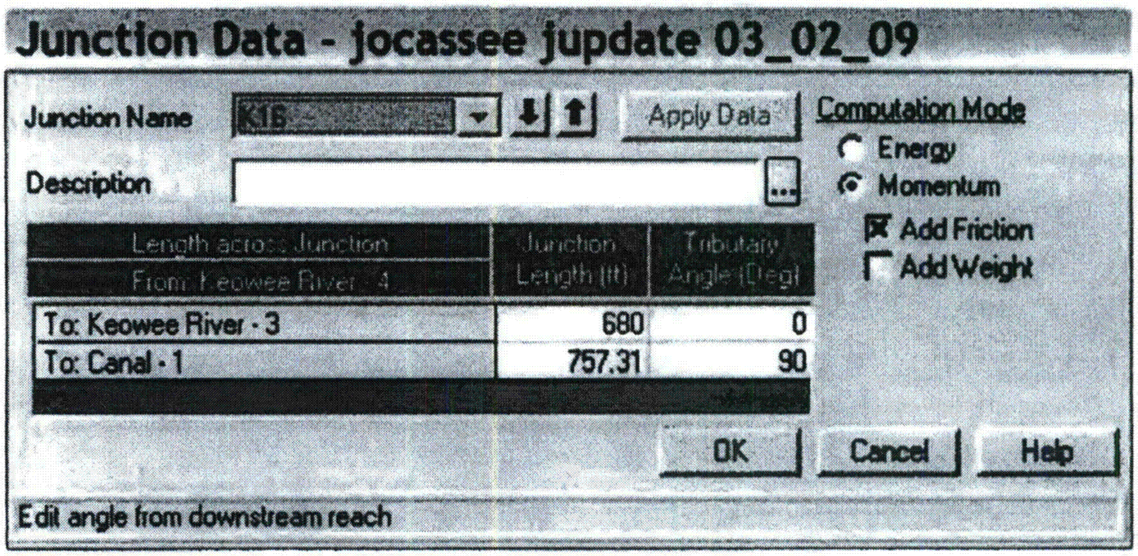
Multiple n values are utilized to address changing land use conditions within a section of the river/reservoir and to assist in stabilizing the initial Model production runs. HEC_RAS is very sensitive to cross sections that are dry. To facilitate a "wet cross section" the modeler can insert a pilot channel at the low point with minimal flow (relative to the dam breach discharge) and use an n value of 1. Cross section 6151 from Figure 5 represents the latter pilot channel case.

A significant n value list is found in Chow's, "Open-Channel Hydraulics" (Chow 1959) and has been incorporated by the USACE in HEC_RAS.

Detailed cross sections were used to define the respective reservoirs for Lake Keowee and Lake Hartwell. HDR|DTA elected to use the Lake Jocassee storage volume curve in lieu of creating a dynamic model of the reservoir.

The confluence of two or more rivers and tributaries are described in HEC_RAS as junctions. Figure 6 represents the typical junction editor in HEC_RAS.

FIGURE 6
TYPICAL JUNCTION EDITOR



Junction K16 represents the confluence between Keowee River and the connecting canal to the Little River basin side of Lake Keowee. Junction K16 notes that the last cross section on Keowee River, Reach Section 3, is 680 ft upstream of the junction. The first cross section on the Canal reach is 757.31 ft from K16 at a 90 degree bend to the Keowee River. Keowee River, Reach Section 4, is downstream of the K16 Junction and HEC_RAS uses the River Stationing (31523 and 30496) from Keowee 3 to Keowee 4 to calculate the revised reach length from K16

to the first cross section in Keowee 4. The calculated distance from K16 to River Station 30496 equates to 269.69 ft ([31523 – 30496] – 757.31).

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 should allow HEC_RAS to use the momentum equation to calculate energy losses. HDR|DTA elected to use the momentum equation at six of 14 junctions. The list of junctions and energy loss methodology is presented in Table 1.

TABLE 1
HEC_RAS MODEL JUNCTIONS

Junction	Reservoir	Location	Momentum or Energy Equation	Tributary Angle (Degrees)
K6		Cane Creek and Keowee Spill (Little River Dam)	Energy	
K8		Crooked Creek and Little Creek S	Energy	
K9		Little Creek S and Powerhouse (ONS Intake Canal)	Momentum	30
K10		Little Creek S, Little Creek N, and Canal	Momentum	90
K11	Keowee	Eastatoe Creek and Keowee River	Momentum	45
K12		Crow Creek and Keowee River	Momentum	60
K16		Keowee River and Canal	Momentum	90
K17		Powerhouse (ONS Intake Canal Dike discharge and Keowee River	Momentum	90
K18		Keowee Spill (Little River Dam discharge) and Keowee River	Energy	
H1		Seneca River and Conneross Creek	Energy	
H2		Seneca River and Deep Creek	Energy	
H5	Hartwell	Martin Creek and Seneca River	Energy	
H7		Twelve Mile Creek and Keowee River	Energy	
H10		Tugaloo River and Seneca River	Energy	

HDR|DTA elected to utilize HEC_RAS storage areas to account for reservoir storage capacity not associated with the defined primary river reach cross sections (i.e., 1,411). Storage areas

allow water diversion from/to the main stem reservoirs at Lake Keowee and Lake Hartwell. The storage areas account for a percentage of the modeled reservoir capacity (acre-feet [ac-ft]) but do not contribute to the calculated discharge through the respective reservoirs. The storage area editor allows the modeler to select the methodology to be used in calculating storage volume. The choices are the Area Times Depth or Elevation versus Volume Curve. HDR|DTA chose the elevation/volume method, which represents the more accurate and realistic reservoir performance as it relates to natural topography. A typical storage area editor is shown in Figure 7.

FIGURE 7
STORAGE AREA EDITOR

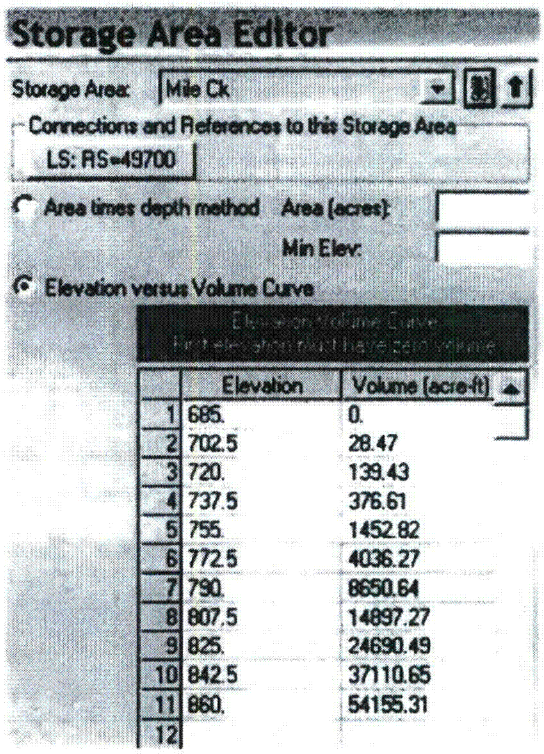


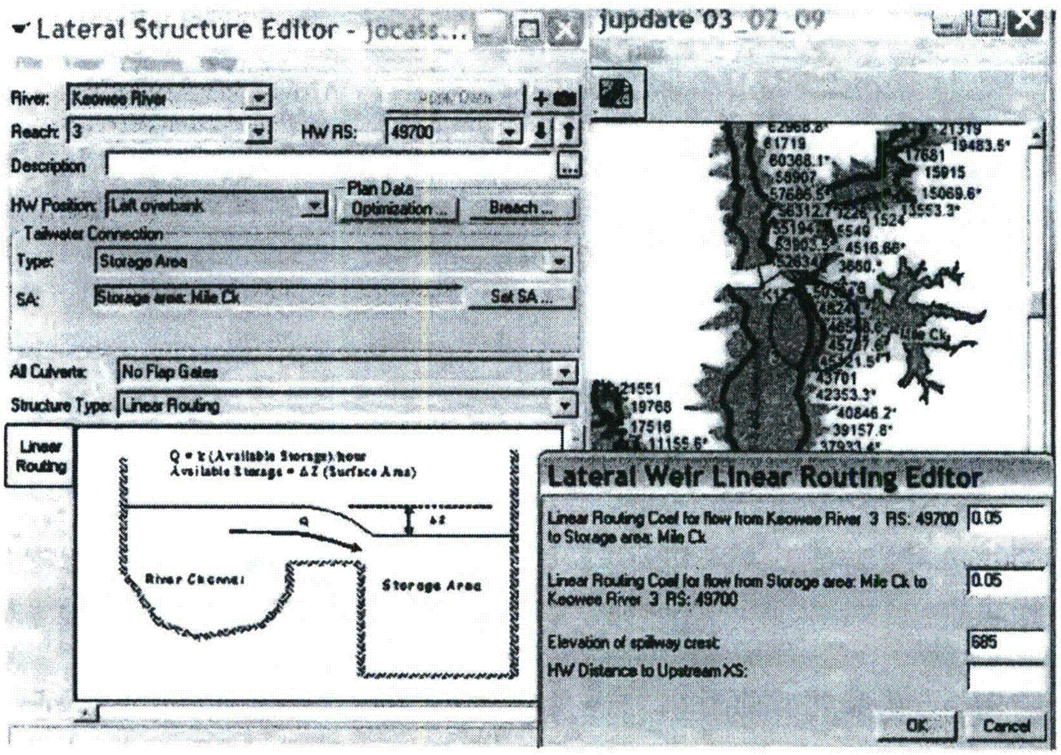
Figure 7 depicts the storage capacity of the Mile Creek Storage Area. Mile Creek adjoins the Keowee River south of Crow Creek at River Station 49700. The interpolated volume at Lake Keowee elevation 798 ft msl is approximately 11,500 ac-ft based on data lines 7 and 8 from Figure 7. Ten storage areas were developed for Lake Keowee and Lake Hartwell, including the Jocassee reservoir. The respective storage areas are shown in Table 2.

TABLE 2
HEC_RAS STORAGE AREAS

Storage Area	Reservoir	River/Tributary	Cross Section
Jocassee	Jocassee	Keowee River	96876
Eastatoe Ck	Keowee	Eastatoe Creek	14240
Mile Ck		Keowee River	49700
Fourmile Ck	Hartwell	Keowee River	26900
H26		Keowee River	20000
H28		Seneca River	52000
H32		Deep Creek	15000
H30		Seneca River	17000
H615		Tugaloo River	23000
H589		Savannah River	24000

The remaining Storage Area Editor sheets as depicted in Figure 7 are presented in Appendix C4. The noted storage areas in Table 2 are connected to their respective river/tributaries by means of lateral structures. Figure 8 depicts the lateral structure supporting the Mile Creek Storage Area.

FIGURE 8
LATERAL STRUCTURE EDITOR



There are a number of ways to connect the storage area to the river reach, including weirs, gated structure, culverts, diversion rating curve, or linear routing. HDR|DTA employed linear routing to move water back and forth between the respective river reaches and storage areas identified in Table 2 with the exception of Lake Jocassee. The Linear Routing Editor window under the Lateral Intake Structure Editor shown in Figure 8 allows the identification of the crest elevation (based on topography at specific storage area) and the applied coefficients to move water in/out of the storage area. HDR|DTA did not have the means or available data against which to calibrate the coefficient selections and relied on engineering experience and judgment from previous modeling efforts. The coefficients and crest elevations are validated in Section 4, Project Assumptions, Quality Assurance, and Model Sensitivity, through comparison of modeled reservoir storage against defined FERC reservoir storage capacity curves. The remaining Lateral Structure Editor sheets as depicted in Figure 8 are presented in Appendix C5.

The Model includes the impact of five dams: Jocassee Dam, Keowee Dam, ONS Intake Canal Dike, Little River Dam, and Hartwell Dam. Dams and lateral structures serve as downstream control points and have direct impact on the hydraulic performance of reservoirs and upstream river reaches. HEC_RAS identifies the characteristics of the structures through the Inline Structure Editor. Four of the dams, with the exception of Hartwell Dam, undergo failure in the Model. Breach parameters are identified under the Inline Structure Editor through the Dam (Inline Structure) Breach Data Editor. Figure 9 depicts a typical breach parameter edit screen in HEC_RAS.

FIGURE 9
DAM (INLINE STRUCTURE) BREACH DATA

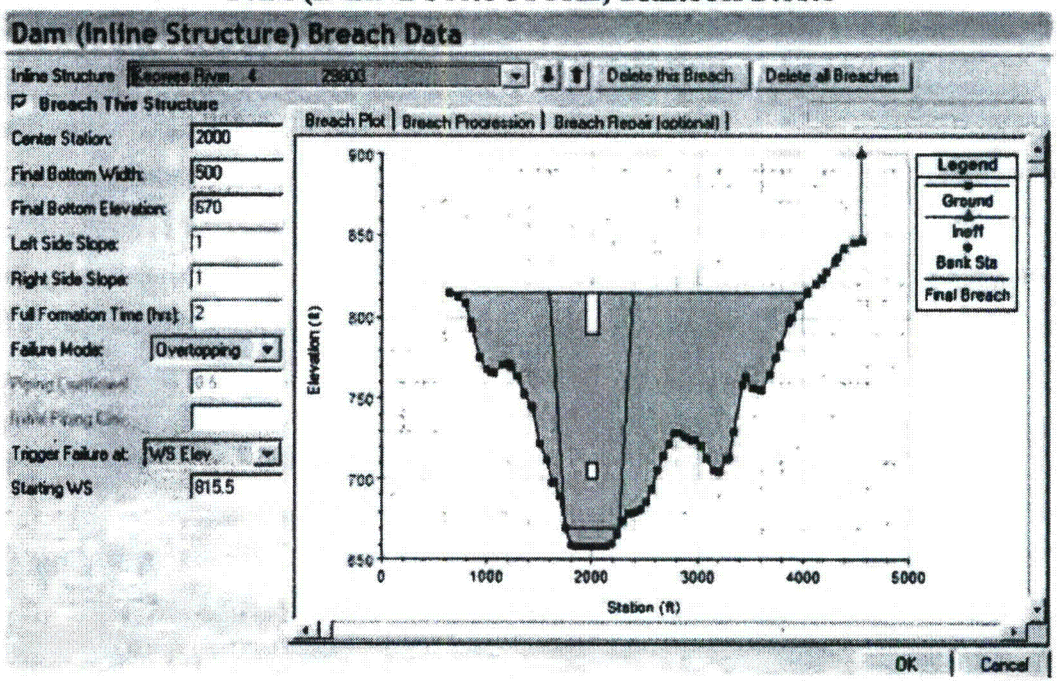


Figure 9 represents the Dam Inline Structure/Breach Data for Keowee Dam. Breach parameters include center stationing (location on structure), bottom breach width, bottom of breach elevation, breach side slopes, and formation time for the full breach development. The remaining Inline Structure/Breach Data sheets are provided in Appendix C6. The modeler can also identify the type of failure (i.e., overtopping or piping) and the triggering elevation to

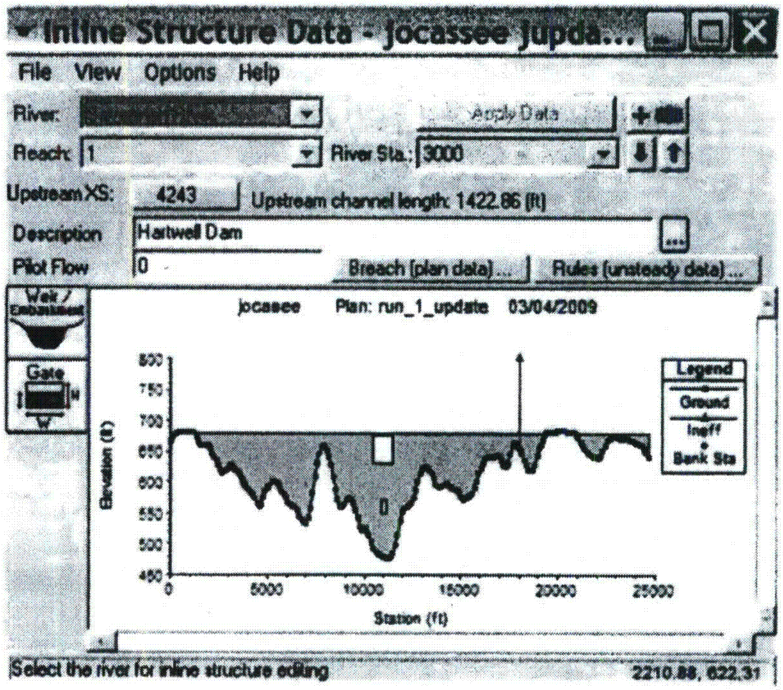
commence dam failure. Table 3 summarizes the respective breach parameters at Jocassee Dam, Keowee Dam, ONS Intake Canal Dike, and Little River Dam.

TABLE 3
DAM BREACH PARAMETERS

Dam/Dike	Failure Mode	Crest Elevation (ft msl)	Bottom Width (ft)	Bottom Elevation (ft msl)	Full Breach Formation Time (hrs)	Side Slopes (ft:ft)	Top Width (ft)
Jocassee (1)	Piping	1125	250	800	4	1:1	900
Jocassee (2)	Piping	1125	250	919	2	1:1	662
Keowee	Overtopping	815	500	670	2	1:1	790
ONS	Overtopping	815	200	715.5	1	1:1	399
Little River	Overtopping	815	290	670	1	1:1	580

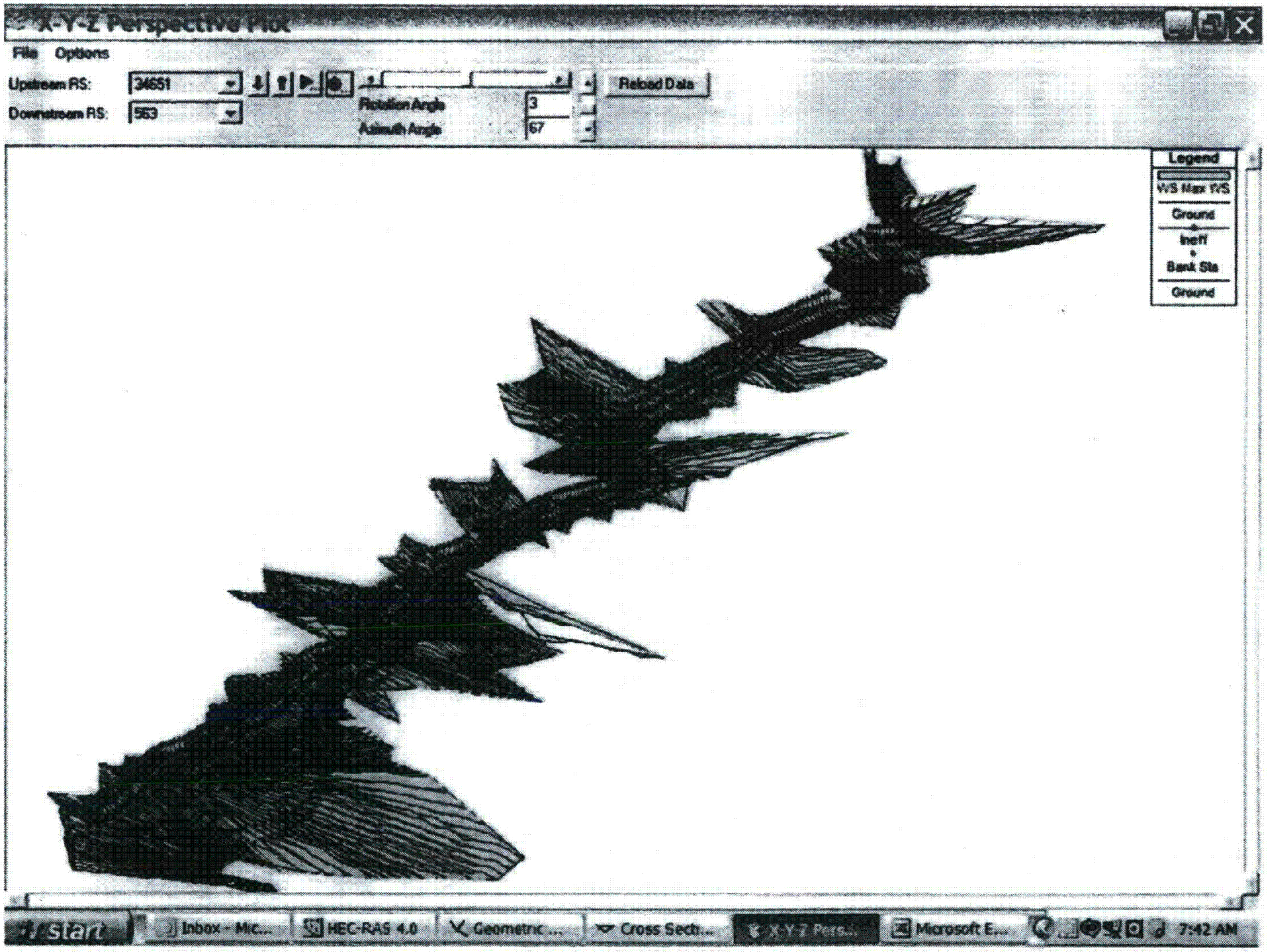
The Jocassee breach parameters are varied depending on which Model parameters are being reviewed. Additional detail is provided in Section 4, Project Assumptions, Quality Assurance, and Model Sensitivity. Hartwell Dam is not failed in the Model and serves as a downstream control section that potentially impacts the performance of the Keowee River. Figure 10 provides an overview of the Inline Structure Editor for Hartwell Dam.

FIGURE 10
HARTWELL DAM INLINE STRUCTURE



As seen in Figure 10, a green arrow is present near the right abutment of the dam. The green arrow serves as a graphic indicator for an ineffective flow area. 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. Left bank designations identify areas to the left of the arrow as ineffective, while right bank arrows designate cross section area to the right. Figure 11 identifies the ineffective flow areas along Twelve Mile Creek.

FIGURE 11
TWELVE MILE CREEK INEFFECTIVE FLOW AREA



HDR|DTA identified ineffective flow areas on six of 17 river reaches within the Model. The six reaches/sections are identified as:

- Twelve Mile Creek,
- Conneross Creek,
- Deep Creek,
- Martin Creek,
- Tugaloo River, and
- Savannah River (near Hartwell Dam).

Ineffective flow area designations were limited to Lake Hartwell tributaries and along the Savannah River overflow banks adjacent to the spillway area.

3.3 Unsteady Flow

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. In addition, boundary conditions are presented at internal model locations such as spillway gates and hydroelectric turbines at the respective dams along with lateral structures and storage areas. Figure 12 and 13 depict the Unsteady Flow Data Boundary Conditions and Initial Conditions, respectively.

FIGURE 12
UNSTEADY FLOW BOUNDARY CONDITIONS

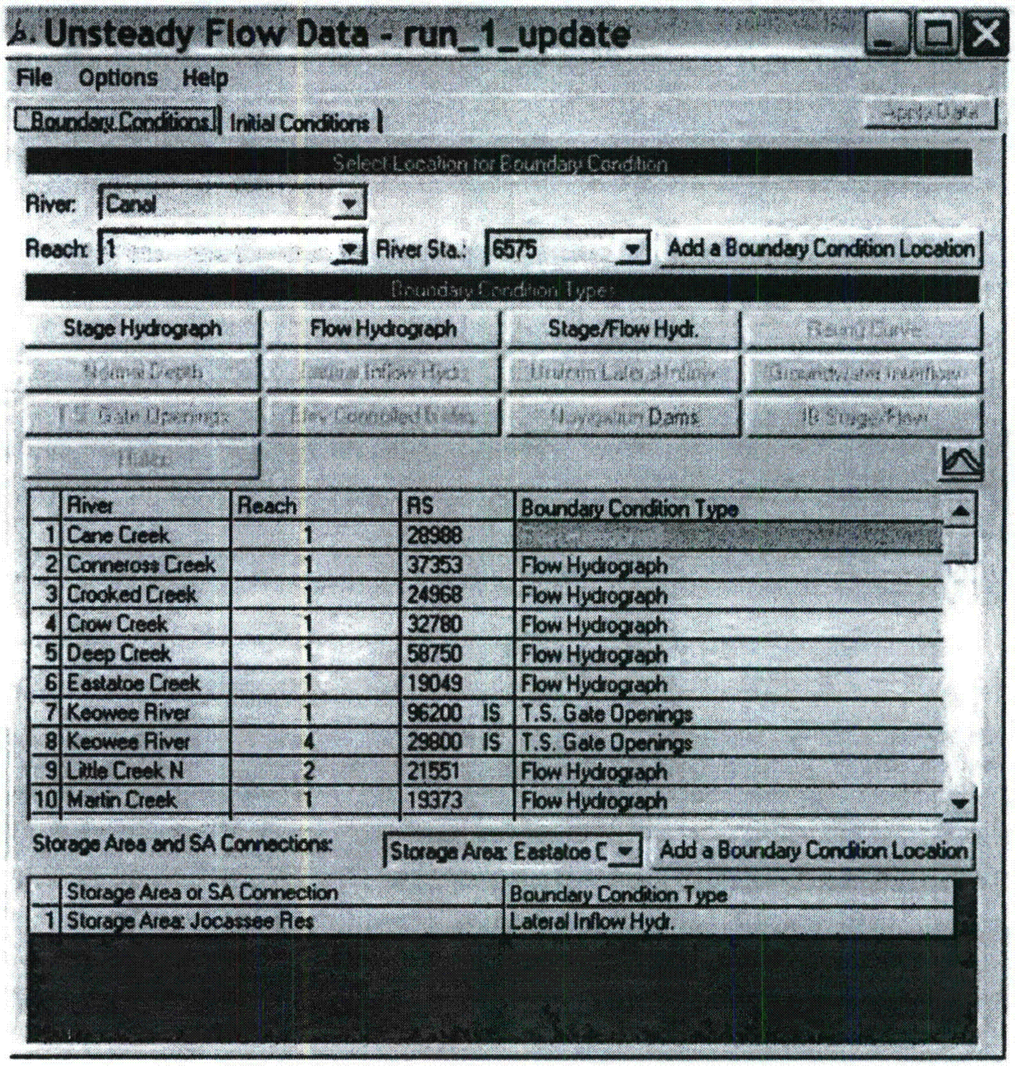
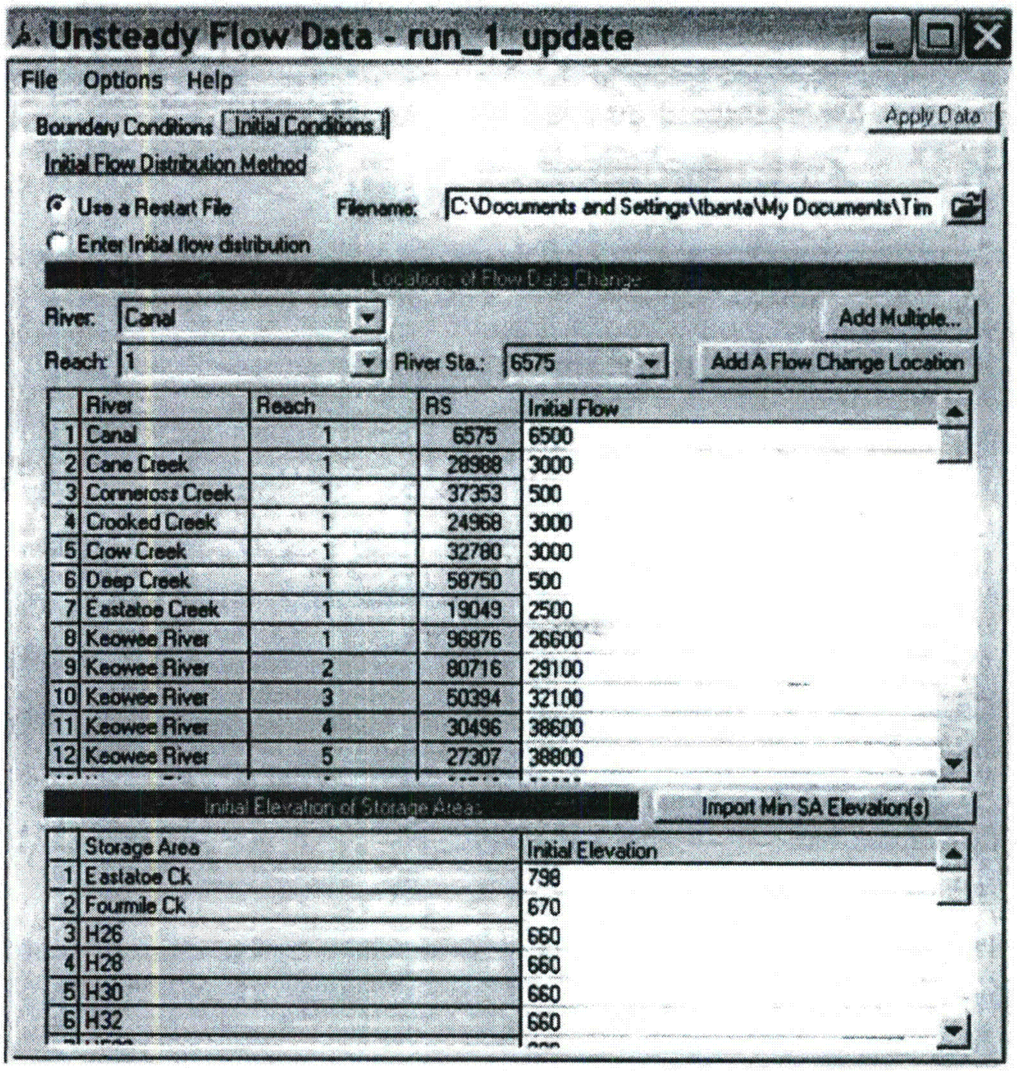


FIGURE 13
UNSTEADY FLOW INITIAL CONDITIONS



There are three types of boundary conditions used in the Model: flow hydrographs, time series gate opening, and normal depth. The complete list of boundary conditions is presented in Table 4.

TABLE 4
UNSTEADY FLOW BOUNDARY CONDITIONS

Reservoir	Tributary Reach/Structure	Boundary Condition
Jocassee	Jocassee Dam	Time Series Gate Opening
Keowee	Eastatoe Creek	Flow Hydrograph
	Crow Creek	Flow Hydrograph
	Cane Creek	Flow Hydrograph
	Crooked Creek	Flow Hydrograph
	Little Creek North	Flow Hydrograph
	Keowee Dam	Time Series Gate Opening
Hartwell	Twelve Mile Creek	Flow Hydrograph
	Martin Creek	Flow Hydrograph
	Conneross Creek	Flow Hydrograph
	Deep Creek	Flow Hydrograph
	Tugaloo River	Flow Hydrograph
	Hartwell Dam	Time Series Gate Opening
Savannah River	Savannah River	Normal Depth

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.

Time series gate openings have been established at Jocassee Dam, Keowee Dam, and Hartwell Dam to account for existing hydroelectric generation operations (i.e., turbine discharge) and spillway gate operations at each facility. The Model utilizes "Gate #1" to account for spillway gate operation and "Gate #2" for turbine operation. HDR|DTA combined the two gates at Jocassee Dam, four gates at Keowee Dam, and 12 gates at Hartwell Dam as one gate for each facility while utilizing the gate heights and total effective spillway width. The Model assumes that Gate #1 is not utilized at Jocassee Dam due to dam failure occurring during turbine discharge only. Table 5 summarizes the time series gate opening conditions for the Model.

TABLE 5
TIME SERIES GATE OPENINGS

Dam	Gate 1-Spillway Simulation			Gate 2-Hydro Operation Simulation
	Spillway Invert Elevation (ft msl)	Initial Gate Opening (ft)	Max Gate Opening Reached at Time (hr)	Discharge (cfs)
Jocassee	N/A	0	0	26,600
Keowee	790	7.4	0:40	8750
Hartwell	630	0	1:00	26,970

The spillway gate features, spillway rating curves, and hydro plant discharge capacity ratings were used to develop the time series boundary conditions for the Model. The spillway rating curves for Keowee Dam and Hartwell Dam are located in Appendix D. The third type of boundary condition is Normal Depth and is applied at the last downstream cross section in the Model. The nominal friction slope of 0.0001 was applied at the last cross section (1480) in the Savannah River reach. Initial elevation conditions for the respective storage areas are shown in Table 6. The initial storage area elevations for Jocassee, Eastatoe Creek, and Mile Creek are variable per each model run. Specific initial elevation values are provided in Section 4, Table 8.

TABLE 6
STORAGE AREA INITIAL CONDITIONS

Reservoir	Storage Area	Initial Elevation (ft msl)
Keowee	Eastatoe Creek	(variable per run)
	Mile Creek	(variable per run)
Hartwell	Fourmile Creek	670
	H26	660
	H28	660
	H30	660
	H32	660
	H589	660
	H615	660
Jocassee	Jocassee	(variable per run)

The initial river reach conditions are shown in Table 7. The initial discharge conditions in Table 7 are relative flows from one river reach section to another, or from a tributary to a river section. The initial discharge magnitudes are significantly small compared to developed breach discharge values and provide assurance that the unsteady flow model remains stable.

TABLE 7
INITIAL REACH CONDITIONS

Reservoir	Reach	Section	Model Schematic Sequential Order	Discharge (cfs)
Jocassee	Jocassee Lateral Storage Area Connector	1	1	26,600
Keowee	Keowee River	1	2	26600
	Eastatoe Creek	1	3	2500
	Keowee River	2	4	29,100
	Crow Creek	1	5	3000
	Keowee River	3	6	32,100
	Cane Creek	1	7	3000
	Little Creek S	1	8	3000
	Crooked Creek	1	9	3000
	Little Creek S	2	10	6000
	Little Creek S	3	11	6000
	Little Creek N	1	12	500
	Canal	1	13	6500
	Keowee River	4	14	38,600
Hartwell	Powerhouse	1	15	200
	Keowee River	5	16	38,800
	Keowee Spill	1	17	200
	Keowee River	6	18	39,000
	Twelve Mile Creek	1	19	500
	Seneca River	1	20	39,500
	Martin Creek	1	21	500
	Seneca River	2	22	40,000
	Conneross Creek	1	23	500
	Seneca River	3	24	40,500
	Deep Creek	1	25	500
	Seneca River	4	26	41,000
	Tugaloo River	1	27	500
	Savannah River	1	28	41,500

As noted in Figure 9, the water surface elevation that initiates Keowee Dam failure due to overtopping is 815.5 ft msl, or 0.5 ft above the crest of the dam. Dam failure is initiated at ONS Intake Canal Dike and Little River Dam at the same water surface elevation.

The unsteady flow Model was fixed at computation intervals of 10 seconds with hydrograph output intervals every 10 minutes. The Model assumes a sunny day failure at Jocassee Dam

resulting in dam failures due to overtopping at Keowee Dam, ONS Intake Canal Dike, and Little River Dam. As discussed earlier, Hartwell Dam is not failed in the Model and serves as a downstream control section that potentially impacts the performance of the Keowee River.

Section 4
Project Assumptions, Quality Assurance, and Model Sensitivity

Eight modeling scenarios were evaluated in parallel with the 1992 Jocassee EAP dam failure scenarios. The 1992 and September 2008 dam failure modeling utilized DAMBRK and a summary of the modeling parameters is shown in Table 8.

TABLE 8
SEPTEMBER 2008 MODEL PARAMETERS

Selected DPC Model Name	Initial Elevation (ft msl)		Breach Parameters				
	Jocassee	Keowee	Breach Failure Reference	Failure Mode	Breach Formation Time	Initial Piping Elevation (ft msl)	Bottom of Breach Elevation (ft msl)
Restored "1992"	1108	798	1992	Piping	4	940	800
"1992" Current Levels	1085	797	1992	Piping	4	940	800
Sensitivity Case 2	1090	797	1992	Piping	4	940	800
Sensitivity Case 5	1080	796	1992	Piping	4	940	800
Sensitivity Case 6	1085	796	1992	Piping	4	940	800
Sensitivity Case 1	1090	796	1992	Piping	4	940	800
Sensitivity Case 4	1108	798	1983	Piping	2	1000.5	919
Sensitivity Case 3	1090	797	1983	Piping	2	1000.5	919

An independent peer review was performed on the Model's geometry, unsteady flow boundary and initial conditions, and results. The Model's complexity and detail resulted in numerous model sensitivity runs in order to optimize the Model's performance and stability. Final production runs involved cross checking the Model's calculated reservoir storage capacity

against actual documented reservoir storage capacities. In addition, several Manning's n sensitivity runs were performed between the assumed n value (normal) and the corresponding maximum/minimum n values for the respective stream conditions.

The reservoir storage capacity assessment at Keowee Dam is based on the nominal reservoir elevation of 798 ft msl. The documented Lake Keowee storage capacity at 798 is approximately 910,400 ac-ft. The calculated Model reservoir capacity at 798 is approximately 886,600 ac-ft, representing a variance of approximately -2.6%. The Model calculations for Lake Keowee are presented in Table 9 and include the volume assessments for each river/tributary and junction.

TABLE 9
LAKE KEOWEE RESERVOIR CAPACITY CALCULATION

Reservoir Capacity Calculation			Reservoir Volume (ac-ft)			
Reach/Storage Area	**Section**	**Xsection**	**Left**	**Center**	**Right**	**Total**
Keowee Spill		14448	8	554	7	569
Cane Creek		28711	5685	142,229	25,570	173,484
Crooked Creek		24668.6	4634	42,714	3253	50,601
Little Creek S	1	27066	0	61,693	48	61,741
	2	21268	5	84,077	57	84,139
	3	5072	42	25,175	0	25,217
Powerhouse		9871	1	4604	1748	6353
Little Creek N		21551	155	30,693	199	31,047
Canal		6575	249	13,529	356	14,134
Junctions	K6		11,084	3097	1117	15,298
	K8		2438	2067	1734	6239
	K9		734	179	1706	2619
	K10		396	58	1828	2282
					Lake Keowee - Little River Arm:	**473,723**
Mile Creek SA						11,545
Eastatoe Creek SA						80
Eastatoe Creek		15908	86	14,003	363	14,452
Crow Creek		26482	2731	56,122	3344	62,197
Keowee River	1	96112.2	2	22,804	251	23,057
	2	80716	2941	86,336	6743	96,020
	3	50394	9058	157,922	7840	174,820
	4	30496	1581	2807	1094	5482
Junctions	K11		1732	390	97	2219
	K12		8178	1937	2442	12,557
	K16		6265	436	2061	8762
Keowee Dam						1727
Reservoir Elevation at 798 ft msl					**Lake Keowee - Keowee River Arm:**	**412,918**
					Lake Keowee Reservoir Total:	**886,641**
					FERC - Keowee Storage (ac-ft):	**910,386**
					Delta Variance:	**-23,745**
					% Variance:	**-2.6%**

Similar reservoir capacity calculations were performed for Lake Hartwell. The documented reservoir storage volume at Lake Hartwell at elevation 660.1 ft msl is approximately 2,555,200 ac-ft. The calculated reservoir volume from the Model is approximately 2,659,300 ac-ft, representing a variance of approximately 4.1%. HDR|DTA's modeling target variance is ±5%.

Manning's n sensitivity model runs were conducted on the "Restored 1992" model scenario, which represents the highest peak water surface elevations at Keowee Dam. Manning's n was varied at ±0.005 from the existing channel n value of 0.035, and ±0.02 from the existing LOB and ROB n value of 0.08. The model results are presented in Table 10.

TABLE 10
MANNING'S N SENSITIVITY ASSESSMENT

Sensitivity Case	Nominal Manning's n Value			Elevation (ft msl)			Breach Discharge (mcfs)	
	Left Overflow	Channel	Right Overflow	Keowee Dam Upstream	Keowee Dam Tailrace	ONS Intake Canal Dike Upstream	Keowee Dam	ONS Intake Canal Dike
Model A: 1992 Restored Final 3/4/2009	0.080	0.035	0.080	830.7	792.5	819.5	3.22	0.55
1A	0.080	0.030	0.080	830.5	788.5	819.6	3.20	0.62
1B	0.080	0.040	0.080	830.7	795.1	819.1	3.26	0.48
2A	0.060	0.035	0.060	830.9	788.7	819.5	3.21	0.55
2B	0.100	0.035	0.100	831.0	789.1	819.5	3.23	0.55
Average Elevation/Breach Discharge:				**830.8**	**790.8**	**819.4**	**3.22**	**0.55**

Section 5

Results

Model results are presented in several formats within the body of this report and appendices including:

- Tabulated numerical results,
- Stage and flow hydrographs,
- Graphical profiles, and
- Three-dimensional (3-D) graphics.

All posted results represent the Model's performance with respect to the "Restored 1992" scenario, as this scenario presents the maximum peak elevations and discharge of the eight modeled scenarios.

The maximum discharge/elevations and overall results range at Keowee Dam are:

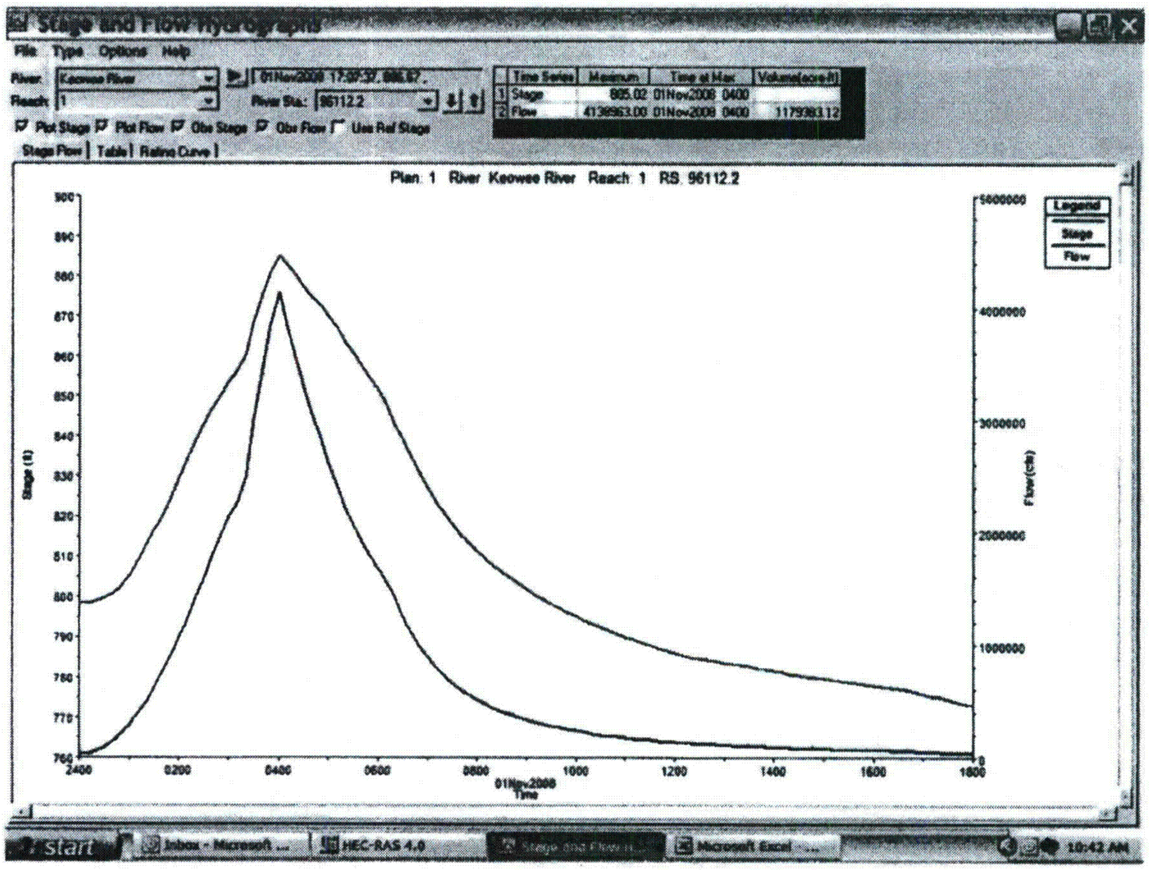
- Keowee Headwater Elevation: 830.7 ft msl with range of 828.1–830.7 (1992 breach parameters) and 817.4–819.8 (1983 breach parameters);
- Keowee Tailrace Elevation: 792.5 ft msl with range of 787.3–792.5 (1992 breach parameters) and 776.2–778.8 (1983 breach parameters);
- Keowee Discharge: 3.22 million cubic ft per second (mcfs) with range of 2.92–3.22 (1992 breach parameters) and 2.62–2.69 (1983 breach parameters);
- ONS Intake Canal Dike Headwater Elevation: 819.5 ft msl with range of 818.9–819.4 (1992 breach parameters) and 816.2–816.9 (1983 breach parameters); and
- ONS Intake Canal Dike Discharge: 0.55 mcfs with range of 0.51–0.55 (1992 breach parameters) and 0.43 mcfs for 1983 breach parameters.

The individual headwater and tailrace results for Jocassee Dam, Keowee Dam, ONS Intake Canal Dike, and Little River Dam are presented below. Table 11 and Figure 14 represent the tailrace performance below Jocassee Dam. The peak tailrace elevation and discharge are 885 ft msl and 4.14 mcfs, respectively. Both events occurred at model time 4:00.

TABLE 11
JOCASSEE DAM RESULTS

	Initial Reservoir Elevations (ft msl)			Jocassee Dam			
DPC Model Name	Jocassee	Keowee	Jocassee Dam Failure Shape	Peak Tailrace Elevation (ft msl)	Model Time	Peak Discharge (mcfs)	Model Time
Restored "1992	1108	798	1992	885.0	4:00	4.14	4:00
"1992" Current Levels	1085	797	1992	876.4	4:00	3.44	4:00
Sensitivity Case 2	1090	797	1992	878.2	4:00	3.58	4:00
Sensitivity Case 5	1080	796	1992	874.6	4:00	3.31	4:00
Sensitivity Case 6	1085	796	1992	876.4	4:00	3.44	4:00
Sensitivity Case 1	1090	796	1992	878.2	4:00	3.58	4:00
Sensitivity Case 4	1108	798	1983	854.1	2:10	2.24	2:00
Sensitivity Case 3	1090	797	1983	846.9	2:10	1.82	2:00

FIGURE 14
JOCASSEE TAILRACE STAGE-FLOW RESULTS



Keowee Dam results are presented in Table 12 and the respective headwater and tailrace stage-flow hydrographs are presented in Figures 15 and 16. The peak headwater elevation is 830.7 ft msl with a discharge of 3.22 mcfs. The peak tailrace elevation is 792.5 ft msl and the peak discharge is 3.22 mcfs.

TABLE 12
KEOWEE DAM RESULTS

	Initial Reservoir Elevations (ft msl)			Keowee Dam						
DPC Model Name	Jocassee	Keowee	Jocassee Dam Failure Shape	Peak Reservoir Elevation (ft msl)	Model Time	Peak Tailrace Elevation @ Dam (ft msl)	Model Time	Peak Tailrace Elevation @ 1663 ft (ft msl)	Peak Discharge (mcfs)	Model Time
Restored "1992	1108	798	1992	830.7	4:40	792.5	6:20	791.7	3.22	5:20
"1992" Current Levels	1085	797	1992	828.6	4:40	788.1	6:30	787.2	2.92	5:30
Sensitivity Case 2	1090	797	1992	829.2	4:40	788.9	6:20	787.9	3.03	5:30
Sensitivity Case 5	1080	796	1992	828.1	4:40	787.3	6:30	786.4	2.94	5:40
Sensitivity Case 6	1085	796	1992	828.7	4:40	788.1	6:30	787.1	2.95	5:40
Sensitivity Case 1	1090	796	1992	829.2	4:40	788.9	6:30	788.0	2.97	5:40
Sensitivity Case 4	1108	798	1983	819.8	3:40	778.8	5:50	777.9	2.69	4:50
Sensitivity Case 3	1090	797	1983	817.4	3:50	776.2	6:10	775.1	2.62	5:10

FIGURE 15
KEOWEE DAM HEADWATER STAGE-FLOW RESULTS

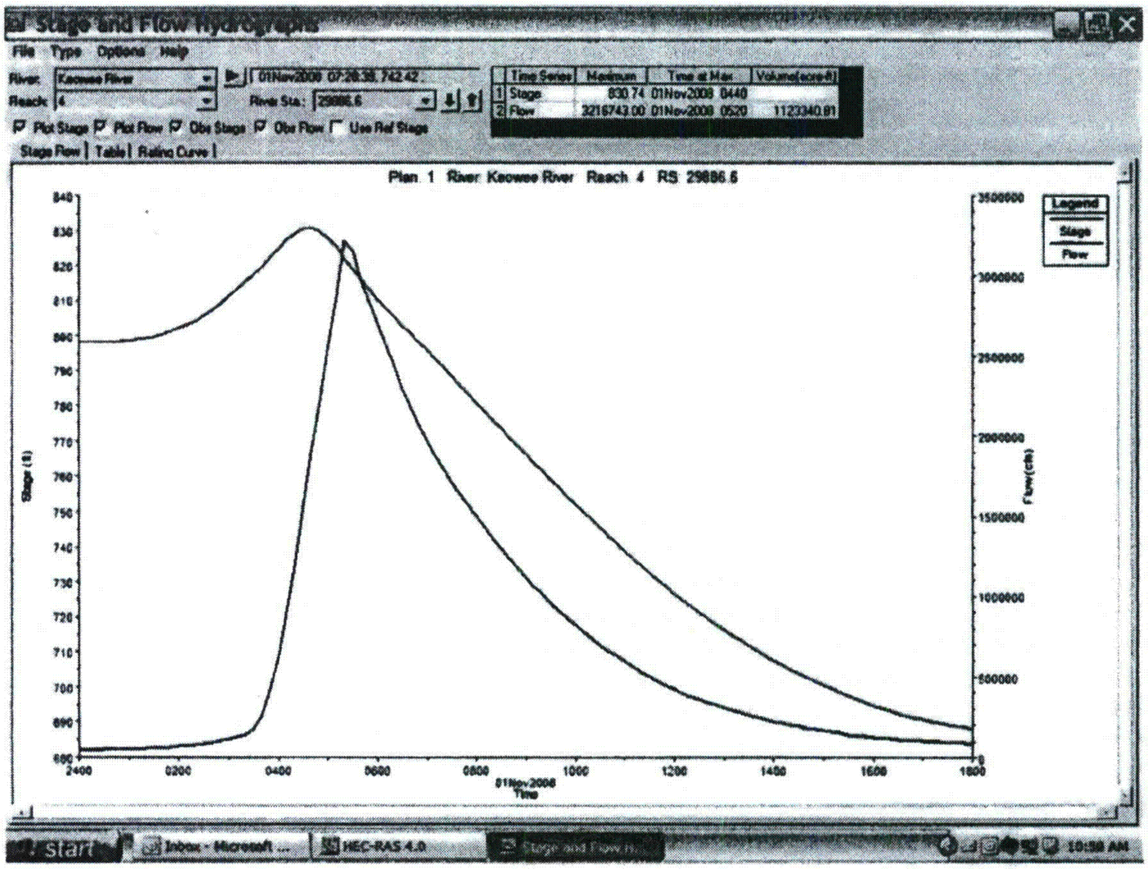
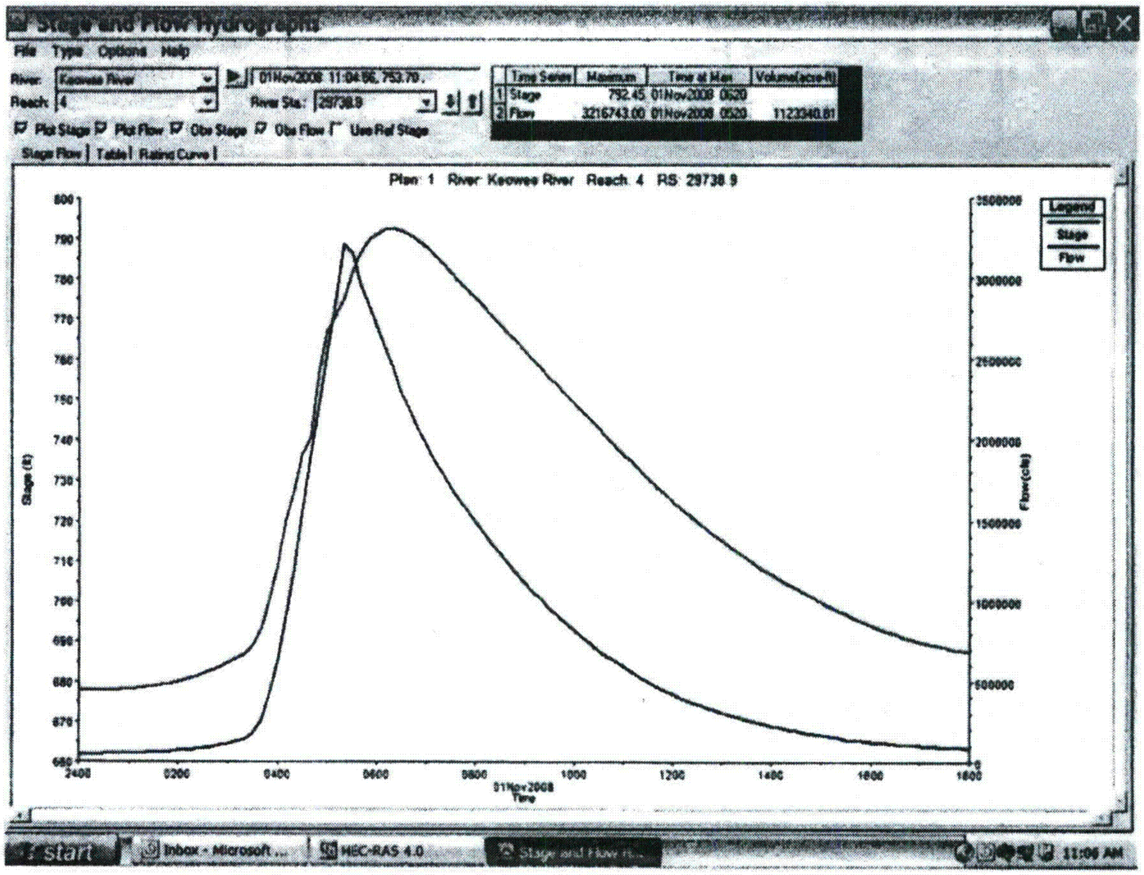


FIGURE 16
KEOWEE DAM TAILRACE STAGE-FLOW RESULTS



The ONS Intake Canal Dike results are presented in Table 13 with the corresponding headwater and tailrace stage-flow hydrographs presented in Figures 17 and 18. The peak headwater elevation at the ONS Intake Canal Dike is 819.5 ft msl and the peak discharge is 0.55 mcfs. The peak tailrace elevation immediately below the dike is 791.8 ft msl with a peak discharge of 0.55 mcfs.

TABLE 13
ONS INTAKE CANAL DIKE RESULTS

	Initial Reservoir Elevations (ft msl)			ONS Intake Canal Dike			
DPC Model Name	**Jocassee**	**Keowee**	**Jocassee Dam Failure Shape**	**Peak Reservoir Elevation (ft msl)**	**Model Time**	**Peak Discharge (mcfs)**	**Model Time**
Restored "1992	1108	798	1992	819.5	4:30	0.55	5:10
"1992" Current Levels	1085	797	1992	819.1	4:40	0.52	5:20
Sensitivity Case 2	1090	797	1992	819.2	4:40	0.53	5:10
Sensitivity Case 5	1080	796	1992	818.9	4:50	0.51	5:20
Sensitivity Case 6	1085	796	1992	819.1	4:40	0.51	5:20
Sensitivity Case 1	1090	796	1992	819.2	4:40	0.55	5:20
Sensitivity Case 4	1108	798	1983	816.9	4:00	0.43	4:40
Sensitivity Case 3	1090	797	1983	816.2	4:10	0.43	5:00

FIGURE 17

ONS INTAKE CANAL DIKE HEADWATER STAGE-FLOW RESULTS

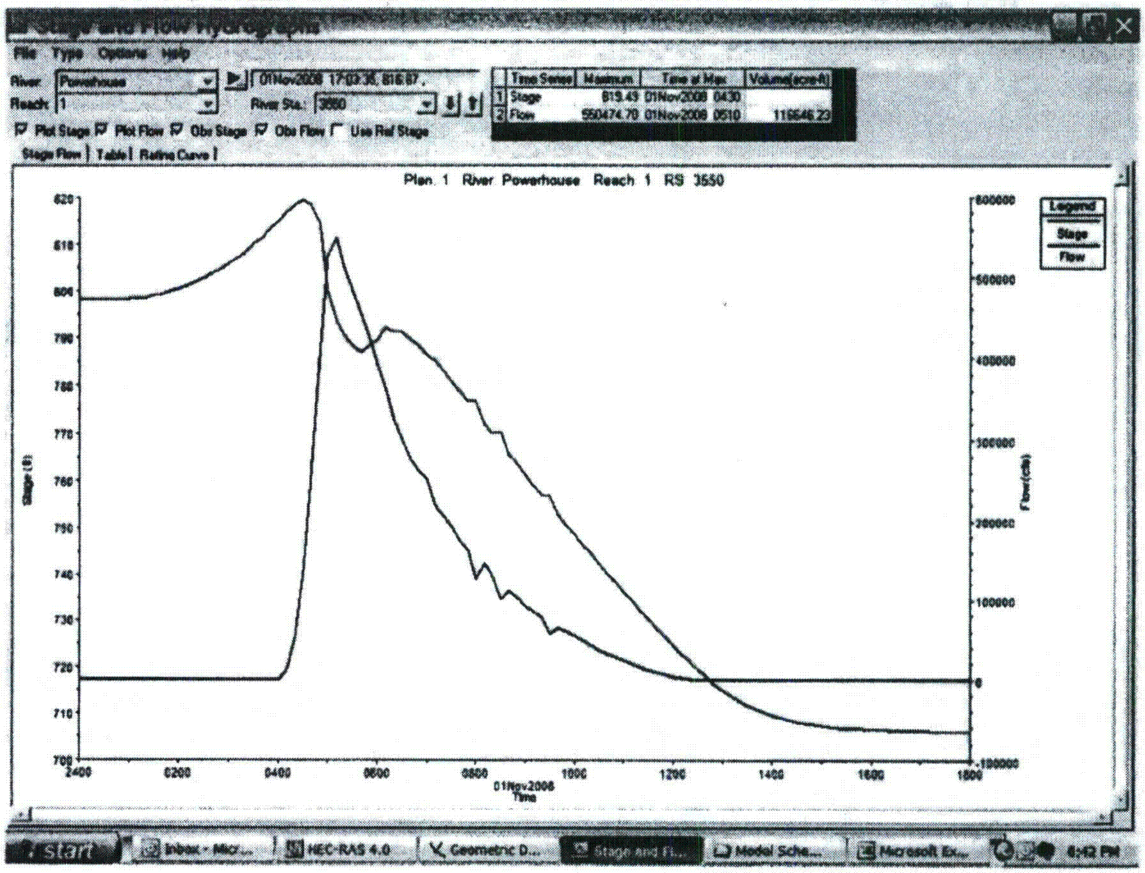
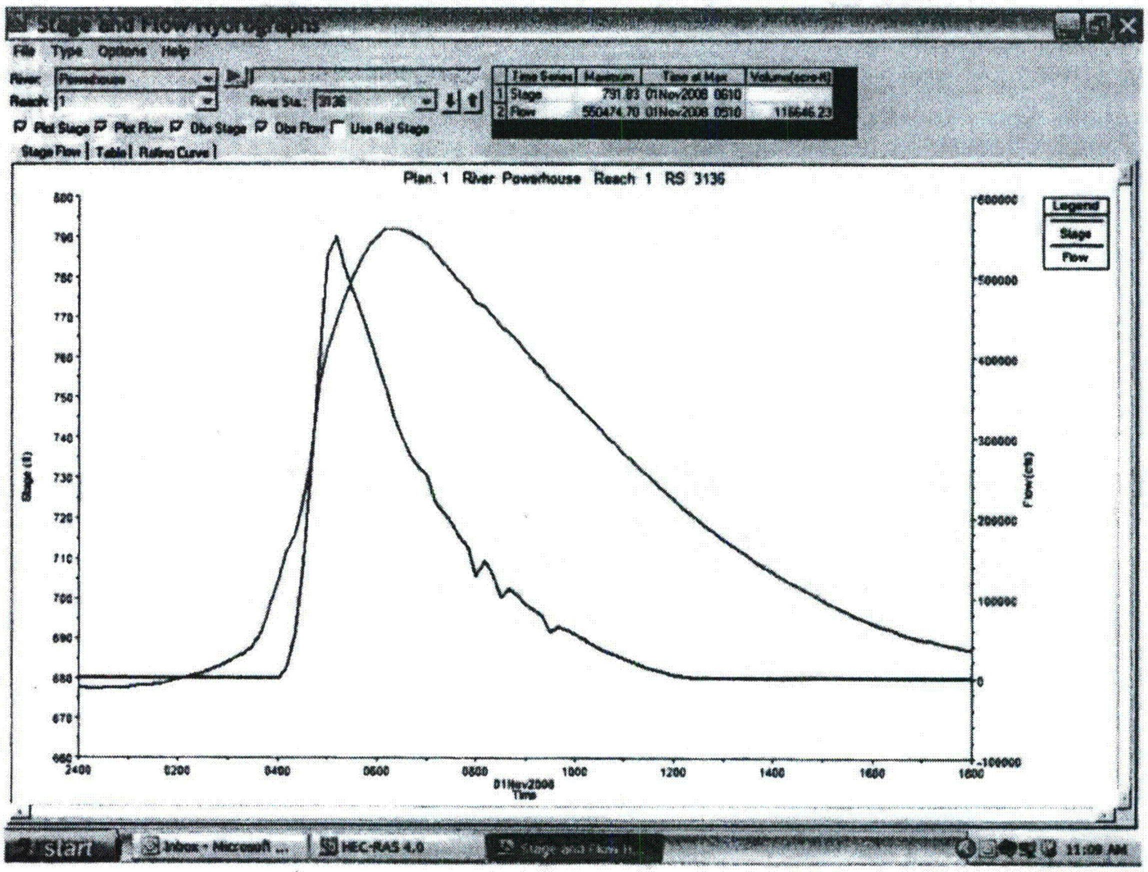


FIGURE 18

ONS INTAKE CANAL DIKE TAILRACE STAGE-FLOW RESULTS



The tabulated results for Little River Dam are presented in Table 14. The peak headwater elevation is 822.8 ft msl and the peak discharge is 2.11 mcfs. The peak tailrace elevation immediately below Little River Dam is 782.5 ft msl and the peak discharge is 2.11 mcfs.

TABLE 14
LITTLE RIVER DAM RESULTS

	Initial Reservoir Elevations (ft msl)			Little River Dam			
DPC Model Name	Jocassee	Keowee	Jocassee Dam Failure Shape	Peak Reservoir Elevation (ft msl)	Model Time	Peak Discharge (mcfs)	Model Time
Restored "1992	1108	798	1992	822.8	5:00	2.11	5:10
"1992" Current Levels	1085	797	1992	822.0	5:00	2.03	5:20
Sensitivity Case 2	1090	797	1992	822.3	5:00	2.03	5:20
Sensitivity Case 5	1080	796	1992	821.7	5:10	1.97	5:30
Sensitivity Case 6	1085	796	1992	821.9	5:00	2.07	5:20
Sensitivity Case 1	1090	796	1992	822.2	5:00	2.08	5:20
Sensitivity Case 4	1108	798	1983	818.1	4:10	1.79	4:40
Sensitivity Case 3	1090	797	1983	817.3	4:30	1.76	5:00

The complete set (headwater and tailrace) of tabulated results for the stage-flow hydrographs at Keowee Dam, ONS Intake Canal Dike, and Little River Dam are presented in Appendix E. Appendix E1 provides results for the tailrace at Jocassee Dam along with the respective headwater results for Keowee Dam, ONS Intake Canal Dike, and Little River Dam. Appendix E2 provides the tailrace results for Keowee Dam and ONS Intake Canal Dike.

Additional results presented in Appendix E include:

- Keowee Dam cross section at peak elevation (Appendix E3);
- Keowee Dam cross section near peak discharge (Appendix E4);
- Keowee Dam headwater and tailrace profile performance at Model times 0:00, 2:30, 3:30, 4:00, and peak headwater/tailrace conditions (Appendix E5);
- ONS Intake Canal Dike cross section at peak elevation (Appendix E6);
- ONS Intake Canal Dike cross section near peak discharge (Appendix E7);
- ONS Intake Canal Profile with maximum headwater and maximum tailrace elevations (Appendix E8);
- Little River Dam cross section at peak elevation (Appendix E9);
- A 3-D perspective of Lake Keowee during normal reservoir conditions (Appendix E10);
- A 3-D perspective of Lake Keowee during peak reservoir conditions associated with the dam failures at Jocassee Dam, Keowee Dam, ONS Intake Canal Dike, and Little River Dam (Appendix E11); and
- Maximum water surface profile along Keowee-Seneca-Savannah rivers (Appendix E12).

The March 2009 Model incorporated the same dam failure scenarios that were simulated in the September 2008 DAMBRK model as referenced in Table 8. The side-by-side results comparison are presented in Table 15. In addition, the December 2008 HEC_RAS model results are presented in Table 16. Recall the DAMBRK model employed 31 cross sections to represent the river reach between Jocassee, Keowee, and Hartwell dams with limited cross section points to define the shape due to model constraints. The December 2008 HEC_RAS model employed 149 cross sections along the same reach, while the March 2009 Model utilized 1,411 cross sections. HEC_RAS is not constrained in defining the cross section geometry as in DAMBRK. The 2008

HEC_RAS and 1992 DAMBRK models did not account for the dam failures at ONS Intake Canal Dike and Little River Dam. An overview of the maximum Keowee headwater and tailrace results is as follows:

- DAMBRK headwater: 823.5 ft msl,
- 2008 HEC_RAS headwater: 831.5 ft msl,
- 2009 HEC_RAS headwater: 830.7 ft msl,
- DAMBRK tailrace: 807.2 ft msl,
- 2008 HEC_RAS tailrace: 793.3 ft msl,
- 2009 HEC_RAS tailrace: 792.5 ft msl,
- DAMBRK discharge: 3.3 mcfs,
- 2008 HEC_RAS discharge: 3.98 mcfs, and
- 2009 HEC_RAS discharge: 3.22 mcfs.

TABLE 15
COMPOSITE RESULTS: SEPTEMBER 2008 DAMBRK AND MARCH 2009 HEC_RAS MODELS

	Initial Reservoir Elevations (ft msl)			Jocassee Dam						Keowee Dam									ONS Dikes				Little River Dam			
DPC Model Name	Jocassee	Keowee	Jocassee Dam Failure Trapezoid	DAMBRK Tailrace Elevation (ft msl)	HEC_RAS Tailrace Elevation (ft msl)	Model Time	DAMBRK Breach Discharge (mcfs)	HEC_RAS Breach Discharge (mcfs)	Model Time	DAMBRK Reservoir Elevation (ft msl)	HEC_RAS Reservoir Elevation (ft msl)	Model Time	DAMBRK Breach Discharge (mcfs)	HEC_RAS Breach Discharge (mcfs)	Model Time	DAMBRK Tailrace Elevation (ft msl)	HEC_RAS Tailrace Elevation (ft msl)	Model Time	HEC_RAS Reservoir Elevation (ft msl)	Model Time	HEC_RAS Breach Discharge (mcfs)	Model Time	HEC_RAS Reservoir Elevation (ft msl)	Model Time	HEC_RAS Breach Discharge (mcfs)	Model Time
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] Current Levels	[illegible]	797	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sensitivity Case [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sensitivity Case [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.97	[illegible]
Sensitivity Case [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sensitivity Case [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sensitivity Case [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sensitivity Case [illegible]	[illegible]	797	[illegible]	[illegible]	[illegible]	[illegible]	1.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	816.2	[illegible]	[illegible]	[illegible]	817.3	[illegible]	1.76	[illegible]

TABLE 16
COMPOSITE RESULTS: SEPTEMBER 2008 DAMBRK AND DECEMBER 2008 HEC_RAS MODELS

	Initial Reservoir Elevations (ft msl)			Jocassee Dam				Keowee Dam					
DPC Model Name	Jocassee	Keowee	Jocassee Dam Failure Trapezoid	DAMBRK Tailrace Elevation (ft msl)	HEC_RAS Tailrace Elevation (ft msl)	DAMBRK Breach Discharge (mcfs)	HEC_RAS Breach Discharge (mcfs)	DAMBRK Reservoir Elevation (ft msl)	HEC_RAS Reservoir Elevation (ft msl)	DAMBRK Breach Discharge (mcfs)	HEC_RAS Breach Discharge (mcfs)	DAMBRK Tailrace Elevation (ft msl)	HEC_RAS Tailrace Elevation (ft msl)
Restored "1992	1108	798	1992	887.0	873.5	4.5	4.20	823.5	831.5	3.3	3.98	807.2	793.3
"1992" Current Levels	1085	797	1992	877.4	866.0	4.0	3.50	822.3	830.4	3.2	3.70	802.7	787.6
Sensitivity Case 2	1090	797	1992	879.6	867.6	4.1	3.60	822.5	830.7	3.2	3.70	803.8	788.0
Sensitivity Case 5	1080	796	1992	875.0	864.8	3.9	3.30	822.0	829.9	3.2	3.60	802.0	785.3
Sensitivity Case 6	1085	796	1992	877.3	866.6	4.1	3.50	822.3	830.5	3.2	3.60	802.8	787.0
Sensitivity Case 1	1090	796	1992	879.5	867.3	4.1	3.60	822.5	830.9	3.2	3.70	803.6	788.2
Sensitivity Case 4	1108	798	1983	843.3	840.7	2.2	1.80	818.4	822.5	3.0	2.90	795.2	771.1
Sensitivity Case 3	1090	797	1983	835.4	834.6	1.9	1.50	816.9	820.1	2.9	2.80	792.2	766.0

The Model complexity was purposely enhanced to evaluate the dynamic performance of Lake Keowee with respect to the dam failures at Jocassee Dam, Keowee Dam, ONS Intake Canal Dike, and Little River Dam. The focus of the Model results is in the immediate upstream and downstream areas at Keowee Dam and the ONS Intake Canal Dike. The stage hydrograph results presented in Figures 19, 20, and 21 reflect the dynamic performance of Lake Keowee. Figure 19 presents the headwater stage hydrograph overlays of Keowee Dam, ONS Intake Canal Dike, and Little River Dam with respect to their dam crest elevation of 815 ft msl. Figure 19 also demonstrates the flood wave attenuation between Jocassee tailrace and Keowee Dam. The stage hydrographs clearly show the dynamic performance of Lake Keowee given the variable peak reservoir elevations at Keowee Dam, ONS Intake Canal Dike, and Little River Dam.

FIGURE 19
HEADWATER STAGE ASSESSMENT

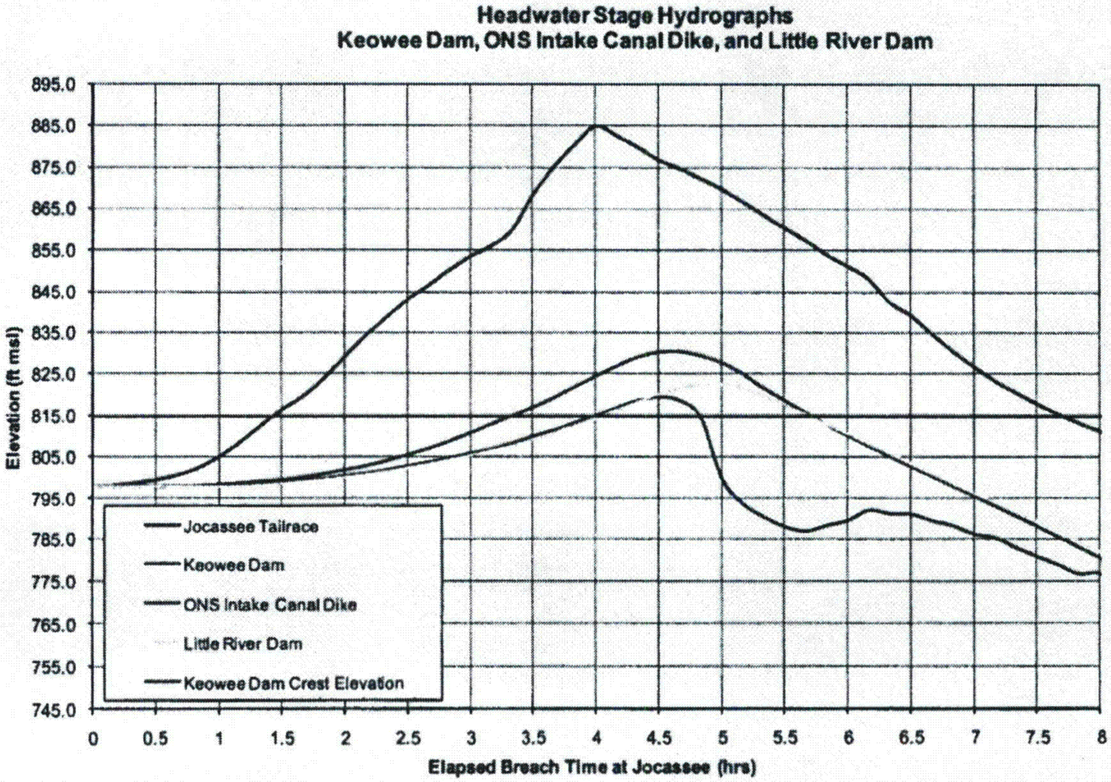


Figure 20 provides the stage hydrograph overlay for the immediate tailrace areas below Keowee Dam and ONS Intake Canal Dike with respect to the ONS station yard elevation of 796 ft msl.

FIGURE 20
ONS STATION YARD, TAILRACE ELEVATIONS

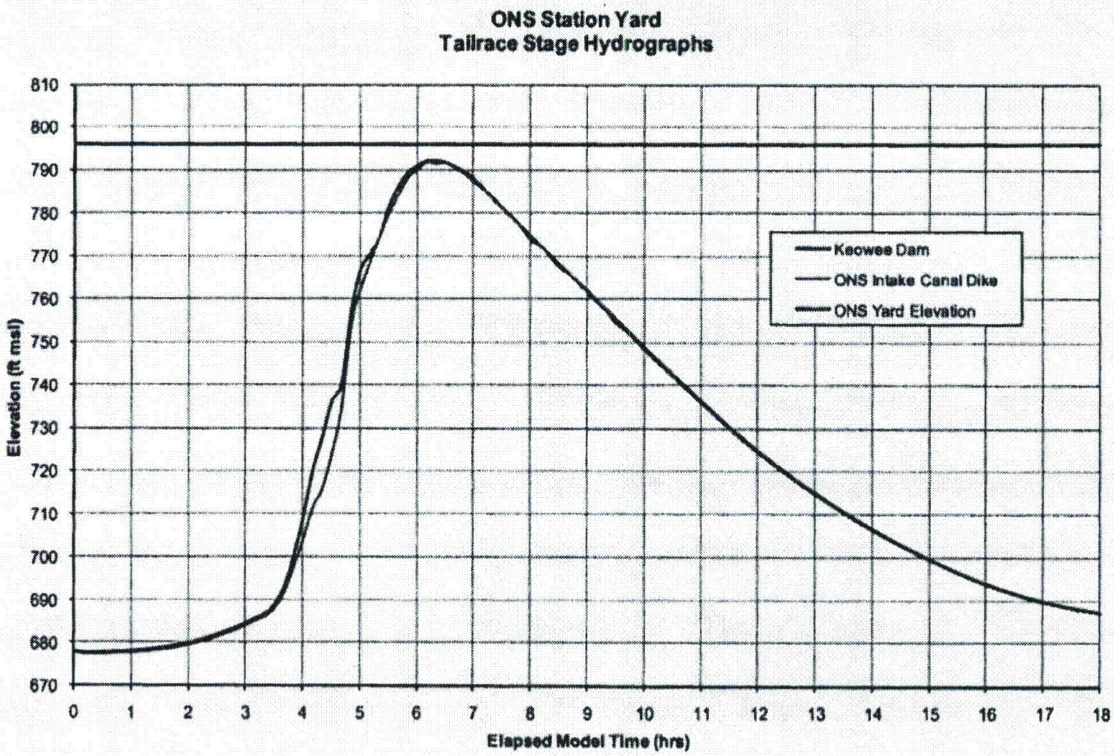


Figure 21 provides the respective stage hydrographs at the excavated connecting canal at the respective entrance points between the Keowee River Basin and Little River Basin. The graph indicates a peak reservoir elevation differential of 9.8 ft from one side of the canal to the other. The modeled channel length conveyed in Figure 21 is approximately 6,800 ft. The peak time differential is 10 minutes. The connecting canal performance represents the dynamic behavior between the two river basins that comprise Lake Keowee. Note that the canal excavation was limited to 710 ft msl at the Little River side of Lake Keowee.

FIGURE 21
CONNECTING CANAL STAGE PERFORMANCE

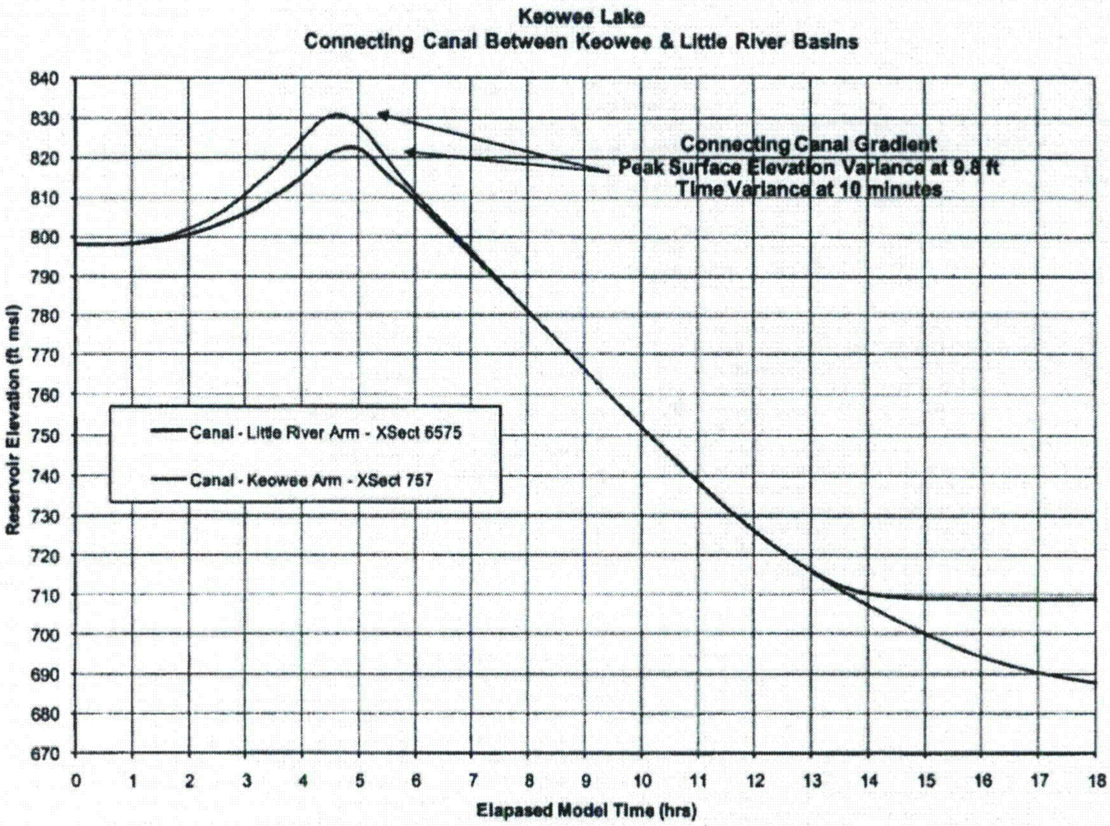


Figure 22 provides the Keowee River peak elevation profile from Jocassee Dam to the confluence with the Little River Dam breach discharge outflow.

FIGURE 22
KEOWEE RIVER PROFILE

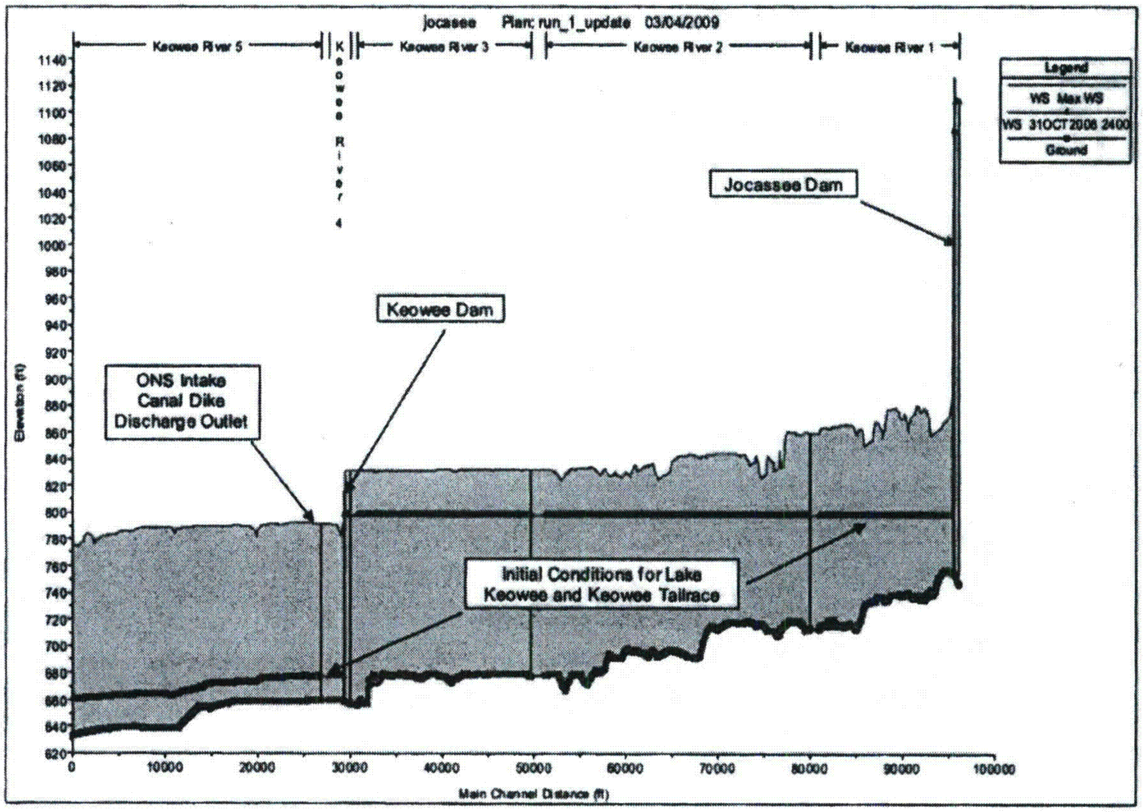
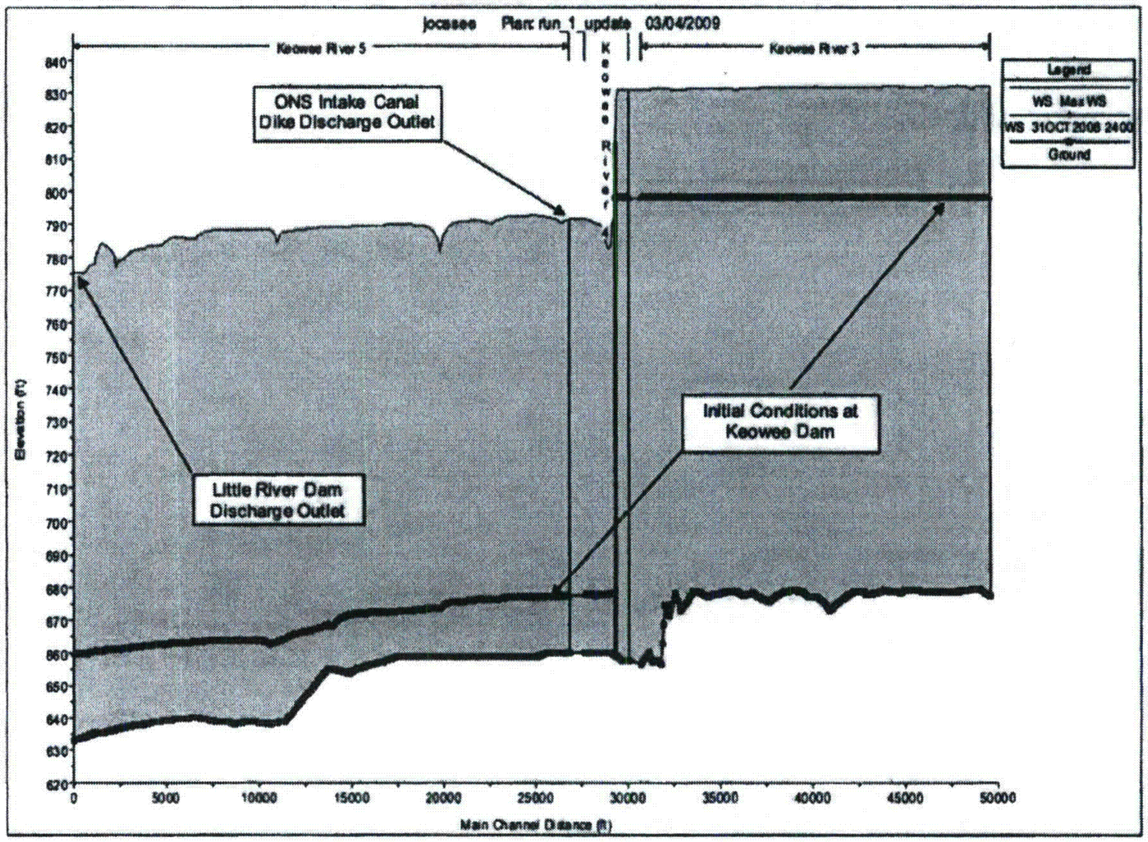


Figure 23 provides a close-up view of the Keowee River peak stage profile upstream and downstream of Keowee Dam. The connecting canal between Keowee River and Little River is located at the upstream end of Keowee River section 3. The ONS Intake Canal Dike breach discharge outflow confluence with the Keowee River is located at the interface between Keowee River sections 4 and 5. The Little River Dam outflow confluence with the Keowee River is located at the downstream end of Keowee River section 5. The dark blue line shown in the profile represents the starting reservoir/river elevations at the very beginning of Jocassee Dam failure.

FIGURE 23
KEOWEE RIVER AT KEOWEE DAM



The Keowee Dam tailrace performance (model time, elevation, and corresponding discharge) is shown in Table 17. The peak tailrace elevation (792.5 ft msl) occurs at elapsed model time 6:20 hours.

TABLE 17
KEOWEE TAILRACE STAGE ASSESSMENT

Keowee Dam Tailrace Performance		
Time (hr)	**Elevation (msl)**	**Discharge (cfs)**
0:00	677.9	45,700
3:30	688.9	172,700
4:00	709.3	627,900
5:00	766.9	2,539,000
6:00	791.2	2,702,000
6:30	792.0	2,297,000
7:00	787.7	1,966,000
8:00	774.9	1,497,000
10:00	750.3	817,700

Figures 24, 25, and 26 provide corresponding graphical results from Table 17. The cross section is located in the immediate tailrace area below Keowee Dam and provides an illustrative representation of the tailrace performance prior to the peak elevation, post Keowee Dam breach, and post breach with receding tailrace.

FIGURE 24A
KEOWEE TAILRACE, PRE-PEAK (TIME 0:00)

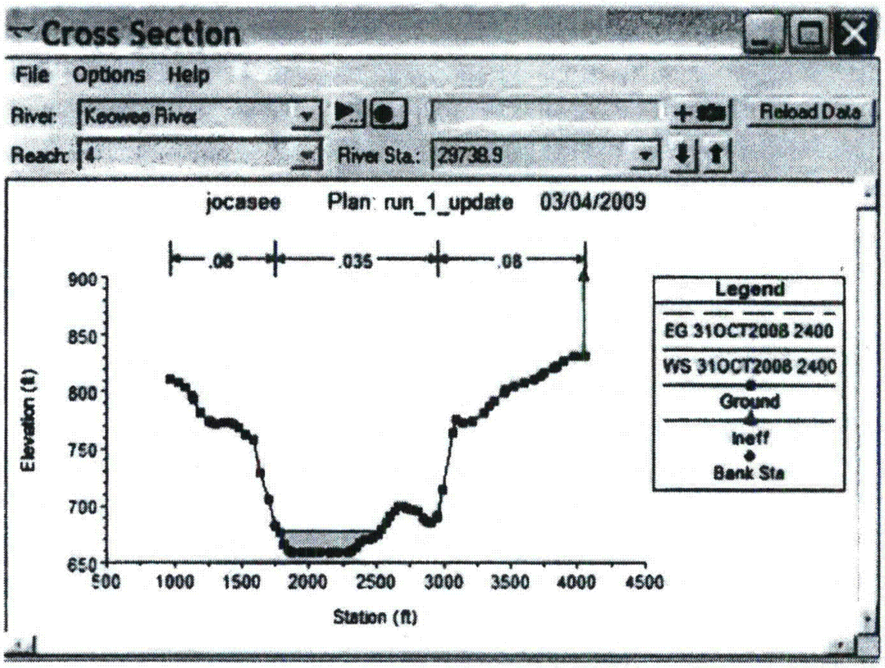


FIGURE 24B
KEOWEE TAILRACE, PRE-PEAK (TIME 3:30)

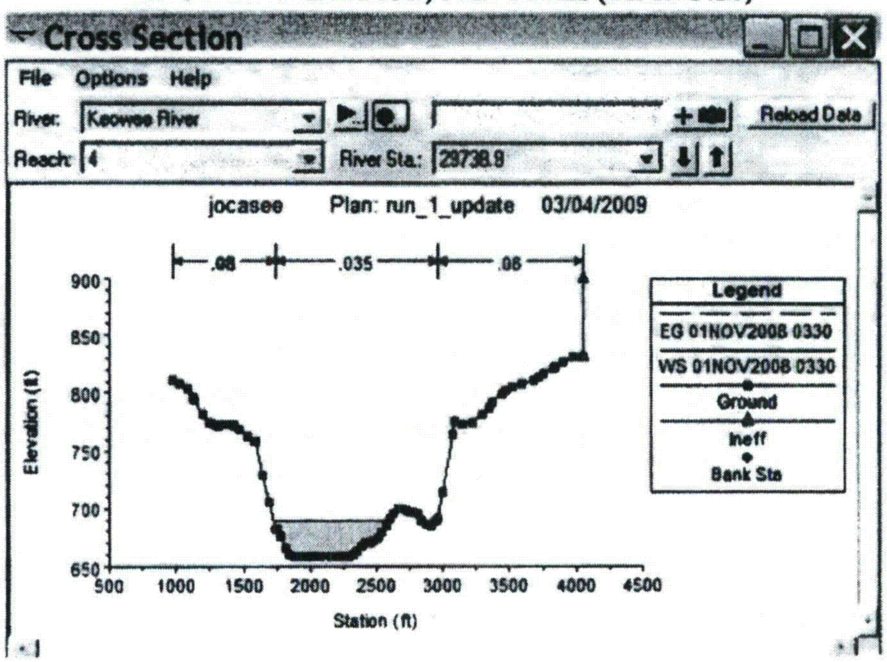


FIGURE 24C

KEOWEE TAILRACE, PRE-PEAK (TIME 4:00)

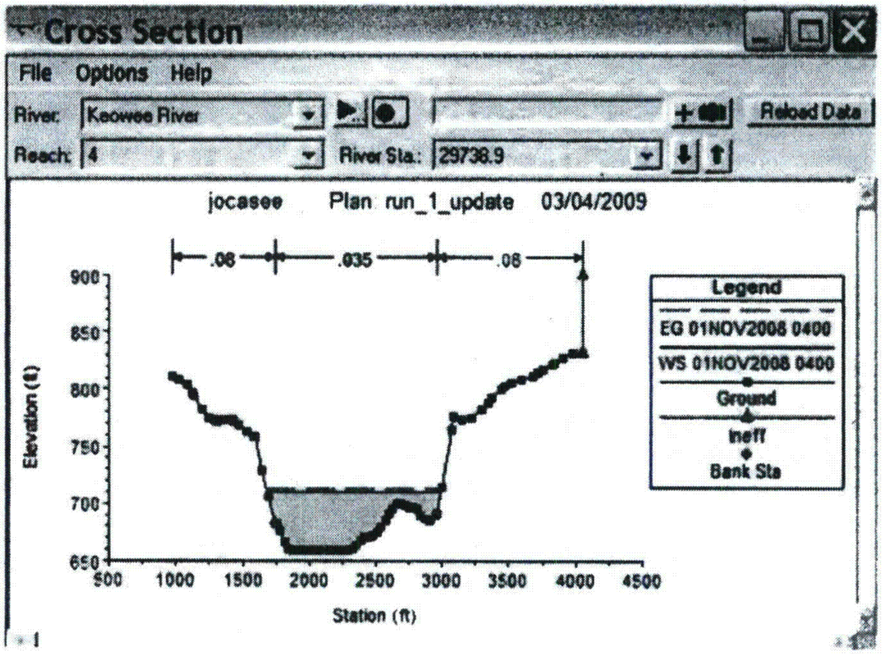


FIGURE 25A

KEOWEE TAILRACE, POST BREACH (TIME 5:00)

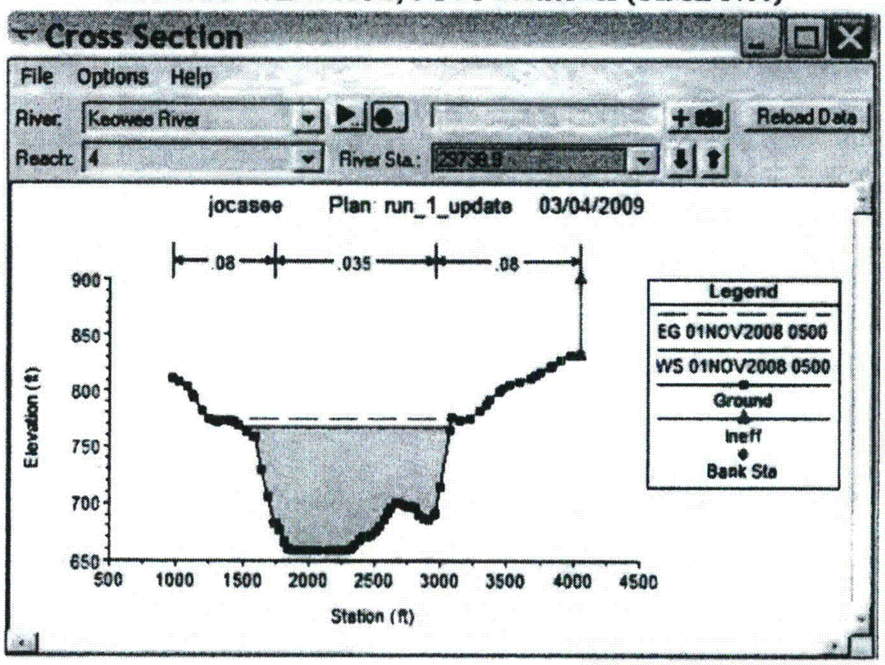


FIGURE 25B
KEOWEE TAILRACE, POST BREACH (TIME 6:00)

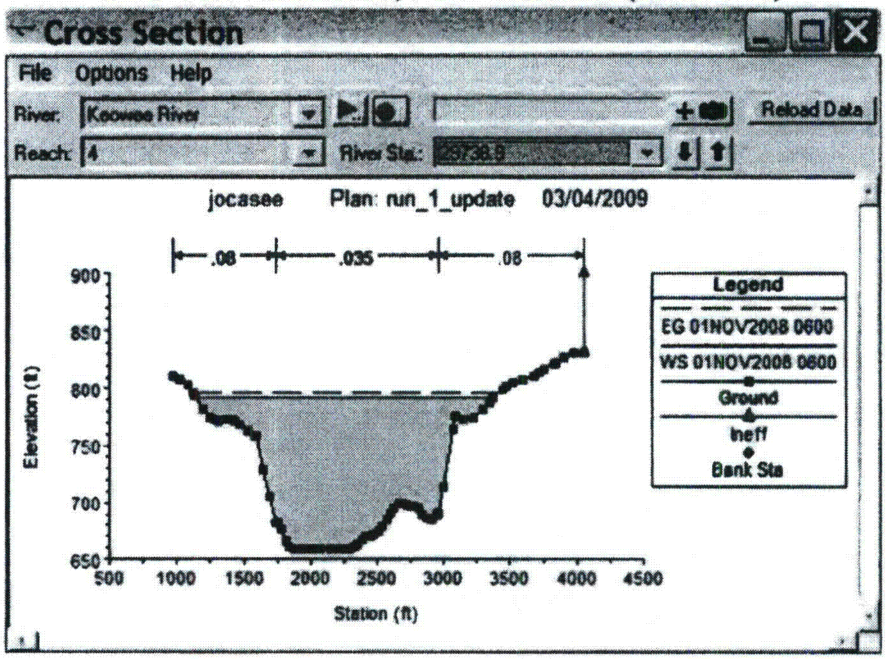


FIGURE 25C
KEOWEE TAILRACE, POST BREACH (TIME 6:30)

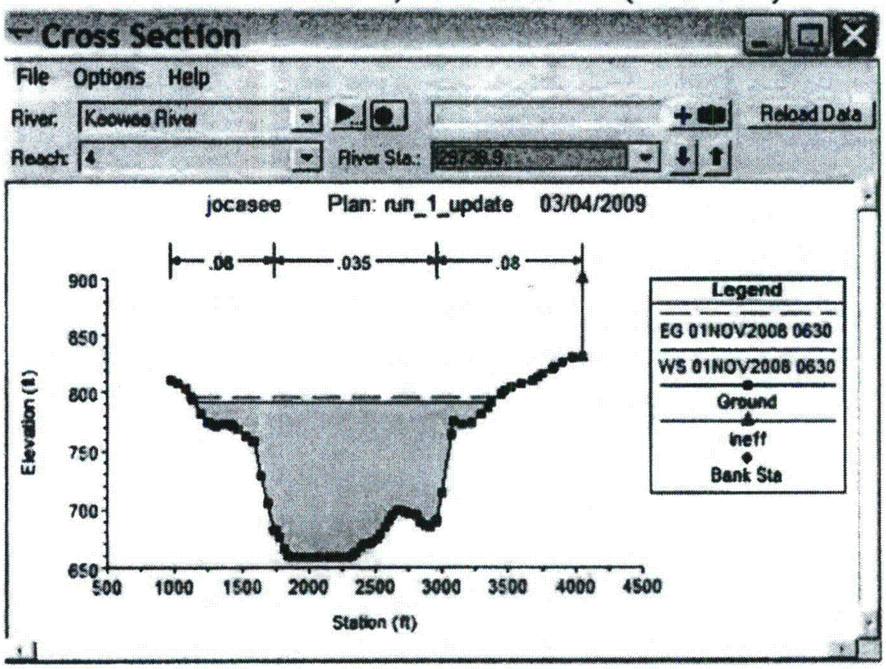


FIGURE 26A

KEOWEE TAILRACE, POST BREACH RECEDING (TIME 7:00)

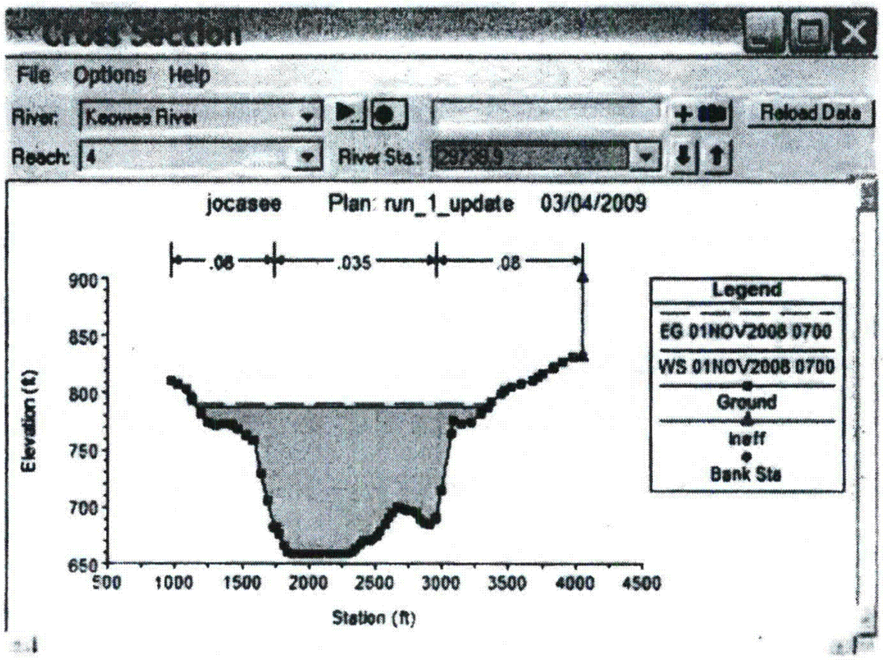


FIGURE 26B

KEOWEE TAILRACE, POST BREACH RECEDING (TIME 8:00)

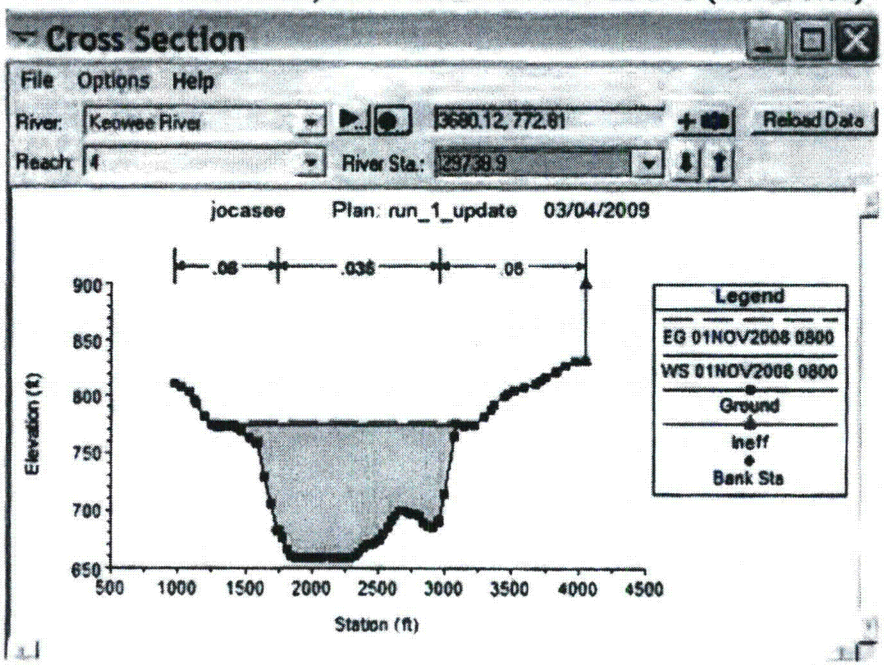


FIGURE 26C

KEOWEE TAILRACE, POST BREACH RECEDING (TIME 10:00)

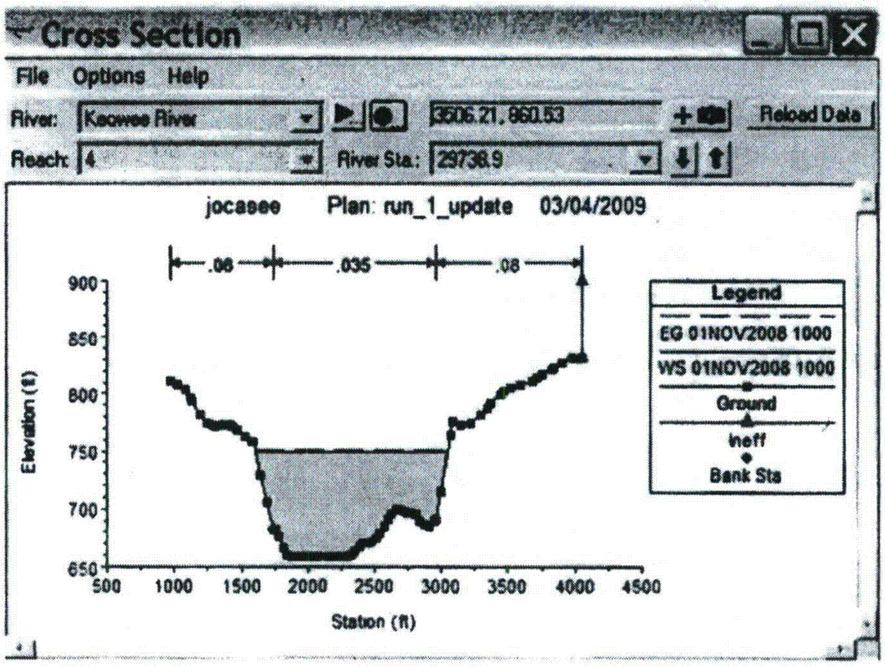


Table 18 provides a time lapse overview of the upstream reservoir performance at Keowee Dam, ONS Intake Canal Dike, and Little River Dam. Featured results include initiation of dam failure due to overtopping (815.5), peak reservoir elevation associated with combined dam breach and overtopping, and post dam breach reservoir recession.

TABLE 18
INITIAL DAM OVERTOPPING ASSESSMENT

Dam/Dike	Time (hr)	Reservoir Elevation (ft msl)
Keowee	0:00	798.1
	3:10	813.2
	3:19	815.0
	3:20	815.2
	3:22	815.5
	3:30	817.2
	4:40	830.7
	5:00	828.0
	5:30	818.8
	5:40	815.9
	5:43	815.0
	5:50	813.0
ONS Dike	0:00	798.1
	4:00	815.0
	4:03	815.5
	4:10	816.9
	4:30	819.5
	4:40	818.7
	4:49	815.0
	4:50	814.7
Little River	0:00	798.1
	4:00	814.7
	4:05	815.5
	4:10	816.5
	5:00	822.8
	5:30	817.8
	5:40	815.5
	5:50	813.0
Peak Reservoir Elevation		
Dam and Dike Crest at 815.0 ft msl		

Section 6
Conclusions

The Model results presented in this report represent a 1-D flow model that contains significantly more geometric and hydraulic channel data than contained in the 2008 HEC_RAS and September 2008 DAMBRK models. Model results of the simulated Jocassee Dam failure indicate the maximum peak reservoir elevation upstream of Keowee Dam is approximately 830.7 ft msl, representing an overtopping depth of 15.7 ft. The overtopping depth and reservoir elevation represent the combined breach and overtopping discharge influence at Keowee Dam. The maximum peak tailrace elevation immediately downstream of Keowee Dam is 792.5 ft msl. The peak discharge immediately above and below Keowee Dam is approximately 3.22 mcfs. The maximum water surface elevation immediately upstream of ONS Intake Canal Dike is approximately 819.5 ft msl, representing an overtopping depth of 4.5 ft. The maximum peak tailrace elevation immediately downstream of ONS Intake Canal Dike is approximately 791.8 ft msl. The peak discharge immediately above and below ONS Intake Canal Dike is approximately 0.55 mcfs.

Model results indicate that the maximum tailrace flood elevations for all scenarios are less than 796 ft msl. The model time representing the peak reservoir elevations at Keowee Dam and ONS Intake Canal Dike are 4:40 hours and 4:30 hours, respectively, and represent the dynamic impacts associated with Lake Keowee cross section geometry, dam failure durations at Jocassee-Keowee-ONS Intake Canal Dike, and breach size. The reservoir elevation and discharge performance at Keowee Dam and ONS Intake Canal Dike behave proportionally with the Jocassee Dam reservoir elevation and dam breach parameters.

The 1992 Jocassee DAMBRK and the September 2008 DAMBRK models consisted of 31 cross sections that defined the 42-mile reservoir system between Jocassee and Hartwell dams. The 2008 HEC_RAS model utilized 149 cross sections for the same reservoir system while the 2009 HEC_RAS model consisted of 1,411 cross sections. The 2008 model represents a five-fold increase in detail over the 1992 DAMBRK model. The 2009 model represents a nine-fold and 45-fold cross section increase over the 2008 and 1992 models, respectively.

The DAMBRK and HEC_RAS model results represent results intended for two different purposes. The 1992 DAMBRK results established the overall relative EAP flood inundation maps associated with a failure at Jocassee Dam. Limited cross sections were required to achieve the inundation objective. An inherent constraint with DAMBRK is the limited definition allowed at any given cross section due to the constraint on the number of coordinates (i.e., stage, elevation). The 1992 DAMBRK and 2008 HEC_RAS models utilized large water storage areas to reflect Keowee Lake tributary performance and did not model the impact of the ONS intake canal or the dam failures at ONS Intake Canal Dike and Little River Dam. The 2009 HEC_RAS Model exchanged the previously modeled large storage areas in Lake Keowee in favor of defined tributary and main stem cross sections to define complex hydraulic channels and terrain associated with the Keowee River and Little River basins including the ONS intake canal. In addition, the final Model results reflect the influence of dam failures at ONS Dike and Little River Dam. The 2009 Model sought focused results at Keowee Dam and ONS Intake Canal Dike through additional geometric definition and simulation options in order to assess postulated dam failure impacts at ONS.

The Lake Keowee reservoir storage capacity calculation results contained in Table 9 along with the Manning's n value sensitivity results in Table 10 provide reasonable acceptance of the model's performance. The Model reservoir volume calculation resulted in a variance of -2.6% when compared against the documented volume at same reservoir elevation. Manning's n sensitivity model runs provided variable results in peak headwater elevations, peak discharge, and peak tailrace elevations. Given the dynamics of an actual dam breach, the overall headwater elevation variance range at Keowee Dam and ONS Intake Canal Dike was <0.5 ft. The Keowee Dam breach discharge variance represents an overall discharge range of <1.9%. The tailrace elevation range is approximately 6.6 ft, representing an overall tailrace depth change of <5%.

Breach times and water surface elevations are approximations limited by the uncertainties associated with dam failure flood routing should not be considered absolute numbers due to the variety of unknowns. Uncertainties of input variables include breach formation size and time to failure, complex geometry of Lake Keowee and Lake Hartwell, assumed spillway gate operations at Keowee and Hartwell dams, and calibrated model performance against known

extreme flood events resulting in reservoir elevations at/near dam crest elevations. There are no known flood-discharge events exceeding full pond (elevation 800 ft msl) in the Keowee Development's history, nor in the history of the Keowee River. The largest pre-impoundment discharge on the Keowee River was around 25,200 cfs (August 1940), which is approximately equal to a 50-year return period flood. The flood of record since the project was constructed occurred on August 17, 1994, as a result of Tropical Storm Beryl. During this time, radial gates 2 and 3 were opened 15 ft and radial gates 1 and 4 were opened 6 ft. The peak discharge from the project during this event was measured to be about 54,000 cfs, including approximately 9,400 cfs through the generating units (Duke 1995).

Section 7
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