KEOWEE-TOXAWAY HYDROELECTRIC PROJECT

FERC NO. 2503

OPERATIONS MODEL STUDY

SAVANNAH RIVER BASIN

MODEL LOGIC AND VERIFICATION REPORT

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EXECUTIVE SUMMARY

The Keowee-Toxaway Hydroelectric Project (FERC No. 2503) (Project), owned and operated by Duke Energy Carolinas, LLC (Duke Energy) is located in the upper Savannah River Basin and consists of two developments: Jocassee and Keowee. As part of the Federal Energy Regulatory Commission (FERC) relicensing of the Project, Duke Energy contracted with HDR Engineering, Inc. of the Carolinas (HDR) to develop an operations model of six hydroelectric facilities within the Savannah River Basin. The operations model developed includes the Duke Energy-owned Bad Creek Project, the Jocasse Development, and Keowee Development as well as three downstream U.S. Army Corps of Engineers (USACE) projects (Hartwell, Richard B. Russell, and J. Strom Thurmond). The six aforementioned Duke Energy and USACE hydro facilities are collectively referred to as "the system." The model is intended to be used as a tool to assist in evaluating various Stakeholder interests and reevaluation of the 1968 Operating Agreement (1968 Agreement) between Duke Energy, the USACE, and the Southeastern Power Administration (SEPA) (Duke Power Company 1968). This was performed by reviewing relative change between proposed operational modifications at the Keowee and Jocassee developments as outlined in the Operations Model Study Plan (Duke Energy 2011).

Two existing operations model platforms have been customized to the appropriate characteristics of the system. CHEOPS™ (Computerized Hydro Electric Operations Planning Software) is a proprietary software model owned by HDR and HEC-ResSim (Hydrologic Engineering Center's Reservoir System Simulation) is a product of the USACE. Both platforms are capable of modeling reservoir operations in the basin and of providing the needed water balance assessments. This report characterizes the development and verification of the customized CHEOPS and HEC-ResSim Models by loading the physical and operational parameters specific to the Project and, as appropriate, the USACE-owned Hartwell, Richard B. Russell, and J. Strom Thurmond Projects into the models. The operating logic for six reservoirs has been added into each model based on existing and future station operating plans in accordance with information provided by Duke Energy and the USACE. Operating logic is a single set of rules per scenario and does not account for changes in external conditions for a single model run. A model calibration and validation process has been developed using a mass balance approach over the period of 1998-2008 applying the basic law of mass continuity between the reservoirs. The period was selected based on the completion of all reservoirs and the best available records of constant plant operation and reservoir elevations. Both models were calibrated and validated using a similar procedure and dataset. A significant portion of the work for the operation model development included the reconstruction of annual inflow hydrology for the Savannah River (SR) Basin. The unimpaired inflow (UIF) data for the SR Basin was generated from existing hourly and/or daily reservoir elevations, generation, spillage and other operations data. The simulation models are decision support tools and are not intended to simulate or predict exact future conditions on a daily or annual basis. The models were constructed to compare different scenarios. Both models use historic inflows (i.e., UIF) to simulate likely future conditions, as if the inflow will occur in the same pattern in the future as occurred in the past.

The description of the two models and the verification results are presented in this report in two separate sections. The CHEOPS model is described in Sections 3 and 4, and the ResSim model in Sections 5 and 6. Description of common inputs has been repeated for each model. This report supersedes the previously submitted February 2012 CHEOPS Model Operations/Verification Report and January 2013 Addendum (HDR 2012, 2013).

Development of the Savannah River CHEOPS Model (SR CHEOPS Model) was based on input and physical characteristics of each facility previously developed for the same river basin as part of the Savannah River ResSim Model (SR ResSim Model) and updated over time as information became available (HDR 2014). The SR ResSim Model was originally developed by the USACE and has since been updated to assist in the reevaluation of the 1968 Agreement between Duke Energy and the USACE (Duke Power Company 1968). In conjunction with the SR ResSim Model, the SR CHEOPS Model, described in this report, was used throughout the FERC relicensing process for the Project (HDR 2014). The SR ResSim Model has been developed and verified using Version 3.1 RC3 Revision 3.1.7.157 Build 3.1.7.157R June 2011 of the USACE HEC-ResSim software (Build 157) (USACE 2007).

Using average daily inflow as input, the SR CHEOPS and SR ResSim Models simulate operations to budget water to ensure that all constraints (physical, environmental, and operational) are met while maximizing peak period hydro turbine energy as a lower priority objective. These models provide for user-defined customization of specific constraints within the system, such as flow requirements, target reservoir elevations, powerhouse equipment constraints, and reservoir storage balancing between hydro development operators.

The purpose of this report is to document inputs and assumptions used in the development of the two models, to demonstrate that the models reasonably characterize operations of the three Duke Energy and three USACE facilities modeled, and to demonstrate the models are adequate for use in evaluating the effects of alternative operating scenarios.

Model verification is intended to validate the input data and ability of the programmed logic in simulating daily hydroelectric and reservoir operations. HDR performed model verification of both the SR CHEOPS and SR ResSim Models using comparisons of actual and model-estimated generation and total discharge. The verification simulations were completed for recent hydrologic years with best available historical reservoir operations over a wide range of hydrologic and reservoir operations conditions.

The SR CHEOPS and SR ResSim Models are coded to run day-to-day operations based on a single set of operating conditions or rules. Actual project operations generally follow the operating rules; however, human intervention periodically deviates from the general operating rules to accommodate day-to-day realities such as equipment failure and maintenance, changing hydrologic conditions, power demands, and other factors.

The verification for the SR CHEOPS and SR ResSim Models was performed using historical operations data provided by Duke Energy and the USACE. Verification scenarios were developed to test the facility operation rules, provided by Duke Energy and the USACE, in an attempt to replicate daily human decision making with respect to typical operating requirements of the system. Verification of the SR CHEOPS and SR ResSim Models was completed using two different scenarios (model runs). For consistency between the SR CHEOPS and SR ResSim Models, the first model run performs a verification of the model input data, logic, and conditions of the Historical Baseline scenario for calendar years 1998 through 2008. In addition to the Historical Baseline scenario, a second verification scenario (v2007) was developed using the SR CHEOPS and SR ResSim Models to simulate the detailed operations for calendar year 2007.

In the opinion of HDR, verification results show the two operations models and the hydrologic inputs compare favorably to historical data, reasonably characterize system operations, and are appropriate for use in evaluating the effects of alternative operating scenarios on generation, reservoir levels, and outflows. The CHEOPS and ResSim software and the Savannah River operations models are tools that, as this report demonstrates, can be successfully used to evaluate the relative sensitivity and response of the system modeled to changing operational constraints. As with any model, accuracy is highly dependent on input data; consequently, model results should be viewed in a relative, rather than an absolute, context.

1.0 INTRODUCTION

The Keowee-Toxaway Hydroelectric Project (FERC No. 2503) (Project), owned and operated by Duke Energy Carolinas, LLC (Duke Energy) is located in the upper Savannah River Basin and consists of two developments: Jocassee and Keowee. As part of the Federal Energy Regulatory Commission (FERC) relicensing of the Project, Duke Energy contracted with HDR Engineering, Inc. of the Carolinas (HDR) to develop an operations model of six hydroelectric facilities within the Savannah River Basin. The operations model developed includes the Duke Energy-owned Bad Creek Project, the Jocassee Development, and Keowee Development as well as three downstream U.S. Army Corps of Engineers (USACE) projects (Hartwell, Richard B. Russell, and J. Strom Thurmond). The six aforementioned Duke Energy and USACE hydro facilities are collectively referred to as “the system.” Two operations models were developed for this system: one model utilized HDR’s proprietary Computer Hydro Electric Operations and Planning Software (CHEOPS) and incorporated the six aforementioned facilities along the main stem of the Savannah River Basin, and the other model utilized Version 3.1 RC3 Revision 3.1.7.157 Build 3.1.7.157R June 2011 of the USACE Hydrologic Engineering Center’s Reservoir System Simulation (HEC-ResSim) software (Build 157) (USACE 2007).

CHEOPS is specifically designed to evaluate the effects of operational changes and physical modifications at multi-development hydroelectric projects. CHEOPS has been applied to evaluate the physical and operational changes considered during the FERC relicensing of more than 25 projects. The Savannah River CHEOPS Model (SR CHEOPS Model), in conjunction with the Savannah River ResSim Model (SR ResSim Model) of the system (HDR 2014) developed to reevaluate the 1968 Operating Agreement (1968 Agreement) between Duke Energy and the USACE (Duke Power Company 1968), was applied throughout the FERC relicensing process for the Project (Duke Energy 2011).

HDR created the CHEOPS hydropower system simulation model as a tool for evaluating a wide range of physical changes (e.g., turbine upgrades) and operational constraints (e.g., minimum flows) associated with relicensing or upgrading single and multiple development hydro systems. One of the many strengths of the CHEOPS model is the degree of customization each individual model contains. The model is tailored to meet the demands of the particular system being modeled. The unique CHEOPS program architecture provides a platform for investigating project-specific features as defined by stakeholder interests, represented by the Operating Scenario Committee (OSC) for the FERC relicensing of the Project. The SR CHEOPS Model was custom-configured for the system based on the specific system constraints such as flow requirements, target reservoir elevations, powerhouse equipment constraints, and reservoir storage balancing between hydro development operators.

The original USACE Savannah River ResSim Model was based on Version 3.1 Beta III Revisions 3.1.4.36 Build 3.1.4.36R October 2008 of the USACE HEC-ResSim software. The USACE model contained minimal logic for the operation of the Jocassee and Keowee Developments and did not include the Bad Creek Project. As previously stated, the SR ResSim Model has since been updated. The SR ResSim Model includes a definition of the physical pumping and generation capabilities at Jocassee Station, physical generation capabilities at Keowee Station, as well as operational logic to reflect actual reservoir operations at both developments. The updated model also includes Bad Creek reservoir operations and physical pumping and generation capabilities. The newer "Build" of the ResSim software provides additional logic support for the system storage balance rule, which is a significant operational driver in this system.

The two models utilize daily flows, plant-generating characteristics, and operating criteria of the system to simulate operation, allocate flow releases, and calculate energy production within the system. The SR CHEOPS Model calculates headwater elevation, headlosses, net head, turbine discharge and spill, and power generation in 15-minute increments. The SR ResSim Model uses a daily time step to perform similar operations calculations. Both models are designed for long-term analysis of the effects of operational and physical changes made to the modeled hydro-system.

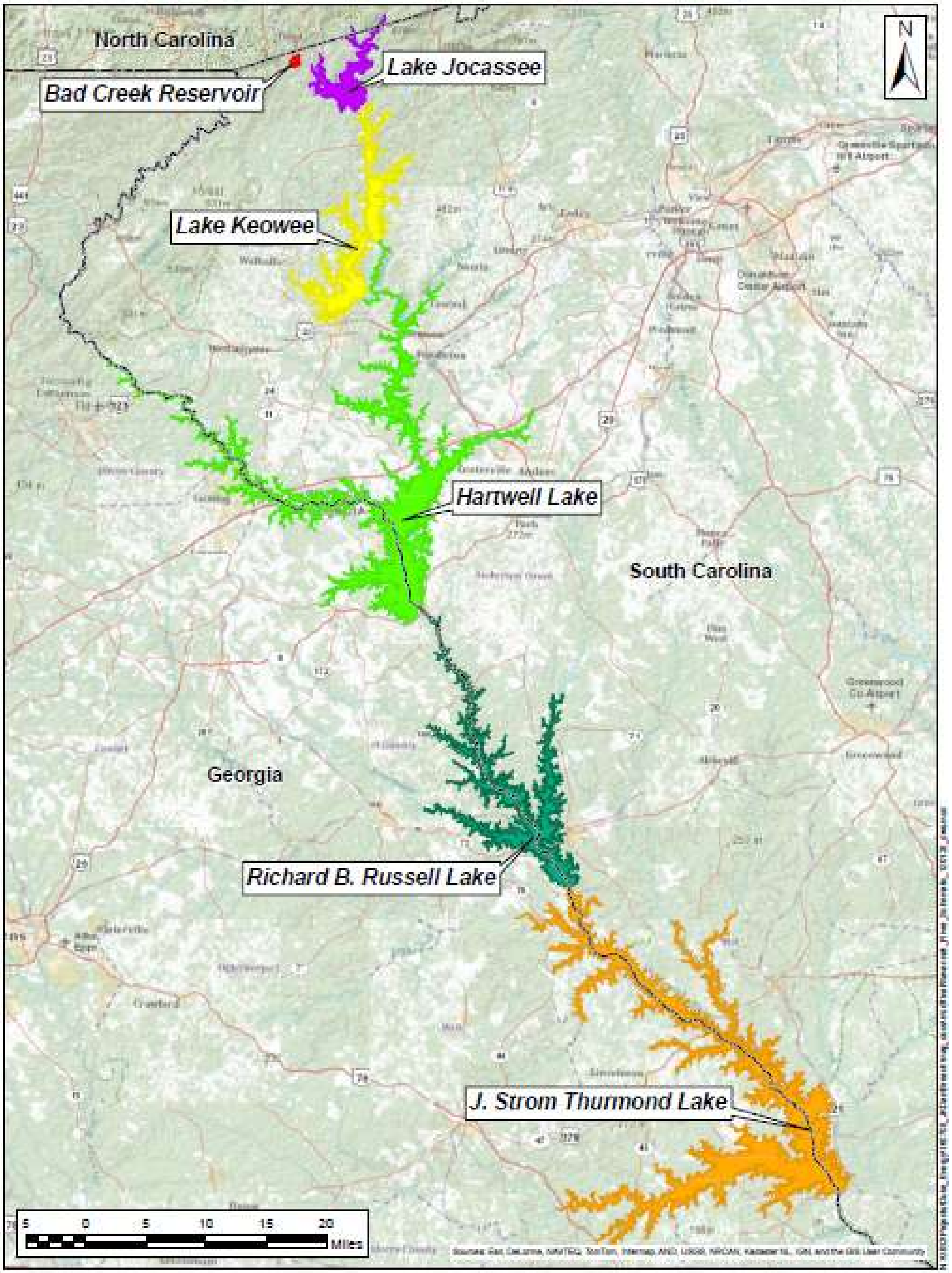
Model verification is intended to validate the input data and ability of the programmed logic in simulating daily hydroelectric and reservoir operations. A "Baseline" scenario was established following the current system-wide operation rules outlined in the model verification process. The Baseline scenario does not include historical USACE drought operations (J. Strom Thurmond Project flow requirements), and historical water use or flow requirements (historical operations) applied in the verification scenarios. The Baseline scenario is used as the baseline or starting point (operating rules and settings) for all subsequent analyses. HDR performed model verification using comparisons of actual and model-estimated generation and total discharge. The verification simulations were completed for recent hydrologic years with best available historical reservoir operations over a wide range of hydrologic and reservoir operations conditions. The purpose of this report is to document inputs and assumptions used in the development of the SR CHEOPS and SR ResSim Models, to demonstrate the models reasonably characterizes operations of the six facilities modeled, and to demonstrate the models are adequate for use in evaluating the effects of alternative operating scenarios.

The SR CHEOPS and SR ResSim Models are coded to run day-to-day operations based on a single set of operating conditions or rules. Actual project operations generally follow the operating rules; however, human intervention periodically deviates from the general operating rules to accommodate day-to-day realities such as equipment failure and maintenance, changing hydrologic conditions, power demands, and other factors. In addition to differences between modeled operations versus actual operations that include human interventions, there are also inherent discrepancies due to input data inaccuracies (e.g., differences in calculated hydrology data, turbine or generator efficiencies, or reservoir storage curves). It is important to understand model results will never completely match historical or future operations due to these differences between actual operating conditions and modeled conditions.

The SR CHEOPS and SR ResSim Models include a definition of the physical pumping and generation capabilities at the Bad Creek, Jocassee, and Richard B. Russell facilities, and physical generation capabilities at the Keowee, Hartwell, and J. Strom Thurmond facilities, as well as operational logic to reflect reservoir operations at all facilities. The system storage balance logic in the model allows the user to define the storage relationship between the reservoirs in the system so the Duke Energy reservoir storage (Lake Jocassee and Lake Keowee) will closely follow the USACE reservoir storage drawdown in accordance with the 1968 Agreement between Duke Energy and the USACE (Duke Power Company 1968). The reservoir storage-volume relationships modeled for the Jocassee, Keowee, Hartwell, Richard B. Russell, and J. Strom Thurmond facilities reflect the 2010 sedimentation estimates developed by HDR. The Duke Energy storage-volume relationships were revised based on bathymetric data collected in 2010, and the USACE storage-volume relationships were updated based on published sedimentation rates from the Savannah River Basin. Sedimentation rates were converted to sediment volume using methods outlined in USACE EM 1110-2-4000 (USACE 1995) and estimated compressed density of the sediment. A summary of the sedimentation calculations is provided in Appendix A.

Major features of the facilities in the basin are shown in Figure 1-1. This schematic is the basis for the conceptual model that was used to develop the SR CHEOPS Model. The SR CHEOPS and SR ResSim Models have six nodes that correspond to the major hydrologic junctures in the modeled river system. The models account for inflows, discharge, change in reservoir storage, and power generation at the various nodes.

FIGURE 1-1
SAVANNAH RIVER BASIN



2.0 PROJECT DATA

Duke Energy owns and operates the Bad Creek Pumped Storage Project and the Keowee-Toxaway Project (consisting of the Jocassee Development and the Keowee Development); the USACE owns and operates the Hartwell Project, Richard B. Russell Project, and J. Strom Thurmond Project. Each development is linked in series within the models and consists of dams and multi-unit powerhouses as shown in Table 2-1.

TABLE 2-1
SAVANNAH RIVER BASIN - MODELED SYSTEM

Facility	Upstream Reservoir	Project Type
Bad Creek	—	Pumped Storage
Jocassee	Bad Creek	Pumped Storage
Keowee	Jocassee	Conventional Hydro
Hartwell	Keowee	Conventional Hydro
Richard B. Russell	Hartwell	Conventional Hydro & Pumped Storage
J. Strom Thurmond	Richard B. Russell	Conventional Hydro

2.1 Bad Creek Project

Bad Creek and West Bad Creek were dammed to form the approximately 300-acre Bad Creek Reservoir located 8 miles north of Salem in Oconee County, South Carolina. Bad Creek Reservoir serves as the upper reservoir for the Bad Creek Project, a pumped storage facility that uses Lake Jocassee as its lower reservoir. The Bad Creek Project began producing energy on March 8, 1991. The powerhouse contains four reversible motor-pump/turbine-generator units.

The Bad Creek Project Normal Full Pond Elevation is 2,310 feet above mean sea level (ft AMSL), and normal minimum elevation is 2,150 ft AMSL (Duke Energy 2008). All vertical elevations referenced in this report are National Geodetic Vertical Datum (NGVD) 1929 unless noted. There is no license-required operating guide curve; rather, the reservoir is operated as needed for generation, typically fluctuating between 2,280 and 2,300 ft AMSL. Historically, some periods show weekly reservoir drawdown with reservoir refill on the weekends. Both the

SR CHEOPS and SR ResSim Models use the Normal Full Pond Elevation of 2,310 ft AMSL and normal minimum elevation of 2,150 ft AMSL for the Bad Creek Project.

2.2 Jocassee Development

The approximately 7,980-acre Lake Jocassee is fed by four rivers: Whitewater, Thompson, Horsepasture, and Toxaway. The Jocassee Development, the upstream development of the Keowee-Toxaway Project, was placed in service on December 19, 1973 (Units 1 and 2) and May 1, 1975 (Units 3 and 4), and is a pumped storage facility that uses Lake Keowee as its lower reservoir.

The Lake Jocassee Normal Full Pond Elevation is 1,110 ft AMSL and the normal minimum elevation is 1,080 ft AMSL (HDR 2010). For modeling purposes, Duke Energy developed an annual cycle conservation pool guide curve where the reservoir is brought to 1,109.5 ft AMSL from May 1 through October 15, then lowered gradually to 1,106 ft AMSL on January 1, then refilled gradually to 1,109.5 ft AMSL on May 1. Both the SR CHEOPS and SR ResSim Models use this conservation pool guide curve for Lake Jocassee.

2.3 Keowee Development

Lake Keowee is formed by two parallel watersheds that are connected by a 2,000-foot-long canal. The watershed draining directly into Lake Keowee is approximately 435 square miles. The reservoir surface area is approximately 17,660 acres at the Normal Full Pond Elevation of 800 ft AMSL (HDR 2012). The hydroelectric station entered commercial operation on April 17, 1971 and contains two conventional turbine-generator units.

The reservoir's normal operation is characterized by maintaining the reservoir level between the lower and upper extremes of the normal operating range, which are 794.6 ft AMSL and 800 ft AMSL, respectively. Historically, Duke Energy has not used a target or guide curve in the operations of Lake Keowee.

For SR CHEOPS modeling purposes, a target curve of 799 ft AMSL from May 1 to October 15, which then lowers gradually to 796 ft AMSL on January 1 and refills gradually by May 1, has been simulated to calculate usable storage for coordination with the USACE. The modeled target (guide) curve from 799 to 796 ft AMSL is used in model scenarios for coordination of storage balance with the USACE. Based on a review of historical operations of Lake Keowee, special code was added to the SR CHEOPS Model for Lake Keowee to retain water in the Jocassee-Keowee pumped storage system for pumping and generating cycles. Because of this unique requirement, the model's target curve is not followed as strictly specified under normal hydroelectric reservoir operating conditions. This was simulated in the SR ResSim Model by a flat guide curve of 799.9 ft AMSL for Lake Keowee.

Based on the additional SR CHEOPS Model control at Lake Keowee, the model will not schedule discretionary releases from Lake Keowee unless the reservoir is nearing Full Pond and available storage for capturing runoff is reduced. This additional logic for Lake Keowee was applied and evaluated through verification of the model. This additional logic is a user input whereby the SR CHEOPS Model can be adjusted to evaluate operational alternatives. The SR ResSim Model simulation of the Jocassee-Keowee pumping and generating cycles is limited to the specified flat guide curve of 799.9 for Lake Keowee.

2.4 Hartwell Project

The 55,900-acre Hartwell Lake is located 7 miles east of Hartwell, Georgia, on the border with South Carolina and 289 river miles above the mouth of the Savannah River. Hartwell Dam is located on the Savannah River 7.1 miles below the point at which the Tugaloo and Seneca Rivers join to form the Savannah River. In addition to the Hartwell Dam, the two Clemson Diversion Dams were constructed to divert flow of the Seneca River around Clemson University. Hartwell Hydro Station has been in operation since April 1962. The powerhouse contains five conventional turbine-generator units.

The Hartwell Project includes 5 feet (ft) of flood control storage from an elevation of 660 to 665 ft AMSL, which contains approximately 293,000 acre-feet (ac-ft) of storage (USACE 1996a). A flood surcharge zone exists from 665 to 679 ft AMSL. A seasonally varying guide curve exists, which provides additional flood control during the winter and early spring. The minimum pool elevation is 625 ft AMSL. Both the SR CHEOPS and SR ResSim Models use this conservation pool guide curve for Hartwell Lake.

2.5 Richard B. Russell Project

The Savannah River flows out of the Hartwell Dam and flows into and through Richard B. Russell Lake. The 26,650-acre lake is impounded by the USACE's Richard B. Russell Dam 30 miles downstream of the Hartwell Dam and approximately 259 miles above the mouth of the Savannah River. The reservoir fill period commenced in October 1983, and the powerhouse was placed in service on January 1, 1985. The powerhouse contains four conventional turbine-generator units and four motor-pump/turbine-generator units. Two small house turbine-generator units were not modeled as part of the modeling effort.

The Richard B. Russell Project includes 5 ft of flood control storage from an elevation of 475 to 480 ft AMSL (USACE 1996b). The limited conservation storage range between reservoir elevation 470 and 475 ft AMSL and fluctuation caused by pumping/generating cycles necessitates a constant guide curve with no seasonal drawdown (USACE 1996b). Both the SR CHEOPS and SR ResSim Models use this conservation pool guide curve for Richard B. Russell Lake.

2.6 J. Strom Thurmond Project

The Savannah, Broad, and Little Rivers flow into J. Strom Thurmond Lake, which is a 71,100-acre lake impounded by the J. Strom Thurmond Dam. The dam is located 37 miles downstream of the Richard B. Russell Dam and approximately 222 miles above the mouth of the Savannah River. The powerhouse contains seven conventional turbine-generator units.

The objective of flood control regulation at the J. Strom Thurmond Project is to reduce flood damages to the lower Savannah River Basin to the maximum extent possible. Normal pool varies seasonally from 330 ft AMSL April 1 through October 15; and between October 15 and

December 15, the pool is drawn down to a seasonal normal pool of 326 ft AMSL to allow for the statistically higher winter and spring inflows. Starting January 1, the pool is refilled to reach 330 ft AMSL on April 1 (USACE 1996c). Both the SR CHEOPS and SR Models use this conservation pool guide curve for J. Strom Thurmond Lake.

2.7 Hydrology

A significant input to both water mass balance models is a reconstructed inflow data set unimpaired by system operations (unimpaired inflow [UIF]), subdivided by reservoir node for each of the six reservoirs included in the models. Investigations of available options for the UIF lead to incorporating an existing Georgia Environmental Protection Division (EPD)-sponsored SR Basin UIF covering the period of 1939-2007. In June 2009, Duke Energy authorized HDR to subcontract with ARCADIS U.S. Inc. (ARCADIS) to modify the existing SR Basin UIF to include separate UIF data divisions for the three Duke Energy facilities and extend the hydrology through 2008. The hydrologic dataset, Savannah River Unimpaired Flow 1939-2008 Time Series Extension Report (ARCADIS 2010, 2013), applied in both the SR CHEOPS and SR ResSim Models was provided by ARCADIS and prepared for Duke Energy, the Savannah District of the USACE, and the Georgia EPD. The study performed by ARCADIS developed UIF time series data (UIF database dated September 16, 2010) for the five main facilities on the Savannah River from the Jocassee Development to J. Strom Thurmond Project. Due to the small size of the Bad Creek watershed, HDR developed the UIF to Bad Creek Reservoir as a portioned 1 percent of the developed Lake Jocassee UIF. As outlined in the Savannah River Unimpaired Flow 1939-2008 Time Series Extension Report released by ARCADIS on August 12, 2010, these data are suitable for the following purposes:

- Reservoir system operational modeling by Duke Energy and the USACE, with USACE serving as a cooperating agency for the FERC relicensing of the Project.
- Reservoir operational planning studies by the USACE; and
- Determination of desired flow regimes and consumptive water-use assessments for Georgia EPD.

The excerpt below from Section 1 of the Savannah River Unimpaired Flow 1939-2011 Time Series Extension Report (ARCADIS 2010, 2013) defines the methods applied in the development of the UIF time series data. All time series data were supplied in HEC-DSS databases.

> *Incremental and cumulative UIFs are developed for the Seneca River at the Jocassee and Keowee sites from historical stream flows and reservoir releases at these locations by removing (1) effects of reservoir regulation (holdouts and releases from storage), (2) differential pre- and post-reservoir net evaporation (i.e., evaporation minus precipitation excess from the reservoir surface area), and (3) consumptive water uses within the respective local drainage areas. General assumptions and methods applicable to UIF development under this study are subsequently described as follows.*
>
> - *The period of record (POR) for UIFs developed under this study uniformly extends from January 1939 through December 31, 2008. UIFs previously developed by Georgia EPD for 1939–2007 (Georgia EPD 2010) were recalculated.*
> - *Daily incremental UIFs were developed at the following nodes within the Savannah River basin: Jocassee (Seneca River); Keowee (Seneca River); Hartwell, Richard B. Russell (U.S. Geological Survey [USGS] gage 02189000, Calhoun Falls); Bell (Broad River, USGS gage 02192000); Thurmond, Augusta (USGS gage 0219700); Burtons Ferry (USGS gage 02197500); Millhaven (Brier Creek, USGS gage 02198000); and Clyo (USGS gage 02198500).*
> - *Georgia EPD has provided daily potential evapotranspiration (PET) time series data computed using the Hamon equation that extend from January 1, 1939 to December 31, 2008. These have been used in the computation of reservoir evaporation following procedures used in the development of the January 1, 1939 to December 31, 2007 UIF time series.*
> - *Federal and non-federal reservoir holdouts, net evaporation, and daily inflows and outflows have been computed and applied as appropriate to UIF derivation. For reservoirs where time series data required for these calculations are not available,*

run-of-river operation has been assumed. Operational data were provided by Duke Energy, including Bad Creek Reservoir elevation time series data and elevation and outflow time series data for the Jocassee and Keowee projects, in addition to elevation-area-storage paired data for the Keowee and Jocassee projects.

- *UIF data development has been primarily accomplished by filling and routing of missing 1939 to 2008 historical flow data and by adjustments for reservoir effects and water uses. Techniques may involve application of Riverside's TSTool software and USACE DSS utilities, interactively and by batch programming. All time series and paired data have been stored in HECDSS databases and map-referenced as approved by Georgia EPD. UIF development has largely relied upon time series previously developed by ARCADIS for Georgia EPD.*
- *Historical water use data, on a daily or monthly time step, have been provided by Georgia EPD in electronic form quality-controlled and suitable for UIF development. Water use data extends from 2005 to 2008.*
- *Routing techniques for observed flow filling and UIF derivation have been selected by ARCADIS for consistency with existing 1939 to 2007 Savannah UIF data previously developed for Georgia EPD.*

The intended use of UIFs by Duke Energy and USACE is operational modeling, as opposed to water-use assessments currently being performed by Georgia EPD.

Additional information on the development of the UIF is available in the Savannah River Unimpaired Flow 1939-2011 Time Series Extension Report revised by ARCADIS on May, 2013 (ARCADIS 2010, 2013).

During the initial stages of the model scenario development phase of the relicensing process, the OSC identified the desire to have a Savannah River Basin inflow dataset that verified well against the most severe historical drought period on record, the 2007-2008 drought. Through a review of inputs and assumptions used in the SR CHEOPS Model from May through July 2012, the OSC concluded there was too much water accounted for in the back calculated incremental inflow time series being used since September 2010. The OSC requested an investigation to determine the source of the apparent inconsistency in the inflow time series during 2007-2008 when comparing modeled results to historical data. ARCADIS assisted HDR with a review of the inflow time series development and documentation. The review compared the inflow time series to USACE calculated inflow series and recommended using a different combination of inflow data (from within the September 2010 HEC-DSS database) for all reservoirs with the most significant differences in the Richard B. Russell Lake. These datasets were pulled from the supplied September 2010 HEC-DSS files and are comprised of the time series outlined in Table 2-2. The OSC approved revising the model inflow data series in both the SR CHEOPS and the SR ResSim Models.

The 1939 through 2008 hydrologic dataset adopted by the OSC in August 2012 was used for model relicensing scenario development from September 2010 through December 2012. In the fall of 2012, Duke Energy, following a recommendation from the OSC, funded an extension of the inflow data set by three years. The inflow data set was extended by ARCADIS using the same methodology developed to construct the original data set expanding the period of record (POR) to 1939 through 2011. The final revised dataset was provided by ARCADIS in May 13, 2013, and extended the existing inflow hydrology files in both the SR CHEOPS and SR ResSim Models. A summary of the hydrology extension is provided in Appendix B, which includes a presentation from ARCADIS dated June 27, 2013, and the May 2013 Savannah River Unimpaired Flow Data Report (ARCADIS 2010, 2013).

TABLE 2-2
INFLOW TIME SERIES

Reservoir	DSS Part: B	DSS Part: C	DSS Part: F
2012 LIF			
Jocassee and Bad Creek Combined	KEOWEE_R-JOCASS_R	FLOW-LOC INC	FILLED 0ADJ
Keowee	KEOWEE_R	FLOW-LOC INC	0ADJ LOC FILL
Hartwell	HARTWL_R	FLOW-LOC INC	0ADJ LOC FILL
Richard B. Russell	RBR_R	FLOW-LOC INC	0ADJ LOC-SMOOTH
J. Strom Thurmond (sum of THRMND_R and BELL)	THRMND_R	FLOW-LOC INC	0ADJ-RES FILL ADJ
	BELL	FLOW-LOC INC	OBS

The holdout time series (net evaporation and water use) used in the review of the inflow time series were also obtained from the revised May 13, 2013 HEC-DSS files and are comprised of the time series outlined in Tables 2-3 and 2-4.

TABLE 2-3
NET EVAPORATION TIME SERIES

Reservoir	DSS Part: B	DSS Part: C	DSS Part: F
Bad Creek	JOCASS_R-BADCR_R	FLOW-EVAPNET	POST-PRE RES
Jocassee	KEOWEE_R-JOCASS_R	FLOW-EVAPNET	POST-PRE RES
Keowee	KEOWEE_R	FLOW-EVAPNET	POST-PRE RES
Hartwell	HARTWL_R	FLOW-EVAPNET	POST-PRE RES
Richard B. Russell	RBR_R	FLOW-EVAPNET	POST-PRE RES
J. Strom Thurmond	THRMND_R	FLOW-EVAPNET	POST-PRE RES

TABLE 2-4
WATER USE TIME SERIES

Reservoir	DSS Part: B	DSS Part: C	DSS Part: F
Keowee	KEOWEE_R	FLOW-DIV NET	COMP-REACH TOTAL
Hartwell	HARTWL_R	FLOW-DIV NET	COMP-REACH TOTAL
Richard B. Russell	RBR_R	FLOW-DIV NET	COMP-REACH TOTAL
J. Strom Thurmond	THRMND_R	FLOW-DIV NET	COMP-REACH TOTAL

2.8 SR CHEOPS Model Logic Enhancements

Modifications to the CHEOPS platform to support the SR CHEOPS Model include functionality enhancements enabling simulation of conditions (e.g. Duke Energy Low Inflow Protocol [LIP], and USACE Drought Plan [DP]), which were developed during the relicensing process, as well as improved logic for upstream/downstream plant interactions, specifically with pumped storage plants in the system. Overall enhancements to the model include adding wicket gate leakage for pumped storage plants when in partial pumping operations, and model administrative capabilities to use OpenOffice instead of Microsoft Excel as the application which reads the model input files.

Additionally, a series of SR CHEOPS Model modifications were required to support specific OSC member group requests developed during relicensing scenario development. The modifications include:

- The ability to specify reservoir fluctuation limits that are not a fixed elevation, but rather dependent upon the start-of-period elevation. This feature was added to support the request for fish spawning reservoir stabilization periods (South Carolina Department of Natural Resources [SCDNR]), and later was modified to be able to turn off this requirement when the LIP stage is other than "Normal."
- Enhanced support by upstream plants of downstream plant outflow requirements. The outflow enhancements take into account the sum of all required flows on the downstream plant, including required powerhouse outflows, wicket gate leakage, withdrawal requirements, and evaporation. This change prevents an upstream pumped storage or hybrid-pumped storage plant from pumping the downstream reservoir elevation too low when the downstream plant cannot meet its required flows releases.
- Pumped storage plant discharge operations may also be triggered/required without the requisite ability to pump back in order to support downstream plant outflow requirements.

3.0 SR CHEOPS MODEL – BASELINE

This section defines the development of the Baseline scenario used for the verification of the SR CHEOPS Model. Each sub-section defines specific inputs used in the SR CHEOPS Model verification to simulate historical operations.

3.1 SR CHEOPS Model Logic

Figures 3-1 and 3-2 give an overview of the model logic in sequence.

FIGURE 3-1
CHEOPS MODEL EXECUTION FLOW CHART

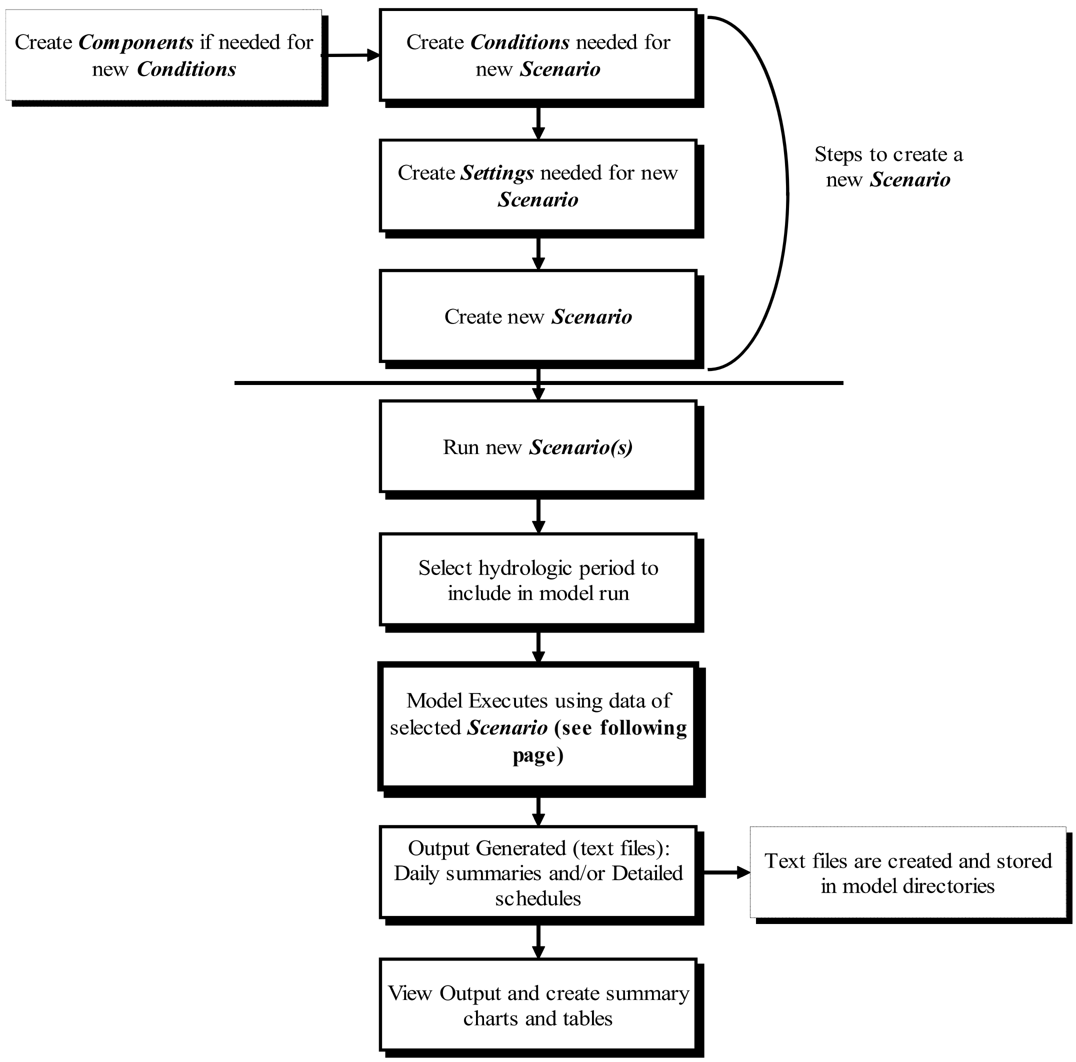
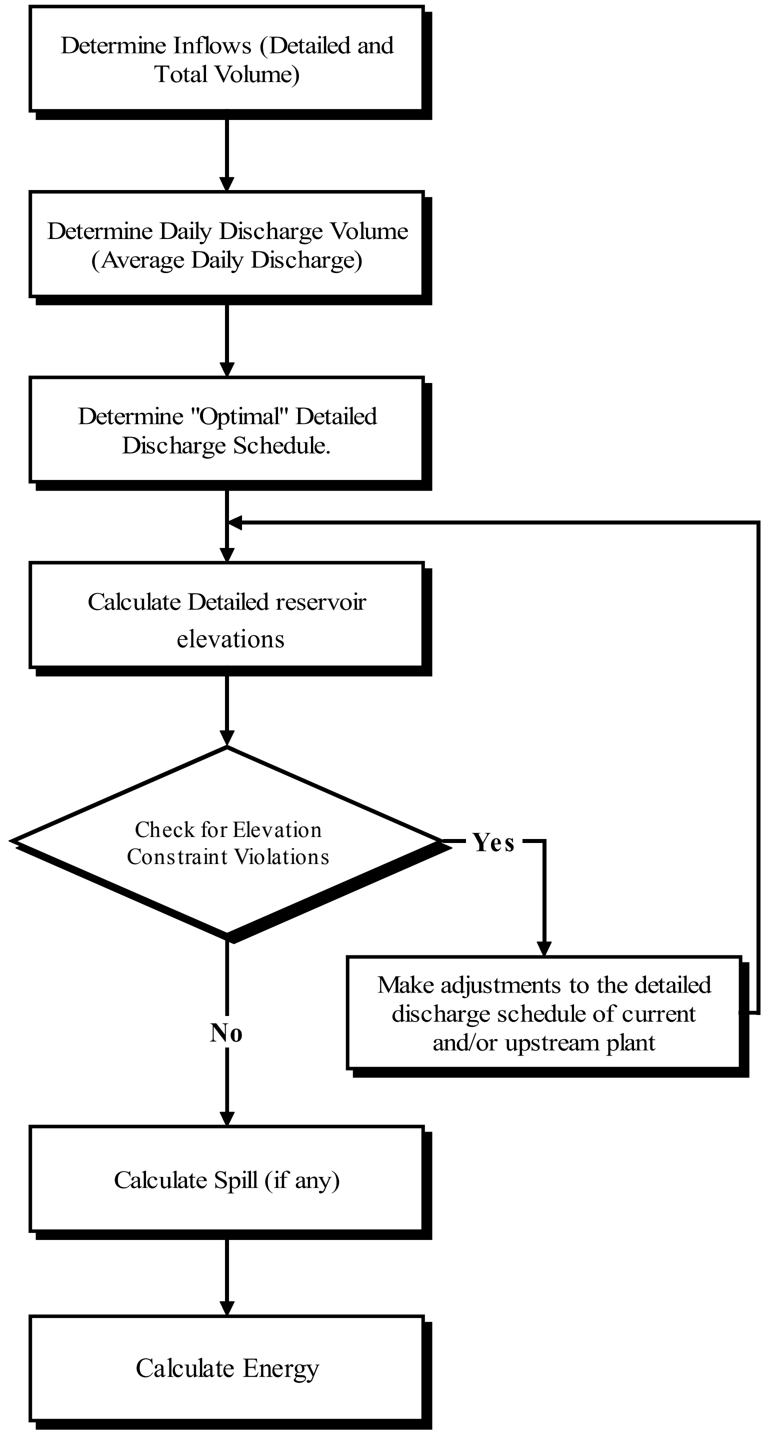


FIGURE 3-2
CHEOPS MODEL SCHEDULING FLOW CHART



3.2 SR CHEOPS Model Scenario Definition/Input Data

The project data listed in the following subsections shows the general operational constraints and physical parameters used in the SR CHEOPS Model to define the current system configuration used in both the Historical Baseline and the Baseline scenario setups. Model scenarios selected for the SR CHEOPS Model verification are the same as used for the SR ResSim Model for consistency and comparison between model architecture. Model verification uses historical data and tests the ability of the model to simulate actual operations of all six facilities. The Historical Baseline and v2007 scenarios presented in this report are based on the No Action Alternative (NAA) (Existing License) (developed for use in SR ResSim Model) scenario with adjustments as defined in the Baseline scenario below. The Baseline scenario was selected over the NAA scenario to more closely simulate historic operating conditions that have been used by Duke Energy for the selected hydrologic testing period (1998 through 2008 – Historical Baseline).

- <u>No Action Alternative (NAA)/Existing License</u>

  The NAA reflects the operating conditions of the Jocassee, Keowee, Hartwell, and J. Strom Thurmond facilities as defined in the 1968 Agreement with no changes and reflects the operations of the Project as outlined in the existing Project FERC License. The 1968 Operating Agreement is based on the concept of equalizing the percentage of combined remaining usable storage at Duke Energy's Lake Jocassee and Lake Keowee with the percentage of combined remaining usable storage at the USACE's Hartwell and J. Strom Thurmond Lakes.

- <u>Baseline (Existing Operations)</u>

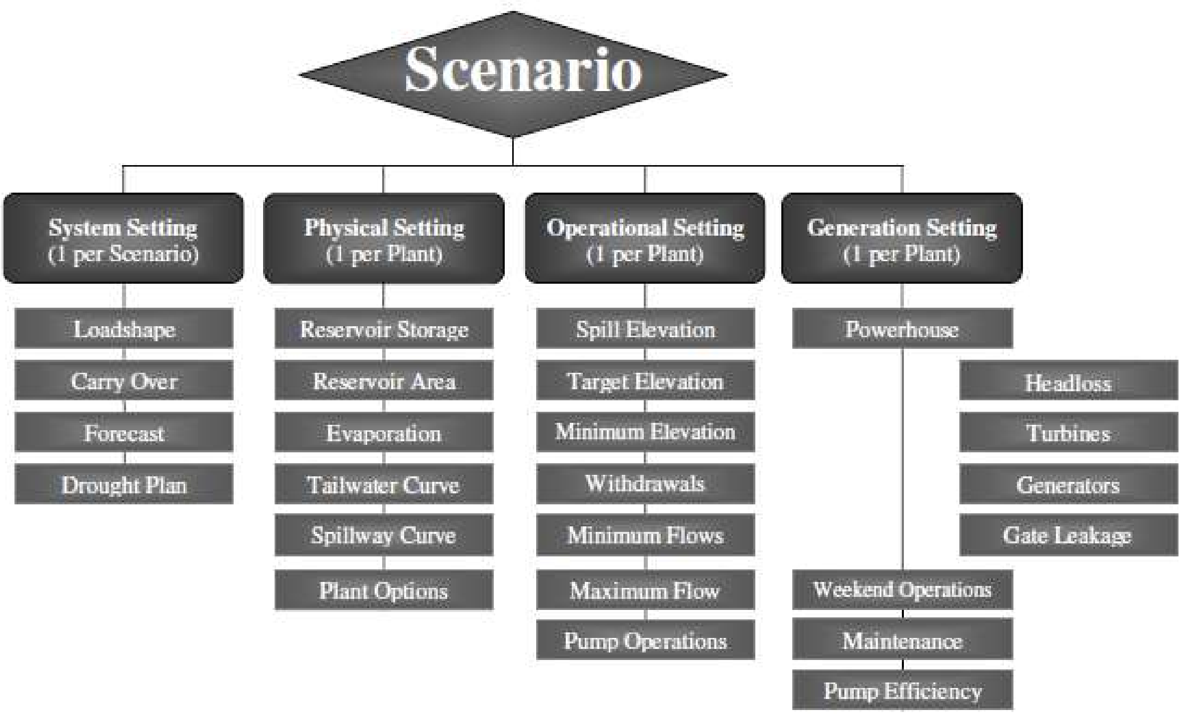
  The Baseline scenario is based on the NAA scenario, except the minimum reservoir elevation at Lake Keowee is increased from 778 to 794.6 ft AMSL. The overall methodology used to determine required weekly releases from Lake Keowee remains unchanged. This scenario best describes the current/existing operations of the Duke Energy reservoirs.

- <u>Historical Baseline (Verification)</u>

  The Historical Baseline is used for model verification and represents the Baseline scenario with the addition of historical water use (median 2003-2008) and USACE flow requirements to simulate actual historical operations.

The following sections are organized following the four components that define an SR CHEOPS Model scenario along with example inputs within each component, as shown in Figure 3-3.

FIGURE 3-3
SR CHEOPS MODEL SCENARIO



3.2.1 System Data

3.2.1.1 Load Shapes and Energy Values

This section contains the load shape and energy value data common to all six facilities on the Savannah River. The SR CHEOPS Model load shape defines the daily schedule of relative power pricing and the hour durations of each price in the peak, off-peak, and shoulder periods, as presented in Table 3-1. The model uses the load shape data to schedule the release of water throughout the day, prioritizing generation during peak periods. Durations for load shape periods were input as a standard 6 by 16 (16 hours of peak period generation). Dollar values for the weekday load shape periods were provided by Southeastern Power Administration (SEPA). Weekend generation values were estimated at 75 percent of the weekday values.

3.2.1.2 Carry-Over Elevations Condition

The SR CHEOPS Model Carry-Over Elevations Condition controls how to treat the beginning- and end-of-year elevations. The model begins the run on January 1 of the start year with each reservoir at its target elevation. If the scenario is run for a multiple year period, then the model can either start subsequent years with the reservoirs at the target elevations or at the end of previous year elevations.

The Carry-Over Elevations is selected (the checkbox is checked) in this model. Therefore, the model will carry-over the end-of-year elevations to the next year, and reservoirs will start the next year at the ending elevations of the previous year.

TABLE 3-1
LOAD SHAPE

Month	Weekday Durations in Hours							Weekday Power Values in "Normalized" Dollars		
	Morning Off-Peak	Morning Secondary Peak	Morning Peak	Afternoon Secondary Peak	Afternoon Peak	Evening Secondary Peak	Evening Off-Peak	Off-Peak	Secondary Peak	Peak
Jan	6	0	8	0	8	0	2	43.48	60.54	77.6
Feb	6	0	8	0	8	0	2	42.76	55.69	68.62
Mar	6	0	8	0	8	0	2	36.53	57.77	79.01
Apr	6	0	8	0	8	0	2	35.7	52.71	69.71
May	6	0	8	0	8	0	2	26.84	46.82	66.79
Jun	6	0	8	0	8	0	2	36.72	64.27	91.81
Jul	6	0	8	0	8	0	2	35.77	63.08	90.39
Aug	6	0	8	0	8	0	2	41.86	64.62	87.37
Sep	6	0	8	0	8	0	2	32.86	48.79	64.71
Oct	6	0	8	0	8	0	2	35.84	48.33	60.82
Nov	6	0	8	0	8	0	2	37.01	47.08	57.15
Dec	6	0	8	0	8	0	2	41.37	57.28	73.19

Month	Weekend Durations in Hours					Weekend Power Values in "Normalized" Dollars	
	Morning Off-Peak	Morning Peak	Afternoon Off-Peak	Afternoon Peak	Evening Off-Peak	Off-Peak	Peak
Jan	6	8	0	8	2	32.61	58.2
Feb	6	8	0	8	2	32.07	51.47
Mar	6	8	0	8	2	27.4	59.26
Apr	6	8	0	8	2	26.78	52.28
May	6	8	0	8	2	20.13	50.09
Jun	6	8	0	8	2	27.54	68.86
Jul	6	8	0	8	2	26.83	67.79
Aug	6	8	0	8	2	31.4	65.53
Sep	6	8	0	8	2	24.65	48.53
Oct	6	8	0	8	2	26.88	45.62
Nov	6	8	0	8	2	27.76	42.86
Dec	6	8	0	8	2	31.03	54.89

3.2.1.3 Forecast Set-Up Condition

The SR CHEOPS Model Forecast Set-Up Condition requires two inputs: a number of forecast days, and an accuracy of the forecast. The number of days is how many days the model looks ahead in the inflow file to calculate how much water the system is going to receive. The model is set up to look 1 day ahead with 100 percent accuracy. Since the model has "perfect" forecasting as it looks at the actual inflow file, the accuracy setting allows the user to adjust the model's ability to forecast accurately. The accuracy setting adjusts inflow by a fixed multiple. The model looks ahead the given number of days, adds up the inflows, multiplies those inflows by the entered accuracy value, then schedules releases based on this forecasted inflow volume. If the accuracy setting is not 100 percent (1), then the forecasted volume is not accurate. By running the model with 90 percent (0.9) accuracy, and then running again at 110 percent (1.1) accuracy, the user can simulate operations where the operator has an ability to forecast inflows with plus or minus 10 percent accuracy.

3.2.1.4 Drought Plan Condition (Storage Balance Operation)

This section provides details of the storage relationship between the Duke Energy and USACE facilities and how the storage relationship is modeled (USACE 1989, 2006, 2011).

On October 1, 1968, Duke Energy's predecessor company, Duke Power Company, entered into the 1968 Agreement with the USACE Savannah District and the SEPA regarding stored water sharing (releases) from the Project (Duke Power Company 1968). The 1968 Agreement defines balancing of the available storage in Duke Energy reservoirs (Lake Jocassee and Lake Keowee) with available storage in the USACE reservoirs (Hartwell Lake and J. Strom Thurmond Lake) according to storage balance rules as outlined in the 1968 Agreement. The SR CHEOPS Model incorporates the terms of the 1968 Agreement through a series of programming rules. These rules are integral in simulating the storage relationships between the facilities and significant time was spent by HDR and the USACE refining these rules in the SR ResSim Model. The SR CHEOPS Model was developed with two options for implementing the 1968 Agreement; as written and as developed and used in the SR ResSim Model. The logic applied in the SR

CHEOPS Model is the "By Agreement" logic which follows the language of the 1968 Agreement.

The SR CHEOPS Model incorporates the terms of the 1968 Agreement through a series of programming rules and follows the language of the 1968 Agreement. When a tandem or parallel reservoir system is defined within SR CHEOPS Model, the model determines the priority and the amount of release to make from each reservoir in order to operate towards a user defined storage balance. For every decision interval, an end-of-period storage is first estimated for each reservoir based on the sum of beginning-of-period storage and period average inflow volume, minus all potential outflow volumes. The estimated end-of-period storage for each reservoir is compared to a desired storage that is determined by using a system storage balance scheme. The priority for release is then given to the reservoir that is furthest above the desired storage. When a final release decision is made, the end-of-period storages are recomputed. Depending on other constraints or higher priority rules, system operation strives for a storage balance such that the reservoirs have either reached their guide curves or they are operating at the desired storage (percent of the active storage zone).

The SR CHEOPS Model follows the 1968 Agreement where balance checks are performed on a weekly basis

3.2.1.5 Low Inflow Protocol (LIP)

This section provides details of the SR CHEOPS Model functionality to simulate the Keowee-Toxaway LIP. The LIP functionality was added to enable LIP stage definitions, and specify required actions for each LIP stage. Model logic measures, on the specified day, the Duke Energy usable storage based on Full Pond Elevations and gage hydrology, then implements the LIP stage change after the appropriate delay. The LIP adds Bad Creek and Richard B. Russell reservoirs to the USACE DP usable storage calculations, which requires modifications to the USACE DP input file. The modifications to the USACE DP file to reflect the proposed LIP include specifying whether or not to include the Bad Creek and Richard B. Russell reservoirs in the usable storage calculation, and also provided cells for inputting the elevation which is considered bottom of usable storage pool for all six reservoirs.

Additionally, Keowee-Toxaway LIP/DP functionality includes the following logic:

- Functionality to allow the user to limit spring lake stabilization to LIP stage -1 (Normal).
- Functionality to allow the user to specify that the USACE and Duke Energy reservoir storage balancing logic use full pond elevation versus target elevation at Duke Energy reservoirs for calculations of usable storage.
- Functionality to fine-tune simulated Lake Keowee operations and limit discharge from Lake Keowee by allowing the user to define a percentage above the target curve (published in the 1968 Agreement) for the model to attempt to maintain a Full Pool.
- Functionality to allow the user to define two Maximum Required Weekly Release volumes from Lake Keowee for LIP stage 4. The first based on a Duke Percent Usable Storage Remaining trigger and the second is the default if less than the defined Duke Percent Usable Storage Remaining.
- Functionality to allow the user to revise the LIP logic to reference "triggered" DP level versus "In-Effect" DP level during LIP recovery. This allows the LIP to more quickly change to a lower stage number during recovery process, eliminating the 2-foot recovery delay in DP protocol.
- Ability to set lake level fluctuation base elevation to be set at the lowest instantaneous elevation from the day prior to the start of the lake stabilization period.

3.2.1.6 System Power

The USACE Projects have a power generation requirement with SEPA to achieve a minimum generation value. The weekly generation requirement can be met by any combination of the three USACE Projects, and the requirement value varies by month. The weekly targets are based on power contracts with SEPA, as listed in Table 3-2. These values are currently entered into the model in the Drought Plan input sheet.

TABLE 3-2
WEEKLY TARGET GENERATION FROM USACE PROJECTS

Month	Weekly Target Generation (MWh)
Jan	27,233
Feb	26,714
Mar	20,669
Apr	18,504
May	21,948
Jun	25,935
Jul	31,195
Aug	32,035
Sep	30,685
Oct	27,304
Nov	26,284
Dec	27,104

3.2.2 Physical Data

3.2.2.1 Reservoir Storage Curves

The Reservoir Storage Curve is a tabulated link between the reservoir elevation and reservoir volume. The elevations are in units of "feet" and the volumes are in "acre-feet." The SR CHEOPS Model uses this curve to calculate elevations based on inflows and model-determined releases. Figure 3-6 shows the Bad Creek reservoir storage curve used in the model. The data is from License Exhibit I (Duke Power Company 1974). The Lake Jocassee and Lake Keowee storage-volume relationships were based on bathymetric data collected in 2010 (Figures 3-7 and 3-8) and the USACE storage-volume relationships for Hartwell, Richard B. Russell, and J. Strom Thurmond Lakes were based on published storage-volume relationships revised based on applying regional sedimentation rates from the Savannah River Basin. Sedimentation rates were converted to sediment volume using methods outlined in USACE EM 1110-2-4000 and estimated compressed density of the sediment (Figures 3-9 through 3-11). A summary of the sedimentation calculations is provided in Appendix A.

FIGURE 3-4
BAD CREEK RESERVOIR STORAGE VOLUME CURVE

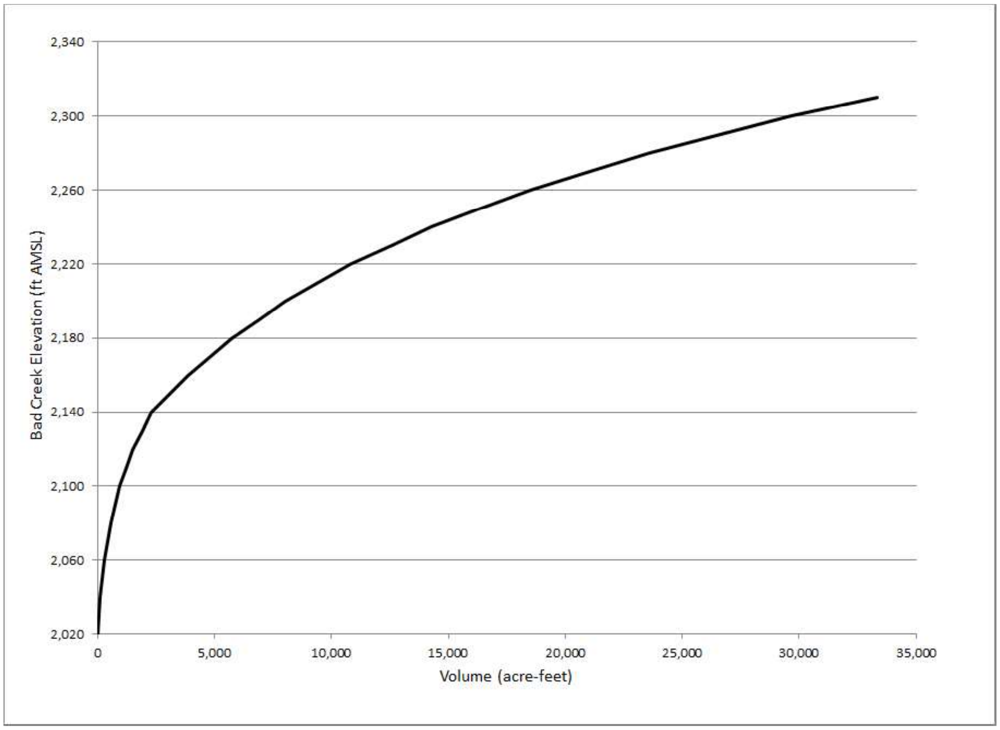


FIGURE 3-5
JOCASSEE RESERVOIR STORAGE VOLUME CURVE

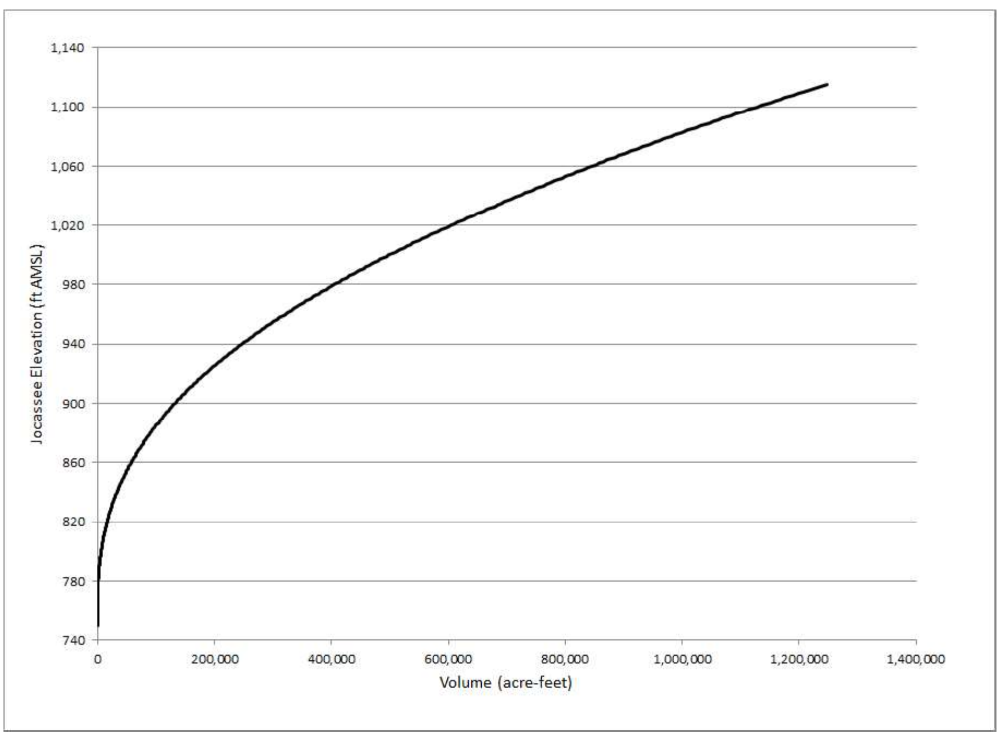


FIGURE 3-6
KEOWEE RESERVOIR STORAGE VOLUME CURVE

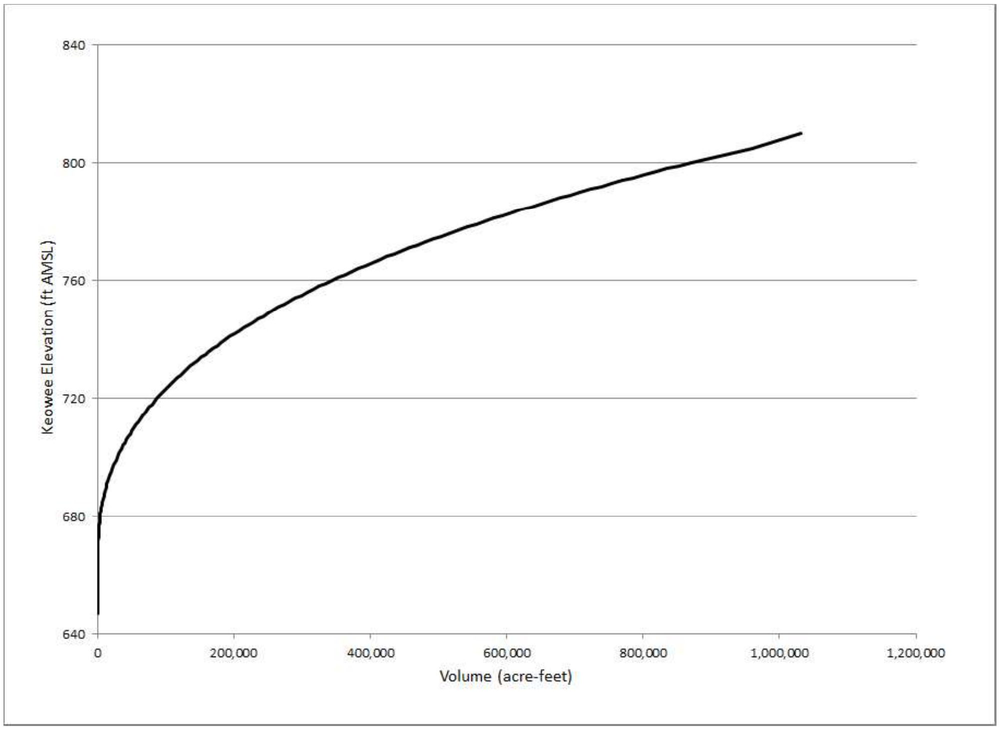


FIGURE 3-7
HARTWELL RESERVOIR STORAGE VOLUME CURVE

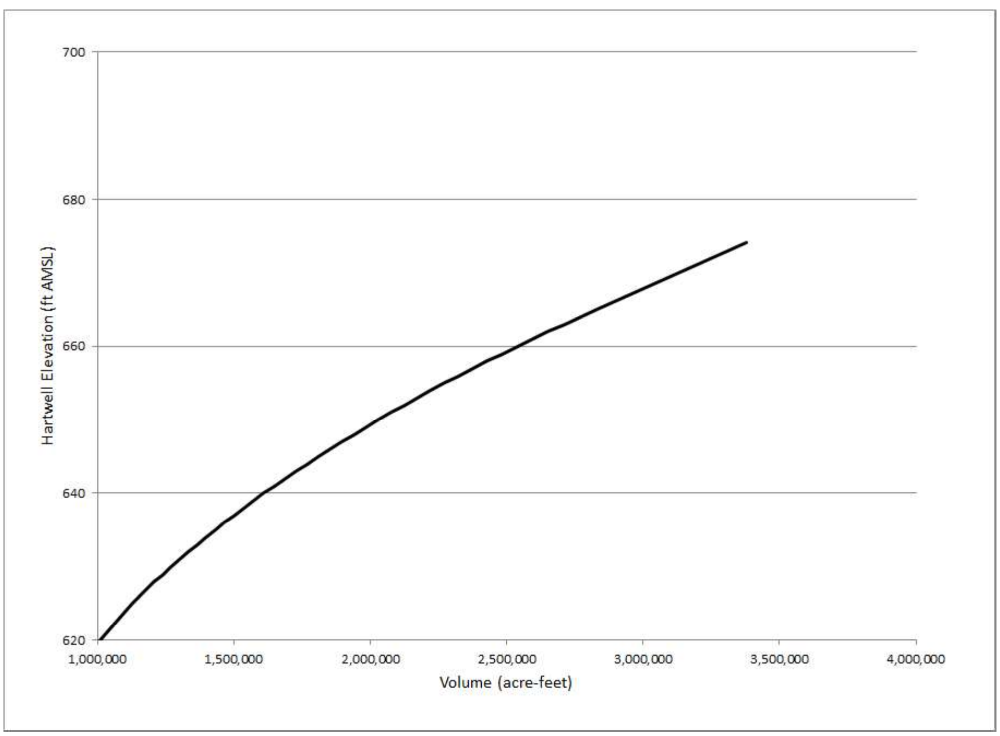


FIGURE 3-8
RICHARD B. RUSSELL RESERVOIR STORAGE VOLUME CURVE

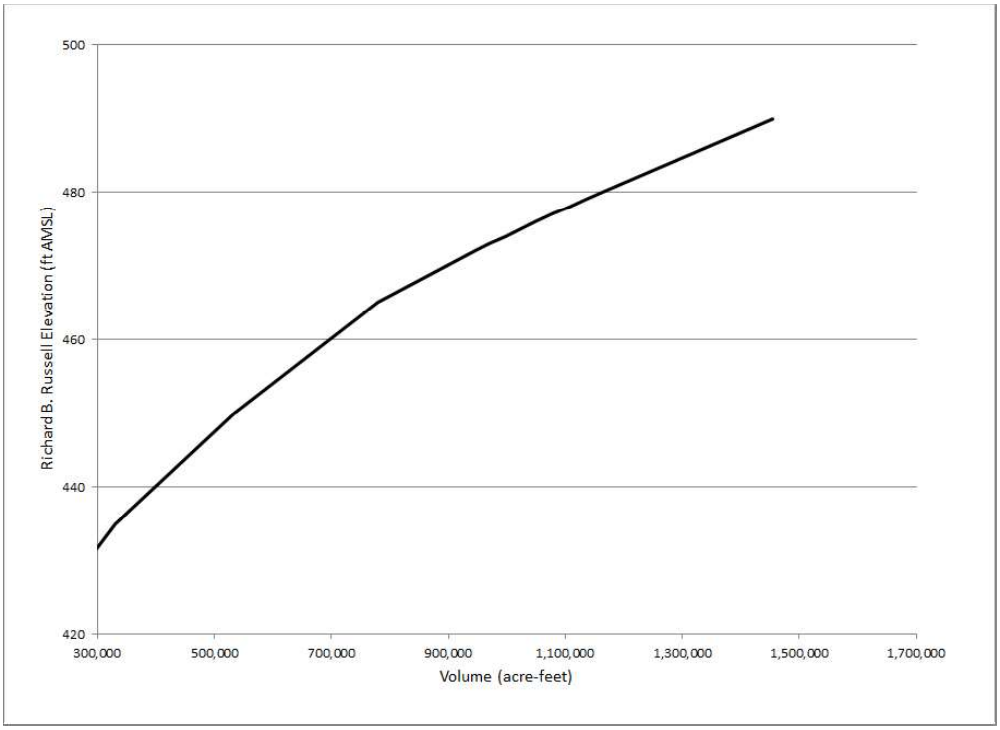
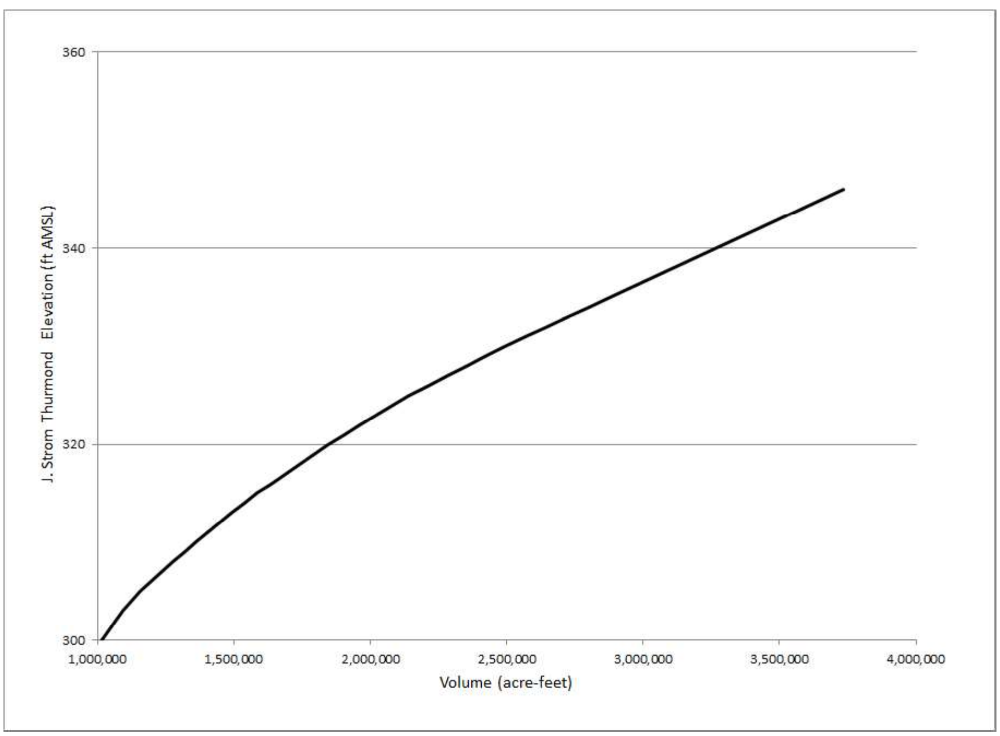


FIGURE 3-9
J. STROM THURMOND RESERVOIR STORAGE VOLUME CURVE



3.2.2.2 Reservoir Area Curves

The Reservoir Area Curve is a tabulated link between the reservoir elevation and reservoir surface area. The elevations are in units of "feet" and the areas are in "acres." The SR CHEOPS Model uses this curve to calculate the surface area and uses this data for computing evaporation losses. Figures 3-12 through 3-17 show the reservoir area curves used in the model.

FIGURE 3-10
BAD CREEK RESERVOIR AREA CURVE

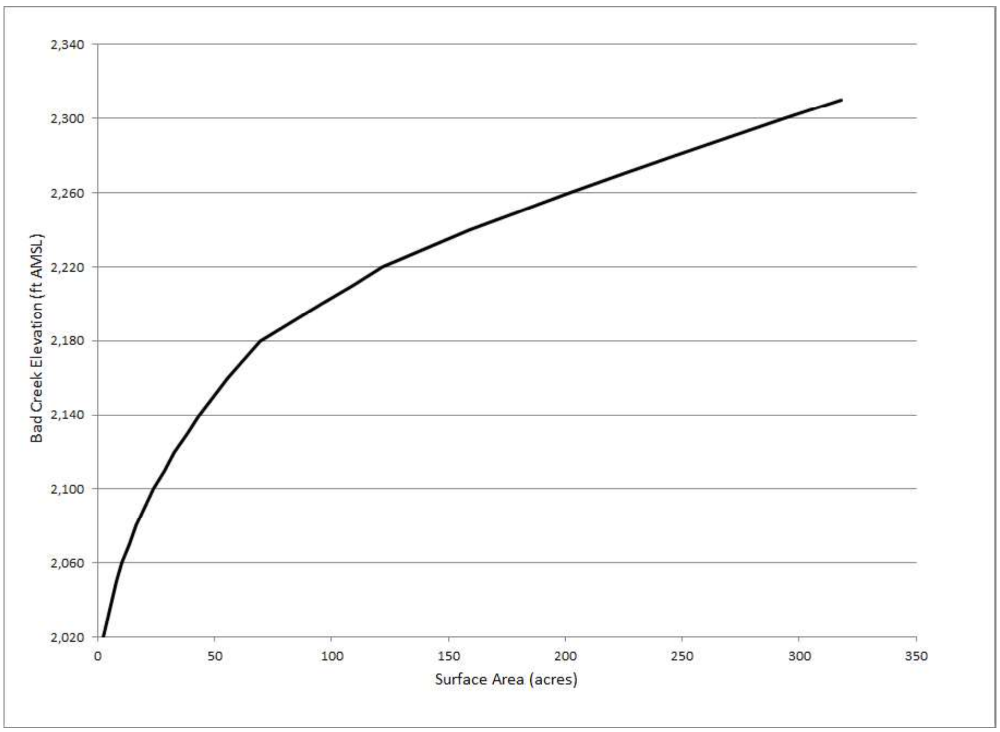


FIGURE 3-11
JOCASSEE RESERVOIR AREA CURVE

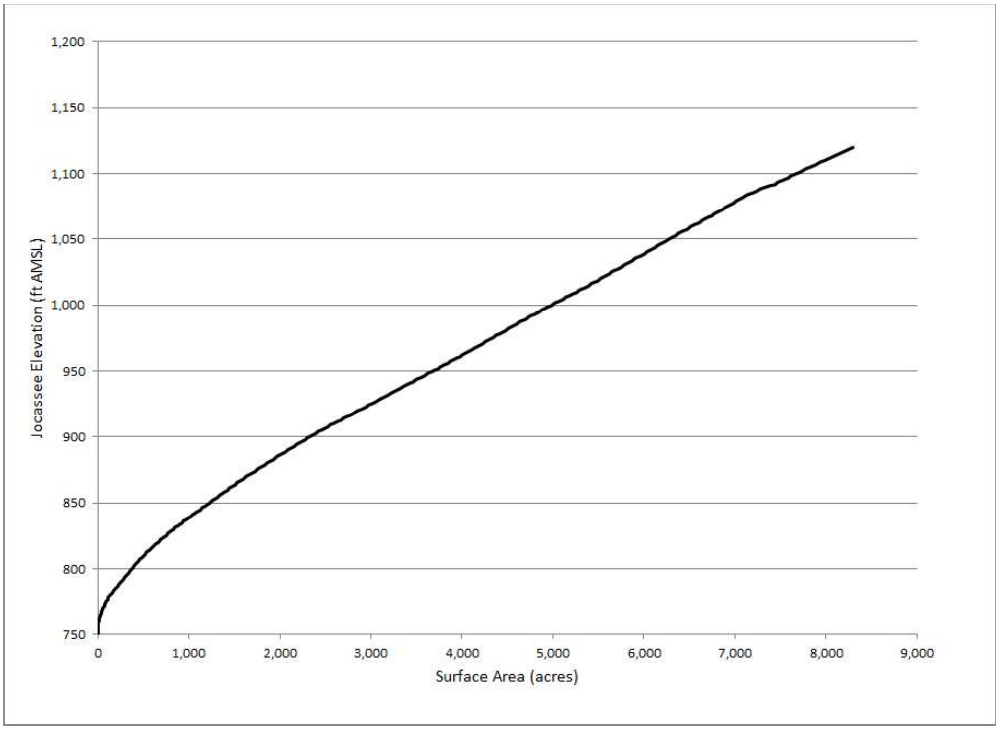


FIGURE 3-12
KEOWEE RESERVOIR AREA CURVE

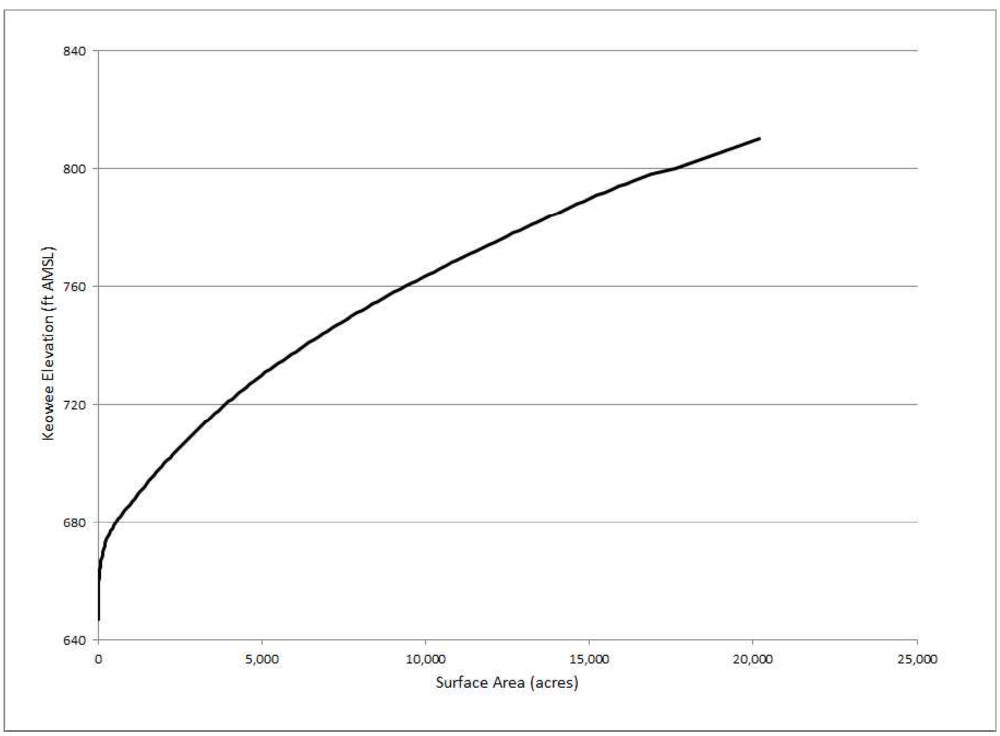


FIGURE 3-13
HARTWELL RESERVOIR AREA CURVE

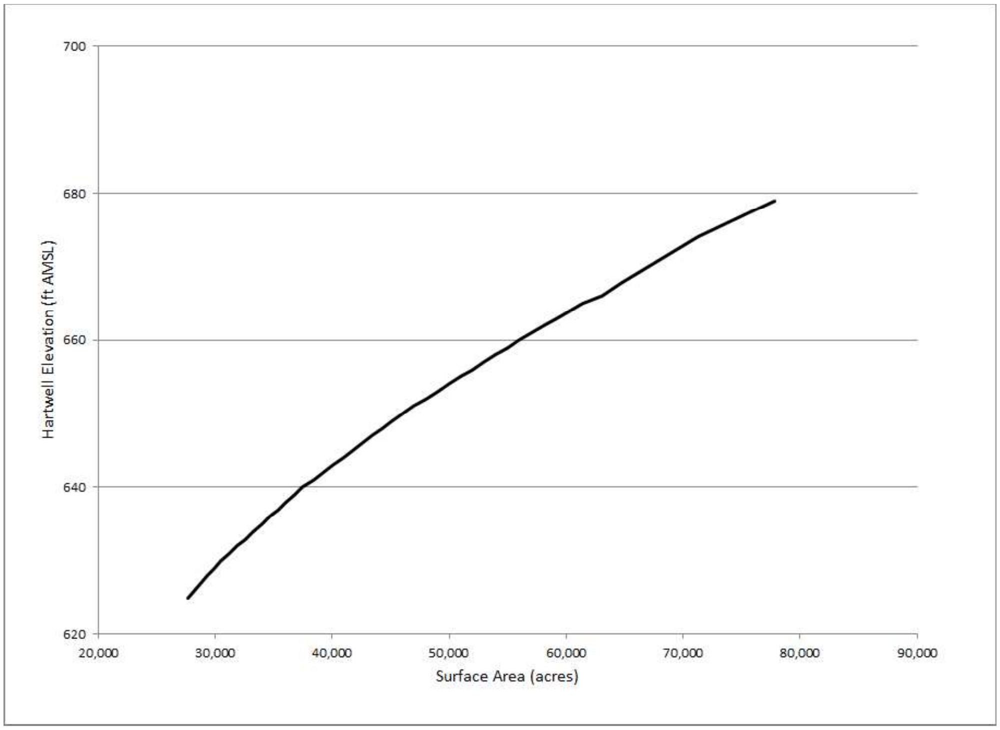


FIGURE 3-14
RICHARD B. RUSSELL RESERVOIR AREA CURVE

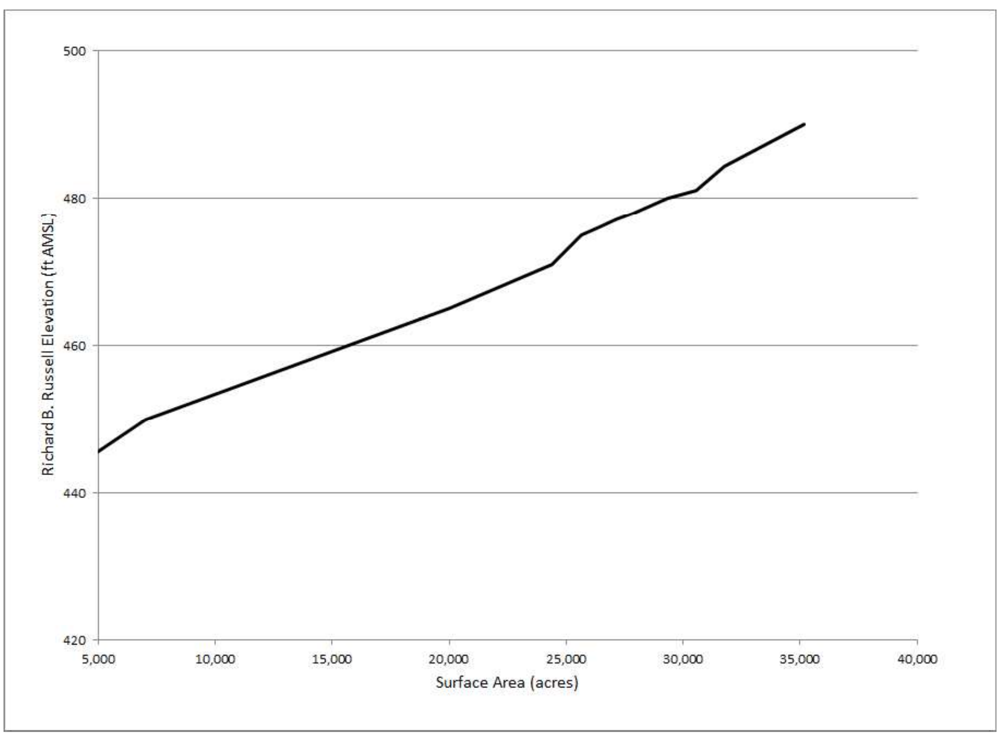
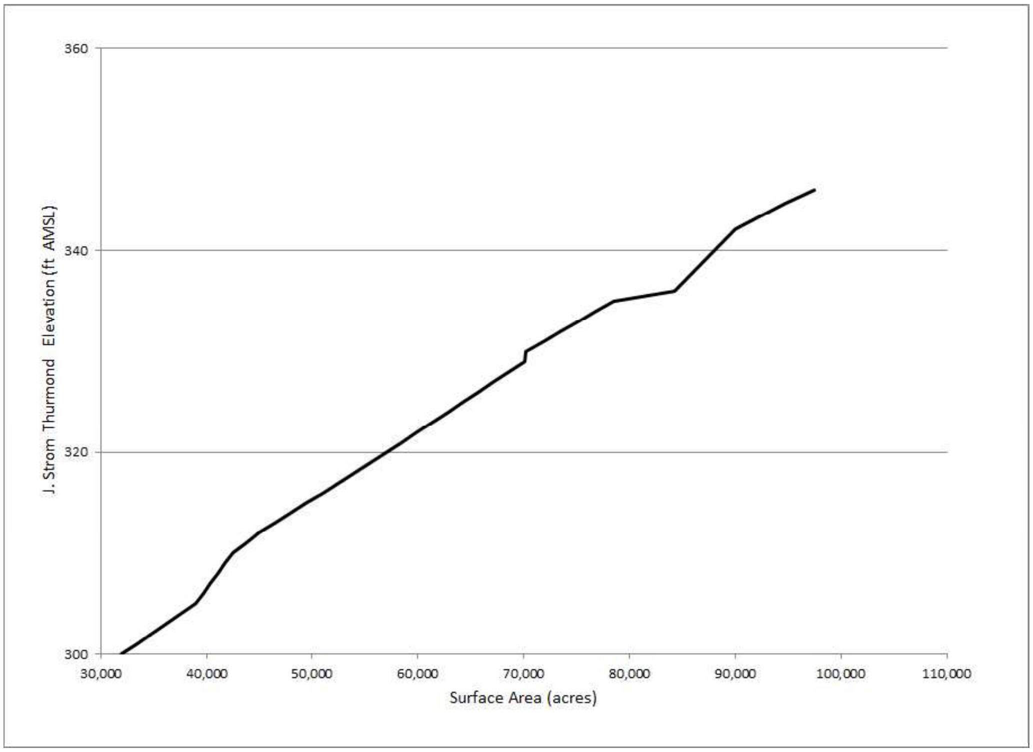


FIGURE 3-15
J. STROM THURMOND RESERVOIR AREA CURVE



3.2.2.3 Monthly Evaporation

Evaporation is based upon a monthly varying coefficient that defines the evaporative loss per reservoir. This evaporative loss is not strictly composed of losses due to evaporation, but rather a net change to inflows due to evaporation, direct precipitation to water surface, precipitation runoff, and changes to evapotranspiration losses. Negative values indicate a net inflow to the reservoir. Based on the median data, the precipitation inflow to the reservoir exceeds the evaporation from the reservoir. This coefficient (which is entered into the model in feet per day per acre) is multiplied by the surface area of the reservoir to compute total evaporative loss volume for the reservoir. Table 3-3 shows the SR CHEOPS Model evaporation loss coefficients for each reservoir by month. The evaporation loss coefficients reflect the monthly 2008 values published by ARCADIS in the Savannah River Basin May 13, 2013, time series release (ARCADIS 2010, 2013). The September 16, 2010 ARCADIS time series release contains the same 2008 evaporation values as provided in the May 2013 release. The modeled evaporation rates in the SR ResSim Model reflect the 2008 evaporation loss coefficients.

TABLE 3-3
EVAPORATIVE LOSS COEFFICIENTS

Month	Bad Creek Evaporation Loss (ft/day/acre)	Jocassee Evaporation Loss (ft/day/acre)	Keowee Evaporation Loss (ft/day/acre)	Hartwell Evaporation Loss (ft/day/acre)	Richard B. Russell Evaporation Loss (ft/day/acre)	J. Strom Thurmond Evaporation Loss (ft/day/acre)
Jan	-4.2E-03	-2.8E-03	-1.5E-03	-1.5E-03	-1.1E-03	-3.2E-03
Feb	-2.3E-03	-7.6E-04	1.0E-04	4.3E-05	-5.7E-04	-1.9E-03
Mar	-6.8E-03	-4.2E-03	6.9E-05	1.6E-05	-6.2E-05	-8.3E-05
Apr	2.5E-03	4.0E-03	4.6E-03	4.1E-03	4.1E-03	3.6E-03
May	6.1E-03	7.4E-03	6.6E-03	7.6E-03	9.6E-03	8.9E-03
Jun	1.1E-02	1.2E-02	1.3E-02	1.2E-02	1.3E-02	1.3E-02
Jul	6.3E-03	8.0E-03	9.1E-03	8.6E-03	6.5E-03	7.8E-03
Aug	-1.2E-03	1.2E-03	1.0E-03	1.9E-03	4.2E-03	3.9E-03
Sep	5.4E-03	6.4E-03	7.1E-03	7.9E-03	6.7E-03	6.4E-03
Oct	7.4E-04	1.8E-03	2.6E-03	2.1E-03	8.5E-04	7.4E-04
Nov	-1.6E-03	-6.5E-04	1.3E-04	1.3E-04	-1.1E-03	-6.4E-03
Dec	-8.8E-03	-6.6E-03	-5.8E-03	-4.9E-03	-3.0E-03	-3.4E-03

3.2.2.4 Tailwater Data

The Tailwater Curve relates the powerhouse tailwater elevation to the facility's outflow. In cases where the powerhouse releases directly into a downstream reservoir, the downstream reservoir's elevation is used to compute tailwater elevation. The elevation is in units of "feet" while the flow is in cubic feet per second, or "cfs." The tailwater elevation is subtracted from the reservoir elevation to calculate the gross head used in determining turbine and pump-turbine hydraulic performance.

Bad Creek Project releases directly into Lake Jocassee, so the elevation of Lake Jocassee is the controlling factor for the Bad Creek Project tailwater elevation. Likewise, the Jocassee powerhouse releases directly into Lake Keowee. Therefore, the elevation of Lake Keowee is the controlling factor for the Jocassee Development tailwater elevation computation.

The Keowee powerhouse discharges into Hartwell Lake. However, due to backwater effects in the upstream lake channel, there is a difference between Hartwell Lake elevation (at Hartwell Dam) and the water surface elevation below the Keowee powerhouse when the turbines are in operation. Table 3-4 shows the Keowee powerhouse tailwater curve in stage units of feet for various powerhouse outflows in cfs.

TABLE 3-4
KEOWEE POWERHOUSE TAILWATER RATING CURVE

Stage (ft AMSL)	Flow (cfs)	Stage (ft AMSL)	Flow (cfs)
657	0	680	39,867
660	5,042	684.8	59,879
665.1	11,345	689.9	85,879
670	16,545	695	113,612
674.9	26,000		

Similar to the Bad Creek Project and Lake Jocassee, the Hartwell powerhouse releases directly into Richard B. Russell Lake without backwater effects. Therefore, the Richard B. Russell Lake elevation is the control for the Hartwell Project tailwater elevation. The SR CHEOPS Model uses the greater of 470 ft AMSL or Richard B. Russell Lake water surface elevation. Reservoir elevation 470 ft AMSL is the minimum tailwater elevation provided by the USACE for modeling purposes. Richard B. Russell powerhouse releases into J. Strom Thurmond Lake. The J. Strom Thurmond Lake elevation is the control for Richard B. Russell Project tailwater elevation. The J. Strom Thurmond Project tailwater rating curve is shown in Table 3-5.

TABLE 3-5
J. STROM THURMOND POWERHOUSE TAILWATER RATING CURVE

Stage (ft AMSL)	Flow (cfs)	Stage (ft AMSL)	Flow (cfs)
187	0	220	280,000
190	15,000	230	440,000
200	65,000	240	640,000
210	155,000	250	870,000

3.2.2.5 Spillway Capacity

The Spillway Curve contains the data relating reservoir elevation (feet) and spillway discharge capacity (cfs). This data allows the model to determine the maximum amount of water that can be spilled at the current reservoir elevation and is the sum of all spillway conveyances with gates open to maximum setting. The SR CHEOPS Model allows for a simple spillway relationship of elevation and flow; therefore, all spillways, including gates, are modeled as a relationship of elevation and flow.

Spillway capacity data for the Bad Creek Project is shown in Table 3-6, derived from the Bad Creek Pumped Storage Project Supporting Technical Information (Duke Energy 2008). The Bad Creek emergency spillway is also known as the East Dike.

TABLE 3-6
BAD CREEK SPILLWAY CAPACITY VALUES

Elevation (ft AMSL)	Capacity (cfs)	Elevation (ft AMSL)	Capacity (cfs)
2,313.5	0	2,315	2,313
2,313.8	17	2,315.5	4,477
2,314.3	477	2,316	7,153
2,314.6	1,051		

Table 3-7 shows the maximum spillway capacity of the two-gated spillways as delineated in the Jocassee Development Supporting Technical Information (HDR 2010).

TABLE 3-7
JOCASSEE SPILLWAY (TOTAL GATED) CAPACITY VALUES

Elevation (ft AMSL)	Capacity (cfs)	Elevation (ft AMSL)	Capacity (cfs)
1,077	0	1102	34,531
1,082	2,762	1107	46,054
1,087	8,117	1112	58,671
1,092	15,374	1117	67,321
1,097	24,248	1122	74,138

Table 3-8 shows the spillway capacity of the four-gated spillways as delineated in the Keowee Development Supporting Technical Information (HDR 2012).

TABLE 3-8
KEOWEE SPILLWAY (TOTAL GATED) CAPACITY VALUES

Elevation (ft AMSL)	Capacity (cfs)	Elevation (ft AMSL)	Capacity (cfs)
765	0	790	63,268
770	5,505	795	82,550
775	15,851	800	102,810
780	29,399	805	123,645
785	45,393	810	144,639

The spillway capacities of the USACE projects are shown in Tables 3-9 through 3-11. These values include original data provided by the USACE, as represented in the SR ResSim Model.

TABLE 3-9
HARTWELL SPILLWAY (TOTAL GATED) CAPACITY VALUES

Elevation (ft AMSL)	Capacity (cfs)	Elevation (ft AMSL)	Capacity (cfs)	Elevation (ft AMSL)	Capacity (cfs)
630	0	657	258,924	666	416,148
635	16,800	658	274,896	667	434,184
640	52,800	659	291,288	668	452,508
645	102,000	660	308,100	669	471,120
650	160,800	661	325,320	670	489,996
653	199,248	662	342,972	671	509,160
654	213,540	663	361,032	672	528,600
655	228,252	664	379,500	673	548,316
656	243,384	665	398,400	674	568,308

TABLE 3-10
RICHARD B. RUSSELL SPILLWAY (TOTAL GATED) CAPACITY VALUES

Elevation (ft AMSL)	Capacity (cfs)	Elevation (ft AMSL)	Capacity (cfs)	Elevation (ft AMSL)	Capacity (cfs)
436	0	473	0	482	630,000
440	0	474	0	483	650,000
450	0	475	0	484	670,000
455	0	476	0	485	690,000
460	0	477	0	486	710,000
465	0	478	0	487	725,000
470	0	479	0	488	740,000
471	0	480	593,000	489	755,000
472	0	481	620,000	490	771,000

*Spill elevation set to 475.3 ft AMSL and spillway capacity set to zero below 480 ft AMSL to support logic to prevent pumping above 475 ft AMSL.

TABLE 3-11
J. STROM THURMOND SPILLWAY (TOTAL GATED) CAPACITY VALUES

Elevation (ft AMSL)	Capacity (cfs)	Elevation (ft AMSL)	Capacity (cfs)
300	0	325	405,000
305	27,000	330	545,000
310	95,000	335	688,000
315	182,000	340	855,000
320	282,000	345	1,025,000

3.2.2.6 Plant Operation Type

The Plant Operation Type is how the SR CHEOPS Model classifies and operates the plants. Four different components are used to describe the operation of the plants.

- Min Powerhouse Flow – All plants in this model have zero (0) value entered, as the turbine input curves accurately define the lowest operating flow of the units.
- Plant Operation Type – This condition specifies what type of scheduling logic is to be used for the plant. Options include Strictly Peaking, Non-generating, Run-of-River, and others. The plant operation types for the nodes in this model are shown below. Pumped storage

plants follow pumping and discharge schedules. Strictly peaking plants use logic to generate as much power as possible during the peak period, followed by secondary-peak and then off-peak periods. Hybrid-pumped storage plants have a pumping schedule, but schedule plant discharge using peaking plant logic.

- Bad Creek – Pumped Storage
- Jocassee – Hybrid-Pumped Storage
- Keowee – Strictly Peaking
- Hartwell – Strictly Peaking
- Richard B. Russell – Hybrid-Pumped Storage
- J. Strom Thurmond – Strictly Peaking

- Delinked Owner – This condition sets the level of water conveyance support a plant receives and provides to other plants operated by the same licensee/operator. All plants in the model have this value unchecked, meaning the plants provide supporting operation to other plants operated by the same owner.
- Delinked System – This condition sets the level of support a plant receives and provides to other plants operated by other licensees/operators in the modeled system. All plants in this model have this condition checked, meaning the default SR CHEOPS Model logic for support between plants is not in effect for plants operated by different operators. In this model, other methods and rules of setting the support between plants and owners are used.

3.2.3 Operational Data

3.2.3.1 Spill and Minimum Elevations

The spill or flood control elevation relates to a variety of physical situations (spillway crest, partial gate coverage, maximum normal pool, etc.), but it represents the elevation at which the model will begin to simulate spill to avoid increasing water elevation. Under a strictly peaking plant, when the model calculates an end of period elevation above the spill elevation, the model will calculate spill as well as the turbine/diversion discharge. The model's logic, under a strictly peaking plant, also attempts to reduce or eliminate occurrences when the reservoir elevation exceeds the spill elevation.

The minimum elevation is the minimum allowable reservoir elevation. The elevation could be set by regulations or by a physical limit (lowest available outlet invert). Bypass flows, withdrawals, wicket gate leakage, and evaporation can draw the reservoir below this level. The model will operate to eliminate occurrences when the reservoir elevation dips below this elevation.

Table 3-12 lists the spill and minimum elevations for each facility in the SR CHEOPS Model.

TABLE 3-12
RESERVOIR SPILL AND MINIMUM ELEVATIONS

Facility	Spill Elevation (ft AMSL)	Minimum Elevation (ft AMSL)
Bad Creek	2,310	2,150
Jocassee	1,110	1,080
Keowee	800	794.6
Hartwell	665	625
Richard B. Russell*	475.3	470
J. Strom Thurmond	335	312

* Richard B. Russell spill elevation set to 475.3 ft AMSL and spillway capacity set to zero below 480 ft AMSL to support logic to prevent pumping above 475 ft AMSL.

3.2.3.2 Target Elevations

The target elevation is the user-defined elevation that the model attempts to meet (targets) as the end-of-day reservoir elevation. The model straight line interpolates between user input points to identify a target elevation for each day. The model will deviate from the target to accommodate forecasted inflows, to meet the plant's own outflow requirements or constraints, and to support downstream minimum flow requirements from the J. Strom Thurmond Project.

Table 3-13 lists the guide curve elevations for the Duke Energy reservoirs (curves needed for modeling), and Table 3-14 lists the guide curves for the USACE reservoirs. Target requirements for the USACE Projects were provided by the USACE with the SR ResSim Model.

TABLE 3-13
GUIDE CURVE TARGET ELEVATIONS OF DUKE ENERGY RESERVOIRS

Day of Year	Bad Creek Target Elevation (ft AMSL)	Jocassee Target Elevation (ft AMSL)	Keowee Target Elevation (ft AMSL)
Jan 1	2,280	1,106	796
May 1	2,280	1,109.5	799
Oct 15	2,280	1,109.5	799
Dec 31	2,280	1,106	796

TABLE 3-14
GUIDE CURVE TARGET ELEVATIONS OF USACE RESERVOIRS

Day of Year	Hartwell Target Elevation (ft AMSL)	Richard B. Russell Target Elevation (ft AMSL)	J. Strom Thurmond Target Elevation (ft AMSL)
Jan 1	656	475	326
Apr 1	660	475	330
Oct 15	660	475	330
Dec 15	656	475	326

3.2.3.3 Water Withdrawals

Historical water use (withdrawals and returns in cfs) were estimated as part of the Savannah River Basin September 16, 2010 UIF time series release (ARCADIS 2010, 2013). The median 2003-2008 monthly water use in cfs was modeled in the Historical Baseline scenario to represent historical municipal and industrial water use from each reservoir. Table 3-15 shows the Historical Baseline scenario modeled withdrawals and returns in cfs. Table 3-15 also represents the equivalent modeled water use in the SR ResSim Model verification. The example calculation below describes the withdrawal calculation for a reservoir for a month:

$$WR_{\mathrm{R1,Month}} = Median(WR_{Day,Year})$$

where: $WR_{R1,Month}$ is the net withdrawal in (cfs) for the reservoir for the month

$WR_{Day,Year}$ is the withdrawal (cfs) for the reservoir for each day of the month for each of the months of interest in the 2003 through 2008 period.

TABLE 3-15
2003-2008 MEDIAN MONTHLY WATER USE – HISTORICAL BASELINE SCENARIO

	Water Withdrawal (avg cfs/day)					
Day of Year	Bad Creek	Jocassee	Keowee	Hartwell	Richard B. Russell	J. Strom Thurmond
01-Jan	0.00	0.00	76.66	29.14	0.00	2.61
01-Feb	0.00	0.00	76.67	29.53	0.00	1.70
01-Mar	0.00	0.00	76.88	30.15	0.00	0.32
01-Apr	0.00	0.00	74.67	33.75	0.00	3.14
01-May	0.00	0.00	71.82	42.23	0.00	7.00
01-Jun	0.00	0.00	84.00	50.51	0.00	7.70
01-Jul	0.00	0.00	84.70	45.39	0.00	7.25
01-Aug	0.00	0.00	83.24	45.92	0.00	8.25
01-Sep	0.00	0.00	88.23	44.03	0.00	7.01
01-Oct	0.00	0.00	79.59	42.82	0.00	6.05
01-Nov	0.00	0.00	68.19	34.16	0.00	5.07
01-Dec	0.00	0.00	74.69	29.75	0.00	3.70
	Water Return (avg cfs/day)					
Day of Year	Bad Creek	Jocassee	Keowee	Hartwell	Richard B. Russell	J. Strom Thurmond
01-Jan	0.00	0.00	0.00	0.00	4.75	0.00
01-Feb	0.00	0.00	0.00	0.00	5.50	0.00
01-Mar	0.00	0.00	0.00	0.00	6.37	0.00
01-Apr	0.00	0.00	0.00	0.00	3.92	0.00
01-May	0.00	0.00	0.00	0.00	1.80	0.00
01-Jun	0.00	0.00	0.00	0.00	1.26	0.00
01-Jul	0.00	0.00	0.00	0.00	1.65	0.00
01-Aug	0.00	0.00	0.00	0.00	1.10	0.00
01-Sep	0.00	0.00	0.00	0.00	0.96	0.00
01-Oct	0.00	0.00	0.00	0.00	1.88	0.00
01-Nov	0.00	0.00	0.00	0.00	2.92	0.00
01-Dec	0.00	0.00	0.00	0.00	4.60	0.00

3.2.3.4 Minimum Flows

The Hartwell, Richard B. Russell, and J. Strom Thurmond Projects have fish spawning rules in the SR CHEOPS Model. The rule requires outflow to equal inflow if the reservoir is at or below target elevation during the month of April. Additionally, the J. Strom Thurmond Project has a required average daily discharge of at least 3,800 cfs year-round.

3.2.3.5 Maximum Flows

The model allows a maximum flow constraint to be applied either at a powerhouse or at a downstream node. This will limit operations to restrict flow to a maximum of the defined limit. The J. Strom Thurmond Project has a maximum flow restriction at the downstream node in Augusta, Georgia depending on the reservoir elevation of the J. Strom Thurmond Lake. If the lake elevation is below 330 ft AMSL, the maximum allowable flow at Augusta is 20,000 cfs; and if the reservoir elevation is greater than or equal to 330 ft, the maximum allowable flow is 30,000 cfs. These flow restrictions are based on goals for normal operation at the development. Under extreme flooding, these flows can be exceeded.

The Richard B. Russell Project has a maximum flow constraint of 60,000 cfs, and the Hartwell Project has a maximum flow constraint of 28,500 cfs.

3.2.3.6 Pump Operations

As previously noted, the Bad Creek Project uses pumped storage logic and the Jocassee Development and Richard B. Russell Project use hybrid-pumped storage logic. These settings require pump operations schedules. The Bad Creek Project pump operations specify pumping and discharge schedules (specified in the tables by number of units available to operate), while the Jocassee Development and Richard B. Russell specify pumping only. In Tables 3-16 through 3-18, pump operations schedules are described by negative numbers. The magnitude of each negative number indicated the number of units available for pumping in a given hour. Table 3-16 also includes positive numbers, which indicate discharge in the given hour.

The model will deviate from the user-specified pumping or generating schedule when certain conditions are encountered, such as when the upper reservoir is approaching the spill elevation, the lower reservoir is approaching the minimum elevation, and when a powerhouse is undergoing maintenance. Additionally, the model will attempt to avoid operations that may empty the upper reservoir, resulting in spill at the downstream reservoir, or end the day significantly different from the target elevation. The model does this by evaluating the starting elevation, desired ending elevation, and user-specified pumping and generating unit-hours for the day. Using pumping and generating volume capacities at the start of the day, the model will adjust (reduce only), the number of unit-hours to balance the generation volume and pumping volume, taking into account the desired daily change in storage. For example, if a user inputs four unit hours of generation and four unit hours of pumping, the model will reduce the generation unit-hours to three so the total volume released from the upper reservoir can be made up with the four unit hours in the pump schedule. The exception to this general rule is when a Drawdown Volume and Drawdown Days have been entered, which is the case for the Bad Creek Reservoir in certain scenarios. This logic will allow the generation volume to be higher than the pumping volume to cause the reservoir to draw down by the volume change identified. If the user inputs 5,000 ac-ft of volume drawdown over five days, the logic will compute the desired end of day elevation to be 1,000 ac-ft less than the target elevation, and will reduce generation and/or pumping hours to allow the 1,000 ac-ft of drawdown.

For hybrid-pumped storage logic, the model will pump with the specified number of units during the hours specified unless the upper reservoir approaches spill elevation, the lower reservoir approaches minimum elevation, or units are in maintenance. The generation release scheduling of a hybrid-pumped storage plant occurs just as if the plant is a typical peaking plant, where outflow is determined by change in storage and inflow, which includes upstream plant discharge, upstream plant bypass flow return, upstream plant spill, incremental accretions, water withdrawal returns, and pumping operations. A powerhouse will not be scheduled to release for generation if an hour has been specified for pumping operations and pumping was actually scheduled.

TABLE 3-16
BAD CREEK PROJECT PUMP OPERATIONS

Month	Day Set	Draw-down Days	Drawdown Volume (acre-ft)	Hour (number of units available per hour of the day)*																							
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	Weekdays	5	5,000	-3	-3	-3	-3	-3	-3	2	3	3	2	2	0	0	0	0	0	0	2	3	3	3	2	-2	-3
Jan	Saturdays			-2	-2	-2	-2	-2	-2	0	0	2	2	0	0	0	0	0	0	0	0	2	2	2	0	0	-2
Jan	Sundays			-3	-3	-4	-4	-4	-3	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	0	-2
Feb	Weekdays	5	5,000	-3	-3	-3	-3	-3	-2	2	3	3	3	3	2	0	0	0	0	0	0	3	3	3	2	0	-3
Feb	Saturdays			-3	-3	-3	-3	-3	-2	0	3	3	3	3	2	0	0	0	0	0	0	2	2	2	2	-2	-3
Feb	Sundays			-3	-3	-3	-3	-3	-3	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	-3	-3
Mar	Weekdays	5	5,000	-3	-3	-3	-3	-3	-3	0	2	2	2	2	2	2	3	2	2	2	2	2	3	3	2	-3	-3
Mar	Saturdays			-3	-3	-3	-3	-3	-3	0	2	3	3	3	2	2	0	0	0	0	0	2	2	3	2	-3	-3
Mar	Sundays			-3	-3	-3	-3	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	3	-3	-3
Apr	Weekdays	5	5,000	-3	-3	-3	-3	-3	-3	0	2	2	2	2	2	2	2	2	2	2	2	2	3	3	2	-3	-3
Apr	Saturdays			-3	-3	-3	-3	-3	-3	0	2	3	3	3	2	2	0	0	0	0	0	2	2	3	2	-3	-3
Apr	Sundays			-3	-3	-3	-3	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	3	-3	-3
May	Weekdays	5	5,000	-3	-3	-3	-3	-3	-3	0	2	2	2	2	2	2	2	2	2	2	2	2	3	3	2	-3	-3
May	Saturdays			-3	-3	-3	-3	-3	-3	0	2	3	3	3	2	2	0	0	0	0	0	2	2	3	2	-3	-3
May	Sundays			-3	-3	-3	-3	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	3	-3	-3
Jun	Weekdays	5	5,000	-4	-4	-4	-4	-4	-4	0	0	0	0	2	3	3	4	4	4	4	4	3	2	2	2	-3	-3
Jun	Saturdays			-3	-3	-3	-3	-3	-3	0	0	0	0	0	2	3	3	3	3	3	3	3	3	2	2	-3	-3
Jun	Sundays			-3	-3	-3	-3	-3	-3	0	0	0	0	0	0	0	2	3	4	4	4	3	2	2	0	-3	-3
Jul	Weekdays	5	5,000	-4	-4	-4	-4	-4	-4	0	0	0	0	2	3	3	3	3	3	3	3	3	3	3	2	0	-4
Jul	Saturdays			-4	-4	-4	-4	-4	-4	0	0	0	0	0	0	2	2	3	3	3	3	3	3	3	2	0	-4
Jul	Sundays			-4	-4	-4	-4	-4	-4	0	0	0	0	0	0	1	1	2	2	2	3	2	2	1	1	-4	-4
Aug	Weekdays	5	5,000	-4	-4	-4	-4	-4	-4	0	0	0	0	2	3	3	3	3	3	3	3	3	2	2	2	0	-4
Aug	Saturdays			-4	-4	-4	-4	-4	-4	0	0	0	0	0	3	3	3	3	3	3	3	3	2	2	2	0	-4
Aug	Sundays			-4	-4	-4	-4	-4	-4	0	0	0	0	0	0	1	2	2	2	2	2	1	1	2	1	0	-4
Sep	Weekdays	5	5,000	-4	-4	-4	-4	-4	-4	0	0	0	0	2	2	3	3	3	3	3	3	3	3	3	2	-4	-4
Sep	Saturdays			-4	-4	-4	-4	-4	-4	0	0	0	0	2	2	3	3	3	3	3	3	3	2	2	0	-4	-4
Sep	Sundays			-4	-4	-4	-4	-4	-4	0	0	0	0	0	0	1	1	2	2	3	3	2	1	1	0	-4	-4
Oct	Weekdays	5	5,000	-4	-4	-4	-4	-4	-4	0	0	2	2	3	3	3	3	3	3	3	3	3	3	3	2	-4	-4
Oct	Saturdays			-4	-4	-4	-4	-4	-4	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	-4	-4
Oct	Sundays			-4	-4	-4	-4	-4	-4	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	-4
Nov	Weekdays	5	5,000	-4	-4	-4	-4	-4	-4	1	3	3	3	3	2	2	2	0	0	0	3	3	3	3	2	-4	-4
Nov	Saturdays			-4	-4	-4	-4	-4	-4	0	0	2	2	2	0	0	0	0	0	0	0	2	3	2	0	-4	-4
Nov	Sundays			-4	-4	-4	-4	-4	-4	0	0	0	0	0	0	0	0	0	0	0	1	2	1	1	0	-4	-4
Dec	Weekdays	5	5,000	-4	-4	-4	-4	-4	-4	0	3	3	3	2	2	0	0	0	0	0	3	3	3	3	2	0	-4
Dec	Saturdays			-4	-4	-4	-4	-4	-4	0	0	2	2	2	2	0	0	0	0	0	3	3	3	3	0	-4	-4
Dec	Sundays			-4	-4	-4	-4	-4	-4	0	0	0	0	0	0	0	0	0	0	0	2	2	3	2	1	-4	-4

*Pumping unit operations are described with negative values.

TABLE 3-17
JOCASSEE STATION PUMP OPERATIONS

Month	Day Set	Draw-down Days	Drawdown Volume (acre-ft)	Hour (number of units available per hour of the day)*																							
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	Weekdays	0	0	-3	-3	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jan	Saturdays			-3	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jan	Sundays			-3	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Feb	Weekdays	0	0	-3	-3	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Feb	Saturdays			-3	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Feb	Sundays			-3	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mar	Weekdays	0	0	-3	-3	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mar	Saturdays			-3	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mar	Sundays			-2	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Apr	Weekdays	0	0	-3	-3	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Apr	Saturdays			-3	-3	-3	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Apr	Sundays			-2	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	Weekdays	0	0	-3	-3	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	Saturdays			-3	-3	-3	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	Sundays			-2	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jun	Weekdays	0	0	-3	-3	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jun	Saturdays			-3	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jun	Sundays			-3	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jul	Weekdays	0	0	-4	-4	-3	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jul	Saturdays			-3	-3	-3	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jul	Sundays			-3	-3	-3	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug	Weekdays	0	0	-4	-4	-4	-4	-4	-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1
Aug	Saturdays			-4	-4	-4	-4	-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug	Sundays			-4	-4	-4	-4	-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sep	Weekdays	0	0	-4	-4	-4	-4	-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2
Sep	Saturdays			-4	-4	-4	-4	-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sep	Sundays			-4	-4	-4	-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1
Oct	Weekdays	0	0	-4	-4	-4	-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-4	-4
Oct	Saturdays			-4	-4	-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oct	Sundays			-4	-4	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-4	-4
Nov	Weekdays	0	0	-4	-4	-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nov	Saturdays			-4	-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nov	Sundays			-4	-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-4
Dec	Weekdays	0	0	-4	-4	-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-4
Dec	Saturdays			-4	-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dec	Sundays			-4	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-4

*Pumping unit operations are described with negative values.

TABLE 3-18
RICHARD B. RUSSELL PROJECT PUMP OPERATIONS

Month	Day Set	Draw-down Days	Drawdown Volume (acre-ft)	Hour (number of units available per hour of the day)*																							
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Annual	Weekdays	0	0	-3	-3	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Saturdays			-3	-3	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sundays			-3	-3	-3	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

*Pumping unit operations are described with negative values.

3.2.4 Generation Data

All unit performance information was modeled based on the information available at the time of model development.

3.2.4.1 Headloss Coefficients

The SR CHEOPS Model allows two common headloss coefficients for each plant and an individual coefficient for each unit. Headloss for each unit is calculated by multiplying the unit's common coefficient by the total flow for that common coefficient squared added to the individual coefficient multiplied by the individual unit flow squared. The formula is:

$$H_i = \left(\sum_{j=1}^{n} F_j \right)^2 h_c + F_i^2 h_i$$

Where:

H_i is the unit headloss in feet

h_c is the common coefficient for the i^{th} unit

h_i is the individual coefficient for the i^{th} unit

F_i is the flow for the i^{th} unit

j runs from 1 to n

n is the number of units that have the same common coefficient as the unit i

Table 3-19 presents the estimated headlosses for each plant as a function of flow (Q):

TABLE 3-19
HEADLOSS COEFFICIENTS

Facility	Common	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8
Bad Creek	1.25E-07								
Jocassee	1.41E-08	6.99E-08	6.99E-08	6.99E-08	6.99E-08				
Keowee	1.22E-08	2.33E-08	2.33E-08						
Hartwell		3.55E-08	3.55E-08	3.55E-08	3.55E-08	3.55E-08			
Richard B. Russell		2.40E-08	2.40E-08	2.40E-08	2.40E-08	2.40E-08	2.40E-08	2.40E-08	2.40E-08
J. Strom Thurmond		1.56E-07	1.56E-07	1.56E-07	1.56E-07	1.56E-07	1.56E-07	1.56E-07	

3.2.4.2 Turbine Efficiency Curves

Turbine performance is entered into the SR CHEOPS Model by plant and as flow versus efficiency at five separate net heads. The Bad Creek powerhouse contains four reversible motor-pump/turbine-generator units with a design head of 1,115 ft AMSL. The modeled performance of the turbines in generation mode is presented in Table 3-20. The Jocassee powerhouse also contains four reversible motor-pump/turbine-generator units, shown in Table 3-21.

The Keowee powerhouse contains two similarly sized conventional turbine-generator units. The modeled performance of these turbines is presented in Table 3-22. The Hartwell powerhouse contains five conventional turbine-generator units, four of which were rehabilitated over the 11-year span of 1997 through 2007. The Richard B. Russell powerhouse contains four similarly sized conventional turbine-generator units and four reversible turbine-generator/motor-pump units. The J. Strom Thurmond powerhouse contains seven similarly sized conventional turbine-generator units. The modeled performance of the USACE turbines is presented in Tables 3-23 through 3-26.

TABLE 3-20
BAD CREEK PROJECT UNITS 1 THROUGH 4
TURBINE EFFICIENCIES OVER A RANGE OF NET HEADS

Units 1 through 4									
Net Head of 975 ft		Net Head of 1,050 ft		Net Head of 1,115 ft		Net Head of 1,165 ft		Net Head of 1,220 ft	
Flow (cfs)	Efficiency	Flow (cfs)	Efficiency	Flow (cfs)	Efficiency	Flow (cfs)	Efficiency	Flow (cfs)	Efficiency
3,460	89.80%	3,180	91.50%	2,930	91.50%	2,825	91.20%	2,720	90.60%
3,530	89.60%	3,285	91.30%	3,140	92.00%	2,965	92.00%	2,860	91.50%
3,600	89.40%	3,390	91.00%	3,285	91.80%	3,105	92.30%	3,000	92.10%
3,670	89.20%	3,495	90.70%	3,425	91.60%	3,250	92.20%	3,070	92.40%
3,745	89.00%	3,600	90.50%	3,565	91.20%	3,390	91.90%	3,145	92.50%
3,815	88.70%	3,710	90.10%	3,700	90.90%	3,530	91.70%	3,285	92.40%
3,885	88.40%	3,815	89.80%	3,850	90.50%	3,670	91.40%	3,425	92.20%
3,955	88.00%	3,920	89.50%	3,990	90.00%	3,815	91.00%	3,565	92.00%
3,990	87.70%	4,025	89.00%	4,130	89.30%	3,955	90.70%	3,710	91.70%
4,025	87.50%	4,235	87.50%	4,415	87.40%	4,095	89.90%	3,850	91.40%

TABLE 3-21
JOCASSEE STATION UNITS 1 THROUGH 4
TURBINE EFFICIENCIES OVER A RANGE OF NET HEADS

Units 3 and 4									
Net Head of 278 ft		Net Head of 289 ft		Net Head of 301 ft		Net Head of 312 ft		Net Head of 323 ft	
Flow (cfs)	Efficiency	Flow (cfs)	Efficiency	Flow (cfs)	Efficiency	Flow (cfs)	Efficiency	Flow (cfs)	Efficiency
7,140	91.17%	6,877	91.06%	6,612	90.93%	6,395	90.70%	6,213	90.18%
7,150	91.19%	6,900	91.13%	6,900	91.50%	6,700	91.47%	6,325	90.64%
7,400	91.50%	7,150	91.64%	7,200	92.25%	6,950	92.00%	6,450	91.15%
7,600	91.50%	7,400	92.00%	7,450	92.56%	7,250	92.65%	6,700	91.83%
7,800	91.40%	7,600	92.10%	7,700	92.45%	7,500	92.95%	6,950	92.43%
8,000	91.10%	7,850	91.80%	8,000	92.00%	7,800	92.70%	7,200	92.80%
8,250	90.56%	8,100	91.41%	8,250	91.60%	8,050	92.40%	7,450	93.16%
8,450	90.10%	8,350	91.00%	8,500	91.25%	8,350	92.00%	7,700	93.15%
8,650	89.45%	8,550	90.62%	8,800	90.80%	8,600	91.67%	7,950	92.82%
8,850	88.70%	8,800	90.00%	9,050	90.10%	8,638	91.60%	8,200	92.55%

TABLE 3-22
KEOWEE STATION UNITS 1 AND 2
TURBINE EFFICIENCIES OVER A RANGE OF NET HEADS

Unit 1 and 2									
Net Head of 90 ft		Net Head of 105 ft		Net Head of 117 ft		Net Head of 125 ft		Net Head of 140 ft	
Flow (cfs)	Efficiency	Flow (cfs)	Efficiency	Flow (cfs)	Efficiency	Flow (cfs)	Efficiency	Flow (cfs)	Efficiency
5,400	54.00%	5,000	51.00%	4,900	48.00%	4,700	44.50%	4,300	43.00%
6,400	66.50%	5,500	62.00%	5,300	60.00%	5,100	55.50%	4,600	50.50%
6,900	72.00%	6,000	68.50%	5,700	66.50%	5,600	65.50%	4,900	56.00%
7,400	77.00%	6,500	74.00%	6,200	73.00%	6,100	73.00%	5,200	62.00%
7,900	81.00%	7,000	78.00%	6,700	77.50%	6,600	77.00%	5,600	68.50%
8,400	84.50%	7,500	81.00%	7,200	81.00%	7,100	81.00%	6,000	73.00%
8,900	88.50%	8,000	84.00%	7,700	84.00%	7,600	84.00%	6,400	76.50%
9,100	90.00%	8,500	88.00%	8,200	87.00%	8,100	87.00%	6,800	79.50%
9,300	91.50%	8,800	90.50%	8,700	90.50%	8,400	89.00%	7,200	82.00%
9,500	92.00%	9,000	92.00%	8,900	91.50%	8,600	90.50%	7,600	84.50%
9,700	91.00%	9,200	93.00%	9,000	92.00%	8,700	91.00%	7,800	86.00%
9,900	90.00%	9,400	93.50%	9,200	93.00%	8,800	91.50%	8,000	87.00%
10,100	88.00%	9,700	92.50%	9,500	93.50%	8,900	92.00%	8,200	88.00%
10,300	86.00%	10,000	91.00%	9,700	93.00%	9,100	93.00%	8,400	89.50%

TABLE 3-23
HARTWELL PROJECT UNITS 1 THROUGH 4
TURBINE EFFICIENCIES OVER A RANGE OF NET HEADS

Units 1 through 4									
Net Head of 170 ft		Net Head of 175 ft		Net Head of 180 ft		Net Head of 185 ft		Net Head of 190 ft	
Flow (cfs)	Efficiency	Flow (cfs)	Efficiency	Flow (cfs)	Efficiency	Flow (cfs)	Efficiency	Flow (cfs)	Efficiency
2,724	81.74%	2,678	80.77%	2,635	79.81%	2,596	78.82%	2,560	77.83%
2,985	83.90%	2,931	83.00%	2,881	82.09%	2,837	81.11%	2,796	80.14%
3,245	85.71%	3,185	84.83%	3,128	83.98%	3,078	83.04%	3,032	82.08%
3,504	87.28%	3,438	86.42%	3,375	85.59%	3,319	84.68%	3,269	83.71%
3,756	88.81%	3,684	87.95%	3,619	87.05%	3,560	86.10%	3,505	85.15%
4,071	90.45%	3,987	89.71%	3,911	88.92%	3,848	87.93%	3,794	86.84%
4,335	91.34%	4,233	90.87%	4,145	90.22%	4,073	89.33%	4,012	88.30%
4,601	92.09%	4,491	91.65%	4,387	91.22%	4,299	90.57%	4,230	89.62%
4,870	92.70%	4,748	92.37%	4,637	91.95%	4,540	91.38%	4,451	90.75%
5,148	93.08%	5,015	92.82%	4,887	92.60%	4,782	92.08%	4,688	91.45%
5,463	92.77%	5,289	93.08%	5,153	92.89%	5,036	92.47%	4,924	92.09%
5,823	91.76%	5,605	92.60%	5,430	92.93%	5,291	92.80%	5,168	92.51%
6,227	90.20%	5,969	91.41%	5,739	92.43%	5,569	92.68%	5,426	92.62%
6,878	86.58%	6,482	89.25%	6,204	90.66%	5,952	91.94%	5,774	92.28%

TABLE 3-24
HARTWELL PROJECT UNIT 5
TURBINE EFFICIENCIES OVER A RANGE OF NET HEADS

Unit 5									
Net Head of 170 ft		Net Head of 175 ft		Net Head of 180 ft		Net Head of 185 ft		Net Head of 190 ft	
Flow (cfs)	Efficiency	Flow (cfs)	Efficiency	Flow (cfs)	Efficiency	Flow (cfs)	Efficiency	Flow (cfs)	Efficiency
2,663	79.74%	2,618	78.77%	2,576	77.81%	2,538	76.82%	2,502	75.83%
2,918	81.90%	2,865	81.00%	2,816	80.09%	2,773	79.11%	2,733	78.14%
3,172	83.71%	3,113	82.83%	3,058	81.98%	3,009	81.04%	2,964	80.08%
3,425	85.28%	3,361	84.42%	3,299	83.59%	3,244	82.68%	3,195	81.71%
3,671	86.81%	3,601	85.95%	3,538	85.05%	3,480	84.10%	3,426	83.15%
3,979	88.45%	3,897	87.71%	3,823	86.92%	3,761	85.93%	3,709	84.84%
4,237	89.34%	4,138	88.87%	4,052	88.22%	3,981	87.33%	3,922	86.30%
4,497	90.09%	4,390	89.65%	4,288	89.22%	4,202	88.57%	4,135	87.62%
4,760	90.70%	4,641	90.37%	4,533	89.95%	4,438	89.38%	4,351	88.75%
5,032	91.08%	4,902	90.82%	4,777	90.60%	4,674	90.08%	4,583	89.45%
5,340	90.77%	5,170	91.08%	5,037	90.89%	4,923	90.47%	4,813	90.09%
5,692	89.76%	5,479	90.60%	5,308	90.93%	5,172	90.80%	5,052	90.51%
6,087	88.20%	5,835	89.41%	5,610	90.43%	5,444	90.68%	5,304	90.62%
6,723	84.58%	6,336	87.25%	6,064	88.66%	5,818	89.94%	5,644	90.28%

TABLE 3-25
RICHARD B. RUSSELL PROJECT UNITS 1 THROUGH 8
TURBINE EFFICIENCIES OVER A RANGE OF NET HEADS

Units 1 through 4									
Net Head of 139 ft		Net Head of 144 ft		Net Head of 151 ft		Net Head of 157 ft		Net Head of 162 ft	
Flow (cfs)	Efficiency	Flow (cfs)	Efficiency	Flow (cfs)	Efficiency	Flow (cfs)	Efficiency	Flow (cfs)	Efficiency
5,100	79.80%	5,190	81.00%	5,300	82.75%	5,300	83.50%	5,300	83.80%
5,400	81.50%	5,400	82.30%	5,600	84.50%	5,445	84.30%	5,550	85.20%
5,625	82.80%	5,725	84.25%	5,850	85.75%	5,700	85.50%	5,800	86.60%
5,900	84.50%	6,000	85.90%	6,100	87.20%	6,000	87.00%	6,100	88.00%
6,125	85.60%	6,225	87.00%	6,350	88.50%	6,200	88.20%	6,250	88.80%
6,400	87.25%	6,450	88.25%	6,600	89.70%	6,480	89.50%	6,400	89.60%
6,590	88.25%	6,690	89.25%	6,850	90.90%	6,700	90.50%	6,590	90.45%
6,800	89.20%	6,900	90.00%	7,050	91.40%	6,990	91.50%	6,750	91.00%
7,000	90.10%	7,100	90.60%	7,250	91.40%	7,200	91.55%	6,900	91.40%
7,150	90.20%	7,250	90.70%	7,400	90.75%	7,350	91.40%	7,095	92.00%
7,325	89.60%	7,450	90.25%	7,575	90.00%	7,500	91.10%	7,255	91.95%
7,575	88.50%	7,680	88.75%	7,840	88.75%	7,690	90.45%	7,450	91.50%
7,800	87.50%	7,900	87.50%	8,040	87.60%	7,875	89.50%	7,500	91.35%

TABLE 3-26
J. STROM THURMOND PROJECT UNITS 1 THROUGH 7
TURBINE EFFICIENCIES OVER A RANGE OF NET HEADS

Units 1 through 7									
Net Head of 114 ft		Net Head of 123 ft		Net Head of 132 ft		Net Head of 141 ft		Net Head of 148.5 ft	
Flow (cfs)	Efficiency	Flow (cfs)	Efficiency	Flow (cfs)	Efficiency	Flow (cfs)	Efficiency	Flow (cfs)	Efficiency
3,110	84.32%	3,140	83.54%	3,230	84.01%	3,450	85.79%	3,570	86.53%
3,210	84.93%	3,180	84.00%	3,310	84.68%	3,570	86.43%	3,680	87.19%
3,340	86.29%	3,310	85.07%	3,430	85.64%	3,600	87.27%	3,790	87.82%
3,490	87.05%	3,440	86.05%	3,550	86.53%	3,790	88.06%	3,900	88.41%
3,640	87.74%	3,570	86.96%	3,670	87.37%	3,900	88.81%	4,010	88.97%
3,790	88.37%	3,710	87.56%	3,790	88.15%	4,020	89.29%	4,120	89.51%
3,940	88.96%	3,840	88.36%	3,910	88.88%	4,130	89.97%	4,230	90.01%
4,090	89.50%	3,980	88.87%	4,040	89.35%	4,250	90.39%	4,340	90.49%
4,230	90.22%	4,110	89.57%	4,160	90.01%	4,370	90.80%	4,450	90.95%
4,370	90.90%	4,240	90.23%	4,280	90.63%	4,490	91.18%	4,560	91.38%
4,520	91.33%	4,380	90.65%	4,410	91.02%	4,610	91.55%	4,680	91.60%
4,670	91.66%	4,520	91.03%	4,550	91.18%	4,740	91.70%	4,810	91.62%
4,850	91.24%	4,670	91.21%	4,690	91.33%	4,830	91.73%	4,940	91.63%
5,310	89.48%	4,840	90.99%	4,840	91.29%	4,930	91.58%	5,030	91.58%
5,520	87.96%	5,150	90.19%	5,230	90.49%	5,230	91.15%	5,070	91.64%

3.2.4.3 Generator Efficiency Curve

The SR CHEOPS Model generator data, like the turbine data, is entered by plant and then associated with a unit. The generator performance data is a relationship of generator output versus generator efficiency.

The generator condition includes a maximum generator output. This value is the maximum generator output the model will allow, assuming there is turbine capacity to meet this limit. The model will limit turbine output based on the generator maximum specified output. The generator efficiency curves for each of the units in the system are shown in Tables 3-27 through 3-33.

TABLE 3-27
BAD CREEK PROJECT UNITS 1 THROUGH 4
GENERATOR EFFICIENCY CURVE

Units 1 through 4			
Efficiency	**Output (MW)**	**Efficiency**	**Output (MW)**
97.06%	78.25	98.76%	234.75
97.80%	110	98.91%	313
98.37%	156.5	98.95%	360

TABLE 3-28
JOCASSEE STATION UNITS 1 THROUGH 4
GENERATOR EFFICIENCY CURVE

Units 1 and 2			
Efficiency	**Output (MW)**	**Efficiency**	**Output (MW)**
95.20%	45	98.25%	150
96.15%	60	98.40%	180
97.50%	90	98.45%	195.5
98.00%	120	98.50%	215

TABLE 3-29
KEOWEE STATION UNITS 1 AND 2
GENERATOR EFFICIENCY CURVE

Units 1 and 2					
Efficiency	**Output (MW)**	**Efficiency**	**Output (MW)**	**Efficiency**	**Output (MW)**
89.00%	10	97.36%	42.5	98.31%	72.5
92.00%	15	97.60%	47.5	98.39%	77.5
94.00%	20	97.79%	52.5	98.44%	82.5
95.30%	25	97.95%	57.5	98.46%	87.5
96.20%	30	98.09%	62.5	98.48%	90
96.80%	35	98.20%	67.5	98.50%	100.625
97.20%	40				

TABLE 3-30
HARTWELL PROJECT UNITS 1 THROUGH 4
GENERATOR EFFICIENCY CURVE

Units 1 through 4					
Efficiency	**Output (MW)**	**Efficiency**	**Output (MW)**	**Efficiency**	**Output (MW)**
89.00%	10	97.41%	39	98.24%	64
92.00%	15	97.64%	43	98.30%	68
94.00%	19	97.83%	47	98.35%	72
95.25%	23	98.00%	52	98.40%	76
96.10%	27	98.11%	56	98.45%	80
96.75%	31	98.18%	60	98.50%	85
97.11%	35				

TABLE 3-31
HARTWELL PROJECT UNIT 5
GENERATOR EFFICIENCY CURVE

Unit 5					
Efficiency	**Output (MW)**	**Efficiency**	**Output (MW)**	**Efficiency**	**Output (MW)**
90.04%	10	96.27%	35	97.53%	60
92.76%	15	96.57%	39	97.64%	64
93.99%	19	96.82%	43	97.75%	68
94.83%	23	97.03%	47	97.84%	72
95.44%	27	97.25%	52	97.93%	76
95.90%	31	97.40%	56	98.04%	82

TABLE 3-32
RICHARD B. RUSSELL PROJECT UNITS 1 THROUGH 8
GENERATOR EFFICIENCY CURVE

Units 1 through 4					
Efficiency	**Output (MW)**	**Efficiency**	**Output (MW)**	**Efficiency**	**Output (MW)**
89.00%	10	97.36%	42.5	98.31%	72.5
92.00%	15	97.60%	47.5	98.39%	77.5
94.00%	20	97.79%	52.5	98.44%	82.5
95.30%	25	97.95%	57.5	98.46%	87.5
96.20%	30	98.09%	62.5	98.48%	90
96.80%	35	98.20%	67.5	98.50%	100.625
97.20%	40				

TABLE 3-33
J. STROM THURMOND PROJECT UNITS 1 THROUGH 7
GENERATOR EFFICIENCY CURVE

Units 1 through 7					
Efficiency	**Output (MW)**	**Efficiency**	**Output (MW)**	**Efficiency**	**Output (MW)**
94.61%	10	97.39%	30	98.33%	50
95.56%	15	97.74%	35	98.45%	55
96.32%	20	98.00%	40	98.56%	60
96.93%	25	98.19%	45		

3.2.4.4 Wicket Gate Leakage

The SR CHEOPS Model wicket gate leakage flow is active only during times of non-generation. Thus, during periods of non-generation, this leakage flow is used to make up all or a portion of the minimum flow requirement. Wicket gate leakage is only modeled at the Jocassee and Keowee Stations, where it is 11 cfs per Jocassee unit and 25 cfs per Keowee unit for a total of 44 cfs and 50 cfs when no units are operating. Wicket gate leakage is not modeled in the SR ResSim Model.

3.2.4.5 Powerhouse Weekend Operations

The Powerhouse Weekend Operations Condition permits the simulation of reduced powerhouse operations during Saturdays and/or Sundays. Minimum instantaneous and minimum daily average flow requirements will be met by bringing the powerhouse online for the required flow only. This condition removes the change-in-storage component from consideration in computing a desired daily discharge. To simulate actual usage, Saturday and Sunday powerhouse operations are minimized at the Keowee Station, Hartwell Project, and Richard B. Russell Project. During high inflow times with little usable storage, the model will bring the powerhouse online to generate with outflows, rather than permit spilling.

3.2.4.6 Maintenance

The maintenance schedule provides the functionality to take a unit out of service for all or part of each year for a scenario run. There are currently no outages modeled in the SR CHEOPS Model.

3.2.4.7 Pump Efficiency

The SR CHEOPS Model Pump Efficiency Condition provides the functionality to enter pump efficiency information for pumped storage plants. This data set is required for plants with plant operation type specified as pumped storage and hybrid-pumped storage. The pump efficiency information modeled for the Bad Creek Project, Jocassee Station, and Richard B. Russell Project is presented in Tables 3-34 through 3-36.

TABLE 3-34
BAD CREEK PROJECT PUMP EFFICIENCY

Net Head (ft)	Efficiency	Minimum Power (MW)	Maximum Power (MW)	Minimum Flow (cfs)	Maximum Flow (cfs)
1,040	92.40%	339.8	340.0	3,565	3,567
1,100	92.70%	331.6	331.8	3,300	3,302
1,160	92.60%	318.3	318.5	3,001	3,003
1,220	92.30%	304.2	304.4	2,718	2,720
1,250	92.00%	294.4	294.6	2,559	2,561

TABLE 3-35
JOCASSEE STATION PUMP EFFICIENCY

Net Head (ft)	Efficiency	Minimum Power (MW)	Maximum Power (MW)	Minimum Flow (cfs)	Maximum Flow (cfs)
286	92.45%	207.4	207.5	7,919	7,921
296	92.80%	205.2	205.3	7,599	7,601
307	93.10%	204.6	204.7	7,329	7,331
318	93.40%	201.8	201.8	6,999	7,001
328	93.50%	196.8	196.8	6,624	6,626

TABLE 3-36
RICHARD B. RUSSELL PROJECT PUMP EFFICIENCY

Net Head (ft)	Efficiency	Minimum Power (MW)	Maximum Power (MW)	Minimum Flow (cfs)	Maximum Flow (cfs)
140	91.20%	93.6	93.6	7,199	7,201
145	91.68%	93.7	93.7	6,994	6,996
150	92.10%	93.6	93.7	6,789	6,791
155	92.50%	93.4	93.4	6,579	6,581
160	92.80%	92.8	92.9	6,359	6,361

4.0 SR CHEOPS MODEL CALIBRATION/VERIFICATION PROCESS

Verification is intended to validate the SR CHEOPS Model input data and logic so the Baseline scenario may be used as the current operations comparison scenario for all subsequent scenario analyses. HDR performed model verification using comparisons of actual and model estimated generation and total discharge from the system. Verification of the model was completed using two different scenarios or model runs. The first (Historical Baseline) performs a verification of the model input data, logic and conditions for calendar years 1998 through 2008, which are the same 11 years used in the SR ResSim Model verification and with the same operations rule logic as the Baseline scenario described in Section 3.2, with modifications for historical water use (Table 3-15) and flow requirements from the J. Strom Thurmond Project (Section 3.2.3.4). This scenario is referred to as the Historical Baseline. In addition to the Historical Baseline scenario, a second verification scenario (v2007) was developed to simulate the detailed operations for calendar year 2007.

Generation data is commonly available for hydropower developments and is a metered value that has good accuracy compared to other forms of data that are not metered or based on estimated values with lower accuracy. Generation is a measure of available flow and storage volume, which relates to inflows and reservoir elevations. When performing verification of water quantity models with power generation, it is common to find discrepancies between observed data and modeled output for generation and reservoir elevation when looking at a small sample of time periods (day, week, or month). This is due to the difference between the set of rules provided in the model versus the day-to-day decisions common in large power developments that respond to power grid demands as well as storm forecasts and other non-measured impacts on the reservoir and equipment. Modeled results for each verification scenario were compared with historic generation, powerhouse flow, and reservoir levels. In addition to verifying the model under different hydrologic conditions, it was also important to select relatively recent years for model verification under conditions that are representative of current operating conditions.

As previously stated, the SR CHEOPS Model is coded to run day-to-day operations based on general operating conditions or rules. The model follows these rules strictly, 24 hours per day and 365 days per year, similar to an automated operation. Actual project operations generally follow the operating rules; however, human intervention periodically deviates from the general operating rules to accommodate day-to-day realities such as equipment failure and maintenance, changing hydrologic conditions, power demands and energy pricing, and other factors. In addition to differences between modeled operations versus actual operations that include human interventions, there are also inherent discrepancies due to input data inaccuracies (e.g., differences in hydrology data, turbine or generator efficiencies, or reservoir storage curves). It is important to understand that, due to these differences between actual operating conditions and modeled conditions, model results will never completely match historical operations.

The verification goal is to obtain less than a 5 percent difference when comparing long-term modeled results to historical generation data over the hydrologic period. In cases where the modeled results exceeded a 5 percent difference, potential causes for the differences were examined to determine whether the difference was due to deviations in model setup, historical deviations in operations, or discrepancies in the reconstructed hydrology data.

4.1 Summary of SR CHEOPS Modeled Results versus Historical Data

Verification of the SR CHEOPS Model was performed using historical operations data provided by Duke Energy and the USACE. Verification of the model was performed using two different scenarios, or model runs. The first scenario (Historical Baseline) performs a verification of the model input data, logic, and conditions for calendar years 1998 through 2008, which are the same 11 years used in the SR ResSim Model verification and with the same operations rule logic as the Baseline scenario discussed in Section 3.2, with modifications for historical water use (Table 3-15) and flow requirements from the J. Strom Thurmond Project (Section 3.2.3.4). The second verification scenario was run using the specific calendar year 2007 (v2007).

4.1.1 SR CHEOPS Model Historical Baseline

The Historical Baseline scenario results were compared to historical operations for the hydrologic period 1998 through 2008. Figures 4-1 through 4-6 show comparisons of the modeled reservoir elevations for the Historical Baseline scenario compared to the historical reported (observed) elevations for the same period. Note this scenario is not strictly based on the water balance rules defined in the 1968 Agreement, but closely represents how the developments have been operated over the simulated hydrologic period. Also, unit rehabilitation of Units 1 through 4 at the Hartwell Project was not complete until May of 2007. Unit outages associated with the rehabilitation were not taken into account in the model and it was assumed the units were operating at post-rehabilitation efficiency and capacity for the entire period.

FIGURE 4-1
SR CHEOPS MODELED AND HISTORICAL BAD CREEK RESERVOIR ELEVATION COMPARISON

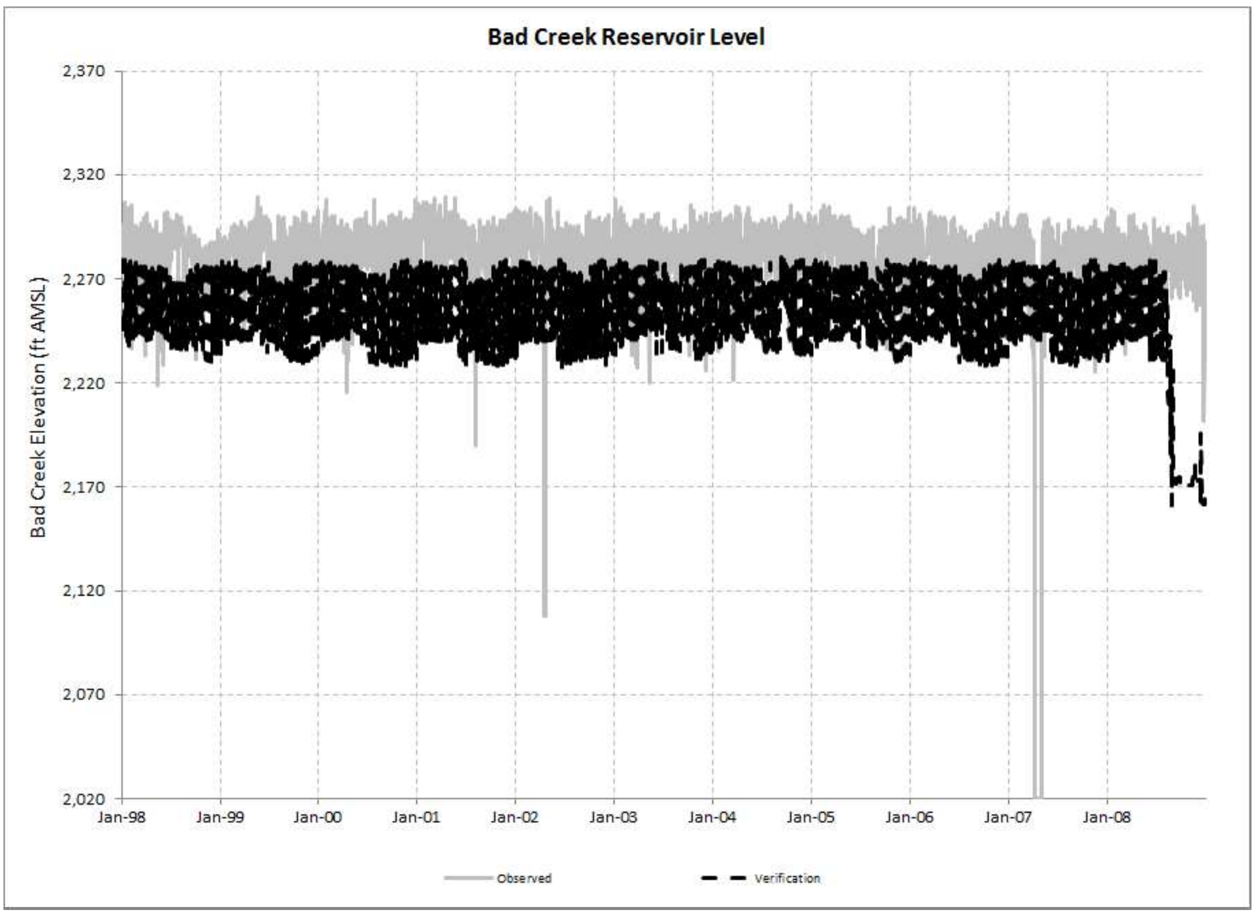


FIGURE 4-2
SR CHEOPS MODELED AND HISTORICAL JOCASSEE RESERVOIR ELEVATION COMPARISON

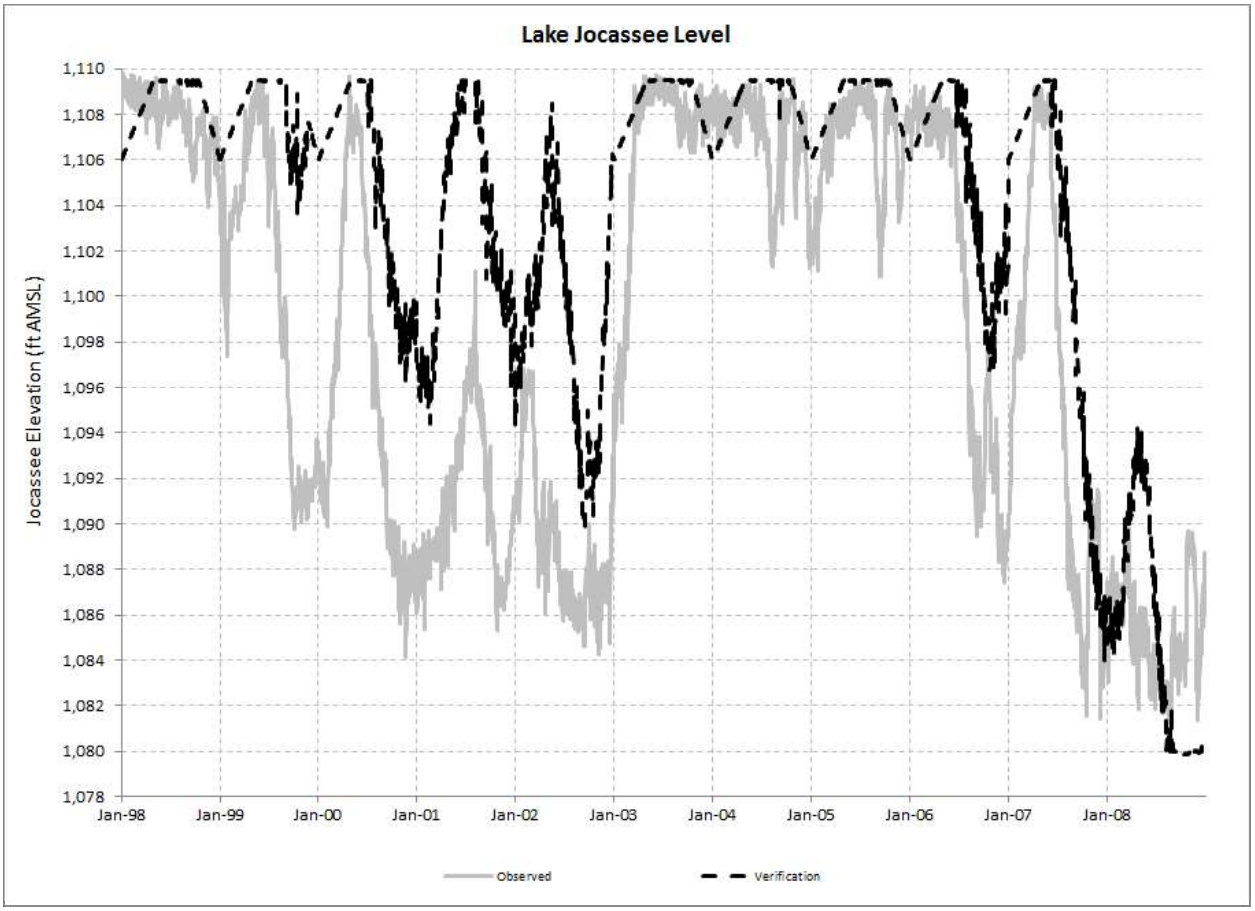


FIGURE 4-3
SR CHEOPS MODELED AND HISTORICAL KEOWEE RESERVOIR ELEVATION COMPARISON

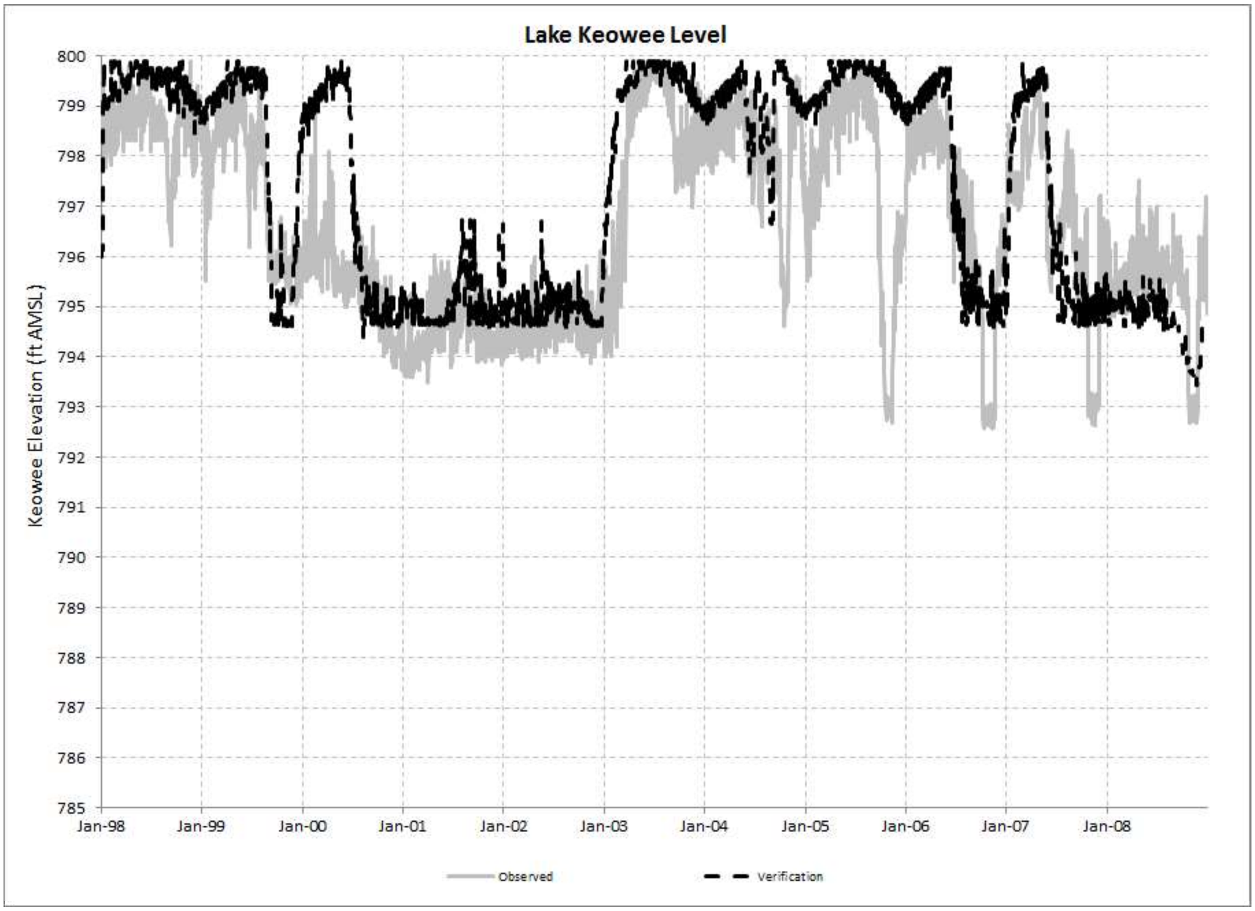


FIGURE 4-4
SR CHEOPS MODELED AND HISTORICAL HARTWELL RESERVOIR ELEVATION COMPARISON

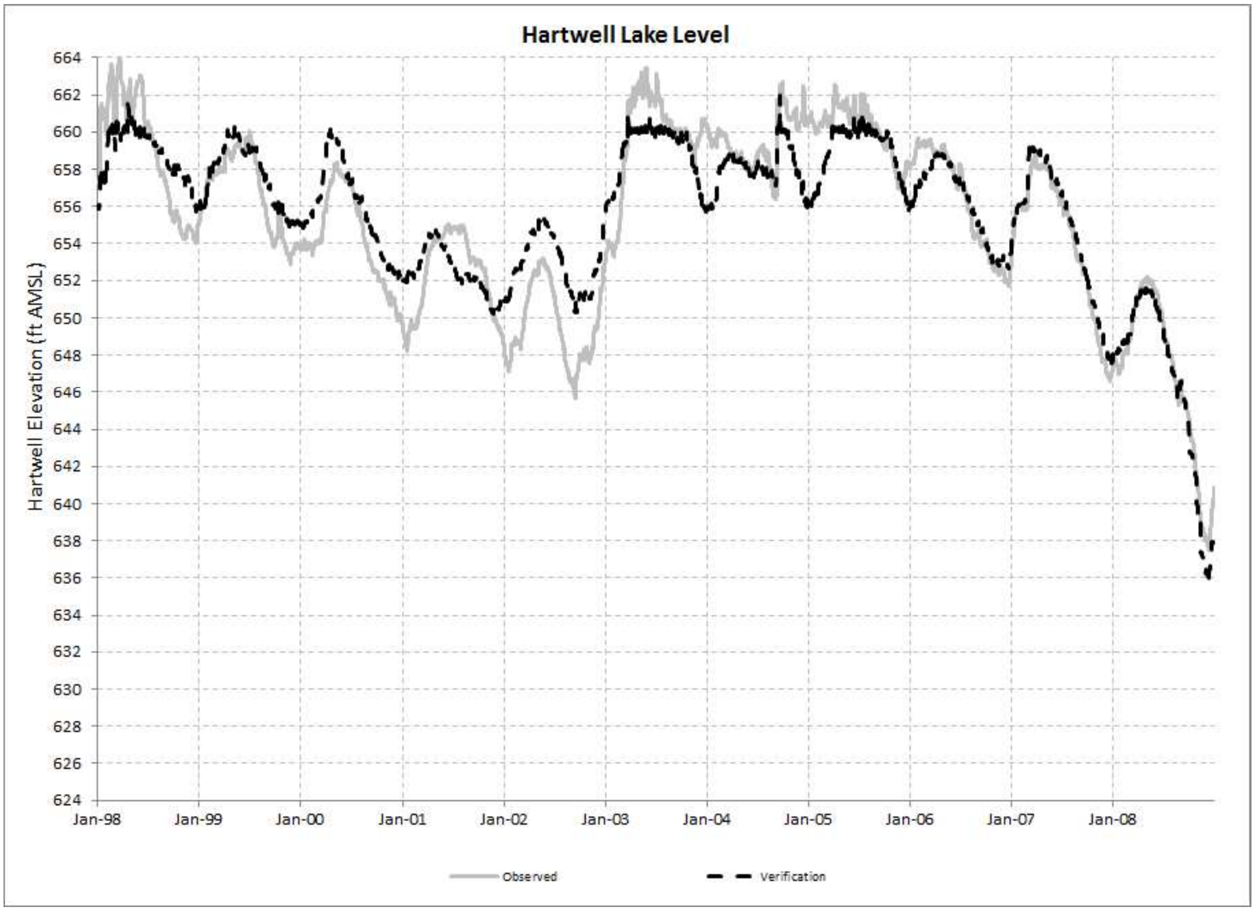


FIGURE 4-5
SR CHEOPS MODELED AND HISTORICAL RICHARD B. RUSSELL RESERVOIR ELEVATION COMPARISON

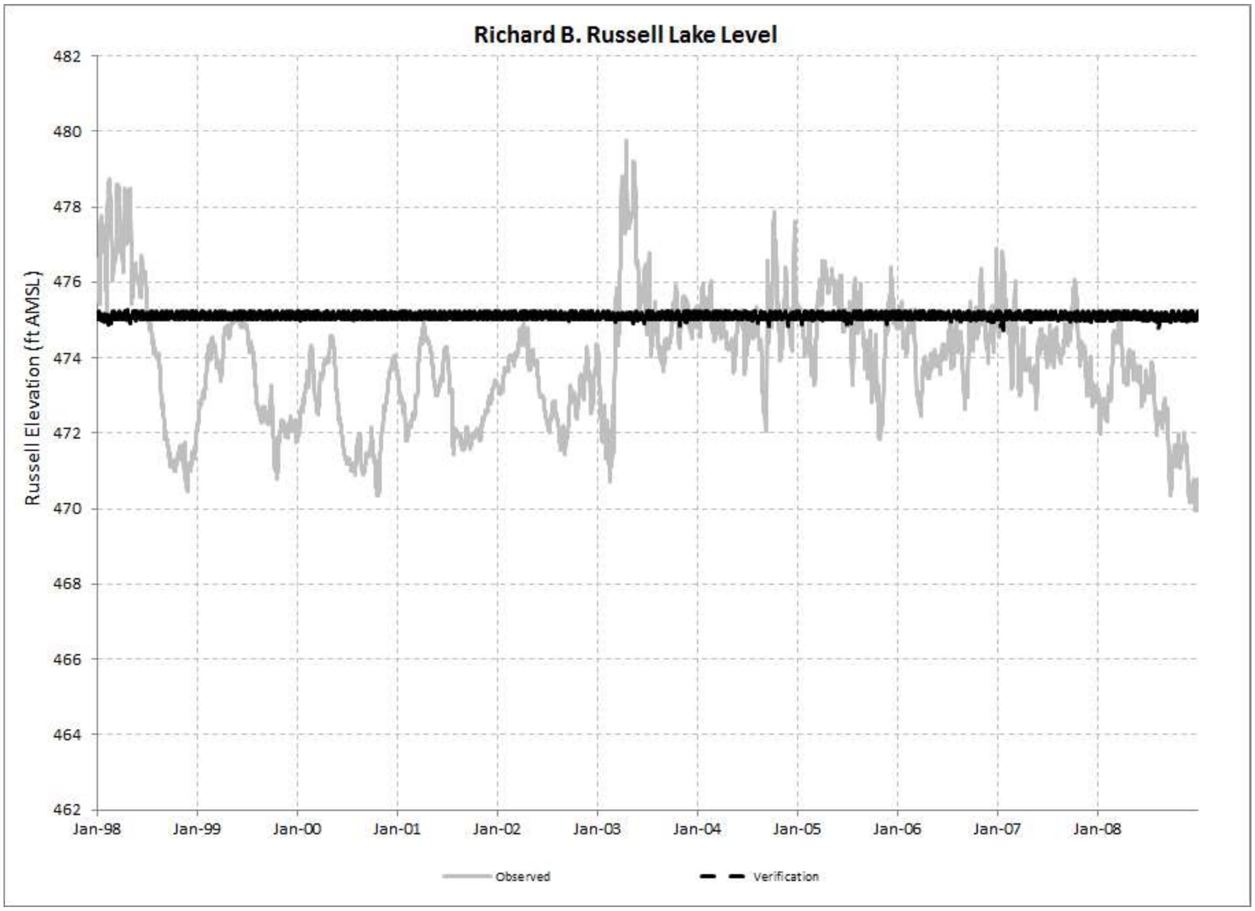
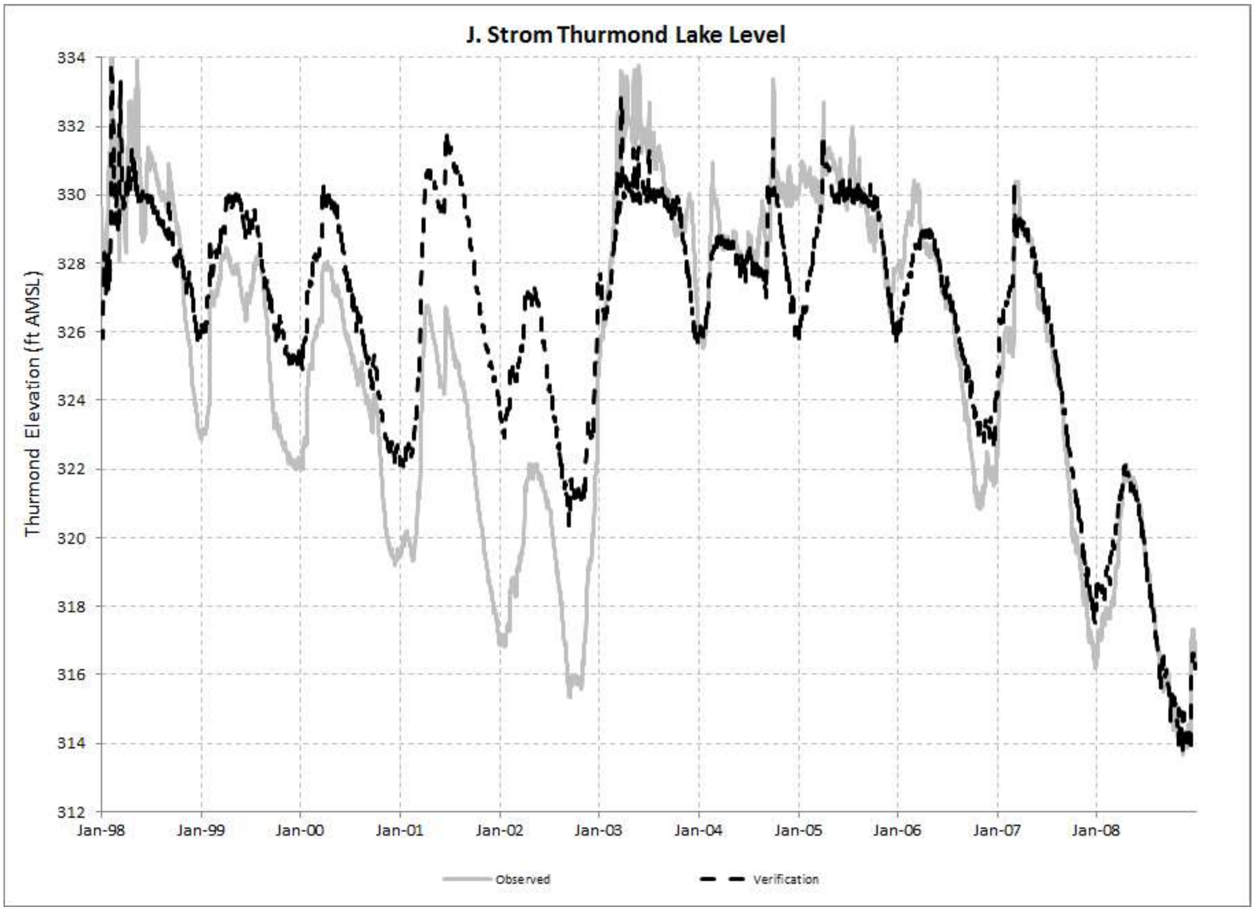


FIGURE 4-6
SR CHEOPS MODELED AND HISTORICAL J. STROM THURMOND RESERVOIR ELEVATION COMPARISON



The SR CHEOPS Model simulation of the Historical Baseline scenario estimated an average annual energy output 4 percent lower than historical generation for the same period, as shown in Table 4-1. Based on available historical generation records, modeled and historical generation were compared for the period 1998 through 2008 at all facilities except for Richard B. Russell. Generation at the Richard B. Russell Project was only compared for the time period 2006 through 2008. Prior to 2006, the Richard B. Russell pump units (four) were rarely operated. There are significant annual swings in the percent difference between historical and modeled operations for the 1998 through 2008 period, with the largest variations at the Duke Energy facilities.

The Duke Energy facilities are operated on demand with a priority on peaking operations to optimize the value of generation based on energy pricing, whereas the USACE facilities are operated on a weekly baseload schedule. The result is that the operations of the Duke Energy facilities (especially pumping operations) vary greatly depending on the value of generation. The Duke Energy system is only required to release water to the system to stay in balance with the system balance as outlined in the 1968 Agreement. The USACE system is driven by a combination of the power requirements to SEPA, the system storage balance, and the minimum discharge requirements from the J. Strom Thurmond Project.

TABLE 4-1
SR CHEOPS HISTORICAL BASELINE: GENERATION COMPARISON

Percent Difference between Modeled and Historical Generation							
([Modeled - Historic]/Historic)							
Year	**Bad Creek**	**Jocassee**	**Keowee**	**Hartwell**	**Richard B. Russell**	**J. Strom Thurmond**	**System Total**
1998	1%	19%	-10%	-2%		-6%	2%
1999	6%	47%	-25%	-1%		3%	11%
2000	-2%	32%	29%	8%		8%	6%
2001	15%	-32%	28%	10%		1%	3%
2002	5%	-45%	-7%	0%		9%	-8%
2003	-13%	-2%	12%	19%		9%	-3%
2004	5%	2%	14%	0%		1%	3%
2005	-9%	-3%	3%	1%		-9%	-6%
2006	4%	0%	-1%	-4%	-10%	-14%	-1%
2007	-10%	2%	51%	18%	-3%	6%	-4%
2008	-44%	-68%	36%	19%	7%	11%	-38%
Period Total (1998–2008)	-5%	-8%	7%	5%	-3%	0%	-4%

Figures 4-7 and 4-8 show the SR CHEOP Model daily and cumulative modeled (verification scenario) discharges from the Hartwell and J. Strom Thurmond Projects as compared to the historical (observed) discharges for the same period. For the period 1998 through 2008, the SR

CHEOPS Model estimated a cumulative discharge from Lake Hartwell and J. Strom Thurmond Lake within 1 percent of the historical cumulative discharge from each facility.

FIGURE 4-7
SR CHEOPS MODELED AND HISTORICAL HARTWELL PROJECT DISCHARGE COMPARISON

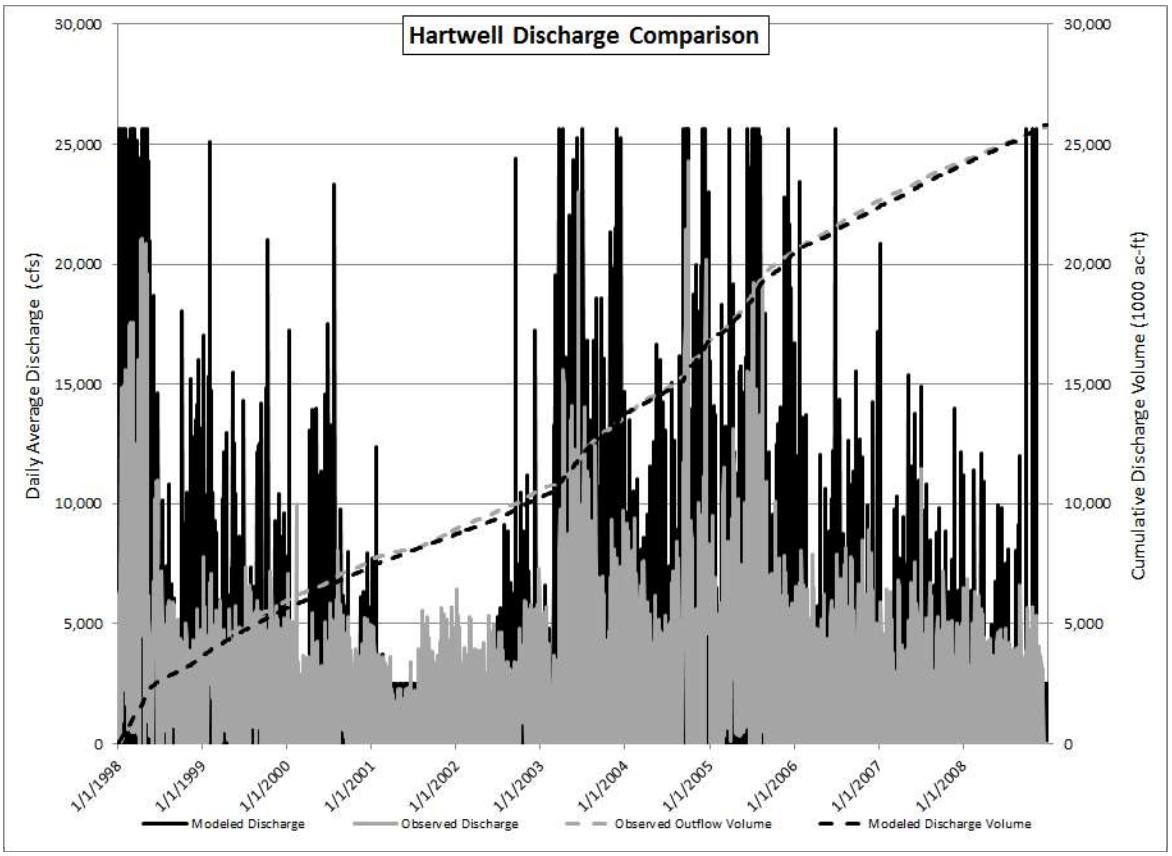
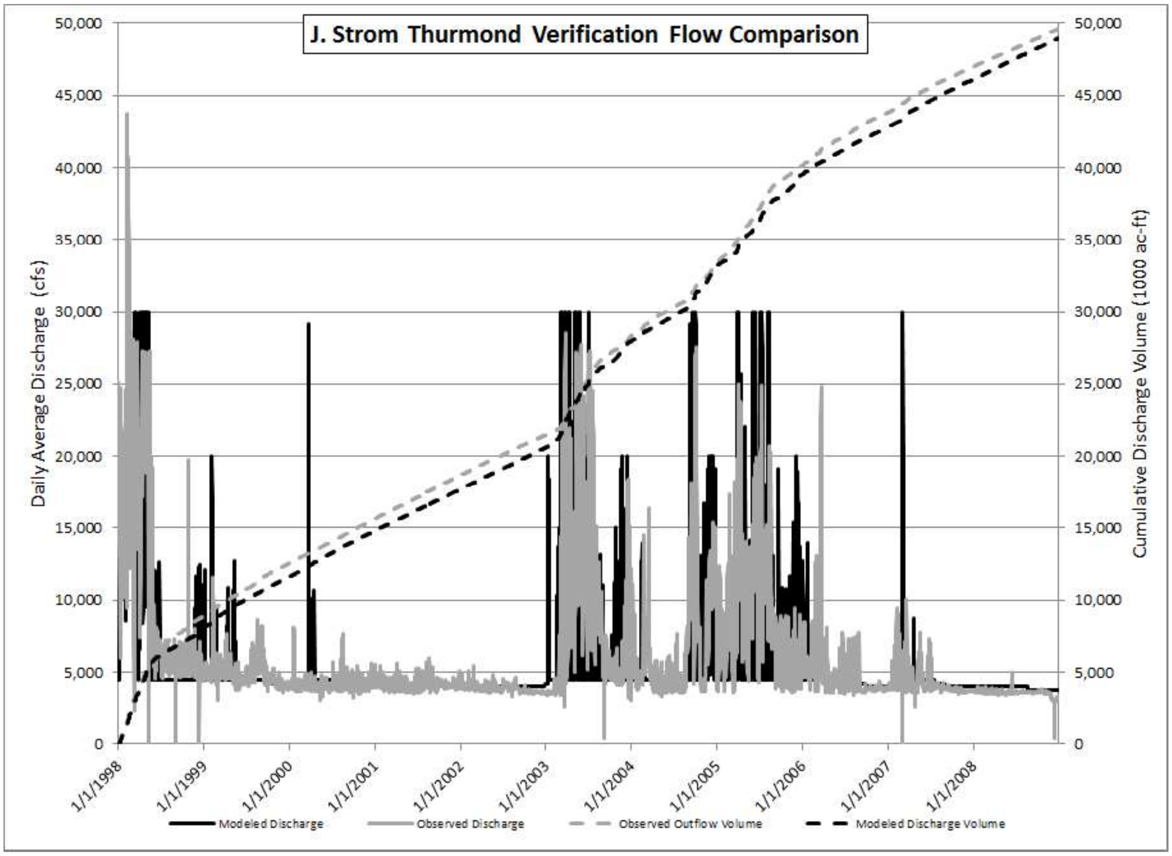


FIGURE 4-8
SR CHEOPS MODELED AND HISTORICAL J. STROM THURMOND PROJECT DISCHARGE COMPARISON



4.1.2 SR CHEOPS Scenario v2007

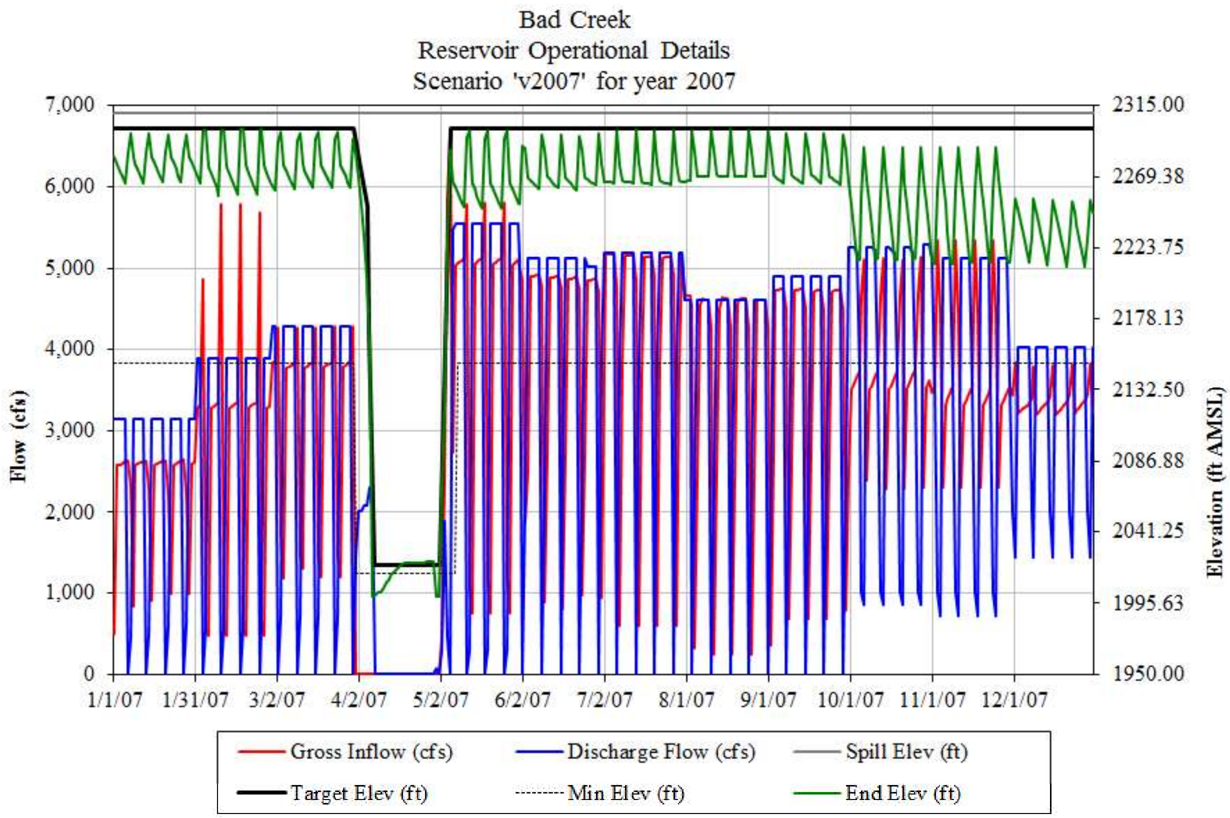
The v2007 scenario was established in the SR CHEOPS Model following the typical operating requirements of the system (same rule logic as the Historical Baseline scenario). Target elevations were applied such that the model will attempt to operate the reservoir pools as they were historically for calendar year 2007. Additionally actual reported 2007 water withdrawals and returns, pumping operations, and unit outages were applied in the v2007 scenario to simulate historical operations (where data was available) for calendar year 2007. Note this scenario is not strictly based on the water balance rules defined in the 1968 Agreement but closely represents how the facilities have been operated over the hydrologic period. Also, rehabilitation of Hartwell Project Units 1 through 4 was not complete until May of 2007. Unit outages associated with the rehabilitation were not taken into account in the model and it was assumed that the units were operating at post-rehabilitation efficiency and capacity for the entire year.

For this scenario, the Bad Creek and Jocassee Reservoirs were set to have target elevations which approximated their end of day elevations on a two-week interval. At the Bad Creek Project, non-typical operations were observed in April into early May, when the reservoir was drawn down significantly, for maintenance procedures. For the remainder of the year, typical weekly cycling of the upper reservoir was observed and mimicked in the SR CHEOPS Model. As shown in Table 4-2, simulated generation at the Bad Creek Project for the v2007 scenario is 67,894 MWh (2.8 percent) higher than historical generation for the same period. A pumping power consumption of 3,116,829 MWh was simulated, which is 1,516 MWh or 0.0 percent higher than historical. Figure 4-9 demonstrates the Bad Creek Reservoir historical elevations and modeled inflows, outflows, and elevations.

TABLE 4-2
SR CHEOPS MODEL V2007: GENERATION COMPARISON

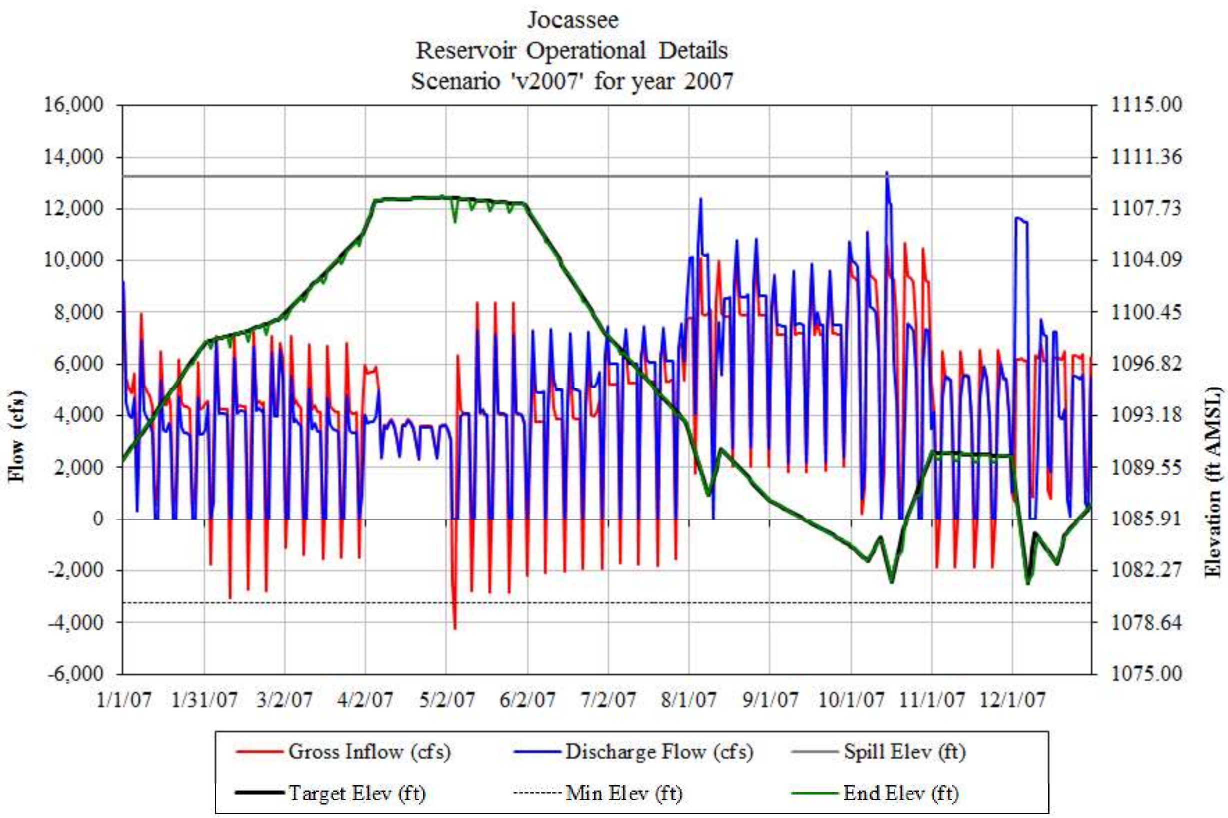
Historical (MWh)													
Facility	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Bad Creek	154,084	169,740	208,316	65,460	169,505	251,916	271,031	247,262	233,231	257,209	227,607	212,309	2,467,670
Jocassee	38,678	31,650	46,173	54,950	51,862	69,014	90,466	129,671	106,902	99,996	59,029	79,662	858,053
Keowee	1,574	2,309	922	1,216	4,944	8,523	3,755	5,552	3,275	0	-87	386	32,369
Hartwell	23,345	22,092	18,907	17,132	26,676	27,224	26,712	23,607	16,568	23,239	16,479	12,440	254,421
Richard B. Russell	64,568	40,196	31,531	20,025	34,772	50,217	48,210	48,657	40,887	54,621	39,602	23,734	497,020
J. Strom Thurmond	32,330	40,057	42,855	29,371	38,724	35,233	30,445	28,555	28,009	27,397	25,393	26,094	384,463
System Total	314,579	306,044	348,704	188,154	326,483	442,127	470,619	483,304	428,872	462,462	368,110	354,625	4,493,996
v2007 (MWh)													
Facility	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Bad Creek	161,415	170,465	207,435	28,516	228,707	247,146	286,458	251,241	239,428	261,656	237,088	216,009	2,535,564
Jocassee	53,075	50,505	48,657	56,744	54,294	72,211	92,211	131,237	108,305	101,577	58,068	79,923	906,807
Keowee	3,866	1,544	1,918	630	5,423	9,590	5,093	6,132	3,531	0	0	0	37,727
Hartwell	30,088	23,691	20,208	18,249	29,927	29,855	27,180	29,015	16,635	24,290	19,123	14,416	282,677
Richard B. Russell	30,782	43,020	45,875	45,820	50,240	48,781	45,272	48,708	31,459	35,020	43,499	41,792	510,268
J. Strom Thurmond	35,559	40,520	40,811	30,579	40,673	33,246	30,296	33,495	30,587	28,972	26,967	26,946	398,651
System Total	314,785	329,745	364,904	180,538	409,264	440,829	486,510	499,828	429,945	451,515	384,745	379,086	4,671,694
Difference (MWh) - (Modeled v2007 - Historical)													
Facility	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Bad Creek	7,331	725	-881	-36,944	59,202	-4,770	15,427	3,979	6,197	4,447	9,481	3,700	67,894
Jocassee	14,397	18,855	2,484	1,794	2,432	3,197	1,745	1,566	1,403	1,581	-961	261	48,754
Keowee	2,292	-765	996	-586	479	1,067	1,338	580	256	0	87	-386	5,358
Hartwell	6,743	1,599	1,301	1,117	3,251	2,631	468	5,408	67	1,051	2,644	1,976	28,256
Richard B. Russell	-33,786	2,824	14,344	25,795	15,468	-1,436	-2,938	51	-9,428	-19,601	3,897	18,058	13,248
J. Strom Thurmond	3,229	463	-2,044	1,208	1,949	-1,987	-149	4,940	2,578	1,575	1,574	852	14,188
System Total	206	23,701	16,200	-7,616	82,781	-1,298	15,891	16,524	1,073	-10,947	16,635	24,461	177,698
Percent Difference - ([Modeled v2007 - Historical]/Historical)													
Facility	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Bad Creek	4.8%	0.4%	-0.4%	-56.4%	34.9%	-1.9%	5.7%	1.6%	2.7%	1.7%	4.2%	1.7%	2.8%
Jocassee	37.2%	59.6%	5.4%	3.3%	4.7%	4.6%	1.9%	1.2%	1.3%	1.6%	-1.6%	0.3%	5.7%
Keowee	145.6%	-33.1%	108.0%	-48.2%	9.7%	12.5%	35.6%	10.4%	7.8%	0.0%	0.0%	-100.0%	16.6%
Hartwell	28.9%	7.2%	6.9%	6.5%	12.2%	9.7%	1.8%	22.9%	0.4%	4.5%	16.0%	15.9%	11.1%
Richard B. Russell	-52.3%	7.0%	45.5%	128.8%	44.5%	-2.9%	-6.1%	0.1%	-23.1%	-35.9%	9.8%	76.1%	2.7%
J. Strom Thurmond	10.0%	1.2%	-4.8%	4.1%	5.0%	-5.6%	-0.5%	17.3%	9.2%	5.7%	6.2%	3.3%	3.7%
System Total	0.1%	7.7%	4.6%	-4.0%	25.4%	-0.3%	3.4%	3.4%	0.3%	-2.4%	4.5%	6.9%	4.0%

FIGURE 4-9
SR CHEOPS MODEL V2007 AND HISTORICAL BAD CREEK PROJECT OPERATIONS



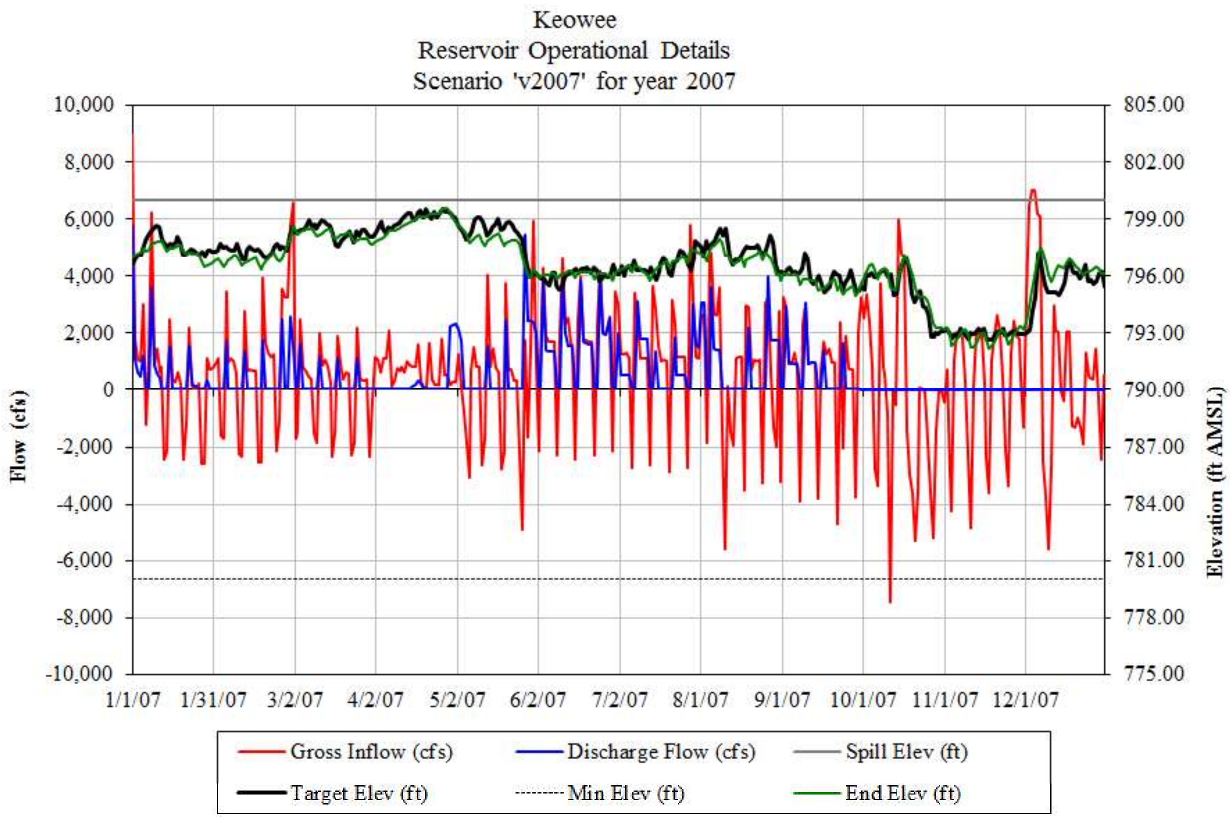
As previously noted, the historical Jocassee Reservoir operations were simulated in the v2007 scenario to mimic actual reservoir operations. Figure 4-10 shows Jocassee Reservoir historical elevation, flows, and modeled elevations and flows. As shown in Table 4-2, the simulated generation is 48,754 MWh (5.7 percent) higher than historical generation. A pumping power consumption 1,088,271 MWh was simulated, which is 1.7 percent less than historical. Negative flows are a result of upstream pumping operations.

FIGURE 4-10
SR CHEOPS MODEL V2007 AND HISTORICAL JOCASSEE DEVELOPMENT OPERATIONS



For each of the remaining four reservoirs, daily target elevations were input in the model to reflect the significantly varying end of day elevations. Figure 4-11 shows Lake Keowee historical and modeled operations for 2007. Negative flows are a result of upstream pumping operations. The model generally follows the trends of the historical elevations. During the fourth quarter of 2007, historical records show that the powerhouse did not release generation flows except for a few hours on December 31. To duplicate these operations, the Keowee powerhouse was modeled in maintenance outage, and wicket gate leakage was duplicated with a bypass flow condition during this timeframe. As shown in Table 4-2, the v2007 modeled generation at the Keowee Station is 5,358 MWh (16.6 percent) higher than historical.

FIGURE 4-11
SR CHEOPS MODEL V2007 AND HISTORICAL KEOWEE DEVELOPMENT OPERATIONS



Figures 4-12 through 4-14 show the USACE reservoir historical and modeled operations for 2007. As shown, the model follows the trends of the historical elevations very closely for each of the USACE reservoirs. Table 4-2 shows the v2007 modeled generation at Hartwell, Richard B. Russell, and J. Strom Thurmond Projects is 28,256; 13,248; and 14,188 MWh (11.1, 2.7, and 3.7 percent) higher than historical, respectively. The higher than historical modeled generation results are supported in the higher than historic discharge volume for the same period, shown in Figures 4-15 and 4-16. The simulated discharge volume from Lake Hartwell is 5.2 percent higher than the historical reported discharge for the 2007 period. Similarly, the simulated discharge volume from J. Strom Thurmond Lake is 3.8 percent higher than the historical reported discharge for the 2007 period.

FIGURE 4-12
SR CHEOPS MODEL V2007 AND HISTORICAL HARTWELL PROJECT OPERATIONS

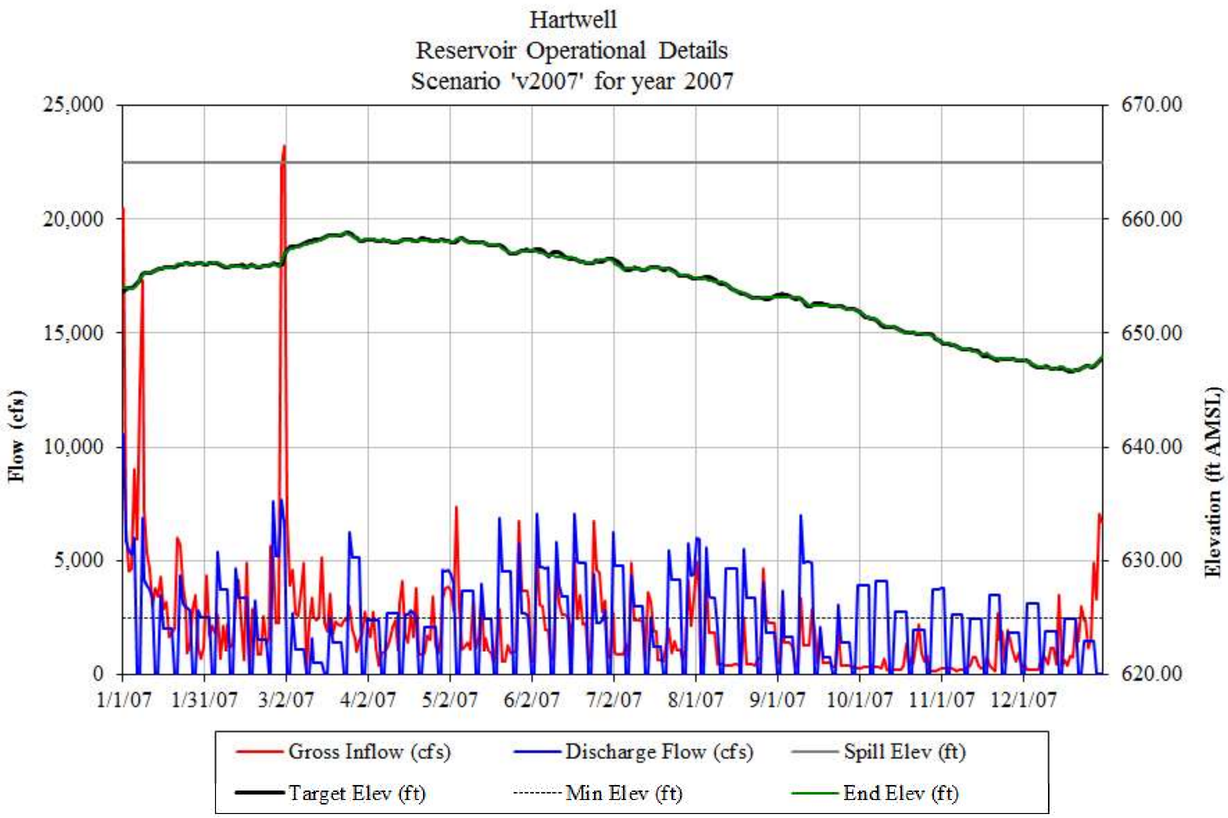


FIGURE 4-13
SR CHEOPS MODEL V2007 AND HISTORICAL RICHARD B. RUSSELL PROJECT OPERATIONS

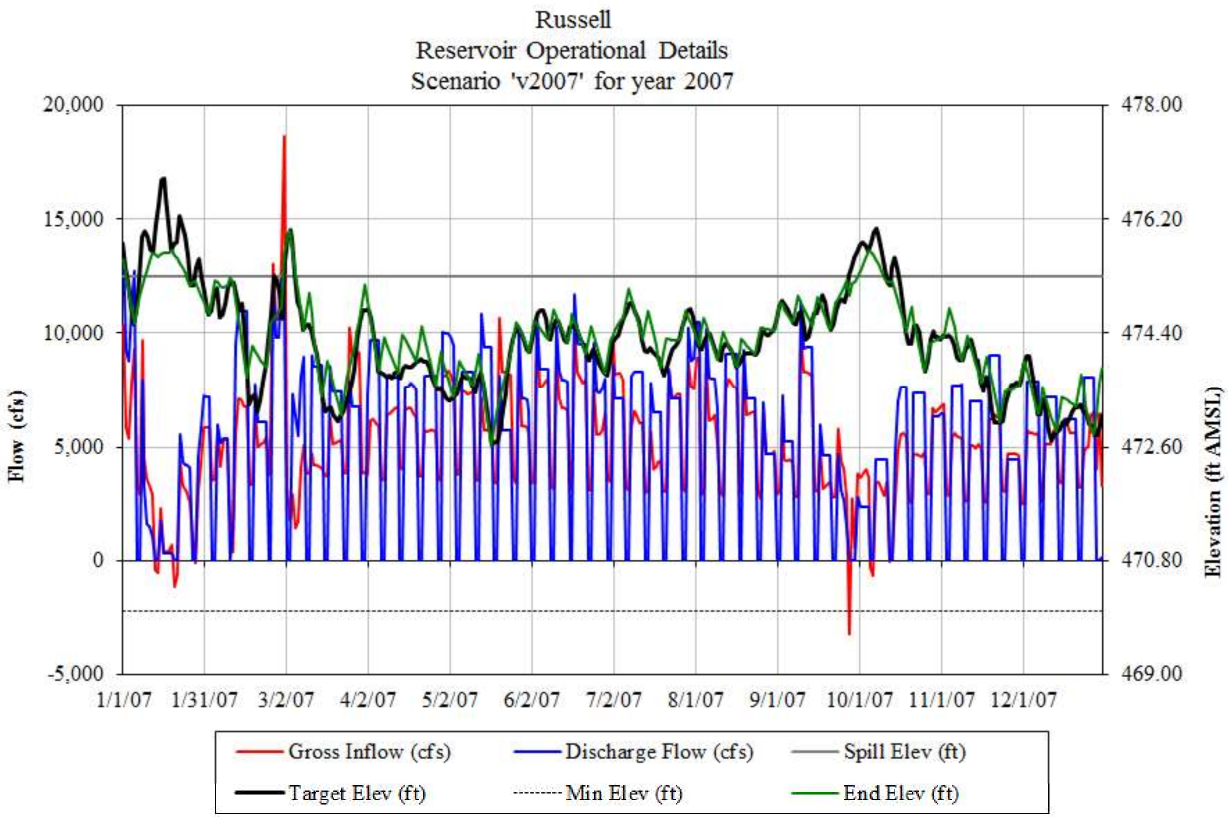


FIGURE 4-14
SR CHEOPS MODEL V2007 AND HISTORICAL J. STROM THURMOND PROJECT OPERATIONS

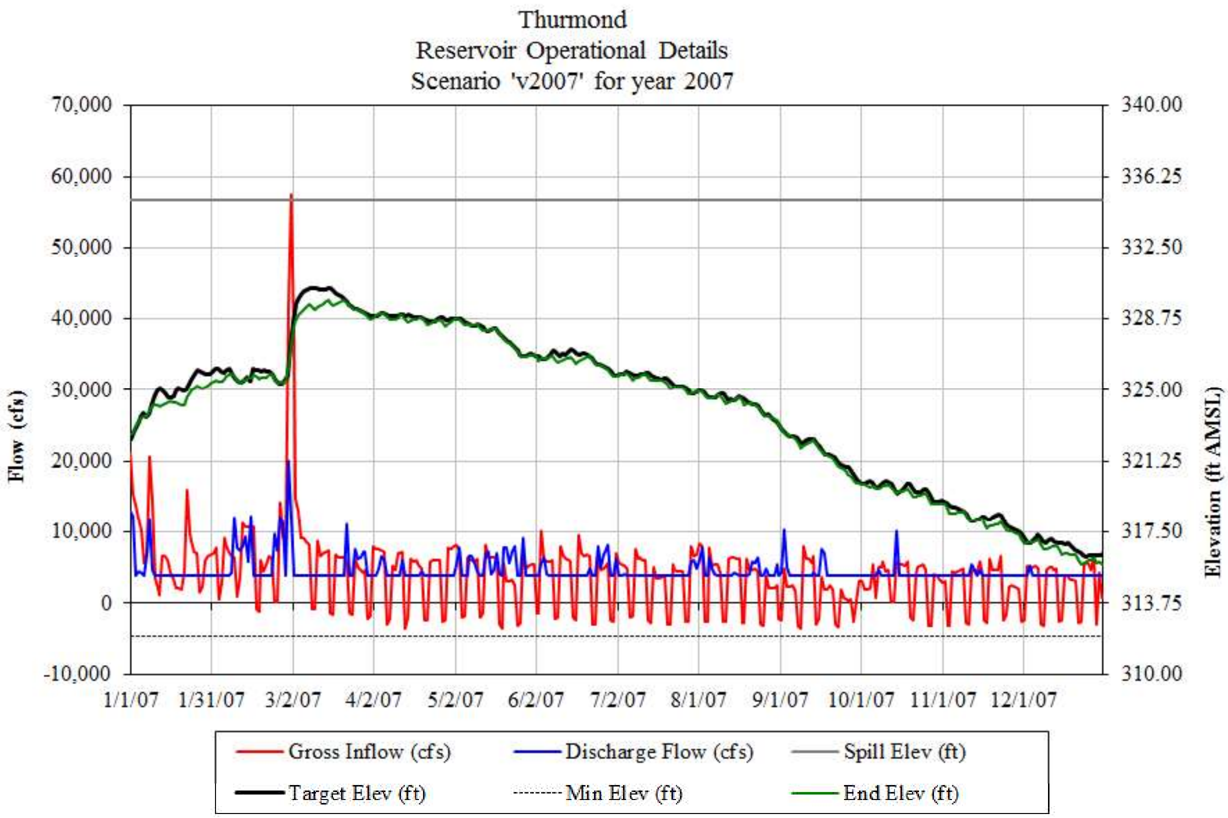


FIGURE 4-15
SR CHEOPS MODEL V2007 AND HISTORICAL HARTWELL PROJECT DISCHARGE COMPARISON

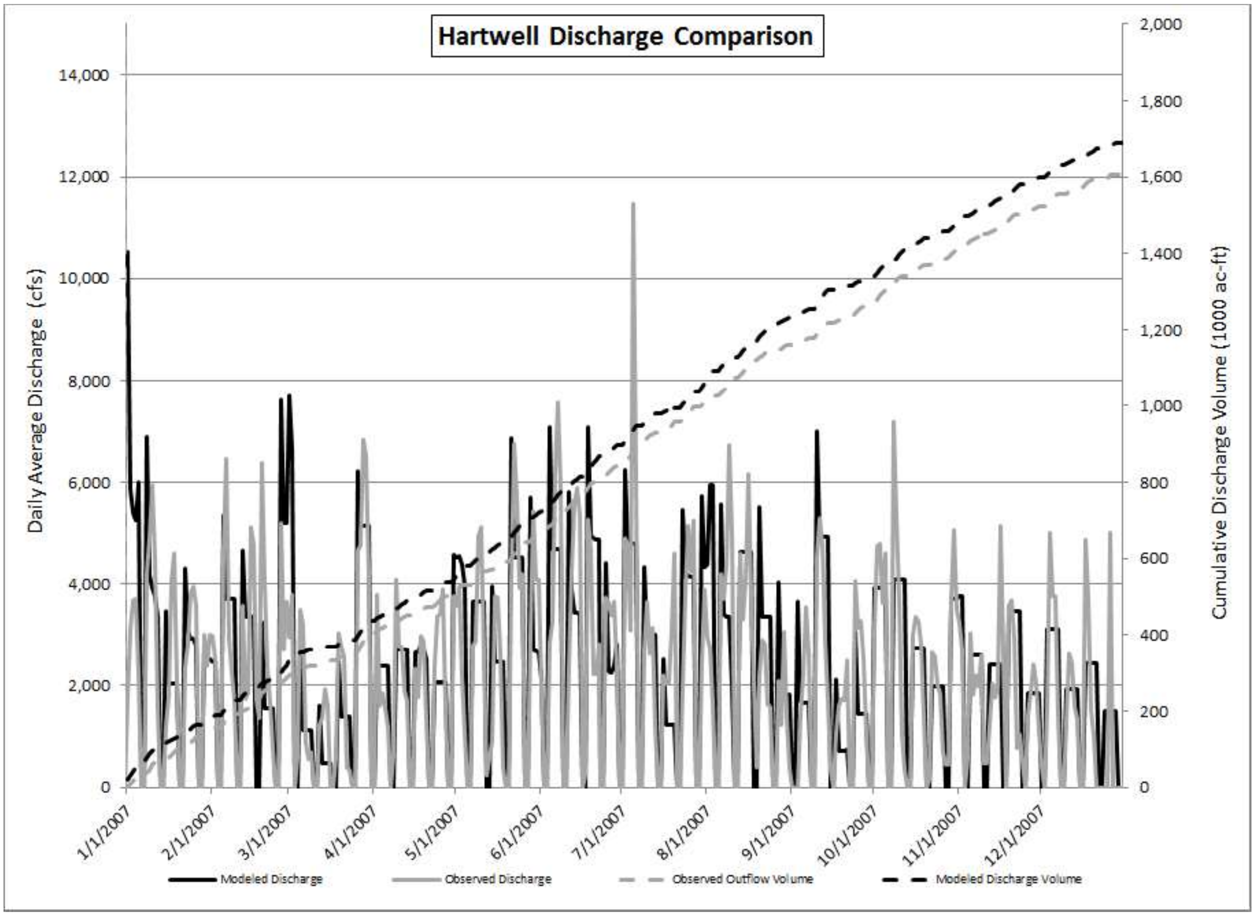
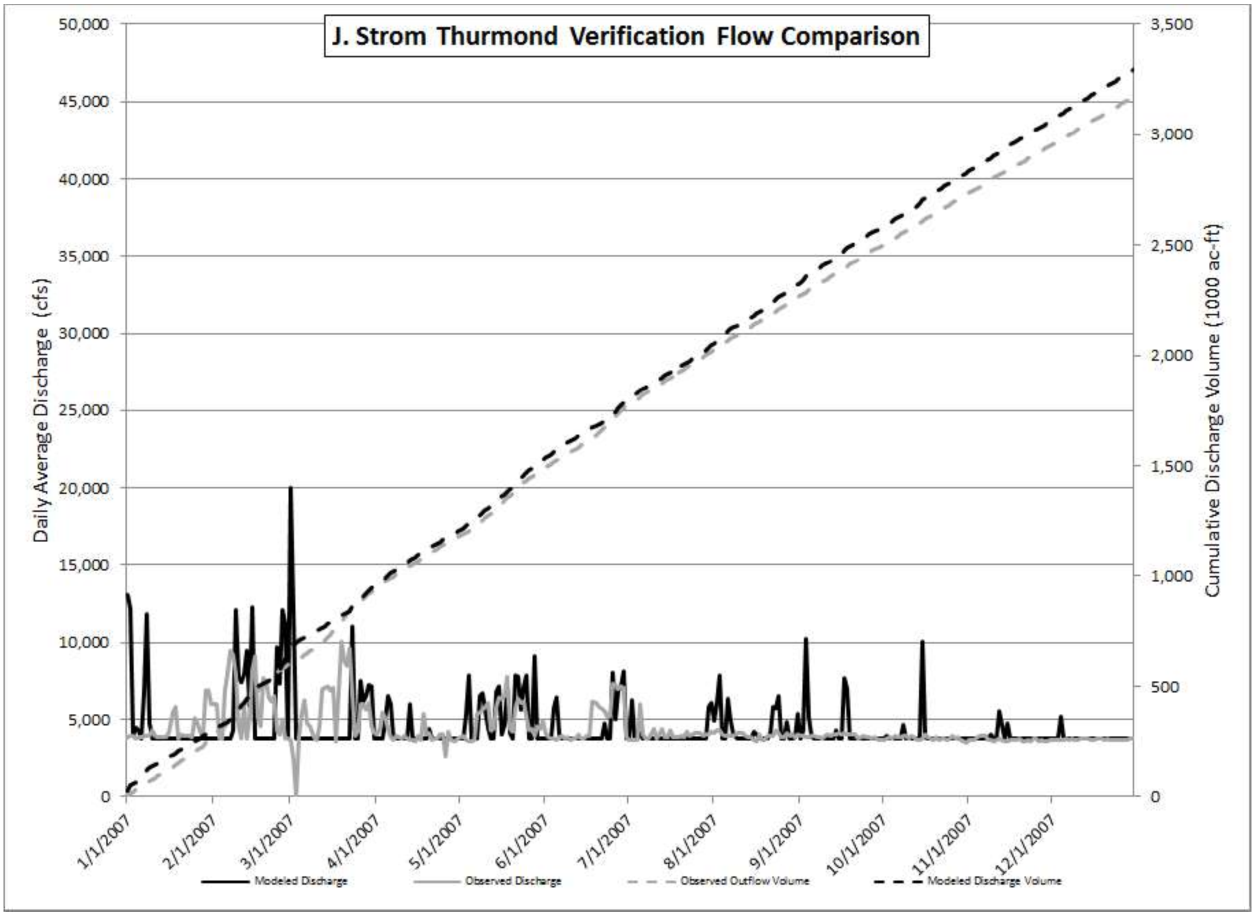


FIGURE 4-16
SR CHEOPS MODEL V2007 AND HISTORICAL J. STROM THURMOND PROJECT DISCHARGE COMPARISON



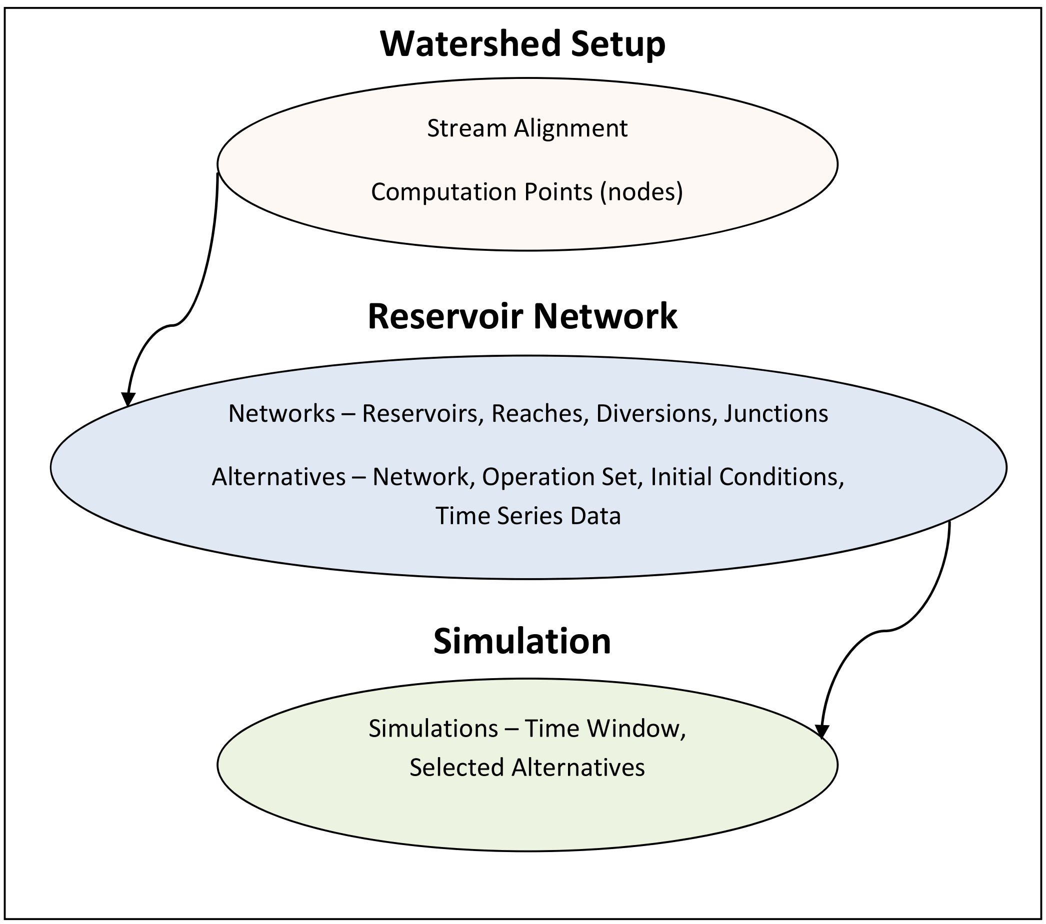
5.0 SR RESSIM MODEL – BASELINE

The following sections define the development of the Baseline scenario used for the verification of the SR ResSim Model. Each sub-section defines specific inputs used in the model verification to simulate historical operations.

5.1 SR ResSim Model Logic

ResSim is divided into three modules: Watershed Setup, Reservoir Network, and Simulation. Figure 5-1 provides an overview of the model logic and sequence (USACE 2007).

FIGURE 5-1
RESSIM MODULES



5.2 SR ResSim Model Input Data

The project data listed in the following subsections shows the general operational constraints and physical parameters used in the SR ResSim Model to define the current system configuration used in both the verification and the Baseline scenario setups. For consistency and comparison between model architecture, the model scenario selected for the SR ResSim Model verification is the same as used for the SR CHEOPS Model. Model verification uses historical data and tests the ability of the model to simulate actual operations of all six facilities. The verification scenario presented in this report is based on the NAA scenario with adjustments as defined in Baseline scenario below. The Baseline scenario was selected over the NAA scenario to more closely simulate historic operating conditions that have been used by Duke Energy for the selected hydrologic testing period (1998 through 2008 – verification).

- No Action Alternative (NAA)/Existing License

  The NAA reflects the operating conditions of the Jocassee, Keowee, Hartwell and J. Strom Thurmond facilities as defined in the 1968 Agreement with no changes and reflects the operations of the Project as outlined in the existing Project FERC license (FERC No. 2503). The 1968 Agreement is based on the concept of equalizing the percentage of combined remaining usable storage at Duke Energy Lake Jocassee and Lake Keowee with the percentage of combined remaining usable storage at the USACE Hartwell Lake and J. Strom Thurmond Lake.

- Baseline (Existing Operations)

  The Baseline scenario is based on the NAA scenario, except the minimum reservoir elevation at Lake Keowee is increased from 778 to 794.6 ft AMSL. The overall methodology used to determine required weekly releases from Lake Keowee remains unchanged. This scenario best describes the current/existing operations of the Duke Energy reservoirs.

- Verification

  The verification scenario is used for model verification and represents the Baseline scenario with the addition of historical water use (median 2003-2008) and reservoir elevations forced to simulate actual historical operations.

5.2.1 Reservoir Storage Curves

The Reservoir Storage Curve is a tabulated link between the reservoir elevation and reservoir volume. The elevations are in units of "feet" and the volumes are in "acre-feet." The model uses this curve to calculate elevations based on inflows and model-determined releases. Figure 5-2 shows the Bad Creek Reservoir storage curve used in the model. The data is from License Exhibit I Feb 4, 1974 (Duke Power Company 1974). The Lake Jocassee and Lake Keowee storage-volume relationships were revised based on bathymetric data collected in 2010 (Figures 5-3 and 5-4) and the USACE storage-volume relationships for Hartwell Lake, Richard B. Russell Lake, and J. Strom Thurmond Lake were updated based on published sedimentation rates from the Savannah River Basin. Sedimentation rates were converted to sediment volume using methods outlined in the USACE EM 1110-2-4000 and estimated compressed density of the sediment (Figures 5-5 through 5-7). A summary of the sedimentation calculations is provided in Appendix A.

FIGURE 5-2
BAD CREEK RESERVOIR STORAGE VOLUME CURVE

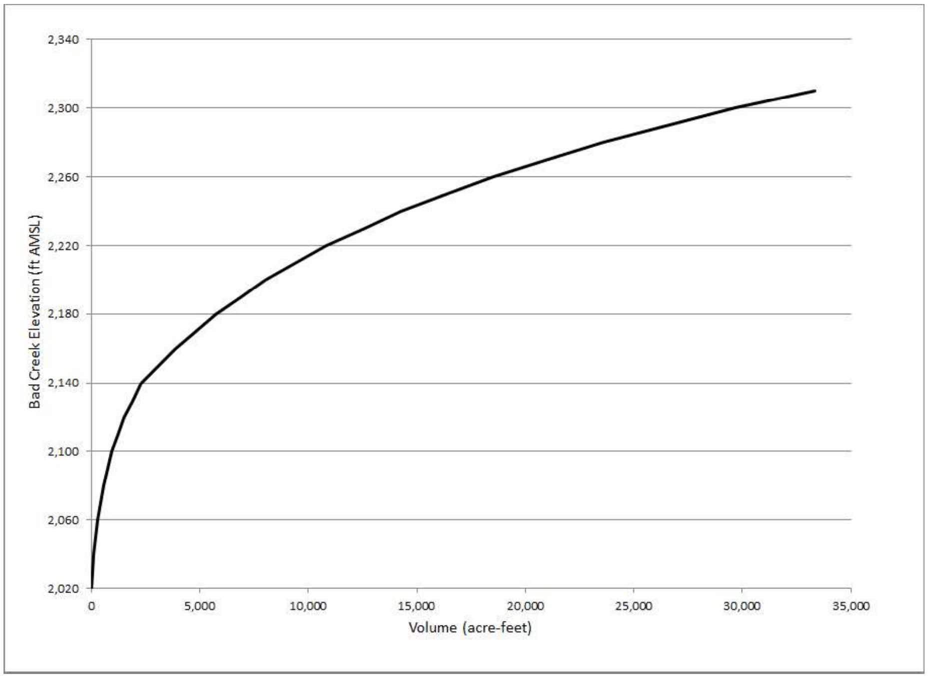


FIGURE 5-3
JOCASSEE RESERVOIR STORAGE VOLUME CURVE

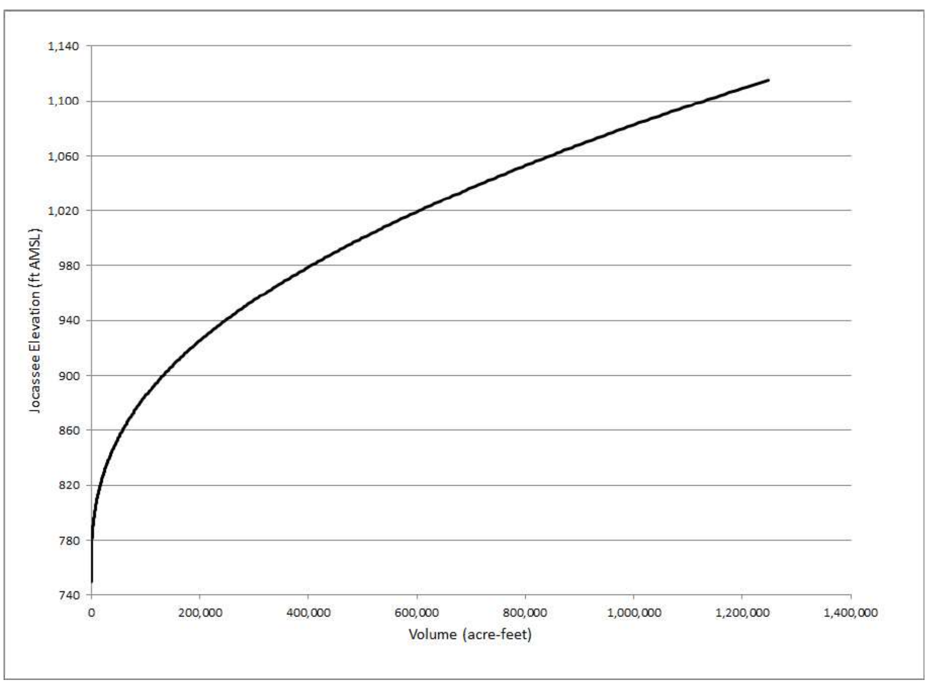


FIGURE 5-4
KEOWEE RESERVOIR STORAGE VOLUME CURVE

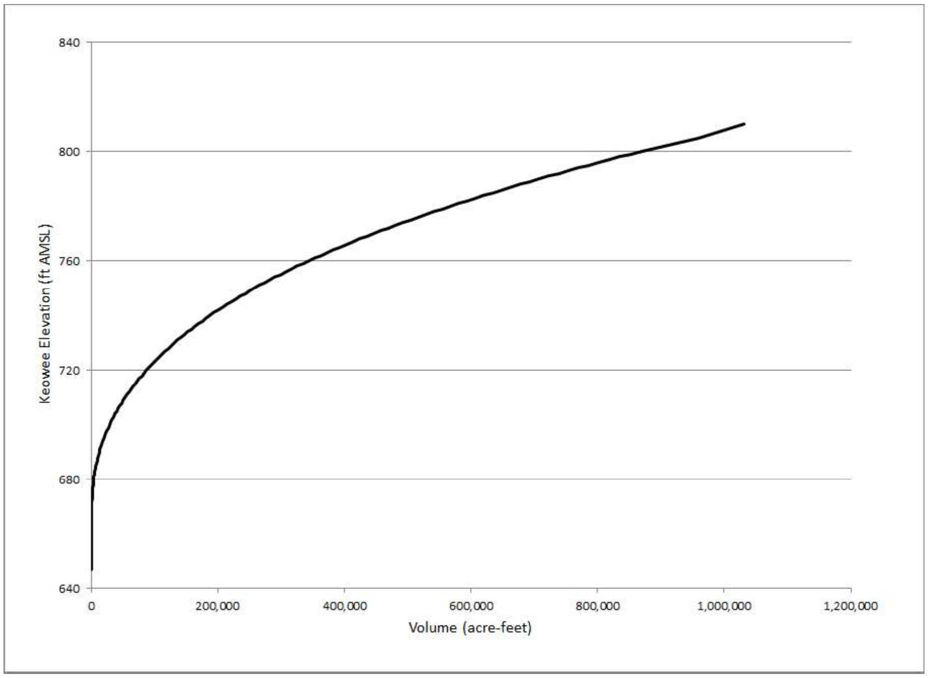


FIGURE 5-5
HARTWELL RESERVOIR STORAGE VOLUME CURVE

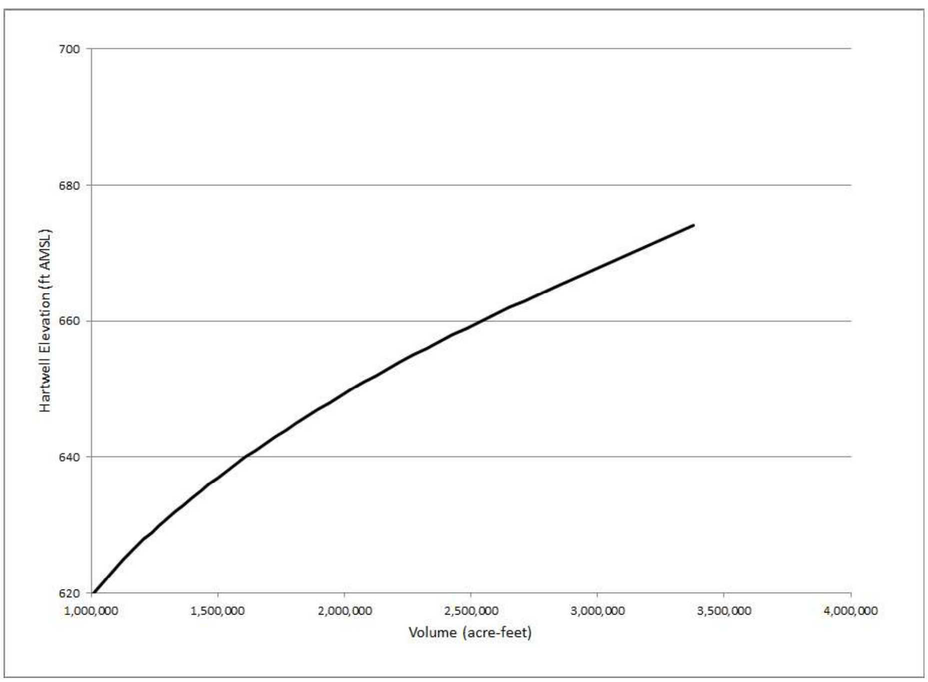


FIGURE 5-6
RICHARD B. RUSSELL RESERVOIR STORAGE VOLUME CURVE

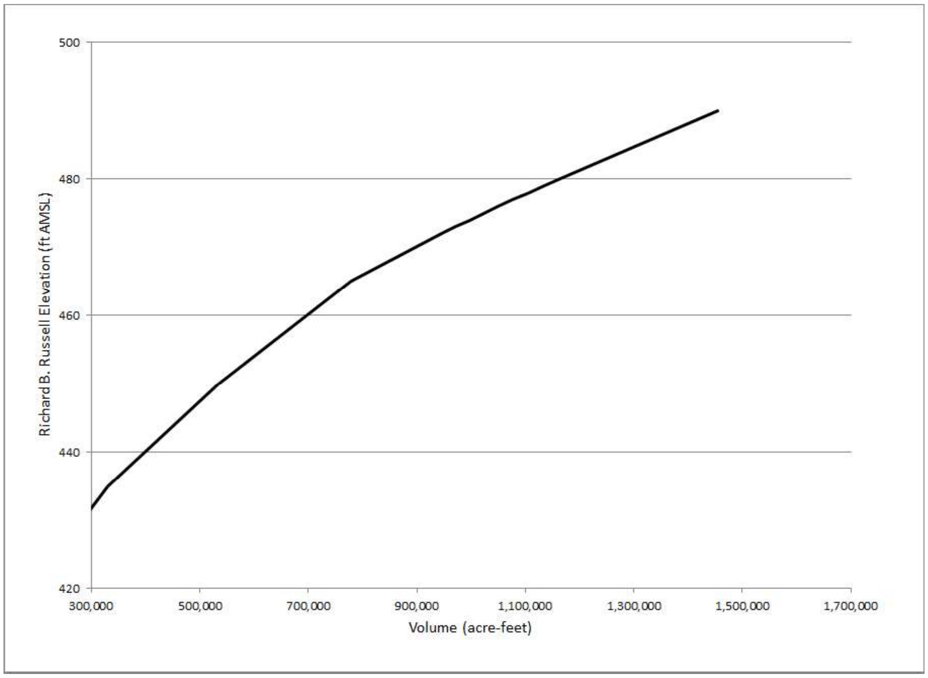
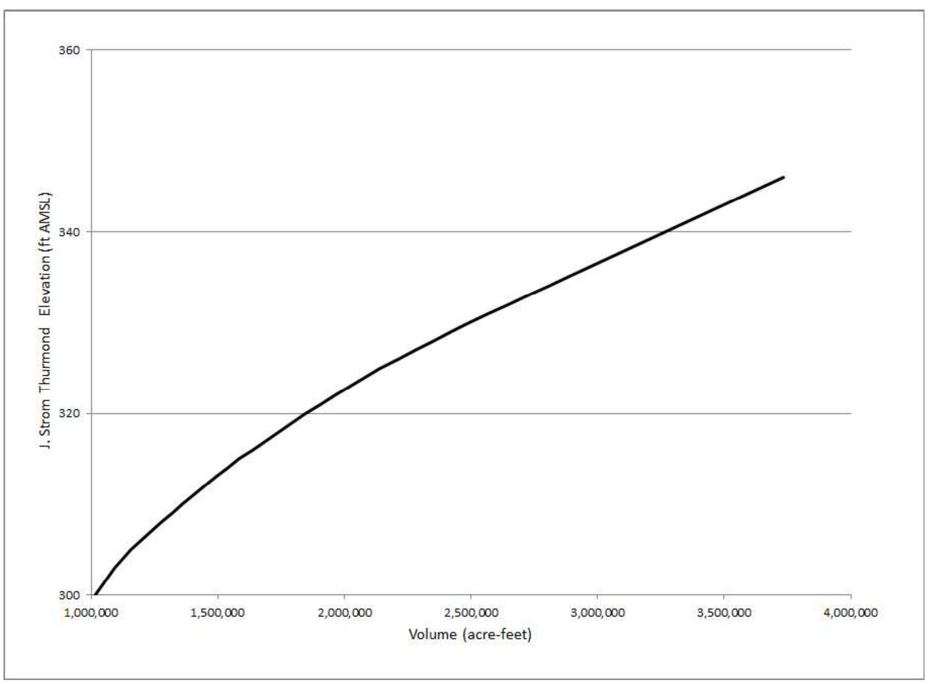


FIGURE 5-7
J. STROM THURMOND RESERVOIR STORAGE VOLUME CURVE



5.2.2 Reservoir Area Curves

The Reservoir Area Curve is a tabulated link between the reservoir elevation and reservoir surface area. The elevations are in units of “feet” and the areas are in “acres.” The model uses this curve to calculate the surface area and uses this data for computing evaporation losses. Figures 5-8 through 5-13 show the reservoir area curves used in the SR ResSim Model.

FIGURE 5-8
BAD CREEK RESERVOIR AREA CURVE

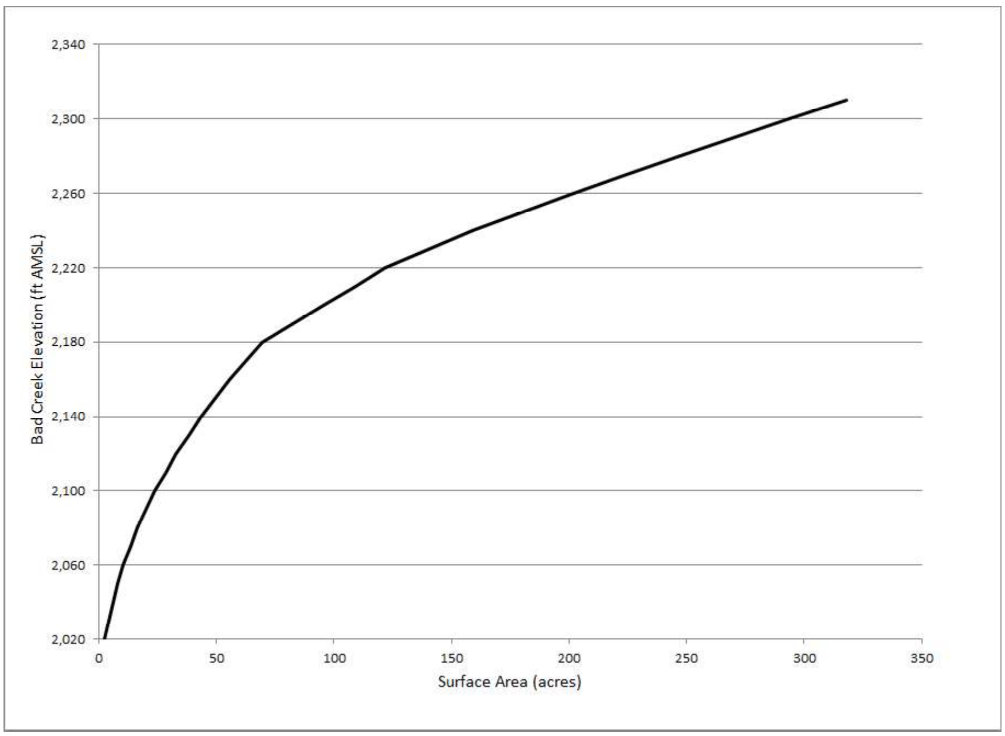


FIGURE 5-9
JOCASSEE RESERVOIR AREA CURVE

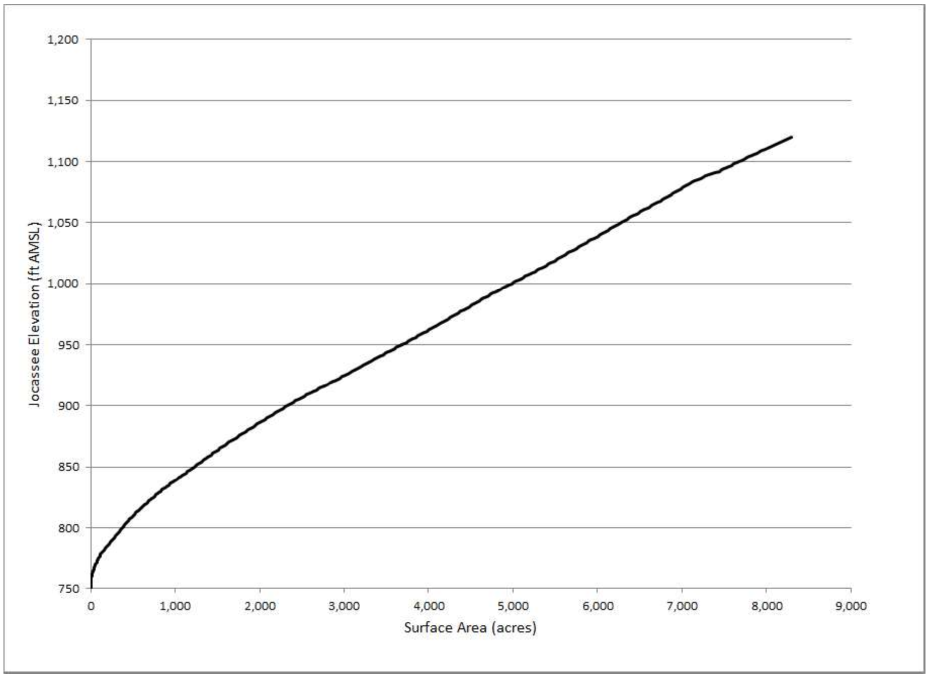


FIGURE 5-10
KEOWEE RESERVOIR AREA CURVE

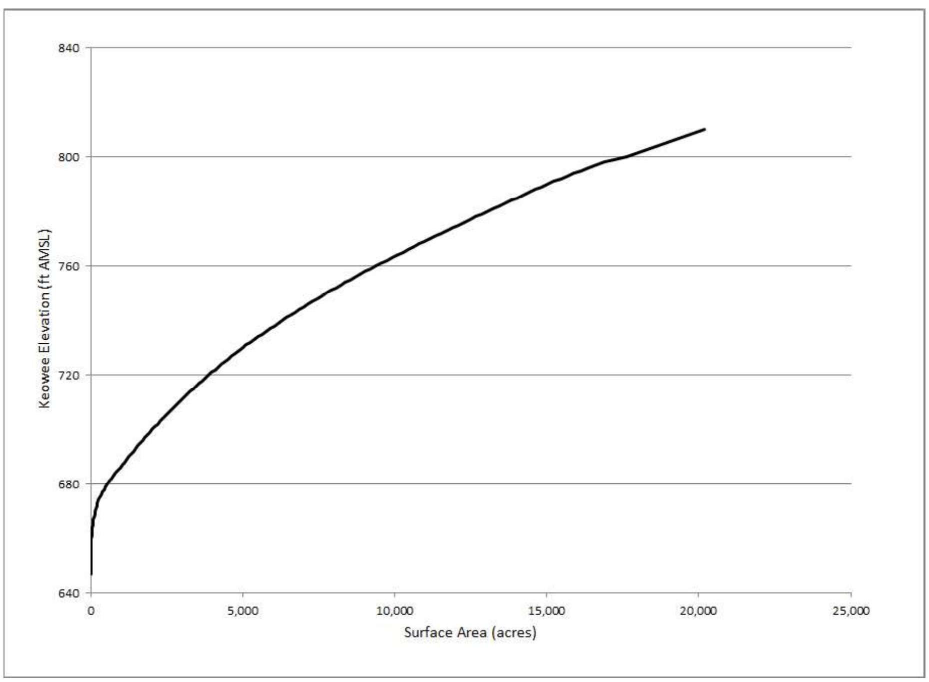


FIGURE 5-11
HARTWELL RESERVOIR AREA CURVE

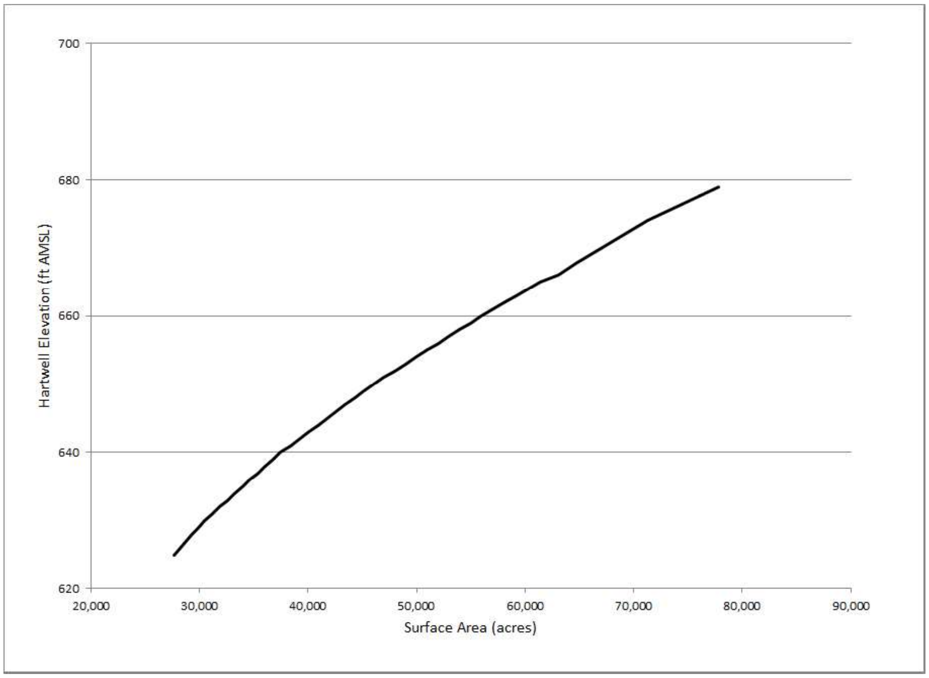


FIGURE 5-12
RICHARD B. RUSSELL RESERVOIR AREA CURVE

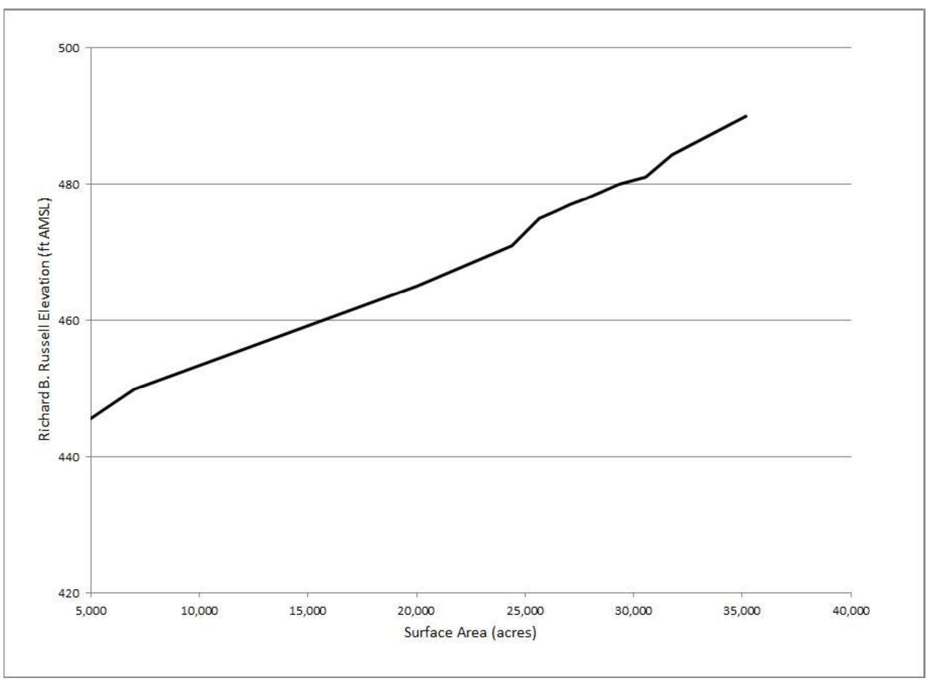
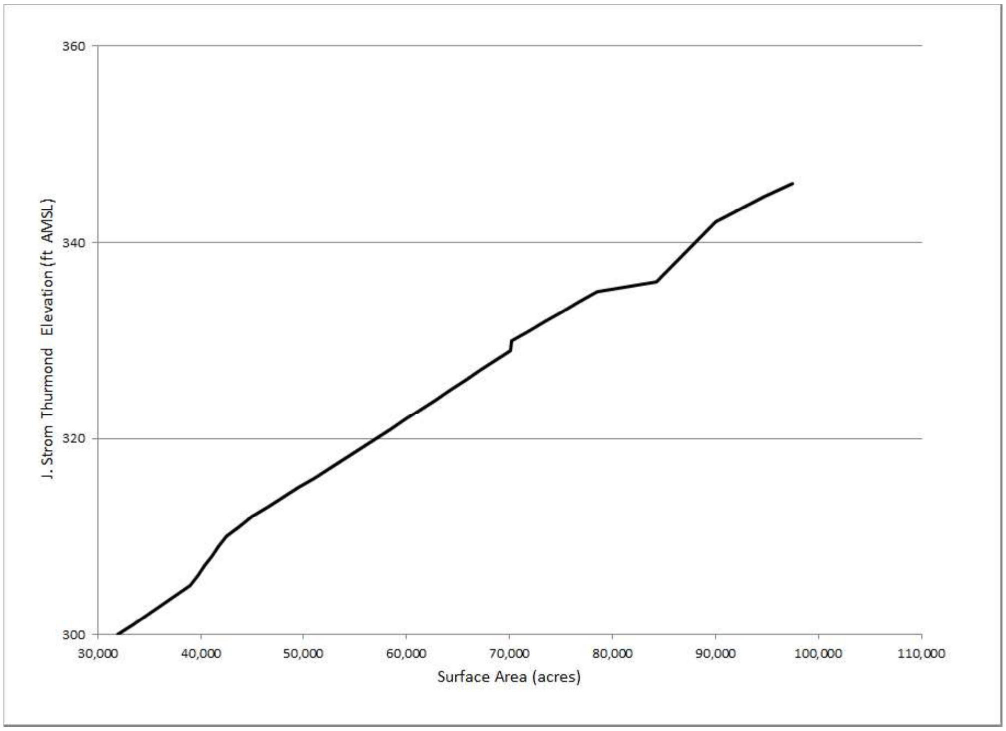


FIGURE 5-13
J. STROM THURMOND RESERVOIR AREA CURVE



5.2.3 Monthly Evaporation

The SR ResSim evaporation is based upon a monthly-varying coefficient that defines the evaporative loss in inches per month. This evaporative loss is not strictly composed of losses due to evaporation, but rather a net change to inflows as a result of evaporation, direct precipitation to water surface, precipitation runoff, and changes to evapotranspiration losses. This coefficient is multiplied by the surface area and divided by the number of days in the month to compute total evaporative loss volume for the reservoir for each day. Table 5-1 shows the evaporation losses for each reservoir by month. The evaporation loss coefficients reflect the monthly 2008 values published by ARCADIS in the Savannah River Basin May 13, 2013, time series release (ARCADIS 2010, 2013). The September 16, 2010 ARCADIS time series release contains the same 2008 evaporation values as provided in the May 2013 release.

TABLE 5-1
SR RESSIM MODEL EVAPORATIVE LOSS COEFFICIENTS

	Bad Creek Evaporation Loss (inches/month)	Jocassee Evaporation Loss (inches/month)	Keowee Evaporation Loss (inches/month)	Hartwell Evaporation Loss (inches/month)	Russell Evaporation Loss (inches/month)	Thurmond Evaporation Loss (inches/month)
Jan	-1.56	-1.04	-0.56	-0.57	-0.40	-1.18
Feb	-0.77	-0.26	0.03	0.01	-0.19	-0.65
Mar	-2.55	-1.55	0.03	0.01	-0.02	-0.03
Apr	0.90	1.45	1.65	1.47	1.47	1.30
May	2.26	2.74	2.44	2.84	3.55	3.33
Jun	4.13	4.49	4.51	4.47	4.73	4.55
Jul	2.36	2.98	3.39	3.22	2.43	2.90
Aug	-0.46	0.44	0.37	0.72	1.58	1.44
Sep	1.94	2.30	2.57	2.83	2.41	2.29
Oct	0.28	0.66	0.98	0.79	0.32	0.28
Nov	-0.58	-0.23	0.05	0.05	-0.40	-2.31
Dec	-3.29	-2.47	-2.17	-1.83	-1.11	-1.27

5.2.4 Tailwater Data

The Tailwater Curve relates the powerhouse tailwater elevation to the developments' outflow. In cases where the powerhouse discharges directly into a downstream reservoir, the downstream reservoir's elevation is used to compute tailwater elevation. The elevation is in units of "feet" while the flow is in "cfs." The tailwater elevation is subtracted from the reservoir elevation to calculate the gross head used in determining turbine and pump-turbine hydraulic performance.

The Bad Creek Project discharges directly into Lake Jocassee, so the elevation of Lake Jocassee is the controlling factor for the Bad Creek Project tailwater. Likewise, the Jocassee powerhouse discharges directly into Lake Keowee, so the elevation of Lake Keowee is the control for Jocassee Development tailwater computation.

The Keowee powerhouse discharges into Hartwell Lake. However, due to backwater effects in the upstream lake channel, there is a significant difference between Hartwell Lake elevation (Hartwell Dam) and the water surface elevation below the Keowee powerhouse when the turbines are in operation. Table 5-2 shows the Keowee powerhouse tailwater curve in stage units of feet for various powerhouse outflows in cfs.

TABLE 5-2
KEOWEE STATION TAILWATER RATING CURVE

Stage (ft AMSL)	Flow (cfs)	Stage (ft AMSL)	Flow (cfs)
657.0	0	680.0	39,868
660.0	5,042	684.8	59,879
665.1	11,345	689.9	85,879
670.0	16,545	695.0	113,612
674.9	26,000		

Similar to the Bad Creek and Jocassee facilities, the Hartwell powerhouse discharges directly into the Richard B. Russell Lake without backwater effects. Therefore, Richard B. Russell Lake elevation is the control for Hartwell Project tailwater. The SR ResSim Model will use the greater of 475 ft AMSL or Richard B. Russell Lake water surface elevation. Reservoir elevation 475 ft AMSL is the minimum tailwater elevation that was provided by the USACE for modeling purposes. The Richard B. Russell powerhouse discharges into J. Strom Thurmond Lake. J. Strom Thurmond Lake elevation is the control for Richard B. Russell Project tailwater. The J. Strom Thurmond Project tailwater rating curve is shown in Table 5-3.

TABLE 5-3
J. STROM THURMOND PROJECT TAILWATER RATING CURVE

Stage (ft AMSL)	Flow (cfs)	Stage (ft AMSL)	Flow (cfs)
187	0	220	280,000
190	15,000	230	440,000
200	65,000	240	640,000
210	155,000	250	870,000

5.2.5 Spillway Capacity

The Spillway Curve contains the data relating reservoir elevation (feet) and spillway discharge capacity (cfs). This data allows the model to determine the maximum amount of water that can be spilled at the current reservoir elevation and is the sum of all spillway conveyances with gates open to maximum setting. The SR ResSim Model allows for a simple spillway relationship of elevation and flow; therefore all spillways, including gates, are modeled as a relationship of elevation and flow.

The tabulated data for Bad Creek Project is shown in Table 5-4 and is taken from the Bad Creek Pumped Storage Project Supporting Technical Information (Duke Energy 2008). The Bad Creek emergency spillway is also known as the East Dike.

TABLE 5-4
BAD CREEK SPILLWAY CAPACITY TABLE

Elevation (ft AMSL)	Capacity (cfs)	Elevation (ft AMSL)	Capacity (cfs)
2,313.5	0	2,315.0	2,313
2,313.8	17	2,315.5	4,477
2,314.3	477	2,316.0	7,153
2,314.6	1,051		

Table 5-5 shows the maximum spillway capacity of the two gated spillways as delineated in the Jocassee Pumped Storage Project Supporting Technical Information (HDR 2010).

TABLE 5-5
JOCASSEE SPILLWAY (TOTAL GATED) CAPACITY TABLE

Elevation (ft AMSL)	Capacity (cfs)	Elevation (ft AMSL)	Capacity (cfs)
1,077	0	1102	34,531
1,082	2,762	1107	46,054
1,087	8,117	1112	58,671
1,092	15,374	1117	67,321
1,097	24,248	1122	74,138

Table 5-6 shows the spillway capacity of the four gated spillways as delineated in the Keowee Supporting Technical Information (HDR 2012).

TABLE 5-6
KEOWEE SPILLWAY (TOTAL GATED) CAPACITY TABLE

Elevation (ft AMSL)	Capacity (cfs)	Elevation (ft AMSL)	Capacity (cfs)
765	0	790	63,268
770	5,505	795	82,550
775	15,851	800	102,810
780	29,399	805	123,645
785	45,393	810	144,639

The spillway capacities of the USACE projects are shown in Tables 5-7 through 5-9 and contain original data received from the USACE and as represented in their SR ResSim Model.

TABLE 5-7
HARTWELL SPILLWAY (SINGLE GATE) CAPACITY TABLE

Elevation (ft AMSL)	Capacity (cfs)	Elevation (ft AMSL)	Capacity (cfs)	Elevation (ft AMSL)	Capacity (cfs)
630	0	657	21,577	666	34,679
635	1,400	658	22,908	667	36,182
640	4,400	659	24,274	668	37,709
645	8,500	660	25,675	669	39,260
650	13,400	661	27,110	670	40,833
653	16,604	662	28,581	671	42,430
654	17,795	663	30,086	672	44,050
655	19,021	664	31,625	673	45,693
656	20,282	665	33,200	674	47,359

*The Hartwell Project includes 12 gates.

TABLE 5-8
RICHARD B. RUSSELL SPILLWAY (SINGLE GATE) CAPACITY TABLE

Elevation (ft AMSL)	Capacity (cfs)	Elevation (ft AMSL)	Capacity (cfs)	Elevation (ft AMSL)	Capacity (cfs)
436	0	473	45,228	482	63,000
440	1,000	474	47,137	483	65,000
450	9,000	475	49,074	484	67,000
455	14,900	476	51,042	485	69,000
460	22,300	477	53,038	486	71,000
465	30,600	478	55,063	487	72,500
470	39,532	479	57,116	488	74,000
471	41,500	480	59,300	489	75,500
472	43,349	481	62,000	490	77,100

*The Richard B. Russell Project includes 10 gates.

TABLE 5-9
J. STROM THURMOND SPILLWAY (TOTAL GATED) CAPACITY TABLE

Elevation (ft AMSL)	Capacity (cfs)	Elevation (ft AMSL)	Capacity (cfs)
300	0	325	405,000
305	27,000	330	545,000
310	95,000	335	688,000
315	182,000	340	855,000
320	282,000	345	1,025,000

5.2.6 Spill and Minimum Elevations

The spill or flood control elevation relates to a variety of physical situations (spillway crest, partial gate coverage, maximum normal pool, etc.), but it represents the elevation at which the model will begin to simulate spill to avoid increasing water elevation.

The minimum elevation, or inactive zone elevation, is the minimum allowable reservoir elevation. The elevation could be set by regulations or by a physical limit (lowest available outlet invert). The model will operate to eliminate occurrences when the reservoir elevation dips below this elevation.

Table 5-10 lists the spill and minimum elevations for each development in the model.

TABLE 5-10
SR RESSIM MODEL RESERVOIR MAXIMUM AND MINIMUM ELEVATIONS

Facility	Spill Elevation (ft AMSL)	Minimum Elevation (ft AMSL)
Bad Creek	2,310	2,150.0
Jocassee	1,110.0	1,080.0
Keowee	800.0	794.6
Hartwell	665.0	625.0
Russell	480.0	465.0
Thurmond	335.0	312.0

5.2.7 Target Elevations

The target elevation, or Conservation Pool Guide Curve, is the user defined elevation which the model attempts to meet (targets) as the end-of-day reservoir elevation. The model straight-line interpolates between user input points to identify a target elevation for each day. The model will deviate from the target to accommodate forecasted inflows, to meet system power requirements, to meet the plant's own outflow requirements or constraints, and maintain storage balance relationship.

Table 5-11 lists the guide curves used for modeling the Duke Energy reservoirs, and Table 5-12 lists the guide curves for the USACE reservoirs. Target requirements for the USACE Project were provided by the USACE with their SR ResSim Model.

TABLE 5-11
SR RESSIM MODEL GUIDE CURVE ELEVATIONS OF DUKE ENERGY RESERVOIRS

	Bad Creek Target Elev (ft AMSL)	Jocassee Target Elev (ft AMSL)	Keowee Target Elev (ft AMSL)
1-Jan	2,280	1,106	799.9
1-May	2,280	1,109.5	799.9
15-Oct	2,280	1,109.5	799.9
31-Dec	2,280	1,106	799.9

TABLE 5-12
SR RESSIM MODEL GUIDE CURVE TARGET ELEVATIONS OF USACE RESERVOIRS

	Hartwell Target Elev (ft AMSL)	Russell Target Elev (ft AMSL)	Thurmond Target Elev (ft AMSL)
1-Jan	656	475	326
1-Apr	660	475	330
15-Oct	660	475	330
15-Dec	656	475	326

5.2.8 Minimum Flows

The Hartwell, Richard B. Russell, and J. Strom Thurmond Projects each have required fish spawning rules in the SR ResSim Model. The rule requires outflow to equal inflow if the reservoir is at or below target elevation during the month of April. Additionally, the J. Strom Thurmond Project has a required daily discharge of at least 3,800 cfs year-round.

5.2.9 Maximum Flows

The model allows for a maximum flow constraint to be applied at either a powerhouse or at a downstream node – this will limit operations to restrict flow to a maximum of the defined limit. The J. Strom Thurmond Project has a maximum flow restriction at the downstream node in Augusta, Georgia, depending on the reservoir elevation of J. Strom Thurmond Lake. If J. Strom Thurmond Lake elevation is below 330 ft AMSL, the maximum allowable flow at Augusta is 20,000 cfs; and if the reservoir elevation is greater than or equal to 330 ft AMSL, the maximum allowable flow is 30,000 cfs. These flow restrictions are based on goals for normal operation at the development. Under extreme flooding, these flows can be exceeded.

The Richard B. Russell Project has a maximum flow constraint of 60,000 cfs, and the Hartwell Project has a maximum flow constraint of 28,500 cfs.

5.2.10 Water Withdrawals

Historical water use (withdrawals and returns in cfs) were estimated as part of the Savannah River Basin September 16, 2010 UIF time series release (ARCADIS 2010, 2013). The median 2003-2008 monthly water use in cfs was modeled in the Verification scenario to represent historical municipal and industrial water use from each reservoir. Additionally, the 2003 through 2008 period represents recent activity at current population levels and industrial uses. Table 5-13 below shows the withdrawals and returns in the baseline condition. Negative withdrawals represent a net flow return to the reservoir. The example calculation below describes the withdrawal calculation for a reservoir for a month:

$$WR_{\text{R1,Month}} = Median(WR_{Day,Year})$$

where: $WR_{R1,Month}$ is the net withdrawal in (cfs) for the reservoir for the month

$WR_{Day,Year}$ is the withdrawal (cfs) for the reservoir for each day of the month for each of the months of interest in the 2003 through 2008 period

TABLE 5-13
WATER WITHDRAWALS

	Water Withdrawal (avg cfs/day)			Water Return (avg cfs/day)
Day of Year	**Keowee**	**Hartwell**	**J. Strom Thurmond**	**Richard B. Russell**
Jan 1	76.66	29.14	2.61	4.75
Feb 1	76.67	29.53	1.70	5.50
Mar 1	76.88	30.15	0.32	6.37
Apr 1	74.67	33.75	3.14	3.92
May 1	71.82	42.23	7.00	1.80
Jun 1	84.00	50.51	7.70	1.26
Jul 1	84.70	45.39	7.25	1.65
Aug 1	83.24	45.92	8.25	1.10
Sep 1	88.23	44.03	7.01	0.96
Oct 1	79.59	42.82	6.05	1.88
Nov 1	68.19	34.16	5.07	2.92
Dec 1	74.69	29.75	3.70	4.60

5.2.11 Storage Balance Operations and SR ResSim Model Alternatives

This section provides details of the storage relationship between the Duke Energy and USACE facilities as defined by the 1968 Agreement. Details of SR ResSim Model Alternatives (model scenarios) are also included in this section as examples of how the SR ResSim Model is set up for study purposes including testing (verification scenarios).

On October 1, 1968, Duke Energy's predecessor, Duke Power Company, entered into the 1968 Agreement with the USACE Savannah District and the SEPA regarding stored water sharing (releases) from the Project (Duke Power Company 1968). The 1968 Agreement defines the balancing of the available storage in the Duke Energy reservoirs (Lake Jocassee and Lake

Keowee) with the available storage in the USACE reservoirs (Hartwell Lake and J. Strom Thurmond Lake). The SR ResSim Model incorporates the terms of the 1968 Agreement through a series of programming rules. These rules are integral in simulating the storage relationships between the developments and significant time was spent by HDR and the USACE refining these rules in the SR ResSim Model (HDR 2014).

The storage balance operations of the system are simulated in ResSim using a combination of the Tandem and the Storage Balance Rules. The tandem operation rule establishes a link between reservoirs to achieve a storage balance. Each reservoir in the system from the Jocassee Development to the J. Strom Thurmond Project is simulated with a tandem rule. The reservoir storage at the Bad Creek Project and Richard B. Russell Project were not included in the 1968 Agreement between the USACE and Duke Energy. Therefore, Bad Creek Reservoir is not linked to the system via the tandem rule. However, for model stability purposes, the Richard B. Russell Lake is included while using a rule-link but no reservoir storage adjustments are required. Each reservoir in the system is linked to its downstream reservoir with the tandem rule (except as noted). The tandem rule is then linked to a system storage balance relationship. The storage balance definition defines the rate of drawdown at each reservoir in relation to the next downstream reservoir and is user definable. The application of the tandem rule and corresponding storage balance definition, plus weekly maximum Keowee Station release limits, simulates the system in accordance with the 1968 Agreement between the USACE and Duke Energy.

Both the Verification and Baseline scenarios include the tandem operations and supporting storage balance definitions for operating conditions currently being followed by Duke Energy. The storage balance definitions (charts) for the Verification and Baseline scenarios are presented in Figures 5-14 and 5-15. As an example of how the SR ResSim Model uses this information, if J. Strom Thurmond Lake is at 320 ft AMSL, then Hartwell Lake should be at 650 ft AMSL, Lake Jocassee should be at 1,086.2 ft AMSL, and Lake Keowee should be at 795.2 ft AMSL.

FIGURE 5-14
USACE RESERVOIR STORAGE BALANCE DRAWDOWN SCHEDULE

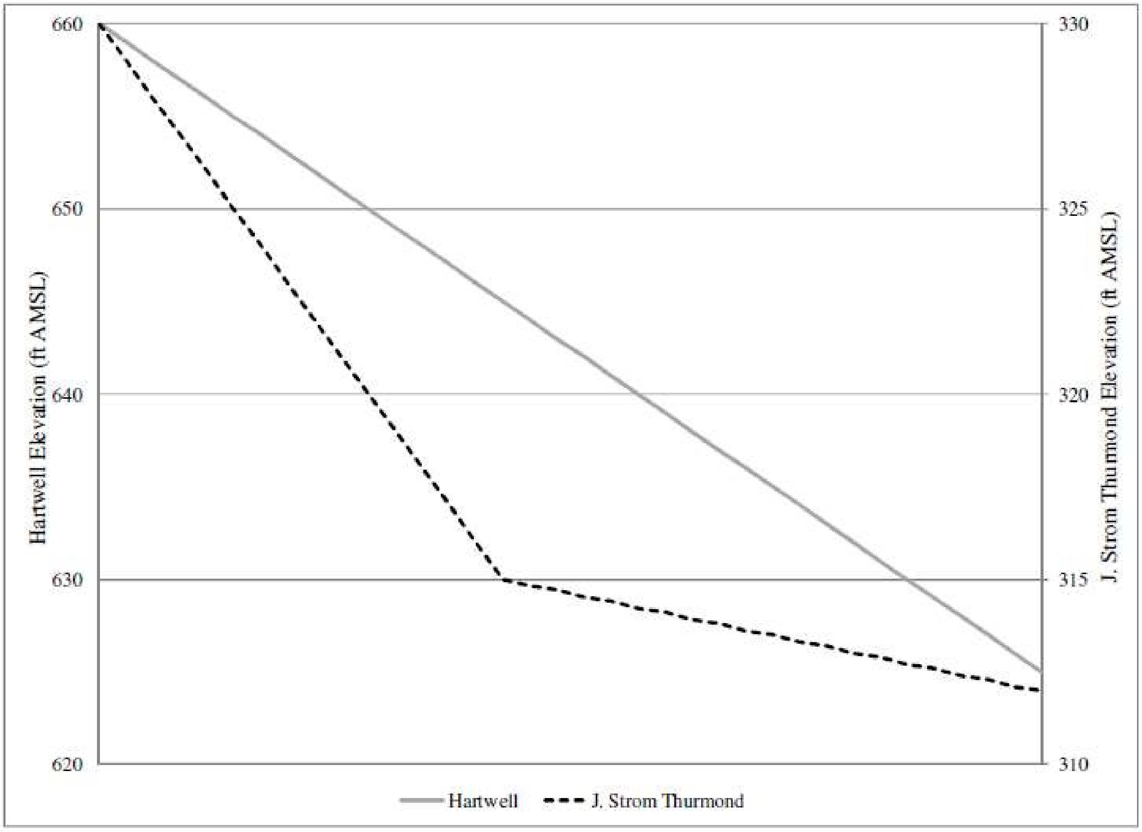
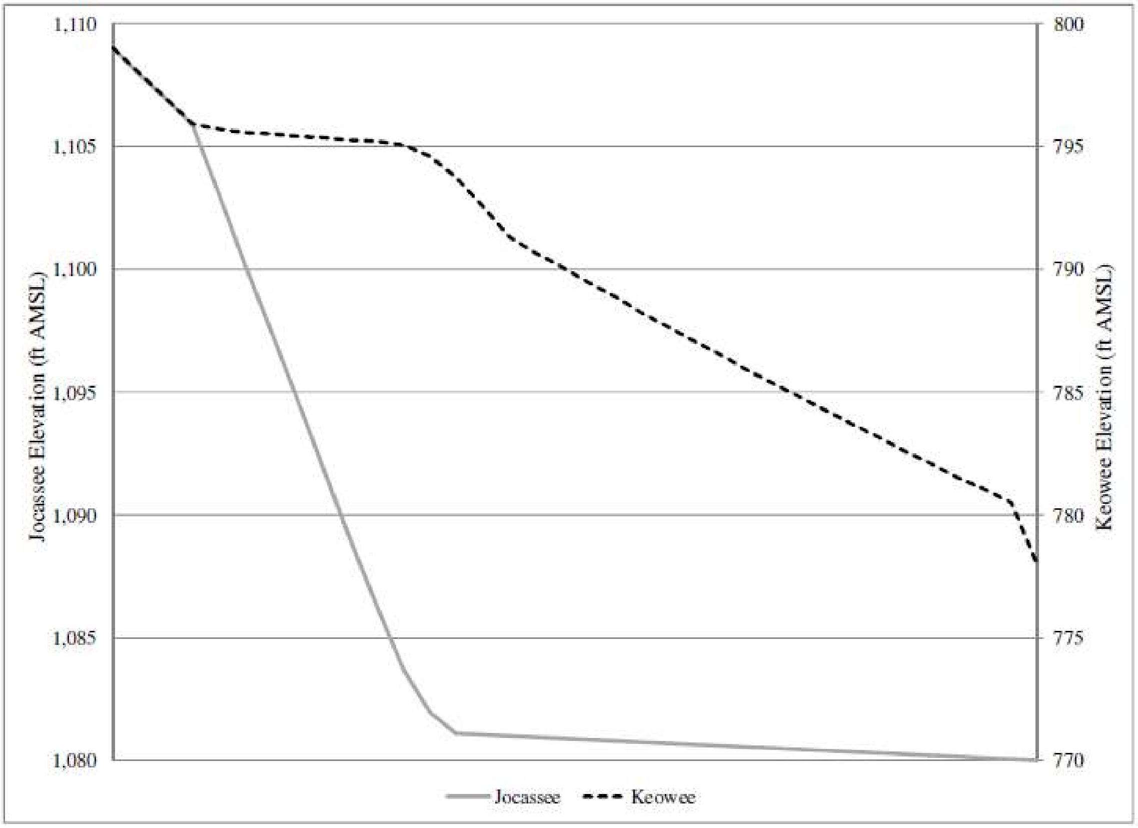


FIGURE 5-15
DUKE ENERGY RESERVOIR STORAGE BALANCE DRAWDOWN SCHEDULE



5.2.12 System Power

The USACE projects have a power generation requirement with SEPA to achieve a minimum generation value. The weekly generation requirement can be met by any combination of the three USACE plants, and the requirement value varies by month. The weekly targets are based on SEPA power contracts. Table 5-14 below lists the requirement.

TABLE 5-14
WEEKLY TARGET GENERATION OF USACE PROJECTS

Month	Weekly Total Generation (MWh)
Jan	27,233
Feb	26,714
Mar	20,669
Apr	18,504
May	21,948
Jun	25,935
Jul	31,195
Aug	32,035
Sep	30,685
Oct	27,304
Nov	26,284
Dec	27,104

5.2.13 Powerhouse Settings

All unit performance information was modeled based on the information available at the time of model development.

5.2.13.1 Bad Creek Project

The SR ResSim Model powerhouse descriptor data for the Bad Creek Project is shown in Table 5-15. The powerhouse contains four reversible motor-pump/turbine-generator units with a design head of 1,115 ft. The SR ResSim Model uses total powerhouse flow and power and not individual unit dispatching calculations.

TABLE 5-15
SR RESSIM MODEL BAD CREEK POWERHOUSE SETTINGS

Descriptor	Value
Outlet Capacity	15,400 cfs
Power Capacity	1,384 MW
Efficiency	90%
Station Use (cfs)	0
Hydraulic Losses	1.1 ft at 2,930 cfs
	37.8 ft at 17,400 cfs

The SR ResSim Model pumping mode inputs include specifying a minimum tailwater elevation of 1,081.0 ft AMSL and maximum head of 1,211 ft. Pump capacity for each unit as a factor of operating head is shown in Table 5-16.

TABLE 5-16
SR RESSIM MODEL BAD CREEK UNIT PUMP RATE VERSUS HEAD

Operating Head (ft AMSL)	Pump Capacity (cfs)
1,040	3,567
1,100	3,302
1,160	3,003
1,220	2,720
1,250	2,561

5.2.13.2 Jocassee Development

The SR ResSim Model powerhouse descriptor data for Jocassee Station is shown in Table 5-17. The powerhouse contains four reversible motor-pump/turbine-generator units. Units 1 and 2 are slightly smaller in flow and power than Units 3 and 4. Units 3 and 4 were upgraded in 2007. Units 1 and 2 were upgraded in 2010. The SR ResSim Model uses total powerhouse flow and power, not individual unit dispatching calculations.

TABLE 5-17
SR RESSIM MODEL JOCASSEE POWERHOUSE SETTINGS

Descriptor	Value
Outlet Capacity	35,892 cfs
Power Capacity	737 MW
Efficiency	85%
Station Use (cfs)	0
Hydraulic Losses	2.7 ft at 5,650 cfs
	10.3 ft at 35,892 cfs

The SR ResSim Model pumping mode inputs include specifying a minimum tailwater elevation of 794.6 ft AMSL and maximum head of 315 ft. Pumping is limited to 794.6 ft AMSL to prevent pumping of Lake Keowee below 794.6 ft AMSL. This is not a physical limitation of the pumps. Pump capacity for each unit as a factor of operating head is shown in Table 5-18.

TABLE 5-18
SR RESSIM MODEL JOCASSEE UNIT PUMP RATE VERSUS HEAD

Operating Head (ft AMSL)	Pump Capacity (cfs)
286	7,921
296	7,601
307	7,331
318	7,001
328	6,626

5.2.13.3 Keowee Development

The SR ResSim Model powerhouse descriptor data for Keowee Station is shown in Table 5-19. The powerhouse contains two similarly-sized conventional turbine-generator units. The SR ResSim Model uses total powerhouse flow and power and not individual unit dispatching calculations.

TABLE 5-19
SR RESSIM MODEL KEOWEE POWERHOUSE SETTINGS

Descriptor	Value
Outlet Capacity	19,446 cfs
Power Capacity	176 MW
Efficiency	76%
Station Use (cfs)	0
Hydraulic Losses	0.7 ft at 4,300 cfs
	6.8 ft at 19,446 cfs

5.2.13.4 Hartwell Project

The SR ResSim Model powerhouse descriptor data for the Hartwell Project is shown in Table 5-20. The powerhouse contains four similarly-sized conventional turbine-generator units, and one slightly smaller turbine-generator unit. The SR ResSim Model uses total powerhouse flow and power and not individual unit dispatching calculations.

TABLE 5-20
SR RESSIM MODEL HARTWELL POWERHOUSE SETTINGS

Descriptor	Value
Outlet Capacity	13,175 cfs at 621 ft Elev.
	31,020 cfs at 678 ft Elev.
Power Capacity	338 MW
Efficiency	91%
Station Use (cfs)	0
Hydraulic Losses	1.5 ft constant headloss

5.2.13.5 Richard B. Russell Project

The SR ResSim Model powerhouse descriptor data for the Richard B. Russell Project is shown in Table 5-21. The powerhouse contains four similarly-sized conventional turbine-generator units and four reversible turbine-generator/motor-pump units. The SR ResSim Model uses total powerhouse flow and power and not individual unit dispatching calculations. Two small station service units are not included in the modeled powerhouse setup.

TABLE 5-21
SR RESSIM MODEL RICHARD B. RUSSELL POWERHOUSE SETTINGS

Descriptor	Value
Outlet Capacity	60,000 cfs
Power Capacity	660 MW
Efficiency	90.5%
Station Use (cfs)	0
Hydraulic Losses	1.5 ft constant headloss

The SR ResSim Model pumping mode inputs include specifying a minimum tailwater elevation of 320 ft AMSL and maximum head of 160 ft. Pump capacity for each unit is a constant 7,000 cfs per unit.

5.2.13.6 J. Strom Thurmond Project

The SR ResSim Model powerhouse descriptor data for the J. Strom Thurmond Project is shown in Table 5-22. The powerhouse contains seven similarly-sized conventional turbine-generator units. The SR ResSim Model uses total powerhouse flow and power and not individual unit dispatching calculations.

TABLE 5-22
SR RESSIM MODEL J. STROM THURMOND POWERHOUSE SETTINGS

Descriptor	Value
Outlet Capacity	36,680 cfs
Power Capacity	412 MW
Efficiency	87%
Station Use (cfs)	80 cfs
Hydraulic Losses	1.5 ft constant headloss

6.0 SR RESSIM MODEL CALIBRATION/VERIFICATION PROCESS

Verification is intended to validate the SR ResSim Model input data and logic so the Baseline scenario may be used as the current operations comparison scenario for all subsequent scenario analyses. HDR performed model verification using comparisons of actual and model estimated generation and total discharge from the system. The Verification simulation was completed for recent hydrologic years with available historical reservoir operations (1998-2008). Generation data is commonly available for hydropower facilities and is a metered value that has good accuracy compared to other forms of data that are not metered or based on estimated values with lower accuracy. Generation is a measure of available flow and storage volume which relates to inflows and reservoir elevations. When performing verification of water quantity models with power generation, it is common to find discrepancy between observed data and modeled output for generation and reservoir elevation when looking at a small sample of time periods (day, week, or month). This is due to the difference between the set of rules provided in the model vs. the day-to-day decisions that are common in large power developments that respond to power grid demands as well as storm forecasts and other non-measured impacts on the reservoir and equipment.

As previously stated, the SR ResSim Model is coded to run day-to-day operations based on general operating conditions or rules. The model follows these rules strictly, 24-hours per day and 365 days per year, similar to an automated operation. Actual project operations generally follow the operating rules; but human intervention periodically deviates from the general operating rules to accommodate day-to-day realities such as equipment failure and maintenance, changing hydrologic conditions, power demands and energy pricing, etc. In addition to differences between modeled operations versus actual operations that include human interventions, there are also inherent discrepancies as a result of input data inaccuracies (e.g., differences in hydrology data, turbine or generator efficiencies, reservoir storage curves, etc.). It is important to understand that, due to these differences between actual operating conditions and modeled conditions, model results will never completely match historical operations.

The verification goal is to obtain less than a five percent difference when comparing modeled results to historical generation data over the hydrologic period. In cases where the modeled results exceeded a five percent difference, potential causes for the differences were examined to determine whether the difference was due to deviations in model setup, historical deviations in operations, or discrepancies in the reconstructed hydrology data.

Modeled results of the Verification scenario runs are presented in Section 4.1. The conclusions regarding model verification are presented in Section 5.

6.1 Summary of ResSim Modeled Results versus Historical Data

The SR ResSim Model verification was performed using historical operations data provided by Duke Energy and the USACE. The Verification scenario was established following the typical operating requirements of the system (same rule logic as the Baseline scenario) with historical water use (median of 2003 – 2008) and forced elevations (rules applied such that the model will attempt to operate the reservoir pools as they were historically for the verification period, 1998-2008). Figures 6-1 through 6-6 show comparisons of the modeled reservoir elevations compared to the historical reported elevations for the same period. Note this scenario is not strictly based on the water balance rules defined in the 1968 Agreement but closely represents how the developments have been operated over the hydrologic period.

FIGURE 6-1
SR RESSIM MODELED AND HISTORICAL BAD CREEK RESERVOIR ELEVATION COMPARISON

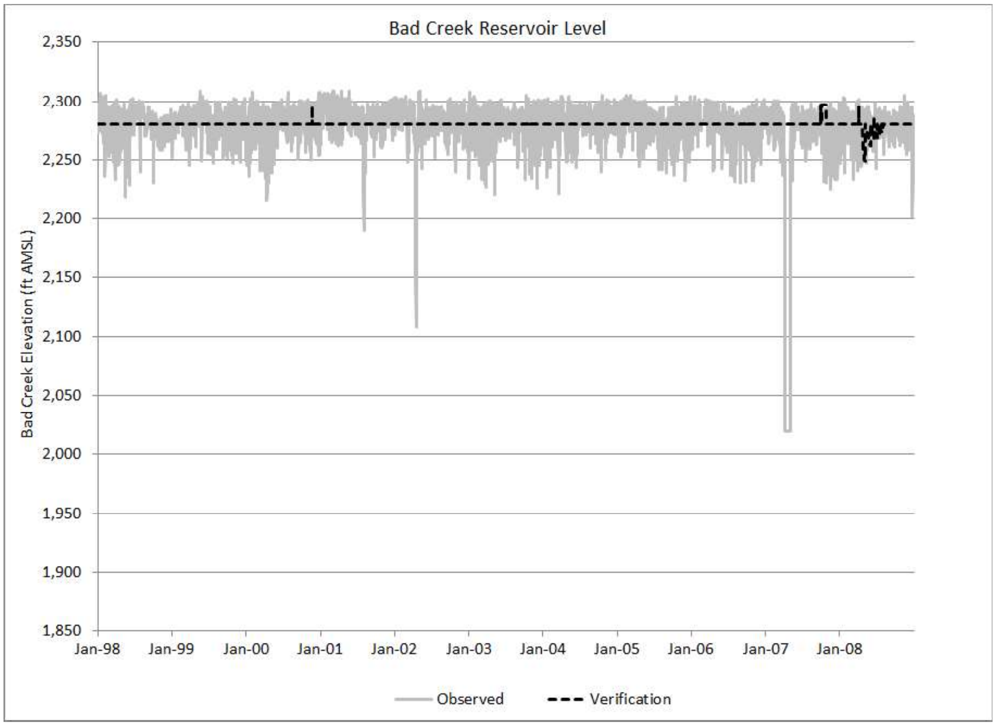


FIGURE 6-2
SR RESSIM MODELED AND HISTORICAL JOCASSEE RESERVOIR ELEVATION COMPARISON

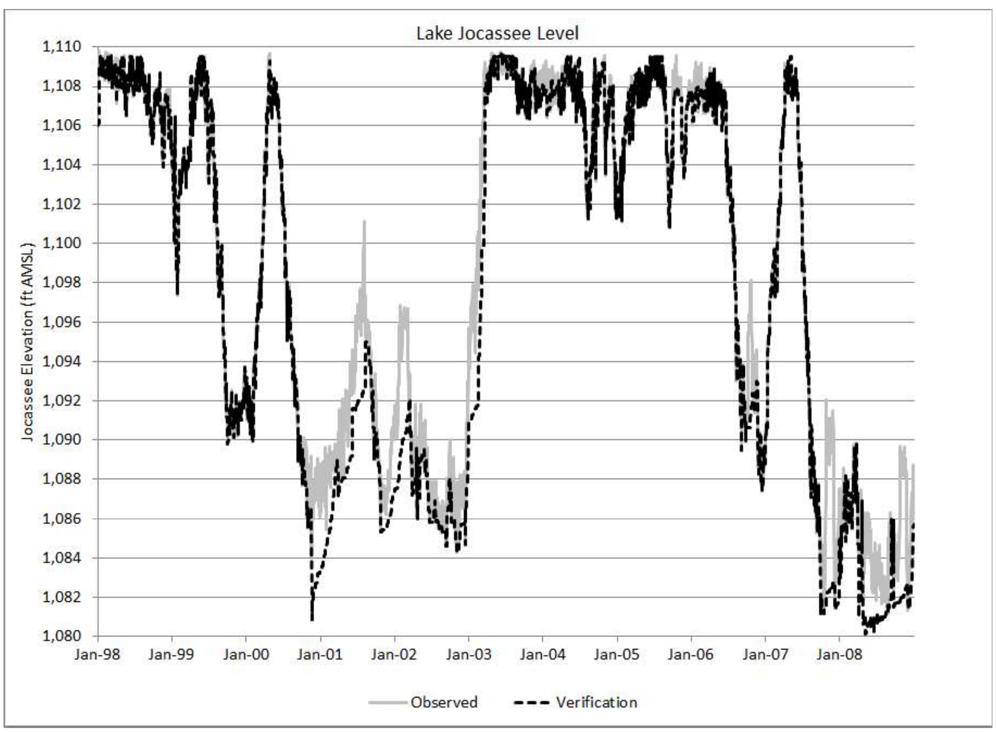


FIGURE 6-3
SR RESSIM MODELED AND HISTORICAL KEOWEE RESERVOIR ELEVATION COMPARISON

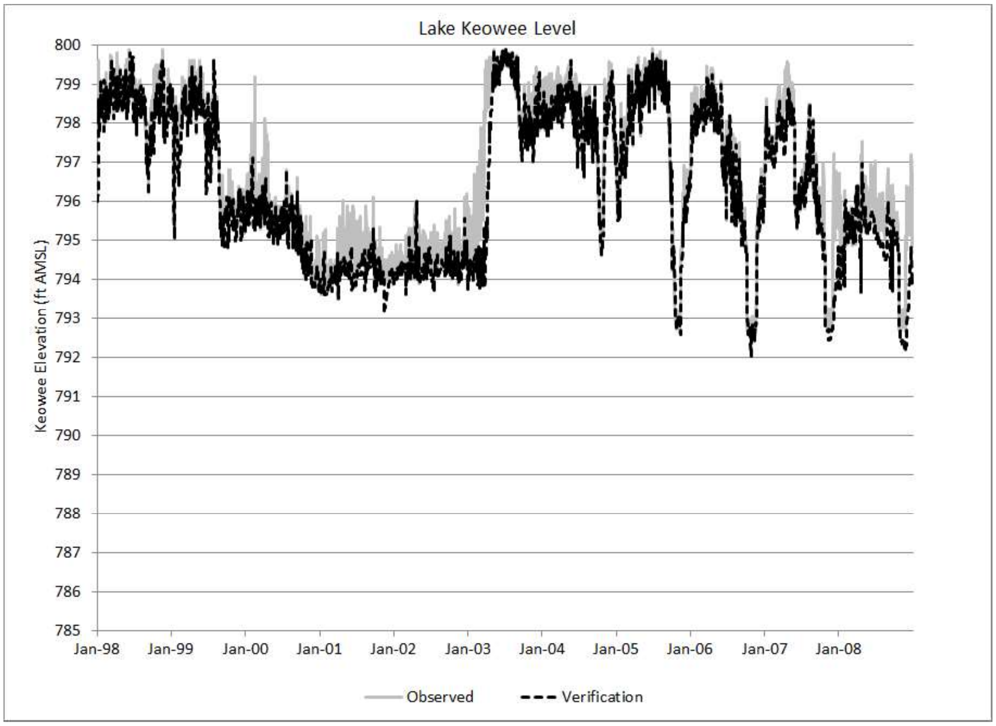


FIGURE 6-4
SR RESSIM MODELED AND HISTORICAL HARTWELL RESERVOIR ELEVATION COMPARISON

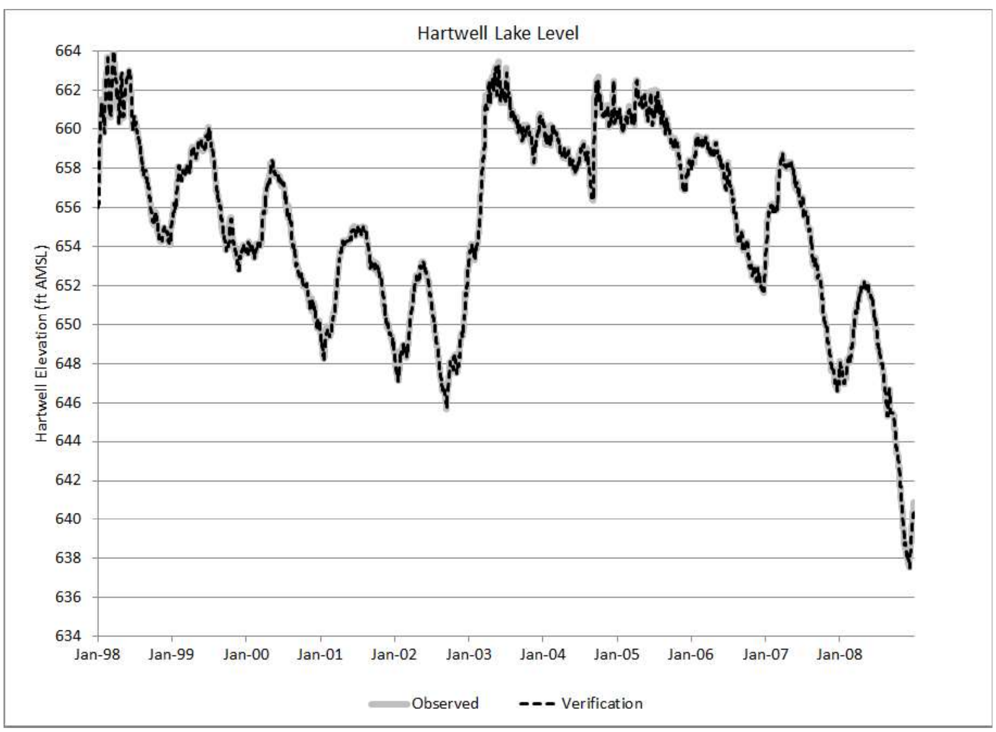


FIGURE 6-5
SR RESSIM MODELED AND HISTORICAL RICHARD B, RUSSELL RESERVOIR ELEVATION COMPARISON

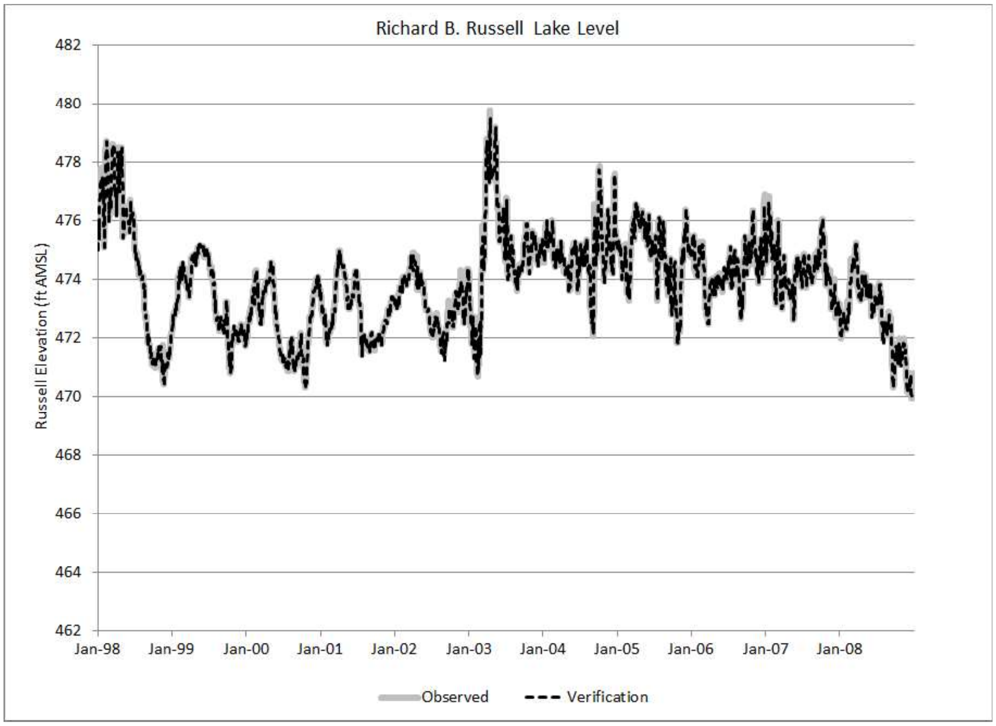
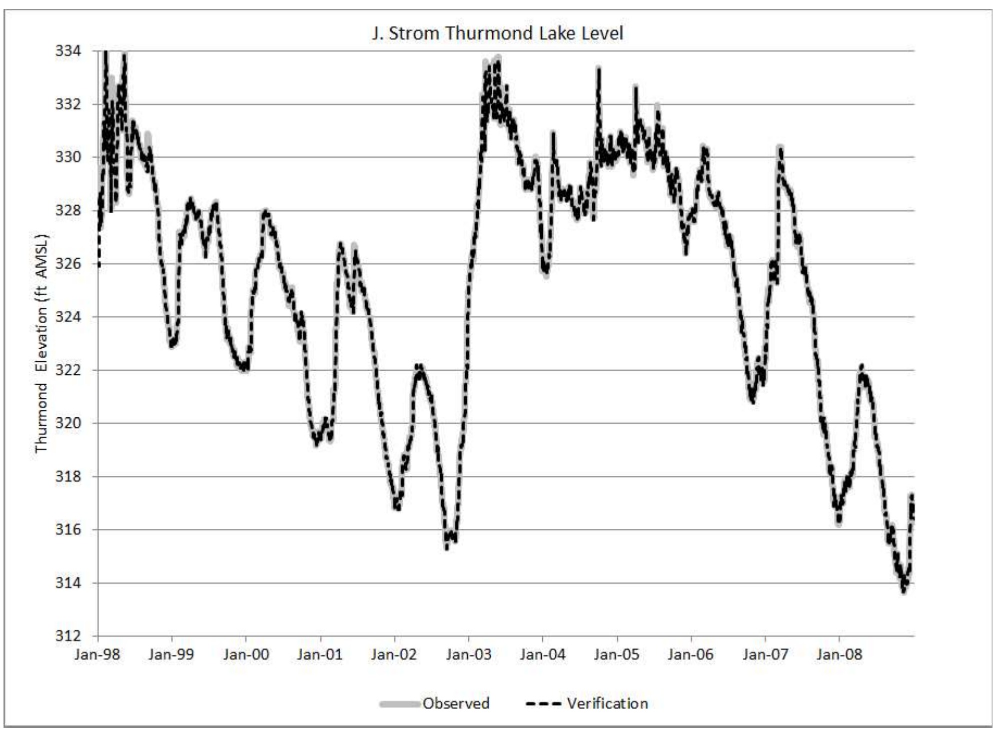


FIGURE 6-6
SR RESSIM MODELED AND HISTORICAL J. STROM THURMOND RESERVOIR ELEVATION COMPARISON



The SR ResSim Model simulation of the Verification scenario estimated an average annual energy output 2 percent lower than historical generation for the same period, as shown in Table 6-1. Based on available historical generation records, modeled and historical generation were compared for the period 1998-2008 at all facilities except for the Richard B. Russell Project. Generation at Richard B. Russell Project was only compared for the time period 2006-2008. Prior to 2006, the Richard B. Russell pump units (4) were rarely operated. There are significant annual swings in the percent difference between historical and modeled operations for the 1998-2008 period, with the largest variations at the Duke Energy facilities. The Duke Energy facilities are operated on demand with a priority on peaking operations to optimize the value of generation based on energy pricing, whereas the USACE facilities are operated on a weekly baseload schedule. The result is that the operations of the Duke Energy facilities (especially pumping operations) vary greatly depending on the value of generation. The Duke Energy system is only required to release water to the system to stay in balance with the system balance as outlined in the 1968 Agreement (Duke Power Company 1968). The USACE system is driven by a combination of the power requirements to SEPA, the system storage balance, and the minimum discharge requirements from the J. Strom Thurmond Project.

TABLE 6-1
SR RESSIM MODEL HISTORICAL BASE: GENERATION COMPARISON

Percent Difference between Modeled and Historical Generation ([modeled-historic]/historic)							
	Bad Creek	**Jocassee**	**Keowee**	**Hartwell**	**Richard B. Russell**	**J. Strom Thurmond**	**System Total**
1998	3%	34%	-3%	-2%		-7%	6%
1999	4%	174%	11%	5%		2%	34%
2000	-3%	102%	24%	8%		2%	17%
2001	11%	-93%	18%	5%		0%	-14%
2002	1%	-89%	13%	4%		-3%	-21%
2003	-11%	-24%	-4%	0%		-4%	-11%
2004	9%	24%	20%	-1%		-6%	9%
2005	-4%	23%	3%	2%		-7%	2%
2006	2%	28%	13%	5%	-6%	-5%	6%
2007	-13%	41%	33%	10%	-8%	0%	1%
2008	-37%	-67%	19%	6%	-34%	-1%	-39%
Average	-4%	6%	10%	3%	-15%	-4%	-2%

Figures 6-7 and 6-8 show the daily and cumulative SR ResSim modeled (Verification scenario) discharges from Hartwell Lake and J. Strom Thurmond Lake as compared to the historical (observed) discharges for the same period. For the period 1998-2008, the model estimated a cumulative discharge from both Hartwell Lake and J. Strom Thurmond Lake that was approximately one percent lower than historical cumulative discharge. The significant daily swings in modeled discharges from J. Strom Thurmond Lake are a result of the forced elevations driving the operations. The daily modeled discharges vary to match the forced elevation for that day, where the historical discharges from J. Strom Thurmond Lake were fairly constant for long portions of the 1998-2008 period.

FIGURE 6-7
SR RESSIM MODELED AND HISTORICAL HARTWELL DISCHARGE COMPARISON

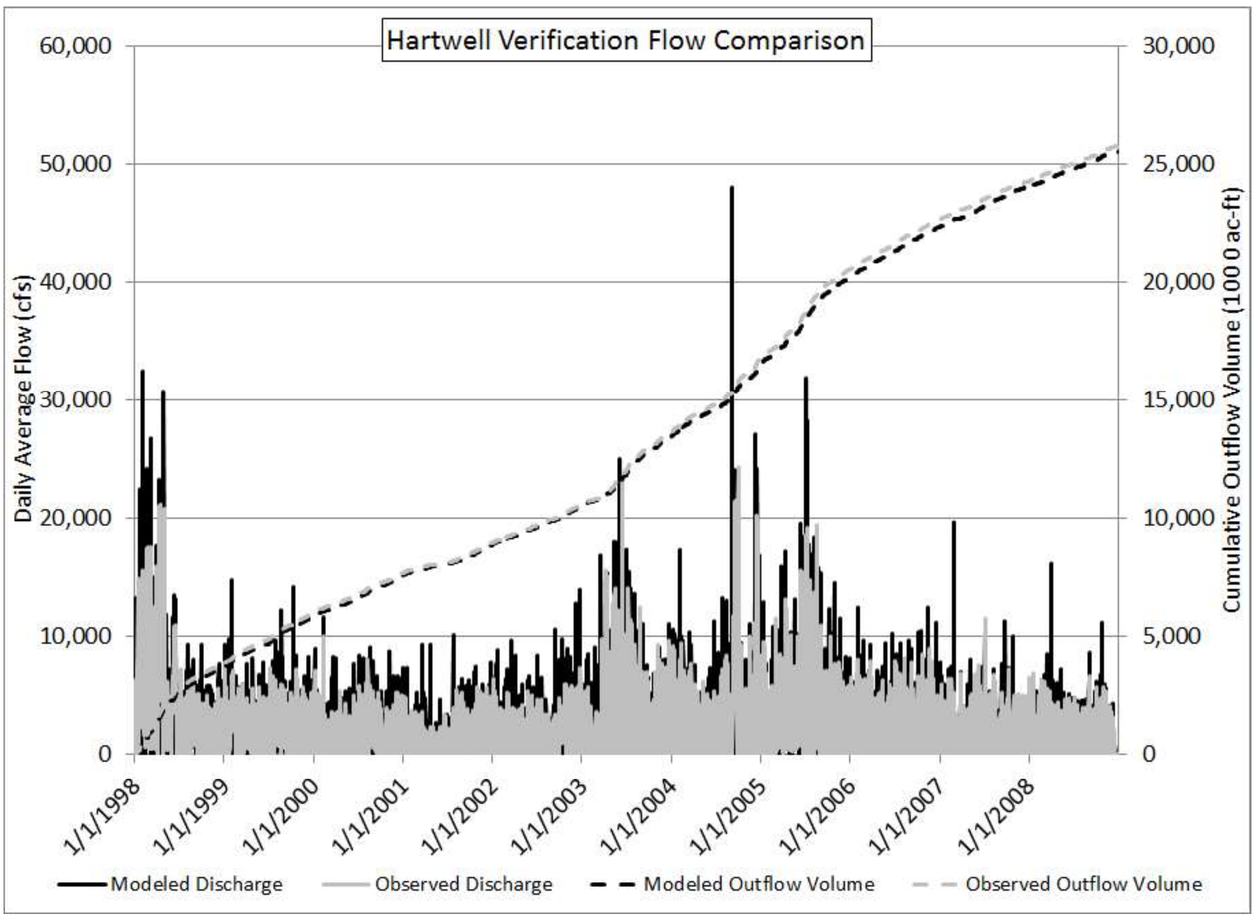
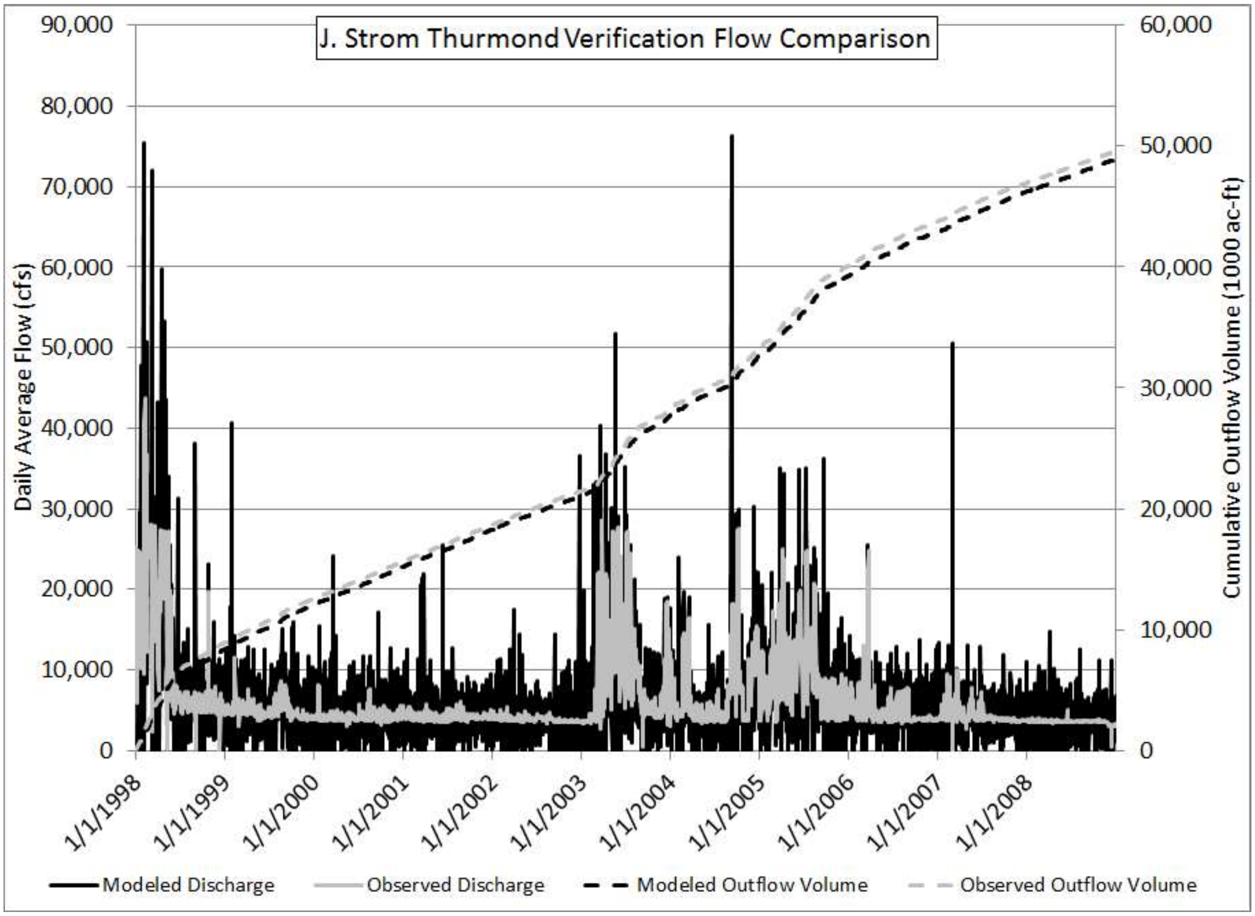


FIGURE 6-8
SR RESSIM MODELED AND HISTORICAL J. STROM THURMOND DISCHARGE COMPARISON



7.0 SR CHEOPS AND SR RESSIM MODELS SUMMARY AND CONCLUSIONS

7.1 Summary

The purpose of this report is to document inputs and assumptions used in the development of the SR CHEOPS and SR ResSim Models; to demonstrate the models reasonably characterizes operations of the system, and to demonstrate that the models are adequate for use in evaluating the effects of alternative operating scenarios. The ResSim and CHEOPS software and the SR CHEOPS Model and SR ResSim Model are tools that, as this report demonstrates, can be successfully used to evaluate the relative sensitivity and response of the Savannah River System to changing operational constraints. The models are tools and do not predict future conditions or outcomes. The model results must be analyzed and interpreted based on knowledge of hydrologic and hydraulic principles and understanding of results viewed in a relative, rather than an absolute, context.

7.2 Conclusions

As discussed in Sections 4 and 6, the model verification process includes comparisons between modeled output and historical data. The goal of this process is to obtain no more than five percent variance when comparing modeled results to historical data for generation on an annual basis. For both the SR CHEOPS and SR ResSim Models, the modeled release from the Project is compared to historical data to show whether the model provides a reasonable representation of Project operations throughout the year (e.g., the timing, magnitude, and duration of operations).

As shown in Tables 4-1, 4-2 and 6-1, there are significant swings between modeled and historical generation. However, there are many factors inherent in the model data and setups that can contribute to output discrepancies (i.e., deviations) when compared to historical data. In many cases, several of these factors may be involved simultaneously, which makes it difficult to isolate individual sources of difference. Four examples of potential sources of deviations from historical data are the standardized pumping rules, hydrology, minimum flow requirements, and historical unit outages:

- Pumping Operations – The models follow a set of defined rules for pumping; however, the historical records demonstrate that pumping operations vary greatly from year to year, month to month, and even day to day. This is probably the greatest source of deviation and swings in the generation comparison and why the goal of this summary is to compare long-term trends rather than monthly or annual values.
- Hydrology – Both the SR CHEOPS and SR ResSim Models use reconstructed UIF data as the input for daily inflow water to the system. The unimpaired hydrology was synthesized based on gage data and plant records, both of which have a certain amount of inherent error especially when multiple locations and data sources are involved. The overall hydrologic data set appears to be a good representation of daily inflows and is acceptable for use in future water management planning.
- Minimum Streamflow Requirements – The models are set up to account for minimum streamflow requirements automatically. As a result, the models are proactive in automatically addressing minimum streamflow requirements rather than reactive in providing excess flow to avoid potential violations, as the case may be in actual operations.
- Unit Outages and Performance – The model has been set up with post upgrade/rehabilitation unit performance information and does not take into account detailed unit outage information. For example, Units 1 through 4 at the Hartwell Project were rehabilitated over the 11-year period of 1997 through 2007. Unit outages associated with the rehabilitation were not taken into account in the model.

In interpreting the information provided in this model operations/verification report, it is important to reflect on the purpose of the model: to reasonably characterize development operations. Comparing model results with historical data confirms use of the model as a tool for simulating "real" operations. It is not possible with reasonable time and budget constraints to account for every outside influence or condition to match historical operations and hydrology.

Small changes in input data or model logic can often result in large swings in output. This is due to a number of reasons including (but not limited to) runoff characteristics, reliance on coordinated operations, and numerous/variable flow requirements. Each of these elements individually contributes to the sensitivity of the system. Combined, they multiply that sensitivity exponentially. The input data and logic in the historical base scenario is an attempt to consolidate the effects of these variables to achieve an approximation of "characteristic operations."

The sensitivity described above also means that those factors that are unable to be accounted for in the model (short-term operations decisions based on pricing, demand, forecasts, etc.) as well as data that is impossible to replicate exactly (synthesized hydrology data, shutdowns due to irregular maintenance, etc.) can result in relatively large discrepancies between modeled output and historical data on a per-month/per-development basis. The factors and sensitivity warrant careful model review with awareness of the potential for outliers. The ultimate acceptance of the results should not hinge on the extremes but rather on the overall impression of consistency between modeled and historical operations.

Most importantly, it must always be foremost in model discussions that the model should always be used to assess the relative impacts between scenarios. What this means is model verification is really the only time it is appropriate to compare model results with historical data. As previously stated, verification is intended to validate the model input data and model logic so the "Baseline" becomes the current operations comparison scenario for all subsequent analyses. The Verification scenario (Historical Baseline) represents the Baseline scenario with the addition of historical water use and flow requirements to simulate actual historical operations.

In the opinion of HDR, verification results show both models compare favorably to historical data, reasonably characterize study area operations, and are appropriate for use in evaluating the effects of alternative operating scenarios. However, appropriate use of the results is cautioned. As with any model, accuracy is highly dependent on input data; consequently, model results should be viewed in a relative, rather than absolute, context. The SR ResSim and SR CHEOPS Models are tools that, as this report demonstrates, can be successfully used to evaluate the relative sensitivity and response of the project to changing operational constraints.

8.0 REFERENCES

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APPENDIX A

ESTIMATED RESERVOIR VOLUME LOSSES ON THE SAVANNAH RIVER DUE TO SEDIMENTATION

Estimated Reservoir Volume Losses on the Savannah River Due to Sedimentation

1.0 Background

The U.S. Army Corps of Engineers' (USACE) HEC-ResSim model is being used by HDR|DTA to evaluate potential changes to the 1968 Operating Agreement between the USACE, Duke Energy Carolinas, LLC (Duke Energy), and the Southeastern Power Administration (SEPA). This model simulates reservoir elevation changes and downstream flow releases based on a set of reservoir operating rules and input assumptions. Stage/volume curves for each of the five reservoirs on the mainstem of the Savannah River are used as input to the HEC-ResSim model. In 2010, Duke Energy collected bathymetry data on the two upper reservoirs in the basin (Lake Jocassee and Lake Keowee). As a result, a minor adjustment was made to the original 1967 Lake Keowee stage/volume curve based on this updated information. No changes were made to the Lake Jocassee stage/volume curve because the 2010 data was very similar to the original 1967 stage/volume curve.

In an attempt to provide consistency with HEC-ResSim model input assumptions, HDR|DTA has evaluated the need to revise the original stage/volume curves for Hartwell Lake, Richard B. Russell Lake (RBR Lake), and J. Strom Thurmond Lake (JST Lake) to year 2010 conditions. The alternative model scenarios will be run using both year 2010 and year 2060 input assumptions, including any necessary changes to reservoir stage/volume curves resulting from sedimentation.

This report outlines the methodology used to project year 2010 stage/volume curves for Hartwell Lake, RBR Lake, and JST Lake, and the year 2060 stage/volume curves for all five reservoirs. The methodology is based on using readily available sediment yield estimates from studies in the Savannah River Basin along with a USACE methodology for distributing sediment within each reservoir based on reservoir shape and size. Results of this analysis are also provided.

2.0 Sediment Yield

The weight of sediment accumulation in the five reservoirs was estimated using published sediment yields from studies conducted in the Savannah River Basin. Sediment yield results are commonly expressed in terms of tons per square mile of drainage area per year (ton/sq mi/yr). In the absence of site-specific stream sediment yield data for the Lake Jocassee and Lake Keowee sub-basins, sediment yield data collected in the Environmental Protection Agency's (EPA) Ecoregion 45 (upstate of Georgia and South Carolina) was used for Lakes Jocassee and Keowee. Sediment yields for EPA Ecoregion 45 are provided in Table 1 for stable, all streams, and unstable watershed conditions.

Table 1. Sediment Yields (tons/sq mi/yr) for EPA Ecoregion 45

Percentile	Stable	All Streams	Unstable
10	17	28	48
25	28	46	74
50	57	80	137
75	**83**	**154**	222
90	108	217	308

Source: Mukundan, Radcliffe, and Ritchie 2010

HDR|DTA's analysis used the 75 percentile values in Table 1 as an estimate of sediment yields in the Lake Jocassee and Lake Keowee sub-basins. As a result, it was assumed that the relatively undisturbed Lake Jocassee drainage basin has a sediment yield of 83 tons/sq mi/yr. The sediment yield for the Lake Keowee drainage basin was assumed to be 154 tons/sq mi/yr ('all streams').

To aid in the development of Total Maximum Daily Loads (TMDLs) for priority pollutants in streams and rivers, the EPA has also collected sediment yield data at various locations in the Hartwell Lake and JST Lake drainage basins. This information is summarized in Tables 2 and 3.

Table 2. Sediment Yields for Streams in the Hartwell Lake Drainage Area

Water Course	Drainage Area (sq mi)	Sediment Yield (tons/sq mi/yr)
Stekoa Creek	21.3	351
Scott Creek	6.1	177
Pool Creek	4.8	106
Chechero Creek	4.2	175
Saddle Gap Creek	2.7	392
Cutting Bone Creek	2.1	149
She Creek	5.5	231
Crawford Creek	7.2	432
Little Crawford Creek	2.7	309
Shoal Creek	29.6	471
Average	8.6	**279**

Source: EPA 2000, 2005a, 2005b, 2005c

Table 3. Sediment Yields for Streams in the JST Lake Drainage Area

Water Course	Drainage Area (sq mi)	Sediment Yield (tons/sq mi/yr)
Rocky Creek	32.4	190
Indian Creek	18.9	45
Upton Creek	23.5	154
South-Bigger Creek	36.4	263
Average	27.8	**163**

Source: EPA 2005b, 2005c

The average sediment yield for Hartwell Lake is 279 tons/sq mi/yr and the average sediment yield for JST Lake is 163 tons/sq mi/yr. For RBR Lake, the average for Hartwell Lake and JST Lake was used (221 tons/sq mi/yr).

To convert sediment yield (in tons) to sediment volume (in acre-feet [ac-ft]), the compressed density of the sediment was determined. The composition of the sediment samples collected in the North Fork Broad River, which drains a sub-basin stretching from the mountains to the piedmont in Georgia, is 27% sand, 54% silt, and 19% clay (Mukundan and Radcliffe 2009). Compression of the sediments on the reservoir bottom is based on years of inundation. Using the method outlined in EM 1110-2-4000 (USACE 1989), the calculated average compressed sediment densities are provided in Table 4.

Table 4. Average Sediment Density

Reservoir	Years of Inundation before 2010	Average Density (lb/ft^3)	Years of Inundation 2010–2060	Average Density (lb/ft^3)
Jocassee	37	N/A	50	70
Keowee	39	N/A	50	70
Hartwell	49	69.9	50	70
RBR	27	68.8	50	70
JST	58	70.3	50	70
Average	42	**70**	50	**70**

Based on the results provided in Table 4, an average density of 70 lb/ft^3 was used to convert the estimated sediment yields to estimated sediment deposition volumes. The resulting sediment deposition volumes for year 2010 and year 2060 are shown in Table 5.

Table 5. Reservoir Volumes Lost to Sedimentation

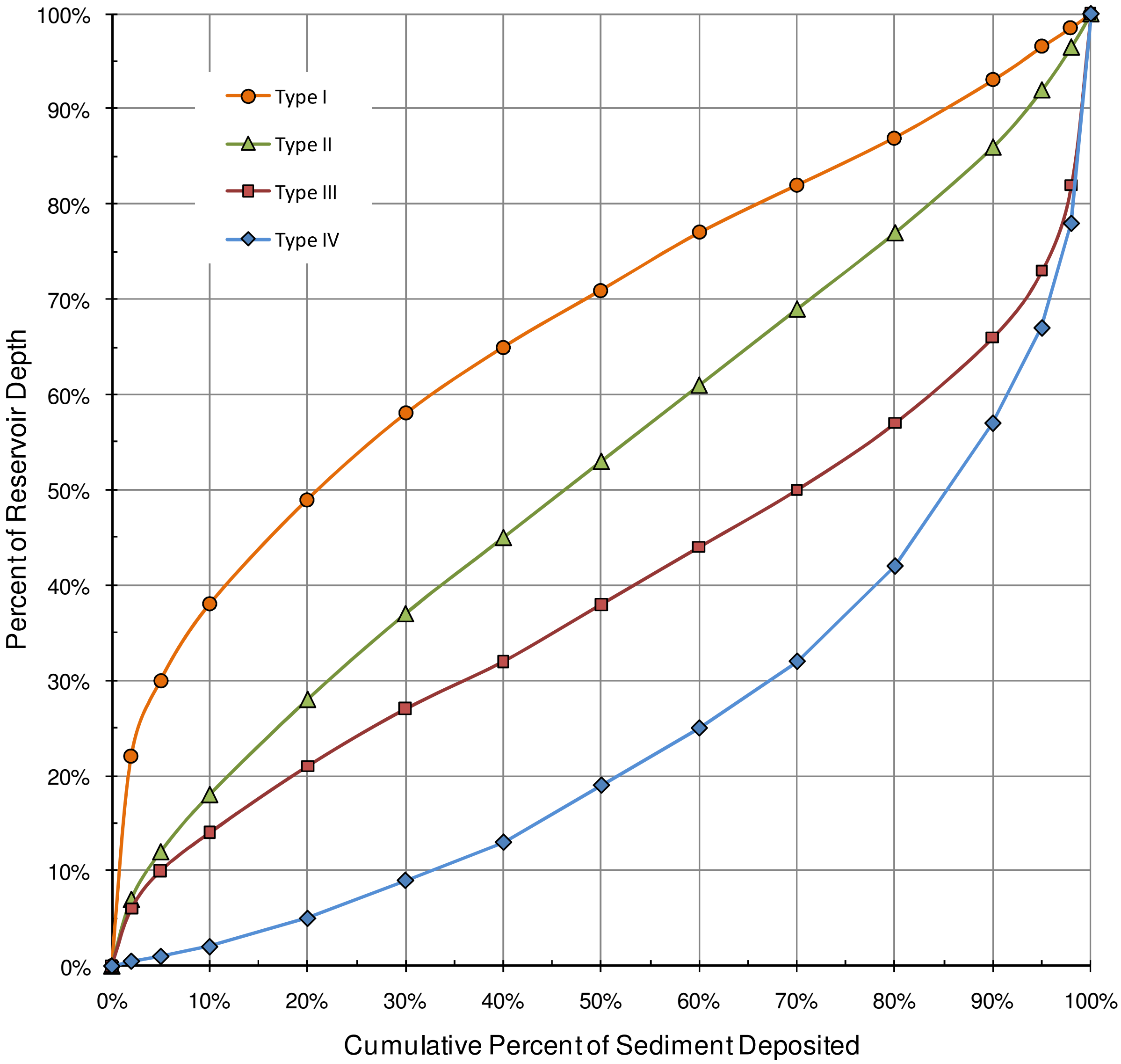
Reservoir	Sediment Yield (tons/sq mi/yr)	Drainage Area (sq mi)	Initial Fill year	Sediment Deposition to Year 2010 (ac-ft)	Sediment Deposition from 2010 to 2060 (ac-ft)
Jocassee	83	148	1973	N/A	403
Keowee	154	288	1971	N/A	1,455
Hartwell	279	1184	1961	10,617	10,834
RBR	221	742	1983	2,904	5,378
JST	163	3290	1952	20,401	17,587

Source: USACE 2010a, 2010b, 2010c

3.0 Sediment Distribution

The estimated amount of sediment deposition in each reservoir was distributed at the appropriate levels within each reservoir. The USACE has developed the "Empirical Area Reduction Method" as described in EM 1110-2-4000 (USACE 1989) to accomplish this task. To use this method, the reservoir type was first determined based on the size and shape of the impoundment. The “m” value (i.e., the change in the log of reservoir storage capacity divided by the change in the log of the reservoir depth) was calculated for each reservoir as an initial step in determining the reservoir type. The “m” values are summarized in Table 6. The reservoir type was used in conjunction with Figure H-4 in EM 1110-2-4000 (USACE 1989), reproduced as Figure 1 below, to distribute the sediment volume within each reservoir. The results are shown in Table 6 as the cumulative percent of sediment volume distributed at percent of depth (bottom to top).

Figure 1. Distribution of Sediment Deposits in Reservoirs



Source: USACE 1989

Table 6. Cumulative Percent of Sediment at Percent of Depth

Reservoir	M	Type	Percent of Depth						
			0	10	20	50	80	90	100
Jocassee	2.35	III	0	5	18	70	97	99	100
Keowee	2.67	II	0	4	12	46	83	93	100
Hartwell	2.84	II	0	4	12	46	83	93	100
RBR	2.72	II	0	4	12	46	83	93	100
JST	3.04	I	0	1	2	21	66	85	100

4.0 Estimated Reservoir Storage Curves

Volumes of sediment in Table 5 were distributed in each reservoir based on the percentages in Table 6, resulting in stage/volume curves for each reservoir for year 2010 and year 2060 (Tables 7 through 11). The volume change percentages (final column in each table) represent the entire reservoir below the corresponding reservoir elevation presented in column 1. Note that the 2010 volume estimates for Lakes Jocassee and Keowee are based on bathymetry data collected in 2010 and not the sediment yield and sediment distribution methodologies described above.

Table 7. Lake Jocassee Estimated Changes in Reservoir Volume due to Sedimentation

Reservoir Elevation (ft msl)	1967 Volume (ac-ft)	2010 Volume (ac-ft)	Volume Change 1967 – 2010 (%)	2060 Volume (ac-ft)	Volume Change 2010 – 2060 (%)
1,110	1,157,993	1,206,797	4.21	1,206,394	-0.033
1,109	1,150,442	1,198,830	4.21	1,198,429	-0.033
1,108	1,142,917	1,190,892	4.20	1,190,491	-0.034
1,107	1,135,416	1,182,987	4.19	1,182,586	-0.034
1,106	1,127,939	1,175,114	4.18	1,174,713	-0.034
1,105	1,120,488	1,167,273	4.18	1,166,872	-0.034
1,104	1,113,061	1,159,462	4.17	1,159,061	-0.035
1,103	1,105,660	1,151,682	4.16	1,151,281	-0.035
1,102	1,098,282	1,143,933	4.16	1,143,532	-0.035
1,101	1,090,930	1,136,213	4.15	1,135,812	-0.035
1,100	1,083,602	1,128,524	4.15	1,128,123	-0.036
1,099	1,076,299	1,120,864	4.14	1,120,463	-0.036
1,098	1,069,021	1,113,233	4.14	1,112,832	-0.036
1,097	1,061,768	1,105,632	4.13	1,105,231	-0.036
1,096	1,054,539	1,098,059	4.13	1,097,658	-0.037
1,095	1,047,336	1,090,516	4.12	1,090,115	-0.037
1,094	1,040,157	1,083,001	4.12	1,082,602	-0.037
1,093	1,033,003	1,075,516	4.12	1,075,117	-0.037
1,092	1,025,874	1,068,059	4.11	1,067,660	-0.037
1,091	1,018,770	1,060,642	4.11	1,060,243	-0.038
1,090	1,011,691	1,053,271	4.11	1,052,872	-0.038
1,089	1,004,637	1,045,936	4.11	1,045,537	-0.038
1,088	997,609	1,038,637	4.11	1,038,238	-0.038
1,087	990,606	1,031,372	4.12	1,030,973	-0.039
1,086	983,628	1,024,141	4.12	1,023,742	-0.039
1,085	976,676	1,016,943	4.12	1,016,544	-0.039
1,080	942,298	981,409	4.15	981,010	-0.041
1,060	811,349	845,564	4.22	845,169	-0.047
1,040	691,189	719,942	4.16	719,551	-0.054
1,020	581,761	604,370	3.89	603,987	-0.063
1,000	483,360	499,169	3.27	498,800	-0.074
980	393,873	404,853	2.79	404,505	-0.086
960	311,689	320,697	2.89	320,375	-0.100
940	238,724	247,057	3.49	246,767	-0.117
920	176,256	184,213	4.51	183,961	-0.137
900	124,721	132,347	6.11	132,133	-0.161
880	83,872	90,529	7.94	90,354	-0.194
860	52,917	57,740	9.11	57,607	-0.230
840	30,680	33,215	8.26	33,122	-0.279
820	15,742	16,544	5.10	16,488	-0.341
800	6,592	6,338	-3.85	6,312	-0.413
780	1,779	1,271	-28.55	1,265	-0.475
760	60	29	-00.00	29	-0.000
750	0	0	-00.00	0	-0.000

Table 8. Lake Keowee Estimated Changes in Reservoir Volume due to Sedimentation

Reservoir Elevation (ft msl)	1967 Volume (ac-ft)	2010 Volume (ac-ft)	Volume Change 1967 – 2010 (%)	2060 Volume (ac-ft)	Volume Change 2010 – 2060 (%)
800	953,659	869,381	-8.84	867,927	-0.17
799	935,448	851,983	-8.92	850,535	-0.17
798	917,460	834,947	-8.99	833,507	-0.17
797	899,696	818,195	-9.06	816,762	-0.18
796	882,152	801,702	-9.12	800,277	-0.18
795	864,829	785,452	-9.18	784,027	-0.18
794	847,725	769,437	-9.24	768,019	-0.18
793	830,839	753,650	-9.29	752,239	-0.19
792	814,169	738,085	-9.35	736,681	-0.19
791	797,715	722,739	-9.40	721,343	-0.19
790	781,476	707,609	-9.45	706,220	-0.20
789	765,450	692,688	-9.51	691,306	-0.20
788	749,637	677,973	-9.56	676,591	-0.20
787	734,034	663,461	-9.61	662,094	-0.21
786	718,641	649,147	-9.67	647,787	-0.21
785	703,457	635,030	-9.73	633,677	-0.21
784	688,480	621,108	-9.79	619,762	-0.22
783	673,709	607,378	-9.85	606,040	-0.22
782	659,143	593,841	-9.91	592,510	-0.22
781	644,782	580,496	-9.97	579,172	-0.23
780	630,623	567,343	-10.03	566,027	-0.23
779	616,665	554,383	-10.10	553,074	-0.24
778	602,908	541,615	-10.17	540,320	-0.24
775	562,825	504,453	-10.37	503,187	-0.25
770	499,910	446,271	-10.73	445,064	-0.27
760	388,103	343,634	-11.46	342,543	-0.32
750	293,919	258,138	-12.17	257,163	-0.38
740	216,022	187,992	-12.98	187,141	-0.45
730	153,025	131,648	-13.97	130,920	-0.55
720	103,487	87,411	-15.53	86,800	-0.70
710	65,909	53,634	-18.63	53,146	-0.91
700	38,737	29,048	-25.01	28,677	-1.28
690	20,352	12,783	-37.19	12,514	-2.11
680	9,078	3,914	-56.89	3,739	-4.46
670	3,173	799	-74.82	712	-10.93
660	828	82	-90.05	61	-26.48
650	171	1	N/A	1	-00.00

Table 9. Hartwell Lake Estimated Changes in Reservoir Volume due to Sedimentation

Reservoir Elevation (ft msl)	1961 Volume (ac-ft)	2010 Volume (ac-ft)	Volume Change 1961 – 2010 (%)	2060 Volume (ac-ft)	Volume Change 2010 – 2060 (%)
665	2,842,700	2,832,083	-0.37	2,821,250	-0.38
664	2,781,900	2,771,336	-0.38	2,760,557	-0.39
663	2,722,200	2,711,689	-0.39	2,700,964	-0.40
662	2,663,600	2,653,089	-0.39	2,642,364	-0.40
661	2,606,100	2,595,642	-0.40	2,584,971	-0.41
660	2,549,600	2,539,195	-0.41	2,528,579	-0.42
659	2,494,200	2,483,795	-0.42	2,473,179	-0.43
658	2,439,700	2,429,349	-0.42	2,418,786	-0.43
657	2,386,300	2,375,949	-0.43	2,365,386	-0.44
656	2,333,800	2,323,502	-0.44	2,312,993	-0.45
655	2,282,400	2,272,155	-0.45	2,261,700	-0.46
654	2,231,800	2,221,608	-0.46	2,211,208	-0.47
653	2,182,200	2,172,008	-0.47	2,161,608	-0.48
652	2,133,600	2,123,461	-0.48	2,113,115	-0.49
651	2,085,900	2,075,814	-0.48	2,065,522	-0.50
650	2,039,100	2,029,014	-0.49	2,018,722	-0.51
649	1,993,200	1,983,167	-0.50	1,972,929	-0.52
648	1,948,200	1,938,220	-0.51	1,928,037	-0.53
647	1,904,100	1,894,173	-0.52	1,884,044	-0.53
646	1,860,900	1,851,026	-0.53	1,840,951	-0.54
645	1,818,600	1,808,779	-0.54	1,798,758	-0.55
644	1,777,100	1,767,332	-0.55	1,757,366	-0.56
643	1,736,500	1,726,732	-0.56	1,716,766	-0.58
642	1,696,700	1,686,986	-0.57	1,677,073	-0.59
641	1,657,800	1,648,139	-0.58	1,638,280	-0.60
640	1,619,700	1,610,092	-0.59	1,600,287	-0.61
639	1,582,500	1,572,945	-0.60	1,563,195	-0.62
638	1,545,900	1,536,398	-0.61	1,526,702	-0.63
637	1,510,100	1,500,651	-0.63	1,491,009	-0.64
636	1,475,100	1,465,704	-0.64	1,456,116	-0.65
635	1,440,800	1,431,457	-0.65	1,421,924	-0.67
634	1,407,200	1,397,963	-0.66	1,388,538	-0.67
633	1,374,300	1,365,116	-0.67	1,355,745	-0.69
632	1,342,100	1,332,970	-0.68	1,323,653	-0.70
631	1,310,500	1,301,423	-0.69	1,292,160	-0.71
630	1,279,600	1,270,576	-0.71	1,261,367	-0.72
629	1,249,300	1,240,329	-0.72	1,231,174	-0.74
628	1,219,600	1,210,735	-0.73	1,201,689	-0.75
627	1,190,500	1,181,688	-0.74	1,172,696	-0.76
626	1,162,000	1,153,241	-0.75	1,144,303	-0.78
625	1,134,100	1,125,394	-0.77	1,116,511	-0.79
610	780,000	772,303	-0.99	764,448	0.00
600	680,000	673,046	-1.02	665,950	-1.05
575	300,000	294,745	-1.75	289,382	-1.82
525	45,000	43,089	-4.25	41,139	-4.53
475	0	0	-0.00	0	-0.00

Table 10. RBR Lake Estimated Changes in Reservoir Volume due to Sedimentation

Reservoir Elevation (ft msl)	1983 Volume (ac-ft)	2010 Volume (ac-ft)	Volume Change 1983 – 2010 (%)	2060 Volume (ac-ft)	Volume Change 2010 – 2060 (%)
480	1,166,166	1,163,262	-0.25	1,157,884	-0.46
479	1,137,100	1,134,210	-0.25	1,128,859	-0.47
478	1,108,581	1,105,706	-0.26	1,100,382	-0.48
477	1,080,603	1,077,743	-0.26	1,072,445	-0.49
476	1,053,159	1,050,313	-0.27	1,045,043	-0.50
475	1,026,244	1,023,413	-0.28	1,018,169	-0.51
474	999,850	997,033	-0.28	991,817	-0.52
473	973,974	971,157	-0.29	965,941	-0.54
472	948,607	945,805	-0.30	940,615	-0.55
465	783,020	780,334	-0.34	775,359	-0.64
450	535,925	533,558	-0.44	529,175	-0.82
435	331,550	329,561	-0.60	325,877	-1.12
420	190,000	188402.8	-0.84	185444.9	-1.57
400	80,000	78925.5	-1.34	76935.69	-2.52
360	5,000	4811.237	-3.78	4461.675	-7.27
340	0	0	-0.00	0	-0.00

Table 11. JST Lake Estimated Changes in Reservoir Volume due to Sedimentation

Reservoir Elevation (ft msl)	1952 Volume (ac-ft)	2010 Volume (ac-ft)	Volume Change 1952 – 2010 (%)	2060 Volume (ac-ft)	Volume Change 2010 – 2060 (%)
335	2,900,000	2,879,599	-0.70	2,862,012	-0.61
334	2,822,000	2,801,803	-0.72	2,784,391	-0.62
333	2,744,000	2,724,007	-0.73	2,706,771	-0.63
332	2,666,000	2,646,211	-0.74	2,629,151	-0.64
331	2,588,000	2,568,313	-0.76	2,551,341	-0.66
330	2,510,000	2,490,517	-0.78	2,473,721	-0.67
329	2,440,000	2,420,721	-0.79	2,404,101	-0.69
328	2,370,000	2,350,925	-0.80	2,334,481	-0.70
327	2,300,000	2,281,129	-0.82	2,264,861	-0.71
326	2,230,000	2,211,333	-0.84	2,195,241	-0.73
325	2,160,000	2,141,435	-0.86	2,125,431	-0.75
324	2,100,000	2,081,639	-0.87	2,065,810	-0.76
323	2,040,000	2,021,843	-0.89	2,006,190	-0.77
322	1,980,000	1,962,047	-0.91	1,946,570	-0.79
321	1,920,000	1,902,251	-0.92	1,886,950	-0.80
320	1,860,000	1,842,455	-0.94	1,827,330	-0.82
319	1,808,000	1,790,659	-0.96	1,775,710	-0.83
318	1,756,000	1,738,965	-0.97	1,724,280	-0.84
317	1,704,000	1,687,169	-0.99	1,672,660	-0.86
316	1,652,000	1,635,373	-1.01	1,621,039	-0.88
315	1,600,000	1,583,577	-1.03	1,569,419	-0.89
314	1,555,000	1,538,781	-1.04	1,524,799	-0.91
313	1,510,000	1,493,985	-1.06	1,480,179	-0.92
312	1,465,000	1,449,291	-1.07	1,435,749	-0.93
311	1,420,000	1,404,495	-1.09	1,391,129	-0.95
310	1,375,000	1,359,801	-1.11	1,346,699	-0.96
309	1,334,000	1,319,005	-1.12	1,306,079	-0.98
308	1,293,000	1,278,311	-1.14	1,265,648	-0.99
307	1,252,000	1,237,515	-1.16	1,225,028	-1.01
306	1,211,000	1,196,821	-1.17	1,184,598	-1.02
305	1,170,000	1,156,025	-1.19	1,143,978	-1.04
304	1,138,000	1,124,331	-1.20	1,112,548	-1.05
303	1,106,000	1,092,535	-1.22	1,080,928	-1.06
280	510,000	501,636	-1.64	494,425	-1.44
255	200,000	195,716	-2.14	192,022	-1.89
240	130,000	127,552	-1.88	125,441	-1.65
230	100,000	98,470	-1.53	97,151	-1.34
220	50,000	49,184	-1.63	48,480	-1.43
175	0	0	0.00	0	0.00

As can be seen in Tables 7 through 11, the total loss due to estimated reservoir sedimentation, when taken as a percentage of the total reservoir volume, is very small (i.e., less than 1% in most cases).

Table 12 provides the volume lost due to estimated sedimentation just within the normal operating range of each reservoir between initial fill year and year 2010.

Table 12. Volume Change Within the Normal Operating Range from Initial Fill Year to 2010

Reservoir	Top of Operating Range (ft msl)	Bottom of Operating Range (ft msl)	Number of Feet (ft)	Volume Lost in Operating Range (ac-ft)	Percent Change (%)
Jocassee	1110	1086	24	8,291	4.755
Keowee	800	778	22	-22,985	-6.553
Hartwell	660	625	35	-1,699	-0.120
RBR	475	470	5	-62	-0.049
JST	330	312	18	-3,774	-0.361

Table 13 provides the volume lost due to estimated sedimentation just within the normal operating range of each reservoir between year 2010 and year 2060.

Table 13. Volume Change Within the Normal Operating Range from 2010 to 2060

Reservoir	Top of Operating Range (ft msl)	Bottom of Operating Range (ft msl)	Number of Feet (ft)	Volume Lost in Operating Range (ac-ft)	Percent Change (%)
Jocassee	1110	1086	24	-4	-0.002
Keowee	800	778	22	-160	-0.049
Hartwell	660	625	35	-1,733	-0.123
RBR	475	470	5	-114	-0.091
JST	330	312	18	-3,254	-0.312

5.0 Conclusions and Recommendations

The volume reductions within the normal operating ranges for each of the five reservoirs on the mainstem of the Savannah River due to estimated sedimentation are relatively small compared to the overall usable volumes.

For Lake Jocassee, the 2010 stage/storage curves that were developed using recently collected bathymetry data and GIS software tools are remarkably similar to the curves that were generated in 1967. The slight increase in total storage is likely the result of very small inaccuracies due to data collection and reduction techniques that were considered best practice in the late-1960's. For Lake Keowee, the 2010 stage/storage curves based on new bathymetry data show an 8.8% reduction in total storage and a 6.6% reduction in storage down to 778 ft msl. The volume loss since 1967 is likely the result of some sedimentation, but also similar inaccuracies in data collection and reduction as described for Lake Jocassee.

For the three USACE reservoirs, the incremental volume lost due to sedimentation from initial fill to 2010 is very small from a percentage standpoint (less than 1%). These sedimentation estimates are heavily influenced by sediment yields that have been measured in the Savannah River drainage basin. For this analysis, average to slightly greater than average sediment yield estimates were used. However, even if the sediment yield estimates used in this analysis were doubled, usable reservoir volume losses would still be very small.

Similarly, the sedimentation estimates projected out to year 2060 are also very small for all five reservoirs. Less than 1% additional volume is lost from the 2010 stage/storage curves. The lost volume is even smaller within the normal operating range as some of the sediment deposits below usable storage elevations.

For HEC-ResSim modeling purposes, these stage/volume changes for 2010 and 2060, though small, will be incorporated into the "current case" and "future case" modeling scenarios as applicable.

6.0 References

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APPENDIX B

SAVANNAH RIVER

2009 – 2011 UNIMPAIRED FLOW RECORD EXTENSION

Savannah River
2009 – 2011 Unimpaired Flow Record Extension

Time-Series Data Development Informational Meeting
Duke Energy/HDR

June 27, 2013

ARCADIS

RIVERSIDE
global science solutions

Scope of services

Extension of 1939-2008 local and cumulative Savannah River UIFs:

- –Seneca River at Jocassee Dam
- –Seneca River at Keowee Dam
- –Savannah River at Hartwell Dam
- –Savannah River at Russell Dam
- –Broad River at Bell
- –Savannah River at Thurmond Dam
- –Savannah River at Augusta
- –Savannah River at Burtons Ferry
- –Brier Creek at Millhaven
- –Savannah River at Clyo
- –Savannah River at Savannah

No modification of 1939 – 2008 local or cumulative UIFs

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Unimpaired flow development tasks

- Water-use inventory and reach aggregation
- Reservoir precipitation time series development
- Reservoir evaporation time series development
- Reservoir holdouts and net reservoir effects determination
- Routing and unregulated local inflow calculation
- Aggregation of impairments and local UIF development
- Flow adjustments
- Quality and consistency checks
- Cumulative UIF determination

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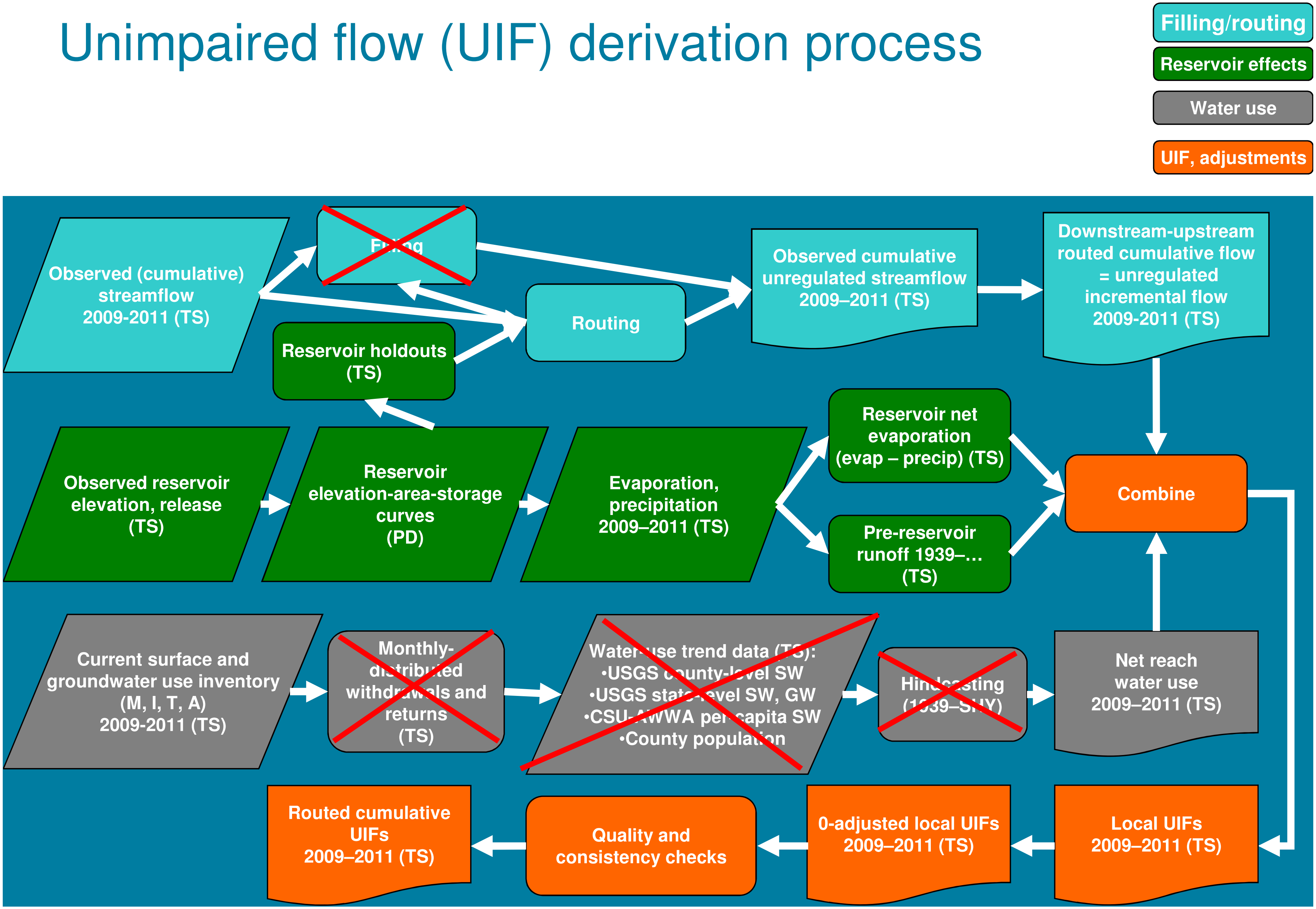
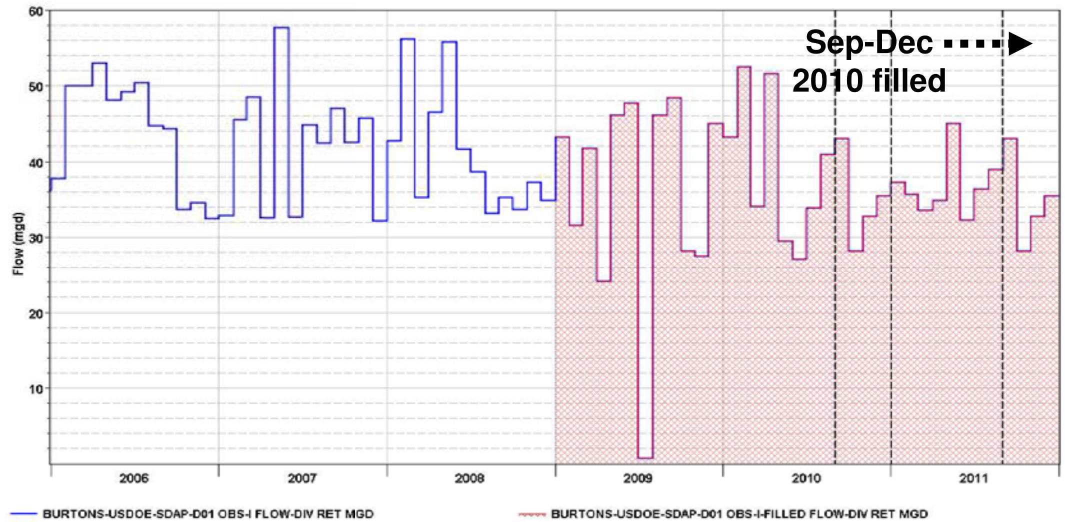
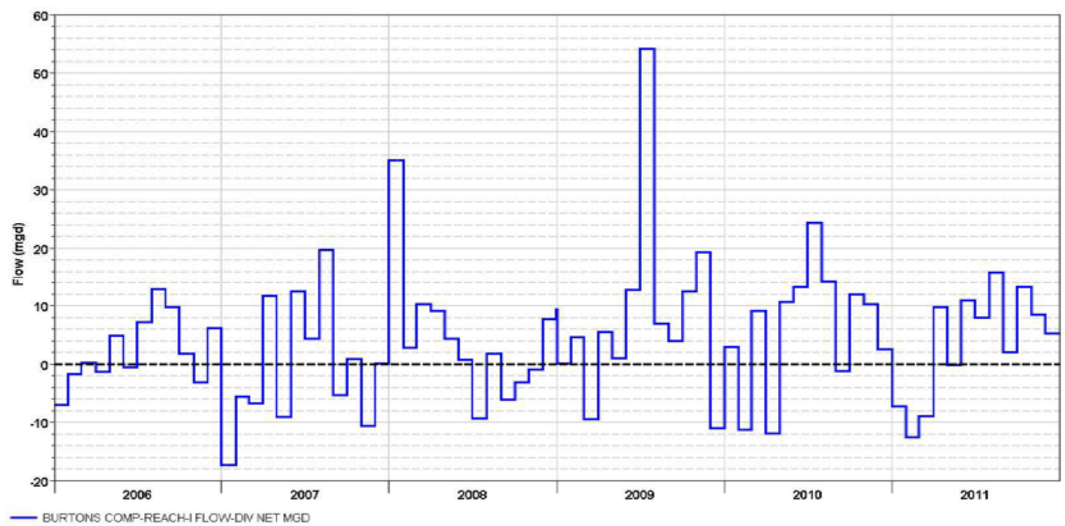
Unimpaired flow (UIF) derivation process



Water-use inventory and reach aggregation

- Filling of missing 2008 – 2011 water withdrawals and returns using 2010 data
  - By user/permittee
  - By reach
  - By month
- Aggregation of 2008 – 2011 M, I, T and A net water uses by reach
  - Net water use = monthly withdrawals – monthly returns
  - mgd to cfs unit conversion
- Conversion of monthly to daily net water use by reach





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Net reservoir losses
Overview

- **Account for differences in runoff before and after the reservoir**
  - **Evaporation from reservoir surface**
  - **Precipitation on reservoir instead of land**

Net Loss Rate = Evap – (1 – Runoff Coefficient) * Precip
Net Loss Volume = Net Loss Rate * Daily Surface Area

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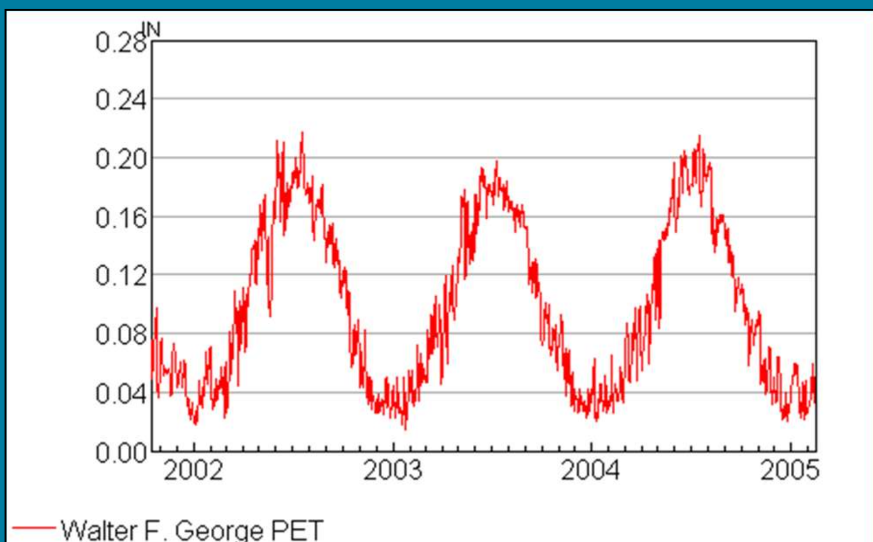
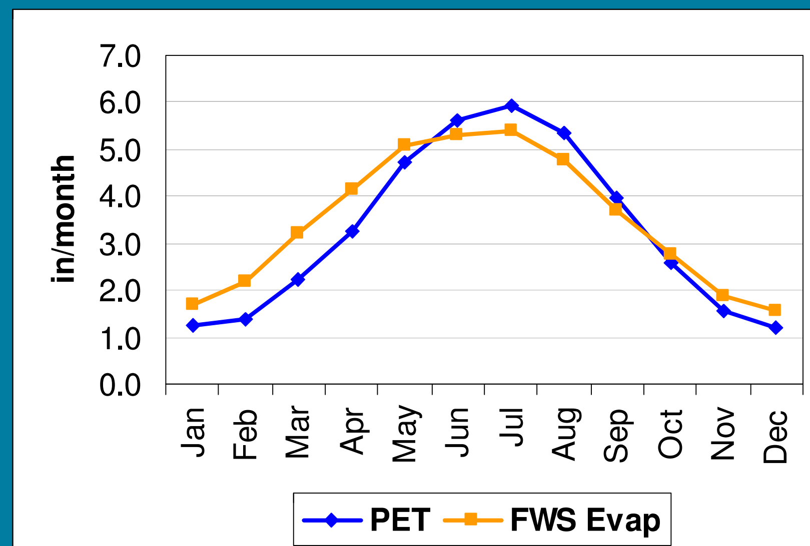
Net reservoir losses
Surface evaporation

- NWS Free Water Surface Evaporation Atlas
- Hamon Method for daily Potential Evapotranspiration (PET)
  - Based on maximum and minimum temperature and latitude
- Adjusted daily PET to long-term evaporation
- Kept 2009-2011 results consistent with earlier results





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Net reservoir losses
Surface precipitation

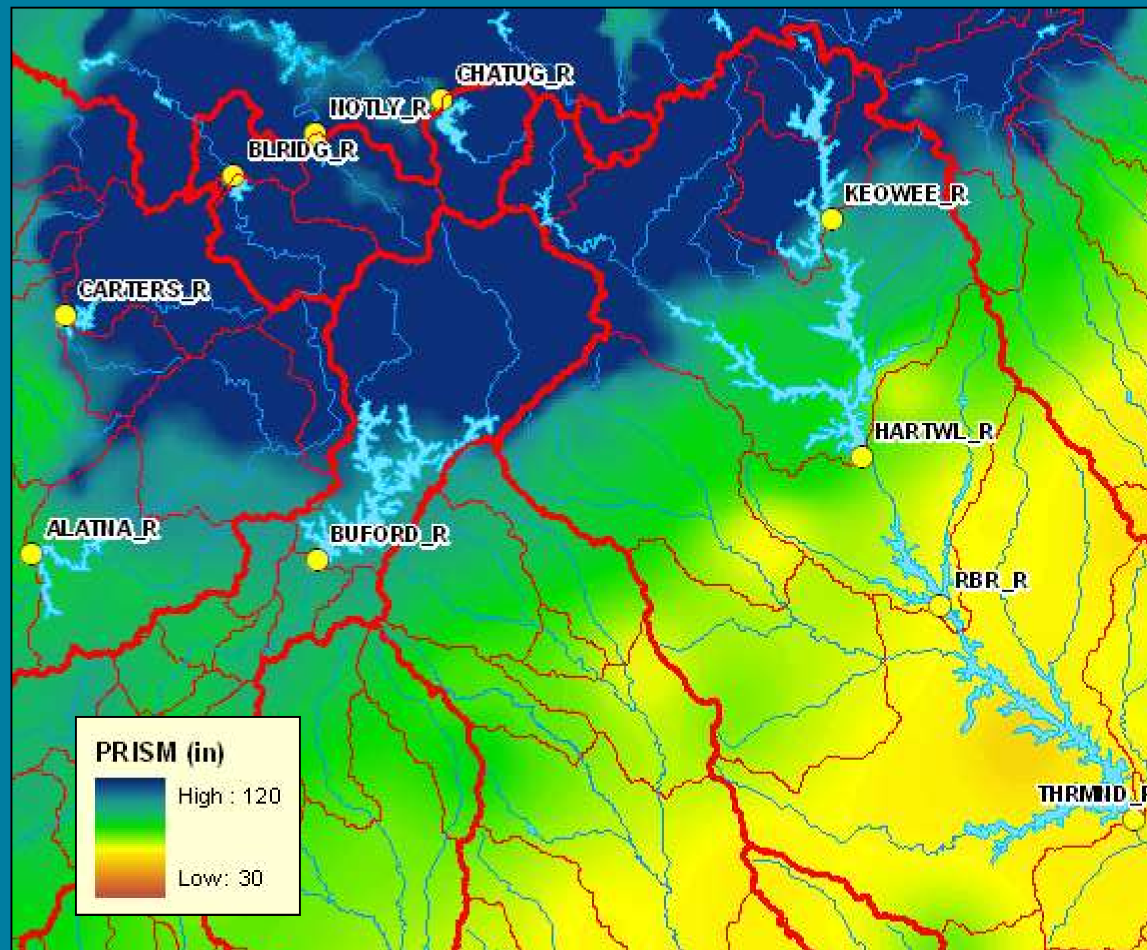
- **Began with SERFC Mean Areal Precipitation (MAP) time series (1950 – 1999 and 1950 – 2004)**
- **Needed to extend time series period of record**
- **Used National Weather Service MAP program with same station inputs as original**
  - **Hourly data not available for December 2011, used only daily data that month**
- **Performed consistency checks of results**

ARCADIS RIVERSIDE global science solutions

Net reservoir losses
Surface precipitation

- **Adjusted MAP to represent long-term precipitation over reservoirs**

$$\text{Adjustment} = \frac{\text{PRISM}_{\text{reservoir}}}{\text{PRISM}_{\text{MAP area}}}$$



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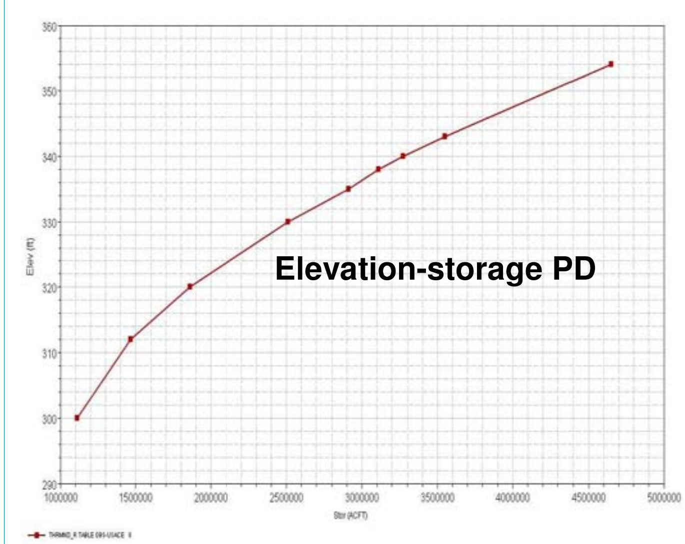
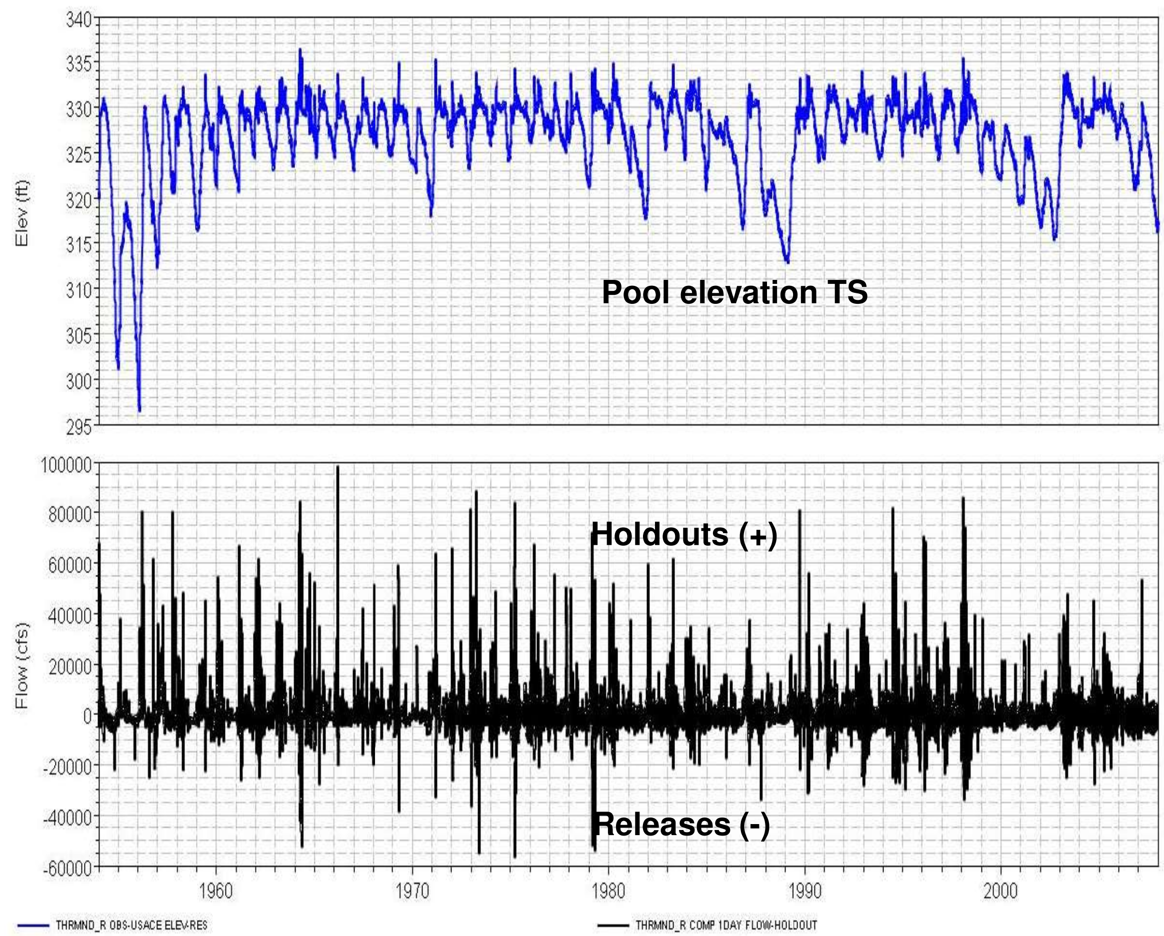
Holdouts and net reservoir effects

- **Holdouts: = +ΔS when**
  O < I (rising pool)
- **Holdouts: = –ΔS when**
  O > I (falling pool)
- **Net RE =**
  E – P + $RO_{natural}$ + holdouts





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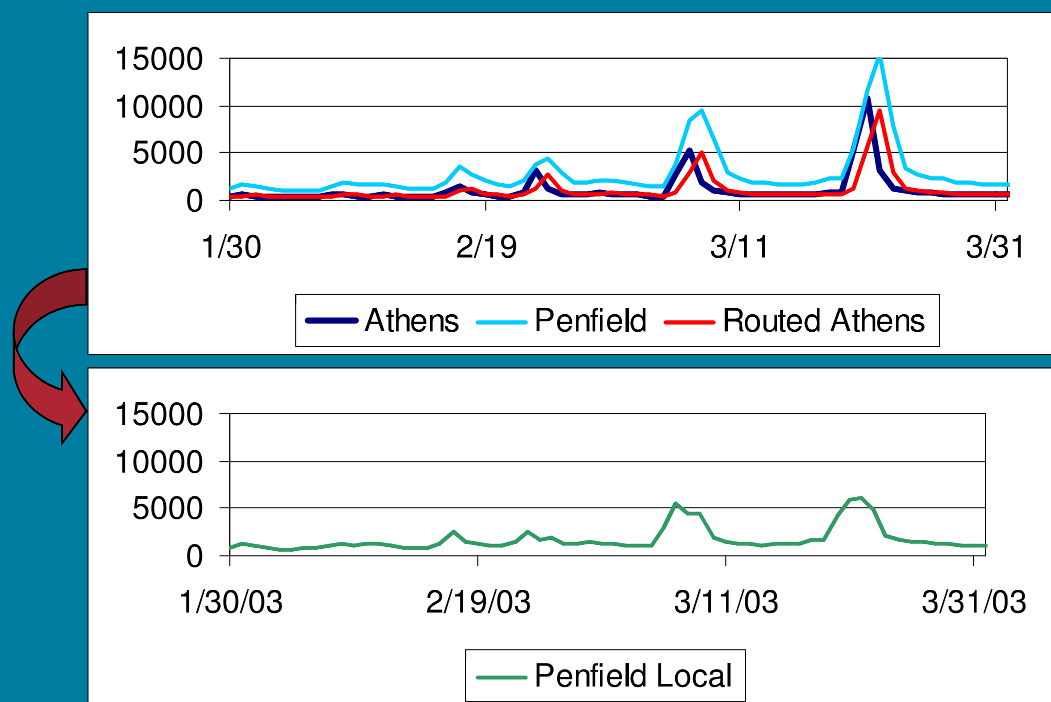
Local incremental flow (LIF) calculation
(RTi)

- **Route upstream cumulative streamflow (+ holdouts) to next downstream node**
- **Subtract upstream routed flow from downstream cumulative flow**



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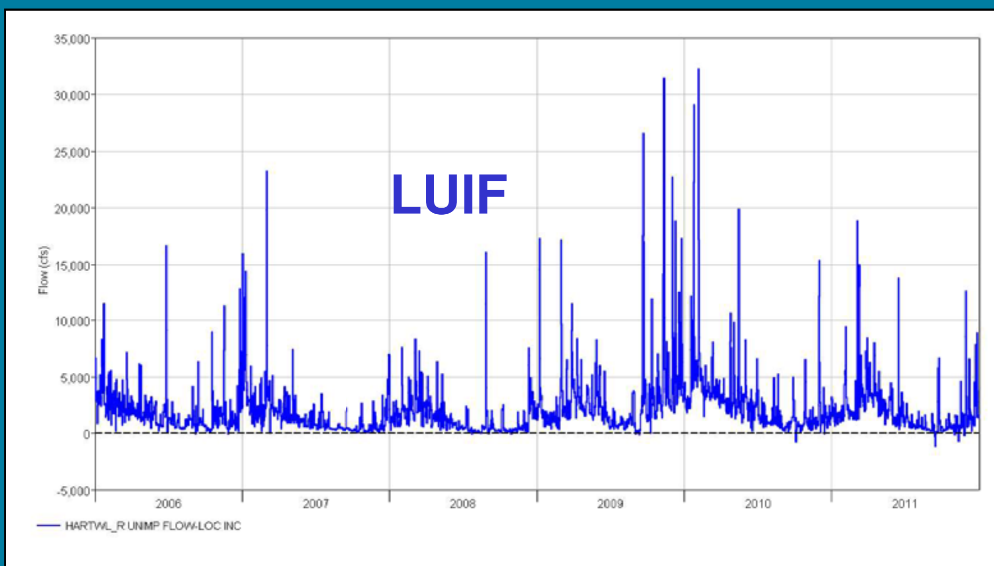
Aggregation of impairments (local UIF development)

Local UIF =

Local incremental flow +

Net water use +

Net reservoir effects



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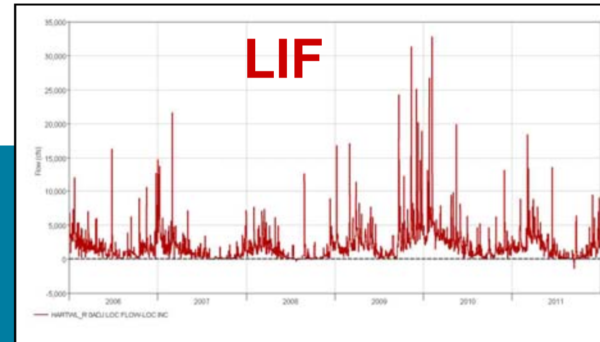

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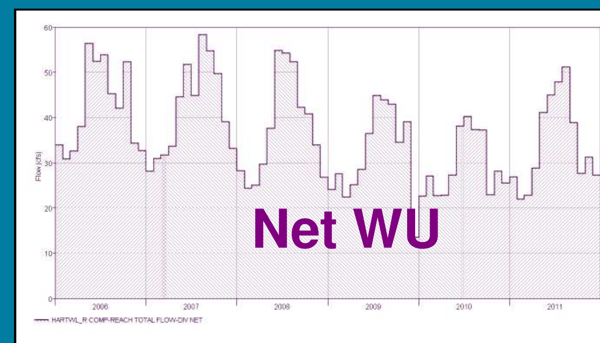

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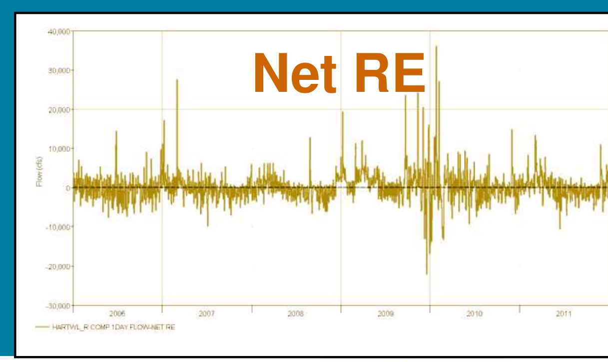
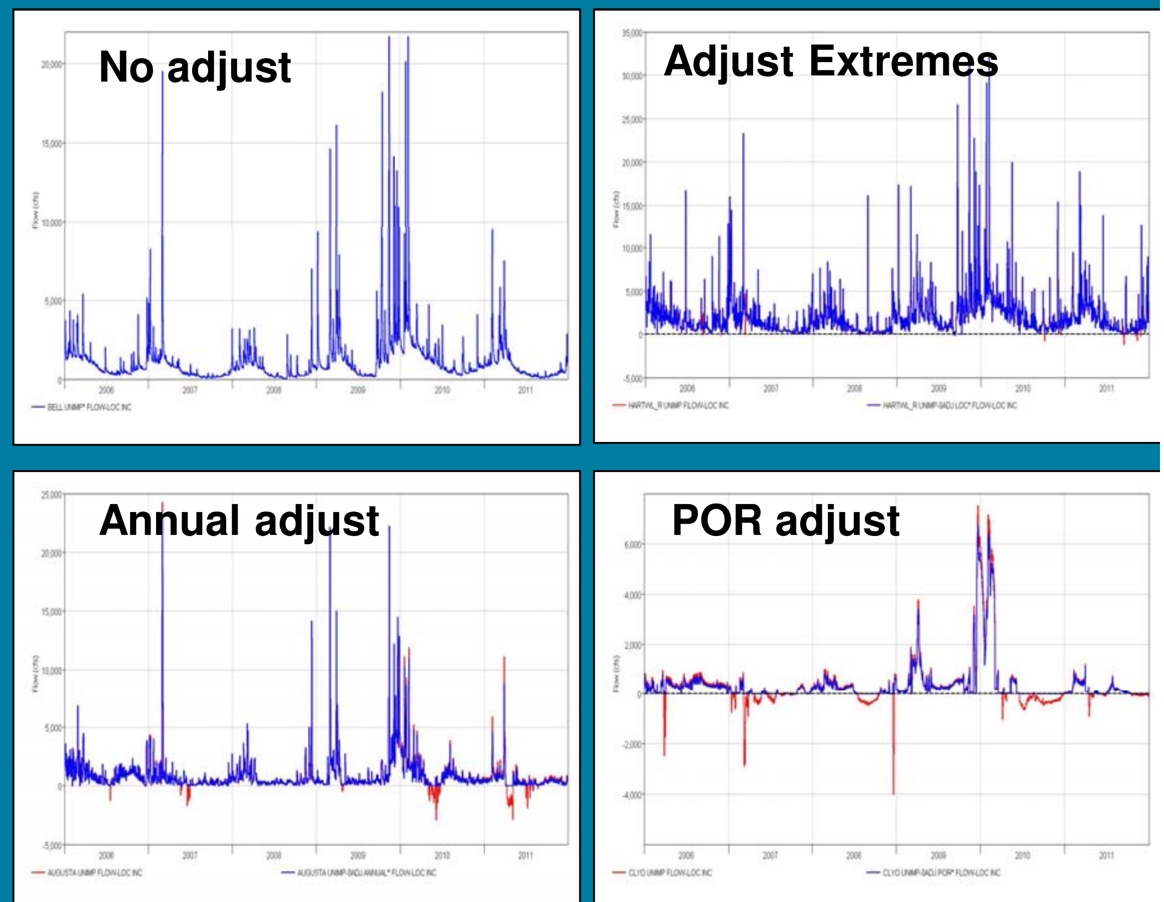


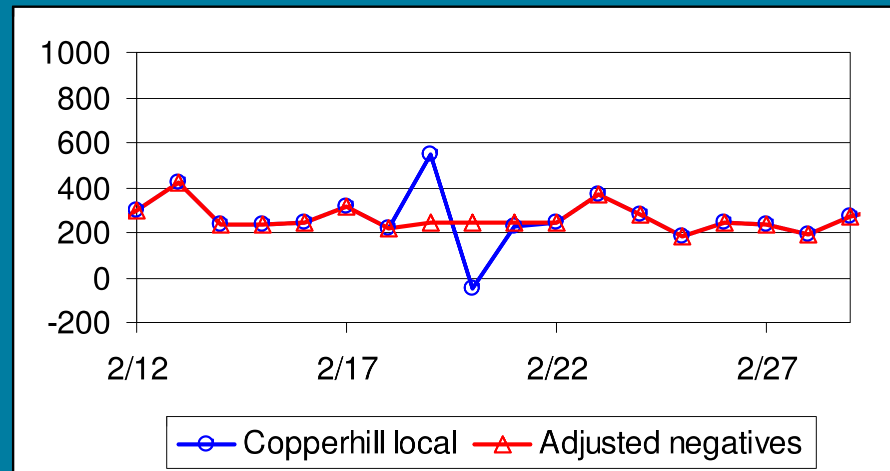
Flow adjustments

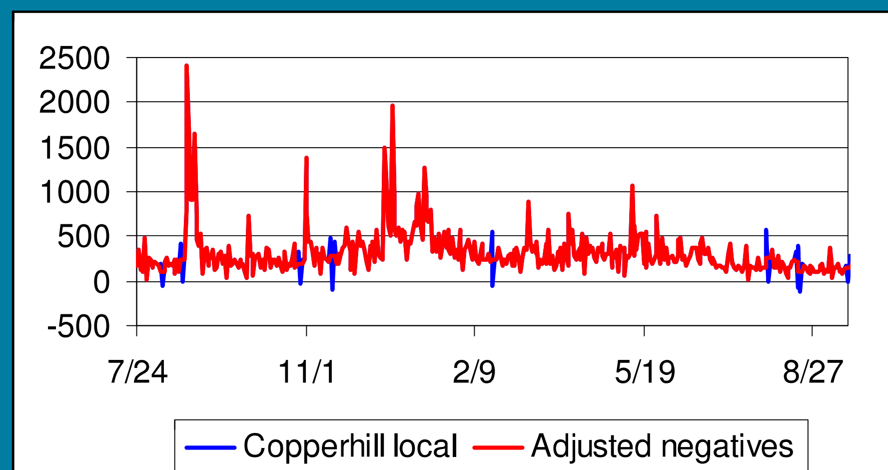
- Objective:
  - Removal of negative LUIFs
  - Flow volume maintenance over minimum time interval
- Procedures:
  - TSTool Adjust Extremes (variable centered-moving average value ≥ 0)
  - Annual adjust (DSSMATH procedure, raise –s to 0, reduce +s to maintain annual flow volume)
  - POR adjust (DSSMATH procedure, raise –s to 0, reduce +s to maintain POR flow volume)



Flow adjustments
TSTool AdjustExtremes

- **Adjustment of localized errors**
  - **Reservoir inflows**
  - **Routing**
- **Inputs**
  - **Specify threshold for adjustments**
  - **Define maximum time window for adjustments**
- **Calculations**
  - **Flags values below threshold**
  - **Computes average of flagged value and surrounding points**
  - **Consecutively increases number of points until average exceeds threshold**





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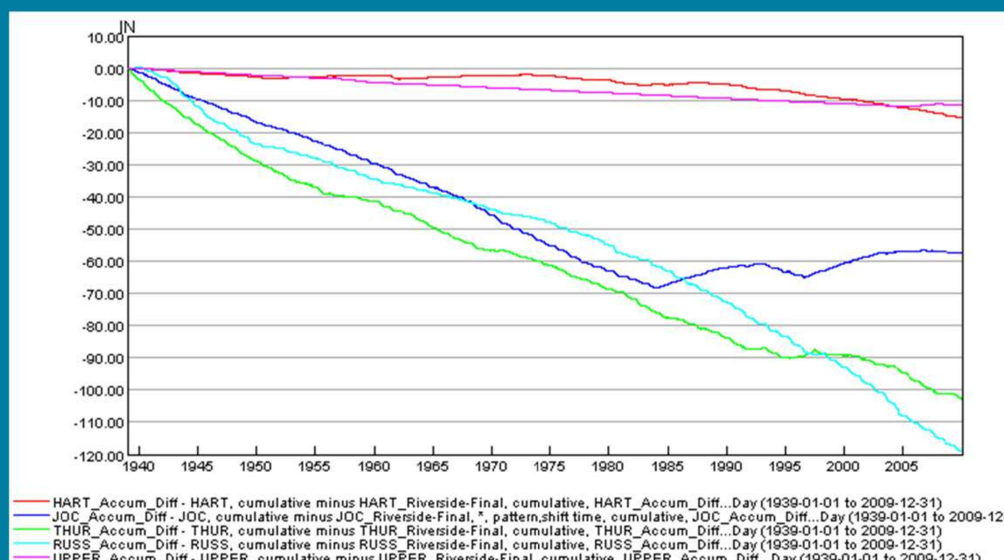
Quality and consistency checks
(RTi)

- MAP Consistency Checks
  - Used DMA to check extended MAPs
  - 2009-2011 data and older data were consistent
- Evap Consistency Checks
  - Used the same temperature station lists to keep results consistent
  - For Jocassee evap, scaled resulting evap to match previous results



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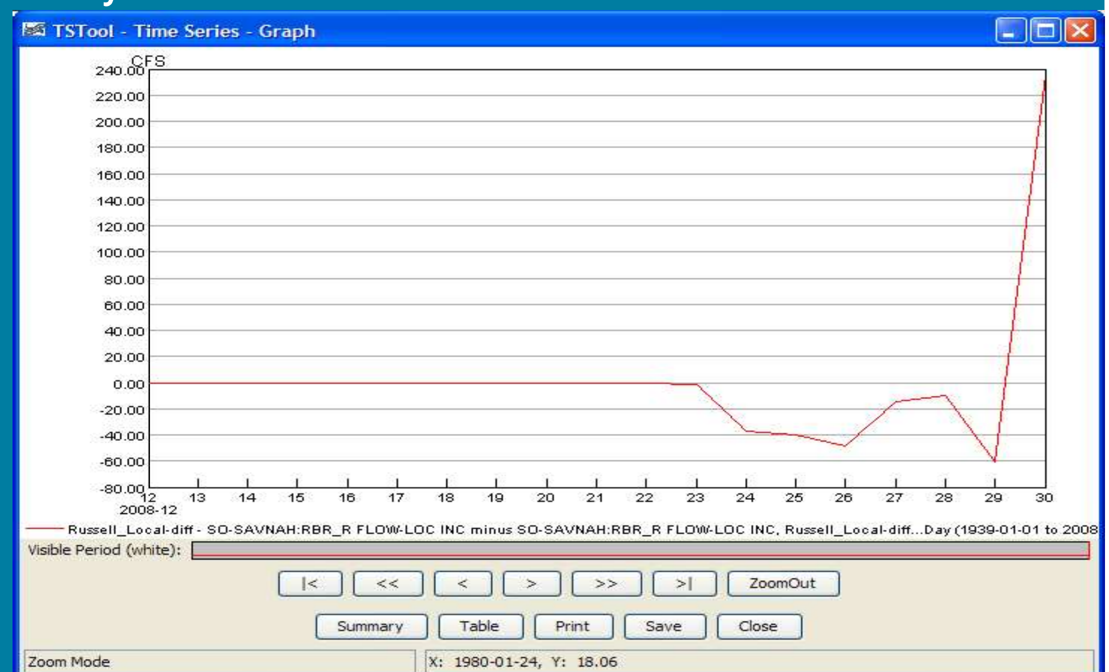
Quality and consistency checks
Local Incremental Flows

- Checked new calculations against original data
  - Some differences near the end of 2008 – more data available now for AdjustExtremes procedure
  - USGS revised flow records at Eden for Nov and Dec 2008 – affects Kings Ferry and Savannah nodes only
- No changes were made to original 2008 data, new data was appended



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Routing and combining (cumulative UIF development)

- **Began with local UIF time series**
- **Routed headwaters to the next node**
- **Summed with local UIF**
- **Routed the sum downstream**

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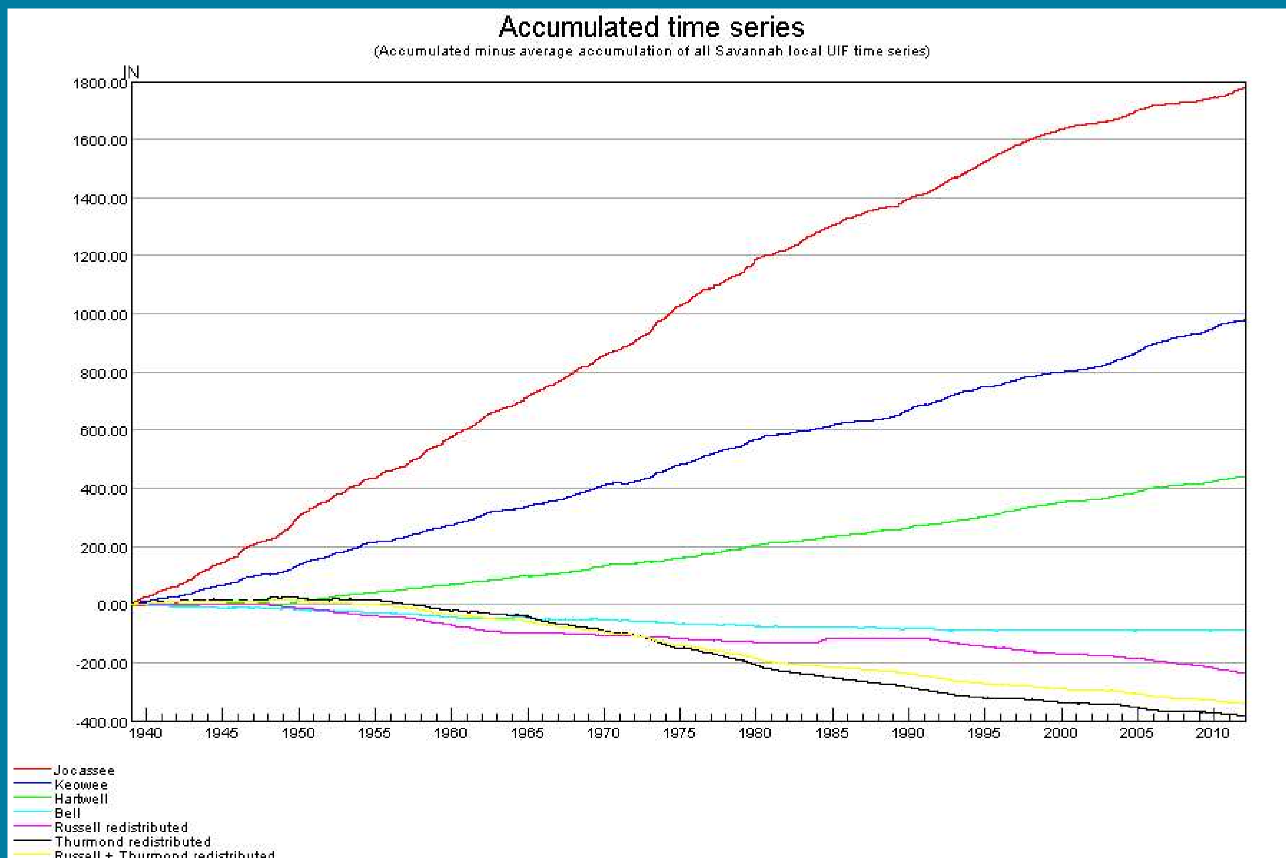
Quality and consistency checks
Unimpaired Flows

- Final local and total unimpaired flows checked for consistency
- No issues



Final steps

- Substitution of actual reported for filled 2011 water-use data

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