PARR-FAIRFIELD OPERATIONS MODELING SYSTEM

PARR HYDROELECTRIC PROJECT

FERC NO. 1894

Prepared for:

South Carolina Electric & Gas Company
Columbia, South Carolina

Prepared by:

Kleinschmidt

Lexington, South Carolina
www.KleinschmidtGroup.com

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SOUTH CAROLINA ELECTRIC & GAS COMPANY

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1.0 INTRODUCTION

South Carolina Electric & Gas Company (SCE&G) is the Licensee of the Parr Hydroelectric Project (FERC No. 1894) (Project). The Project consists of the Parr Shoals Development and the Fairfield Pumped Storage Development. Both developments are located along the Broad River in Fairfield and Newberry Counties, South Carolina.

This document provides a description of the development of the Hydrologic and Project Operations Modeling system as part of the Parr and Fairfield relicensing project. This modeling system will be used to assess the ability to change project operations, and the resulting effects of potential modifications to project operations. The effects that could result from proposed changes in project operation include energy, capacity and generator availability, flood control, and water budget. The intent of this effort is to develop a modeling tool that can be used to incorporate stakeholder requests as parameters to provide outputs and results that can be easily interpreted.

This report includes sections covering the development of the modeling tools, and the data required to run the models, including:

- Description of the models and software;
- river routing model development (HEC-RAS);
- reservoir routing model development (HEC-ResSim);
- hydrologic data used in the models; and
- modeling system data management.

It is important to note that the vertical datum for the reservoir model is NGVD29, while the HEC-RAS model is NAVD88. This discrepancy does not affect the performance of the models, since the only data interchange between the models is outflow from Parr Reservoir. The reason for the difference lies in the fact that all elevation references for the two reservoirs has consistently been stated as NGVD29 values, and the terrain data for the HEC-RAS model (Source: USGS) is in NAVD88. Unless stated otherwise, all elevation data cited in this report will follow this convention.

2.0 MODELS AND SOFTWARE

The modeling system is comprised of two USACE models and the accompanying DSS data storage system. Full descriptions of the software may be found on the USACE-HEC website. The URLs for each of the software components are included in the following brief descriptions.

2.1 RIVER ROUTING MODEL (HEC-RAS)

The reservoir routing model is the U.S. Army Corps of Engineers HEC-RAS http://www.hec.usace.army.mil/software/hec-ras/). HEC-RAS (v4.1) is a 1-dimensional model designed to perform hydraulic calculations for a full network of natural and constructed channels. The HEC-RAS model will simulate the flow releases from Parr Reservoir and the resulting water level stage in the river downstream. Wave travel times, rates of rise, and stage recession times will also be available from this model.

2.2 RESERVOIR ROUTING MODEL (HEC-RESSIM)

The reservoir routing model is the U.S. Army Corps of Engineers HEC-ResSim (http://www.hec.usace.army.mil/software/hec-ressim/). This software package was developed by the U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center, and is used to model reservoir operations for single or multiple reservoir systems. The software accepts a variety of operational constraints and goals, and can be used to simulate ranges of inflows and response of the reservoir operations. The entire period of record can be simulated or specific events such as flood inflows or drought conditions can be routed to evaluate the response based on the constraints and goals. The results of these simulations facilitate decisions on adjusting one or more constraint or goal to better meet the interests of stakeholders.

2.3 MODEL DATABASE MANAGEMENT (HEC-DSSVUE)

The time series data used in the analyses are stored in direct access database files, in the USACE DSS database format. The DSS data storage system was developed by the Corps, and has been integrated into all HEC modeling systems, including HEC-ResSim and HEC-RAS. The DSS software, similar to the models, is public domain software and available for download at http://www.hec.usace.army.mil/software/hec-dssvue/. The use of the DSS system allows for the storage of time series data in a manner that allows the HEC models to read and write data to facilitate the exchange of data from one model to another. For the Parr-Fairfield Operations Model, the DSS data files are used to store streamflow and reservoir stage data, subsequently used as input to the HEC-ResSim model, followed by the storage of HEC-ResSim output data to be used as input for the HEC-RAS model.

3.0 RIVER ROUTING (HEC-RAS) MODEL DEVELOPMENT

The model of the downstream reach of the Broad River below Parr Shoals Dam was developed using readily available data to simulate the hydraulic effects of flow releases. The modeled reach below the Parr Shoals Dam extends down to the Columbia Diversion Dam, a distance of approximately 24 miles. The results of the model simulations can be used to determine flow and stage estimates for other interests in the project, such as navigation, recreation, or habitat benefits.

The geometric data and mapping were developed using an ArcGIS Geographic Information System (GIS). These data were utilized in conjunction with the HEC-GeoRAS v4.1 GIS extension for development of the model geometry, which was then exported to the HEC-RAS model.

3.1 DATA SOURCES

Data used in the development of the model were acquired from a number of sources and assembled in a GIS. The following is a list of items used in the development of the model:

- Aerial Imagery – Environmental Systems Research Institute (ESRI) Aerial Color Imagery Server, and Google Earth imagery.
- Topographic Data – South Carolina Digital Elevation Model (DEM) derived from LiDAR data.
- Flow vs. stage rating tables – The flow vs. stage data were obtained from the USGS web portal for two gage sites within the model domain.[1]
- Flow and stage time series data were obtained from the USGS web portal
- River stage time series data were monitored for approximately at 12 locations by SCE&G using Solinst Levellogger® dataloggers. These data series were converted to elevation data, by adding the stage readings to the surveyed elevation datum values for each datalogger. Barometric compensation was also performed using data collected with a Solinst Barologger® datalogger.

[1] A third discontinued USGS gage exists within the model domain, but has less than two years of overlapping flow data, and only has stage data available for peak annual events. For these reasons, the gage was not used to develop the model. See Section 3-5 and Figure 3-6.

3.2 GEOMETRY DATA

The simulation covers the reach of river from the tailwater of the Parr Shoals Dam to the Columbia Dam, a total length of approximately 24 miles. The cross-section geometry was derived from digital terrain data from the South Carolina GIS web portal. The terrain dataset was derived from LiDAR data, developed by the South Carolina LiDAR Consortium[2]. The processed DEM has an effective horizontal resolution of approximately 10 feet and supports 2-foot contours.

Cross-section locations were sampled using the ArcMap HEC-GeoRAS v.4.1 GIS extension. Figure 3-1 through Figure 3-3 show the cross-section locations from the HEC-RAS model.

The digital terrain data required by the HEC-RAS model consist of a series of river cross-sections, represented by a series of X-Y points for cross-sectional width and vertical range of interest in the channel. Although the GIS terrain data is adequate for the near-bank and overbank portions of the cross-section, the portion of the channel that is typically underwater must be augmented by other means. The thalweg elevation of the channel is typically estimated from previous models, such as detailed FEMA Flood Insurance Studies (FIS), but the coverage of FIS data on the Broad River is currently limited to the downstream-most 8 miles of the model.

[2] http://www.dnr.sc.gov/GIS/lidar.html

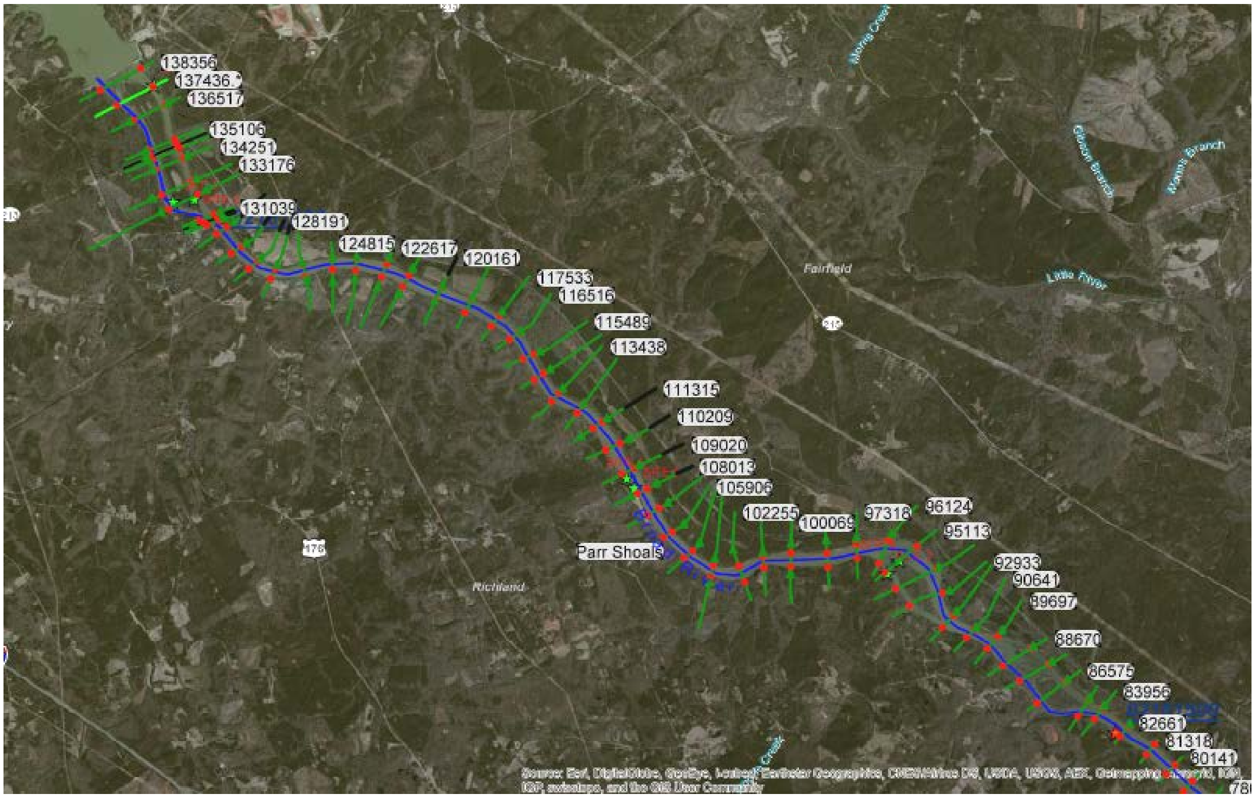

FIGURE 3-1 HEC-RAS SECTIONS (1 OF 3)

FIGURE 3-2 HEC-RAS SECTIONS (2 OF 3)

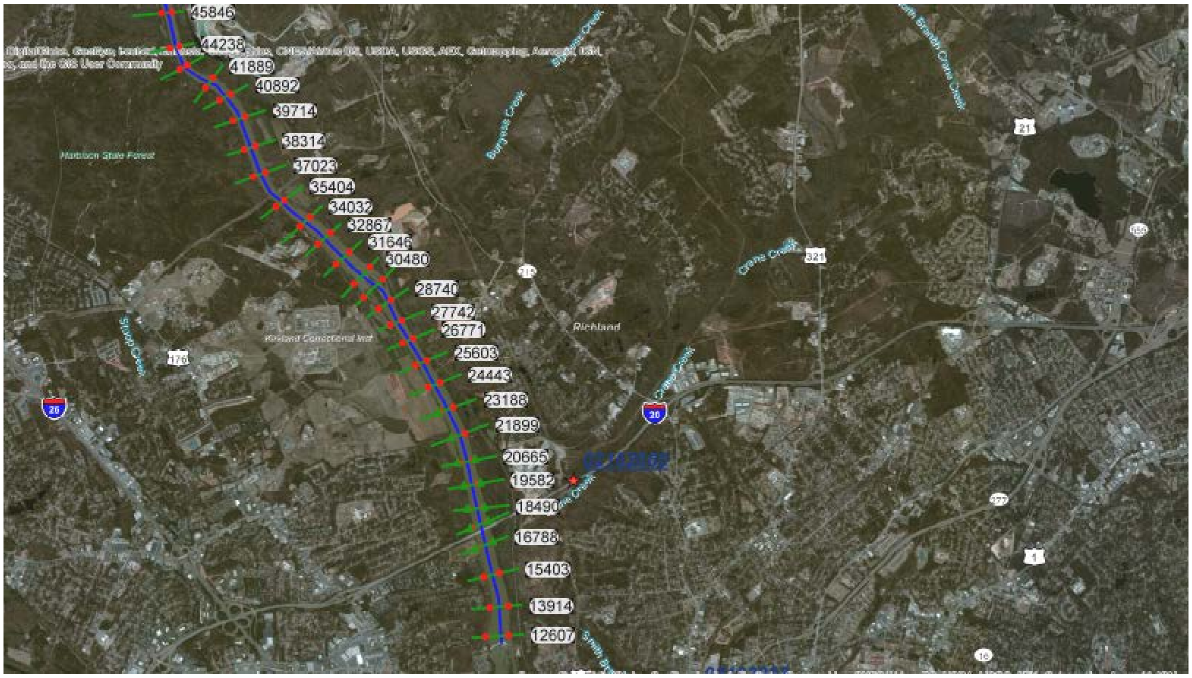

FIGURE 3-3 HEC-RAS SECTIONS (3 OF 3)

The instream cross-section data for this model were estimated by two methods. Datum elevations from the two USGS gages within the model domain were used as reference elevations, and the remaining portion of the channel reach was interpreted from the GIS terrain data. Investigation of the digital terrain data indicated that the LiDAR data were developed during a period when the streamflow rate was approximately 3,000 cfs. Based on this approximation, the configuration of the instream channel cross-section were developed as trapezoidal sections with a depth that would produce the approximate river surface elevation as indicated by the digital terrain data. The vertical adjustment of the instream cross-section data was refined based on the datalogger stage readings as part of the calibration process. The datalogger readings included periods of low flows, which provided an indication of the channel invert at each of the datalogger cross-sections.

3.3 ROUGHNESS COEFFICIENTS

The water surface elevation computation in the HEC-RAS model is a function of the channel and overbank conveyance; the conveyance is a function of the cross-sectional area and the roughness of the composite channel. The roughness values used in the model were developed as a function of the following factors:

- Land cover, as shown in aerial photography;
- the channel sinuosity; and
- the hydraulic connectivity between the channel and overbank areas.

The preliminary roughness values were also readjusted during the calibration process.

3.4 BOUNDARY CONDITIONS

The downstream boundary condition for the model is a rating curve at the Columbia Dam. The flow rating curve was developed using a combination of observed stage vs. flow readings from the USGS gage (Broad River near Columbia, No 02162035), and augmented with computed values. This USGS gage has been in operation since July 2011, and has experienced flows as high as 62,000 cfs. The rating curve is shown graphically in Figure 3-4.

The upstream boundary condition for the HEC-RAS model is an inflow time series. The inflow data series will be the outflow from HEC-ResSim model, which has an hourly time increment. For the purposes of calibrating the RAS model, the inflow data were assumed to be equal to the flows from the USGS gage site at Alston.

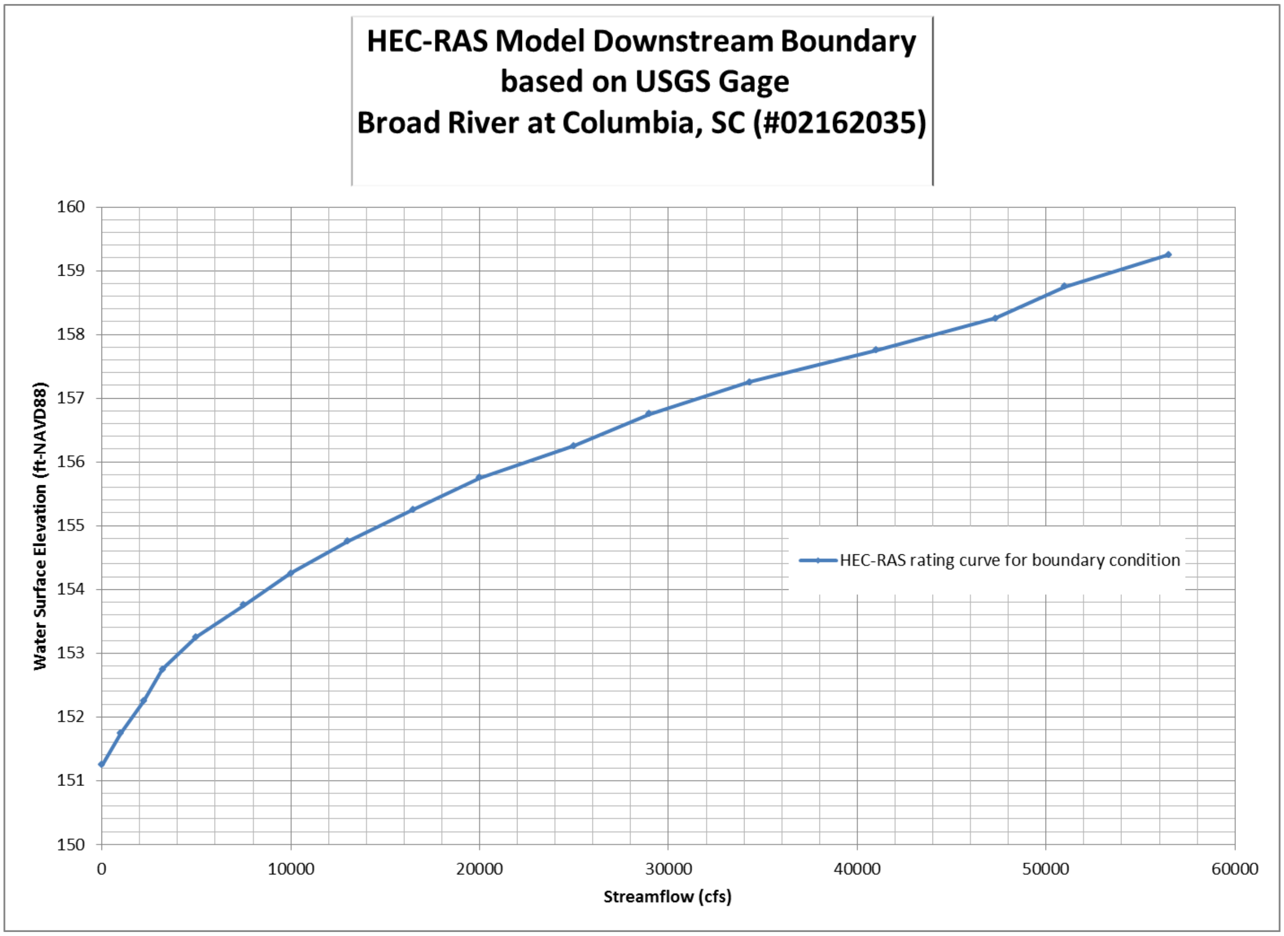

FIGURE 3-4 HEC-RAS DOWNSTREAM BOUNDARY

3.5 CALIBRATION – USGS GAGES

The calibration of the HEC-RAS model was performed using two methods. The first method was the use of the stage vs. flow rating tables from the two USGS gage sites within the model domain. The second method was the use of stage data measured and recorded by dataloggers at several locations.

The model was calibrated to the rating table from the USGS gage at Alston, South Carolina, by adjusting the channel and overbank roughness values. The USGS rating table data included a range of flows from near zero to 120,000 cfs, which encapsulated the range of flows for this model. The calibration process resulted in the model producing results (see Figure 3-5) within one foot of the USGS rating for the entire range of flows.

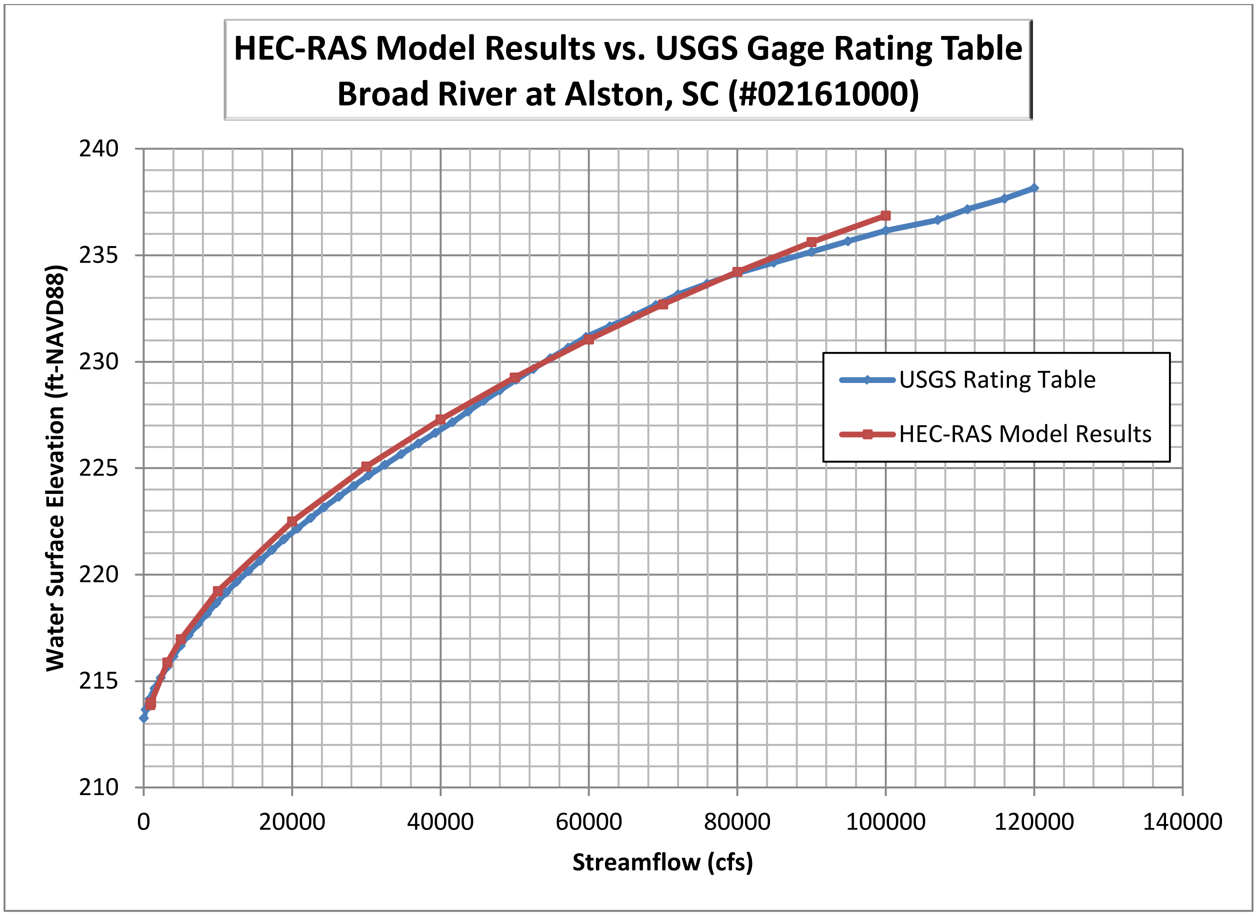

FIGURE 3-5 CALIBRATION RESULTS – ALSTON SITE

The model calibration (see Figure 3-6) was also compared to data from the discontinued USGS gage at Richtex, South Carolina. The data from this site was limited to annual peak flows measured at the site during the period 1925 to 1983, which was not useful for calibrating to typical daily flows. The USGS data included a range of flow/stage data points from 23,000 cfs (stage = 191.9 NAVD88) to 228,000 cfs (stage = 214.8 NAVD88).

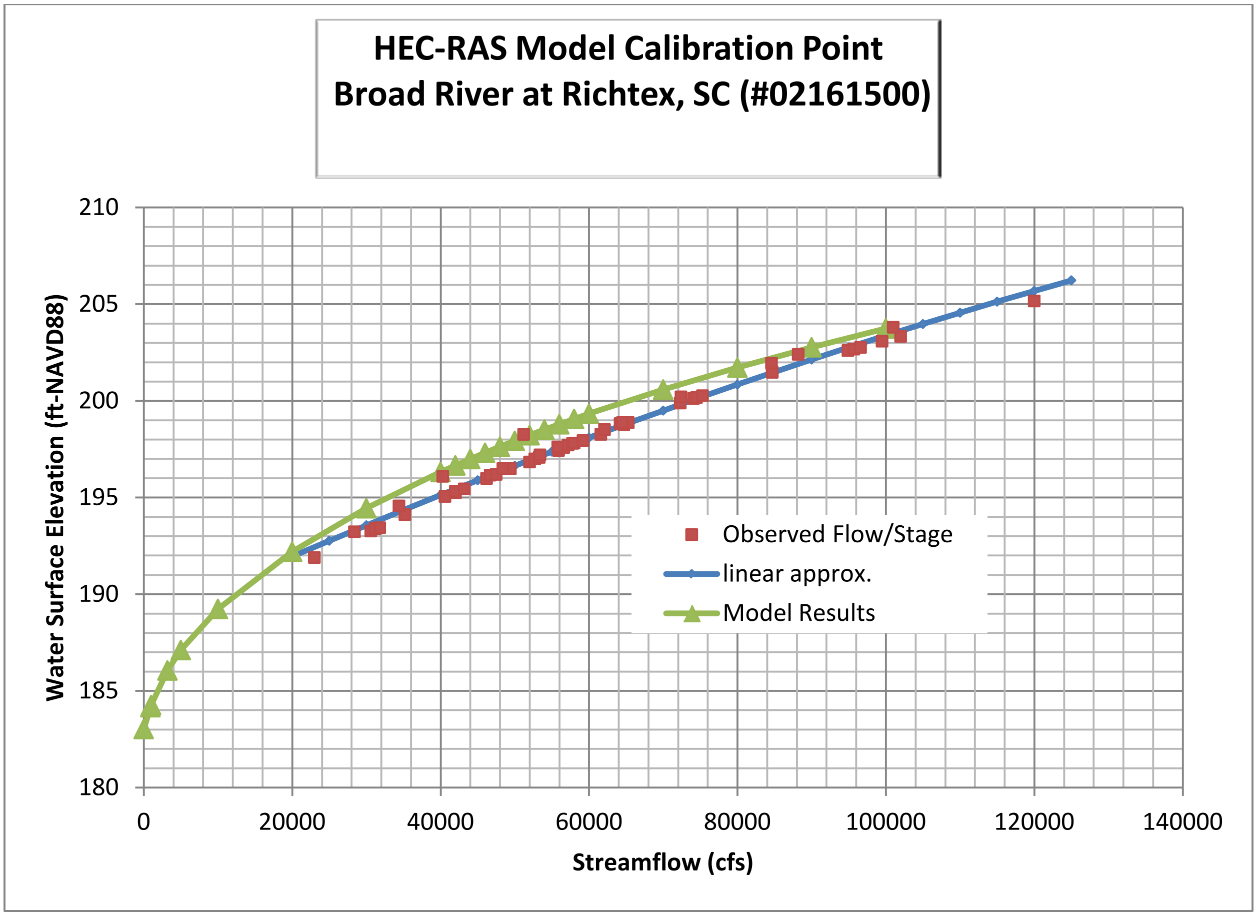

FIGURE 3-6 HEC-RAS CALIBRATION AT RICHTEX GAGE SITE

3.6 CALIBRATION – MONITORING DATA AND SURVEYS

During the initial model development, field data were gathered to refine the model with the intent of improving the resolution of the estimates of the water surface elevations at various locations. The field data gathered on October 23, 2013, consisted of bathymetric elevations measured at four transects (see Figure 3-7) downstream of the dam. The measured elevations were used to improve or confirm the configuration of the wetted portion of the cross-sections coded into the initial model.

FIGURE 3-7 TRANSECT LOCATIONS

The elevation data points from the field measurements confirmed that the original cross-section configurations were reasonable, and provided additional information on the slope of the channel thalweg. The field data, in conjunction with the digital terrain data, indicates that the channel has mild slopes in the 10,000 foot reach downstream of the railroad bridge (sections 120,000 to 130,000 in the HEC-RAS model).

Leveloggers® were deployed in twelve locations (see Figure 3-8) along the Broad River in June, 2014. The Levelogger® data consists of river stage readings on 30-minute intervals. The data recorded during the months of June and July, 2014 included periods in which the flow cycled between low flows (less than 1,000 cfs) and greater than 10,000 cfs. The Leveloggers'® elevations were surveyed to allow conversion of the data to the same elevation datum as the HEC-RAS model (NAVD88). These data were used to adjust the vertical offset of the HEC-RAS cross-sections, in addition to the roughness coefficients. The resulting calibrated stage hydrographs from the Levelogger® collection sites are included in Appendix A.

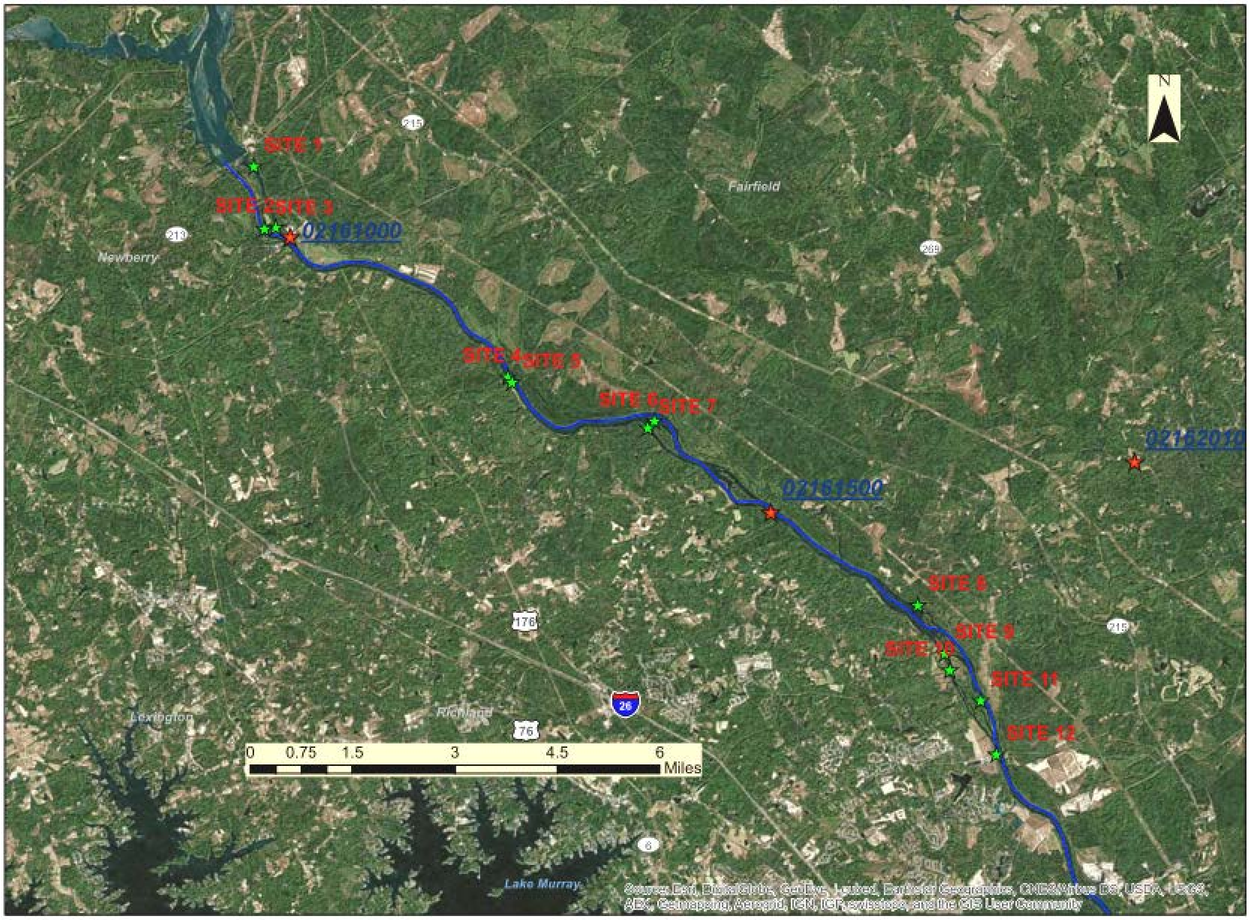

FIGURE 3-8 LEVELOGGER® SITES

4.0 RESERVOIR ROUTING (HEC-RESSIM) MODEL DEVELOPMENT

4.1 OBJECTIVES AND MODEL SETUP

The reservoir routing model (HEC-ResSim) has numerous simulation capabilities that were designed to allow the user to perform optimizations of river flows and hydroelectric generation. The model requires two general types of input, static and temporal, as well as operational rule sets. The static input consists of the fixed, physical setup of the river and reservoir system. Examples of this include the surface area and volume of the reservoir, and the capacity of the spillway and hydropower equipment. The temporal input data include the time series of reservoir inflows and evaporation. The operational constraints of the reservoir system are coded into the model input in one of two ways – as fixed values to be used in all scenarios, and operational constraints that vary among the different scenarios. Examples of this include the conservation or minimum pool level, which may be deemed a fixed value for a given project. The variable constraints may include seasonal minimum flows, which could be varied among the different scenarios.

The ResSim model for this project is configured with emphasis on the management of river flows and system losses, including evaporation. The model configuration includes the inflow to the Parr Reservoir, the pumping and generation cycles between Parr and Monticello Reservoirs, and the downstream releases from the Parr Reservoir via the spillway and powerhouse.

4.2 STATIC MODEL INPUT AND DATA SOURCES

The static model input includes the parameterization of the capacity components of the model, such as the reservoir size, the spillway capacity, and the power generation capacity. Some of the values are a single number, such as the power generation capacity of a turbine/generator unit, while others are input as rating tables, such as stage-storage curves. Static single number inputs to the model are summarized in Table 4-1. It should be noted that the hydropower computations in HEC-ResSim require efficiency parameters, but these values do not affect the simulated outflow amounts as coded in this model.

The HEC-ResSim model generates numerous time-series datasets during the simulation process. In addition to the simulated outflow and power generation values, the model generates output datasets that are primarily used to debug the model logic. A large number of output time series datasets are produced, many of which may not be useful for review (such as a reservoir threshold, representing a single value for the entire dataset series). As the Parr model produces over 280 time series datasets, an abridged tabulation of the datasets is included in Appendix B. This list contains the datasets that will be the primary focus during the evaluation of simulated operational schemes. The pathname shown in the table refers to the datasets within the model output HEC-DSS file, which is typically named “simulation.dss” and is located in the same folder as the simulation input files.

TABLE 4-1 STATIC MODEL INPUT VALUES

PARAMETER	VALUE
Generating Capacity – Parr	6 Units, total capacity 14.88 MW
Hydraulic Capacity – Parr	6,000 cfs (1,000 cfs per unit)
Generating Capacity – Fairfield	8 units, total capacity 511 MW
Hydraulic Capacity – Fairfield (Generating)	50,400 cfs (6,300 cfs per unit)
Pumping Capacity – Parr to Monticello	8 Pumps, 5,225 cfs at median head per unit
Assumed Hydropower Efficiency – Parr	70%
Assumed Hydropower Efficiency – Fairfield	85%

The following figures include the reservoir stage-area-storage curves for Parr and Monticello, the Parr tailwater curve, and the Parr spillway capacity.

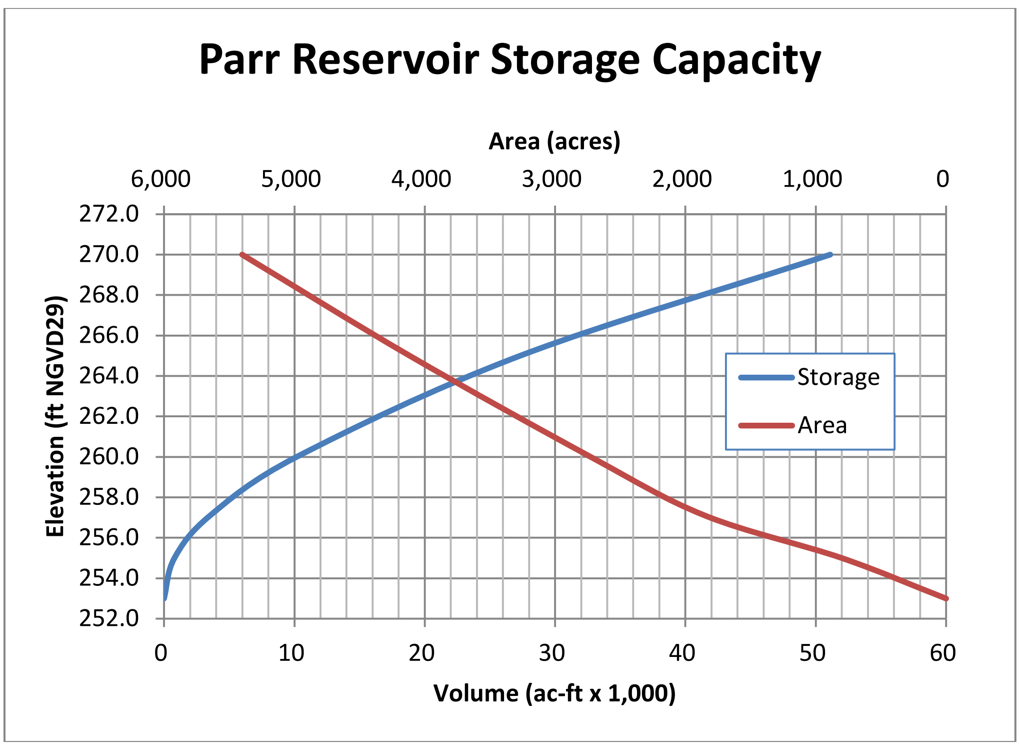

FIGURE 4-1 PARR RESERVOIR STORAGE CAPACITY

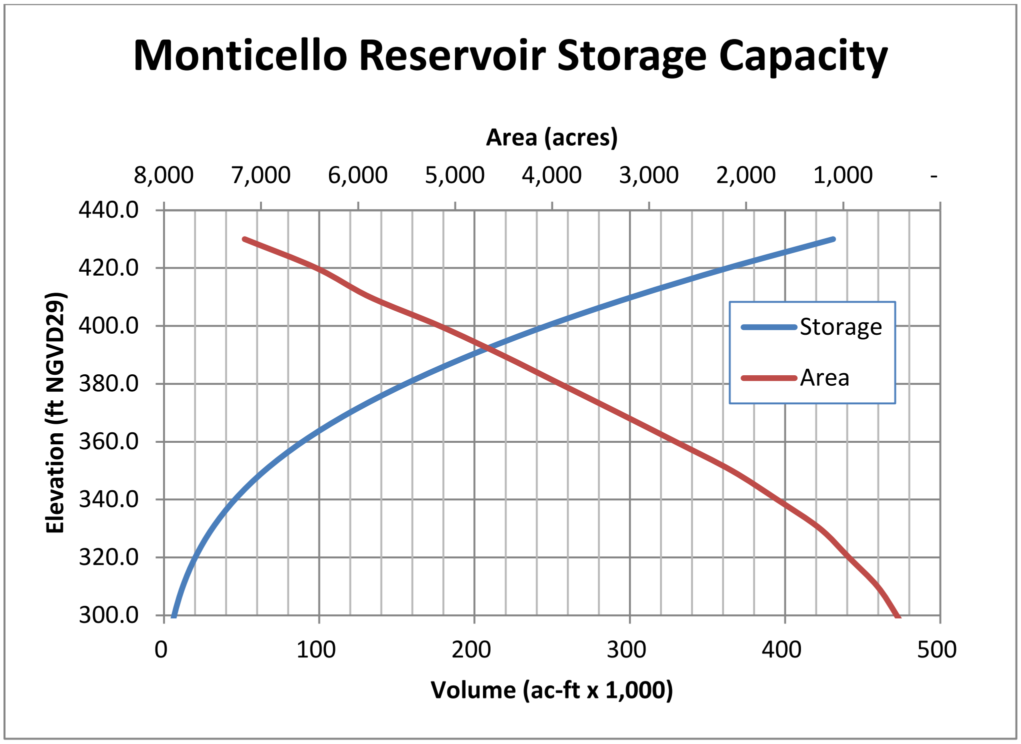

FIGURE 4-2 MONTICELLO RESERVOIR STORAGE CAPACITY

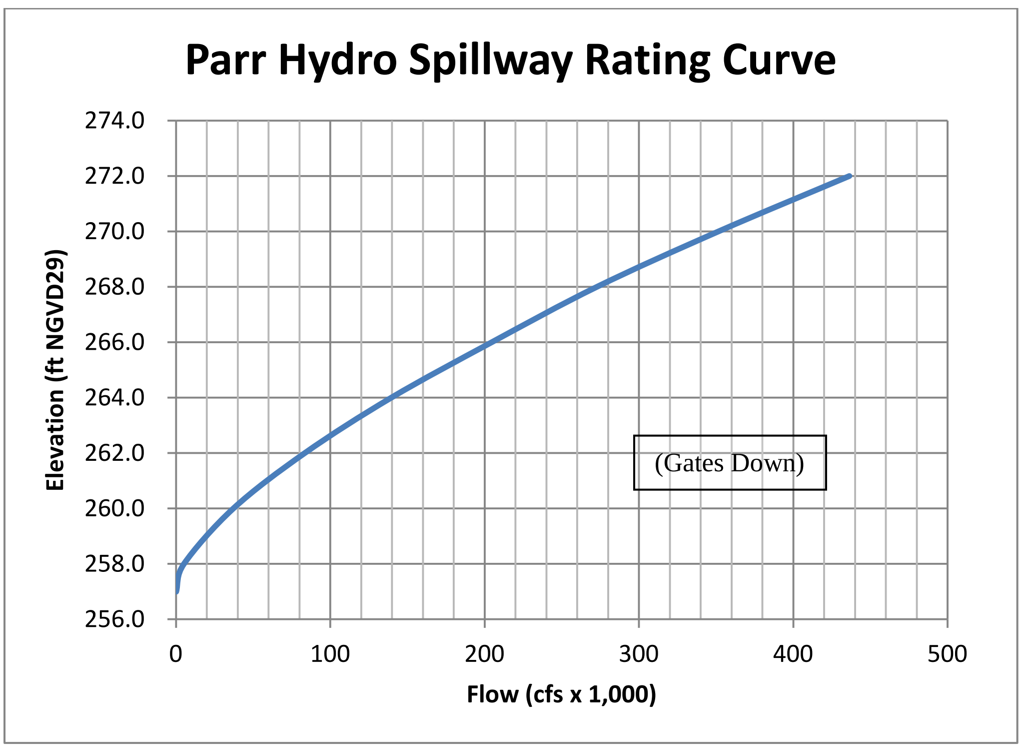

FIGURE 4-3 PARR HYDRO SPILLWAY RATING CURVE

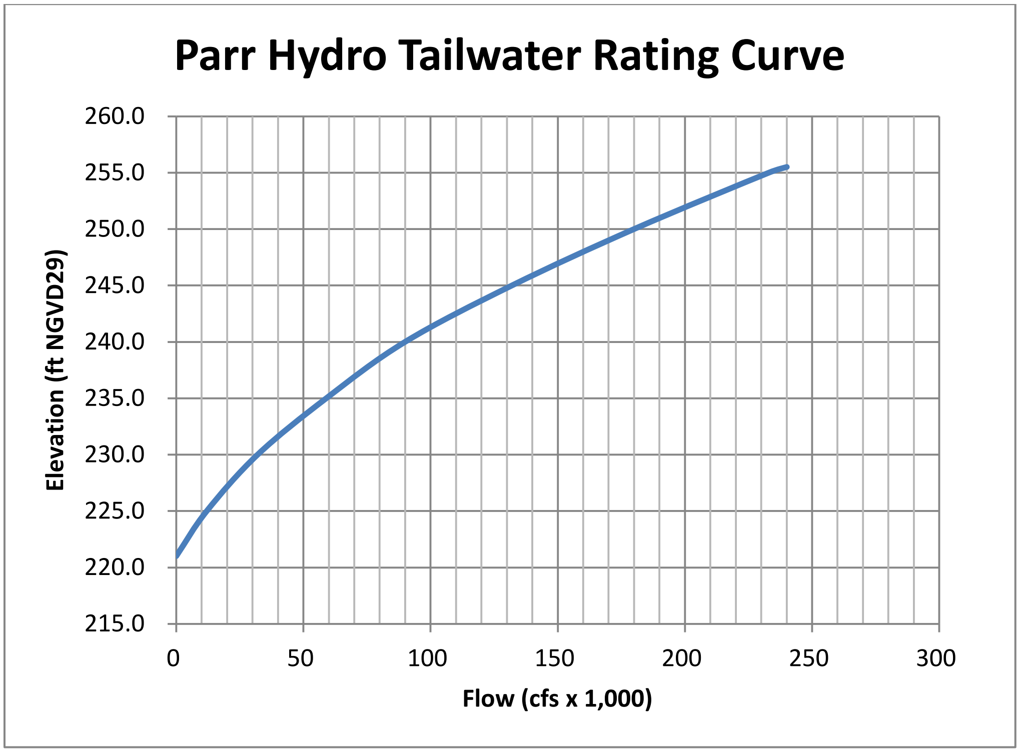

FIGURE 4-4 PARR HYDRO TAILWATER RATING CURVE

4.3 TEMPORAL MODEL INPUT - STREAMFLOW

Statistical analyses were performed to develop weighting factors to apply to the streamflow records for the nearest upstream gages on the Broad, Enoree, and Tyger Rivers. For discussion purposes, a brief synopsis of the statistical analysis follows; the complete documentation of the data development is provided in Kleinschmidt's "Inflow Dataset Development: Statistical Methodology; Parr Hydroelectric Project," August, 2014, available at: http://parrfairfieldrelicense.com/studyreport.html.

The statistical analyses used monthly and annual flow data rather than daily average flows. The daily data are affected by Project operations, which introduce a significant degree of variability due to the cyclic transfer flows between the upper and lower reservoirs. Flow releases from the project may be vastly different at any given hour from the inflows to the Parr reservoir. The monthly and annual flow data statistics are much less affected by day-to-day operations.

A multivariate regression was performed to determine the fitted regional exponent (γ), and a fitted regional coefficient (α) for estimating the inflow to Parr Reservoir based on the flows measured at three upstream USGS gages. The equation is a summation of the three upstream flow values multiplied by scaling factors, which include the ratio of the total drainage area represented by each to that gage's actual drainage area.

Equation 1: $ParrInflow = \langle \alpha * BRC\left(\frac{3250.8}{2790}\right)^{\gamma}\rangle + \langle \alpha * TRD\left(\frac{807.9}{759}\right)^{\gamma}\rangle + \langle \alpha * ERW\left(\frac{731.3}{444}\right)^{\gamma}\rangle$

where,

BRC – Broad River at Carlisle
TRD – Tyger River near Delta
ERW – Enoree River at Whitmire
α – Fitted Regional Coefficient
γ – Fitted Regional Exponent

The regional exponent was developed by quantifying the relationship between monthly streamflow averages and drainage area (see Figure 4-5) using two unregulated stream gages on the Enoree River with the longest overlapping periods of record. The result of this regression produced the drainage area regional exponent (γ) of 0.599.

Monthly flow averages from 1981 through 2013, inclusive, were normalized to perform the second regression for the drainage area coefficient (α). The target data used in the regression was the monthly average flow at the Alston gage, which was adjusted by adding the estimated evaporation from both the Monticello and Parr reservoirs (including the thermal plume effects cause by V.C. Summer Nuclear Station). The regression analysis yielded an α – coefficient of 1.041. These fitted regional values were used to produce daily inflow estimates for the 1981-2013 time periods.

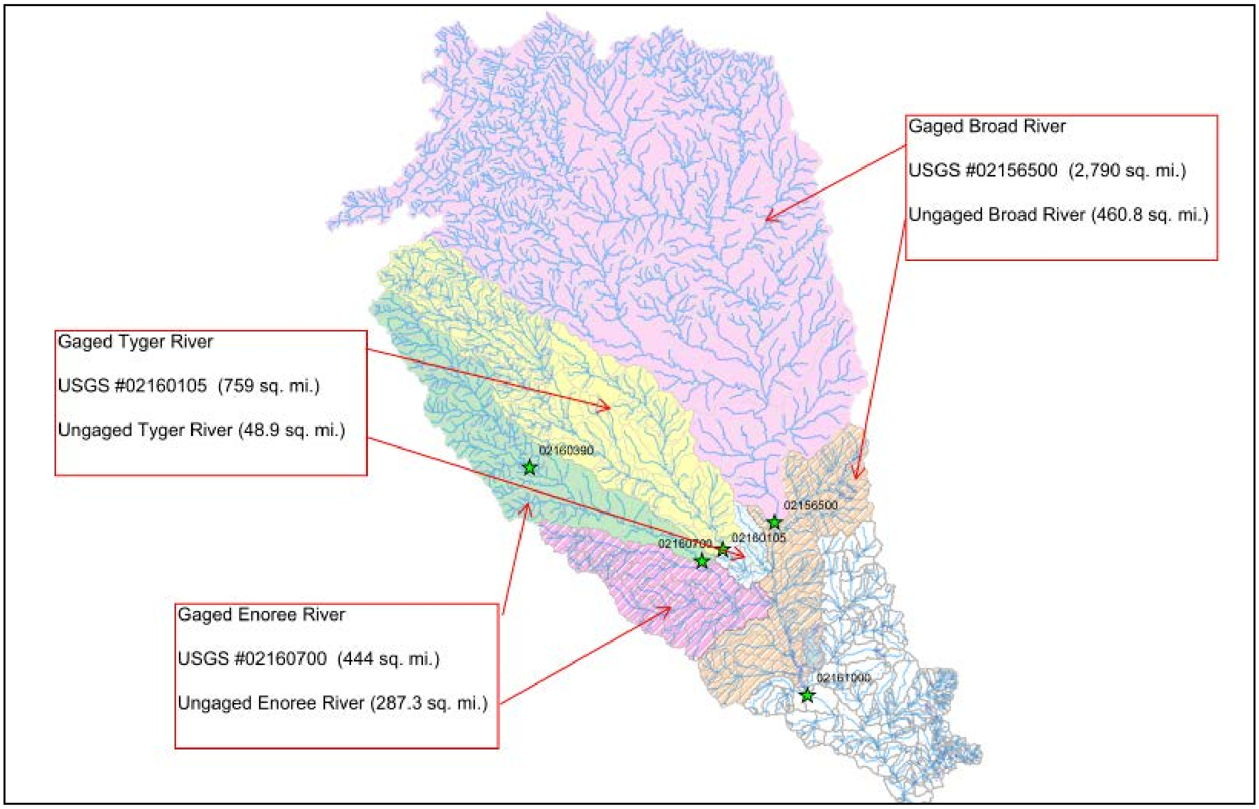

FIGURE 4-5 GAGED AND UNGAGED BROAD RIVER SUBWATERSHEDS

4.4 TEMPORAL MODEL INPUT – EVAPORATIVE LOSSES

The evaporation lost from the reservoir system is computed as a function of the daily pan evaporation and the water surface area. The pan evaporation estimate used in the HEC-ResSim model was based on values obtained from the South Carolina State Climatology Office web portal (http://www.dnr.sc.gov/climate/sco/Publications/pan_evap_tables.php#12). The Elgin pan values were used in the model, and were adjusted by a pan coefficient of 0.73, which was obtained from NOAA Technical Report NWS 33, *Evaporation Atlas for the 48 Contiguous States* (June, 1982). The monthly evaporation rates used in the model are listed in Table 4-2. Evaporation rates from the Parr and Monticello reservoirs are computed during each time step of the model simulation, based on the simulated surface area for that step.

Additional evaporation caused by the V.C. Summer Nuclear Station thermal plume effects in Monticello Reservoir is included in this analysis, and is simulated in the model as a flow diversion with a fixed monthly pattern. These monthly evaporative rates were obtained from SCE&G, and ranged in value from 20 cfs in January to 26 cfs for July.

TABLE 4-2 EVAPORATION RATES

	AVG. ELGIN PAN RATE, 1963-92 (INCH/MONTH)	ADJUSTED RATE, 0.73X (INCH/MONTH)	ADJUSTED RATE (CFS/1000 AC.)	VCS PLUME EVAP. RATE (CFS)
January	1.80	1.31	1.78	20
February	2.72	1.99	2.98	21
March	4.76	3.47	4.71	21
April	7.34	5.36	7.50	23
May	7.81	5.70	7.73	24
June	8.23	6.01	8.41	25
July	8.49	6.20	8.40	26
August	7.12	5.20	7.04	25
September	5.88	4.29	6.01	24
October	4.79	3.50	4.74	23
November	3.19	2.33	3.26	21
December	1.98	1.45	1.96	20

5.0 BASELINE SIMULATION

The general usage of the HEC-ResSim model is to simulate a range of operational schemes for a reservoir system to compare the effects of operational changes on a wide range of metrics, such as:

- Flow magnitudes and frequency;
- reservoir levels and frequency; and
- hydropower generation.

As such, the first step in the investigation process is to develop a baseline model to serve as a basis for comparison. The Parr/Fairfield baseline model (see schematic Figure 5-1) was developed with the following constraints.

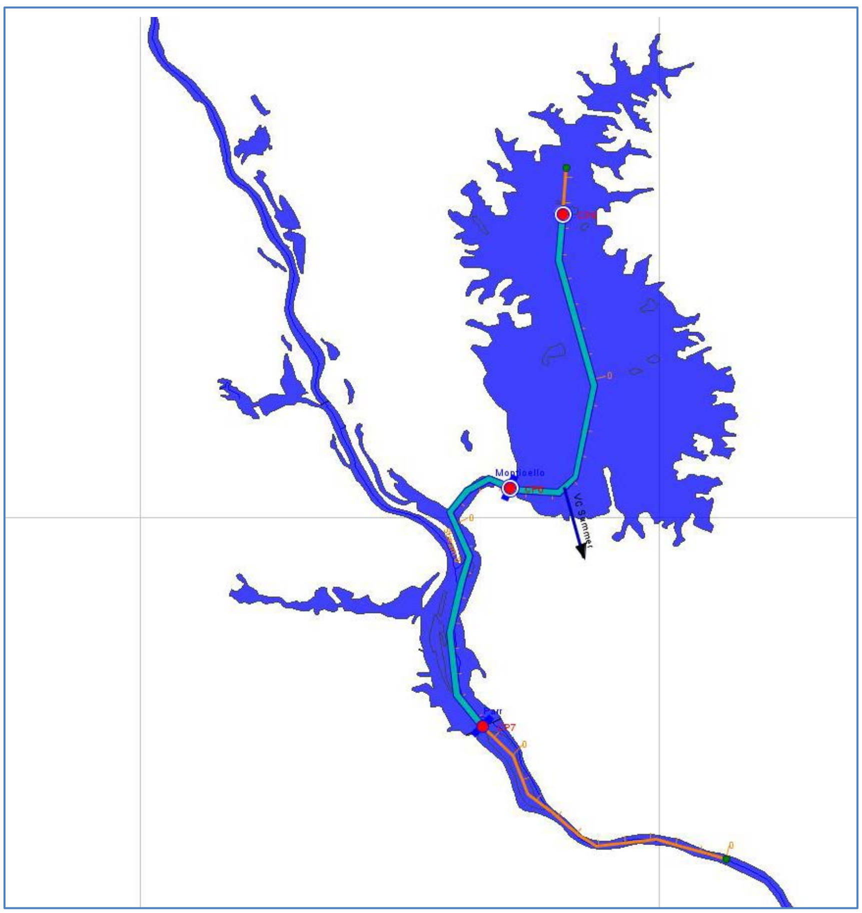

FIGURE 5-1 HEC-RESSIM SCHEMATIC

5.1 Reservoir Minimum and Maximum Stage

The model requires inputs to constrain the minimum and maximum levels. The elevation constraints are coded as conditional, which directs the model to alter operations as a function of reservoir level. The baseline model has been coded to allow fluctuations of Parr Reservoir between elevations 256.0 and 266.0 feet, and Monticello between elevations 420.5 and 425.0 feet, according to the existing license conditions.

5.2 Parr Reservoir Minimum Outflow

The baseline minimum outflow constraint for Parr Reservoir has been coded as a combination of two factors, both according to existing license conditions. The minimum outflow is set at 800 cfs for the months of June through February, and 1,000 cfs for the months of March through May. This daily minimum flow changes during periods in which the net inflow to Parr Reservoir drops below the seasonal flow. The baseline model is coded to evaluate the net inflow to Parr on a daily basis, and the model uses the greater of 150 cfs or the net inflow as the minimum flow.

5.3 Power Generation – Parr Shoals

The baseline model is coded to generate power from Parr Reservoir during periods for which the outflow is sufficient. The general constraint is to produce power for outflows in the range of 1,000 to 6,000 cfs. The simulated power generation is computed using the net head differential on a time-step basis, using the computed Parr Reservoir level and a tailwater rating curve. For the baseline condition, there are no time-dependent generation requirements coded into the model.

5.4 High Flow Releases – Parr Shoals

Gates atop the Parr Shoals dam spillway are lowered as flows increase beyond the hydraulic capacity of the powerhouse. As flows increase, gates are lowered more to pass the flows without raising the headpond above license conditions, or incur flooding of an upstream railroad (see Section 5.5). Higher inflows result in decreased gate elevations to pass inflows. The baseline model is coded to pass inflows above 6,000 cfs from the Parr Reservoir as spilled flows, within the bounds of the total outflow rating curve.

5.5 MAXIMUM RESERVOIR LEVEL LIMITATION FOR PARR – HIGH INFLOWS

The baseline model has a constraint for the maximum level for Parr Reservoir, which is a function of the reservoir inflow. The intent of this constraint is to reduce the upstream railroad inundation risk that occurs during above-average flows. This constraint limits Parr Reservoir to an elevation of 266.30 feet for an inflow of 3,000 cfs, and varies linearly to an elevation of 263.28 feet for an inflow of 40,000 cfs. This control is of lower priority than the previously noted maximum reservoir constraint of elevation 266.0, therefore that elevation is not exceeded under the low flow conditions.

5.6 POWER GENERATION – FAIRFIELD

The baseline model is coded to generate power from Fairfield on a daily basis. The simulated power generation is computed using the net head differential on a time-step basis, using the computed Parr Reservoir level as the tailwater elevation. For the baseline condition, the model is coded to limit power generation to between the hours of 8 AM and 6 PM; however, there are no daily generation requirements coded into the model. The power generation continues within these hours until the power pool is depleted, which is set at elevation 420.5 feet.

5.7 HIGH-FLOW POWER GENERATION CUTOFF – FAIRFIELD

There is a conditional rule for the power generation for Fairfield that constrains the power generation during high inflows. The model checks the total inflow to Parr Reservoir on a time-step basis to limit Fairfield generation as total inflow to Parr Reservoir approaches 40,000 cfs.

5.8 PUMPING FROM PARR TO MONTICELLO

The baseline model is coded to pump from Parr to Monticello every evening, between the hours of 9 PM and 6 AM. The model simulates the beginning of pumping at the specified time, and simulated pumping continues until the target (full) upper pond level is achieved.

5.9 EVAPORATIVE LOSSES

The baseline model is coded to account for evaporative losses at Parr and Monticello Reservoirs, and V. C. Summer Nuclear Plant (VCS) Unit 1. The evaporative losses from VCS are represented in the model as a direct diversion from the Monticello Reservoir.

6.0 MODELING SYSTEM VALIDATION

The use of numerical models as part of a decision support system requires a series of validation checks to verify that the models are producing results within the expected bounds of accuracy. The Parr-Fairfield Operations Modeling System is comprised of three major components:

1. A statistically-derived streamflow dataset, representative of the daily inflows to Parr Reservoir for the period 1981 through 2013;
2. a reservoir routing model (HEC-ResSim) to simulate the operations of the Parr Reservoir and the Fairfield pumped storage project, and the resulting downstream releases to the Broad River; and
3. a river routing model (HEC-RAS) to simulate the flows released from Parr Reservoir.

The validation of the modeling data inputs and the model performance has been and will continue within each phase of the system development and deployment. The sequence of validation checks and the status of each are summarized below.

6.1 TEMPORAL MODEL INPUTS

The temporal model inputs include the streamflow and evaporation time series data. The derivation of these data sets was described in detail in a previous report, and a summary is provided herein under Section 4.3. The validation of the data was quantified by various goodness-of-fit statistics, also described in the previous report.

6.2 RESERVOIR ROUTING MODEL

The primary HEC ResSim model has been developed, and the performance of the model has been evaluated from two distinct aspects. The primary model was developed to be used as a base-case framework, from which modifications/restrictions can be applied. The operational constraints within the primary model, as described in Section 5, were developed with the intent of testing the base model's ability to simulate the full range of operations as allowed by the current license and equipment capacities. The performance evaluations of the model included the following checks:

- A check of the model for a mass balance of inflows and outflows
- A check of the model to determine if the simulated operations adhered to the intended operational constraints under varying hydrologic conditions
- A comparison of the flow duration curve from the Alston gage to the simulated outflows from Parr Reservoir

The mass balance check was performed by computing the average values of the reservoir inflow, evaporative losses, and simulated Parr Reservoir outflows over the 33-year period of record. The values, as shown in Table 6-1, show that the net balance is essentially zero. There are minor discrepancies, attributable to round-off error and differences in reservoir storage at the beginning and end of the simulation period, and historic operations that deviated from the base-case framework, which could slightly alter evaporation rates due to differences in free water surface areas on the stage-area curve. The Alston gage has an average flow of 5,195 cfs for the same period of record, approximately 205 cfs higher. This is due to an intended bias of regression to more accurately fit low flows, which are of greater interest to the stakeholders. This bias is discussed in the previous report on the inflow dataset development *(Inflow Dataset Development: Statistical Methodology, Kleinschmidt, August 2014*).

The performance of the model was also spot-checked with respect to modeling constraints. An example of this would be the minimum flow during drought conditions. The spot check was performed for a 24-hour period, starting at noon on Sep.2, 2011. The average inflow to Parr for this period was 398 cfs, which is less than the seasonal minimum flow of 800 cfs. The model is coded to release flows from Parr Reservoir in the amount of the average inflow minus the evaporative losses. The evaporative losses for the 24-hour period were approximately 84 cfs, which produces a net value of 314 cfs. The model simulated a release of 315 cfs for this period.

There were numerous other spot-checks performed in a similar manner, with respect to maximum and minimum pond levels and maximum releases. Figure 6-1 illustrates the cycling of the Monticello reservoir level between 420.5 and 425. Parr reservoir has similar pool elevation constraints (see Figure 6-2), with an additional constraint to decrease the maximum pool level during periods of increased upstream inflows. There are constraints on operation at Fairfield, which are intended to eliminate Fairfield generation when Parr outflows are in excess of 40,000 cfs.

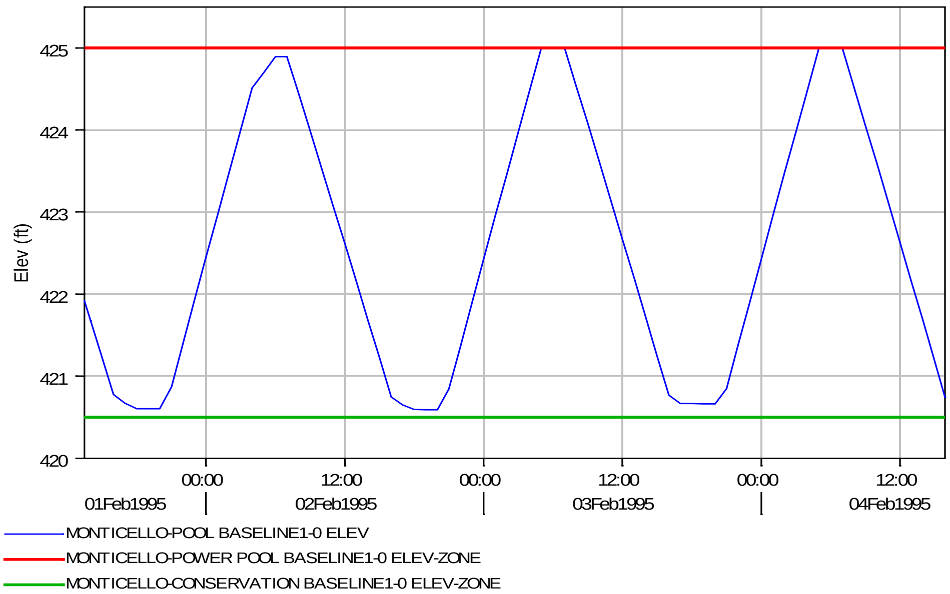

FIGURE 6-1 MONTICELLO - MAX/MIN POOL

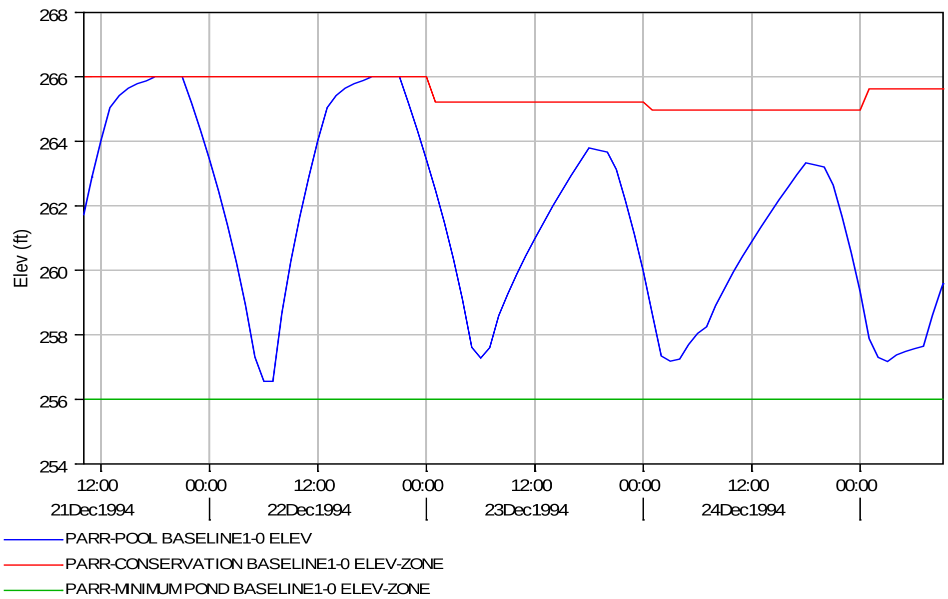

FIGURE 6-2 PARR MAX/MIN POOL

7/7 – normal Fairfield generation	7/8 – increased Parr inflow, decreased Fairfield generation	7/9 – high Parr inflow, no Fairfield generation	7/10 – increased Parr inflow, decreased Fairfield generation

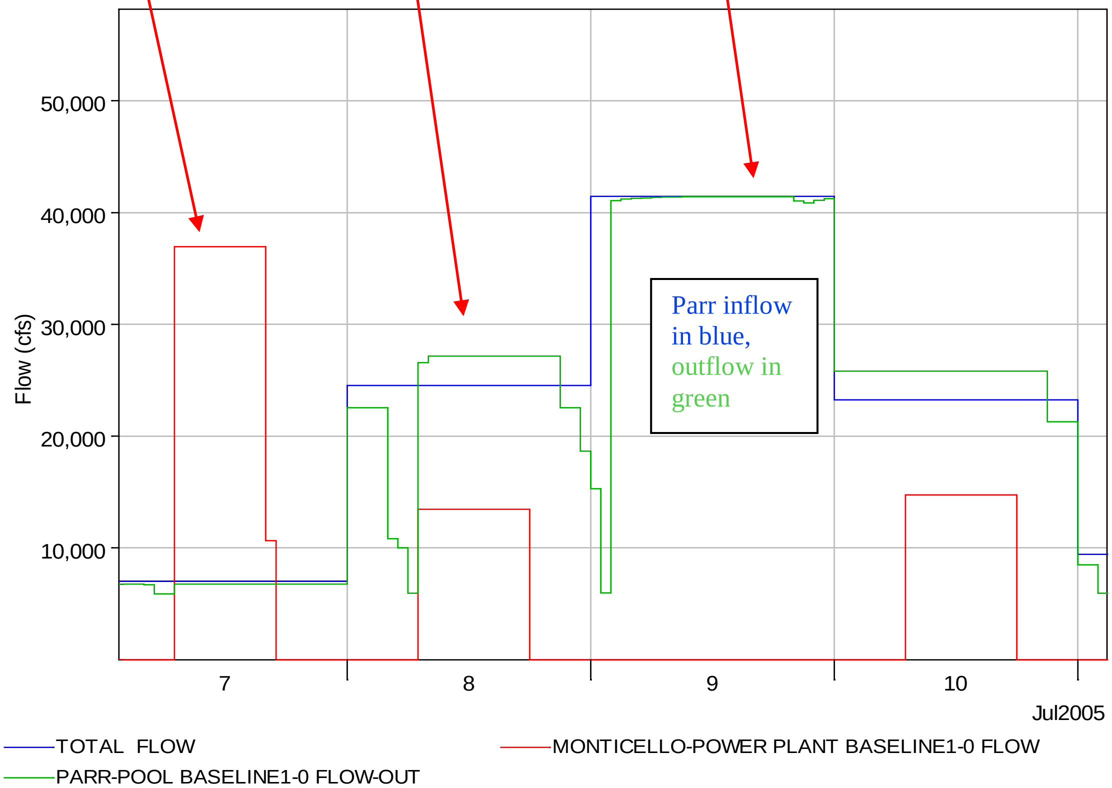

FIGURE 6-3 FAIRFIELD GENERATION CURTAILMENT

Figure 6-3 illustrates a simulated time period that includes a cycle of increasing and decreasing Parr inflows, and the constrained Fairfield generation during the time periods such that the added Fairfield outflows do not artificially induce downstream flooding.

TABLE 6-1 HYDROLOGIC MASS BALANCE

Hydrologic Component	Average Value, 1981 – 2013 (cfs)
Estimated Inflow to Parr Reservoir (/Parr Reservoir/Total/Flow/*/1Hour/-Baseline1-0/)*	5066.7
Simulated evaporation from Parr Reservoir (/ /Parr-Pool/Flow-Evap/Flow/*/1Hour/-Baseline1-0/)*	17.7
Simulated evaporation from Monticello Reservoir (//Monticello-Pool/Flow-Evap/Flow/*/1Hour/-Baseline1-0/)*	35.7
Assumed evaporative losses at VC Summer Nuclear Plant Unit 1 (//Monticello-VC Summer Tailwater/Flow/*/1Hour/Baseline1-0)*	22.8
Estimated Inflow minus Evaporative Losses)	4990.5
Simulated outflow from Parr Reservoir (/ /Parr-Pool/Flow-Out/Flow/*/1Hour/-Baseline1-0/)*	4990.3

*Data set from DSS output file

As a final check of the base model, the flow duration curve of the simulated outflow from Parr Reservoir was computed for the 33-year period of record. This flow duration curve was compared to that of the Alston gage, for the same time period. The resulting comparison, shown graphically in Figure 6-4 and Figure 6-4, show that the flow duration curves match very closely for flows below 1,000 cfs, and are within 3% of expected frequency for the flows greater than 1,000 cfs. This comparison is indicative of the combination of the statistical derivation of the estimated inflows and the results of simulating the estimated inflows with HEC-ResSim. Therefore, discrepancies between the flow duration curves may be attributable to either component.

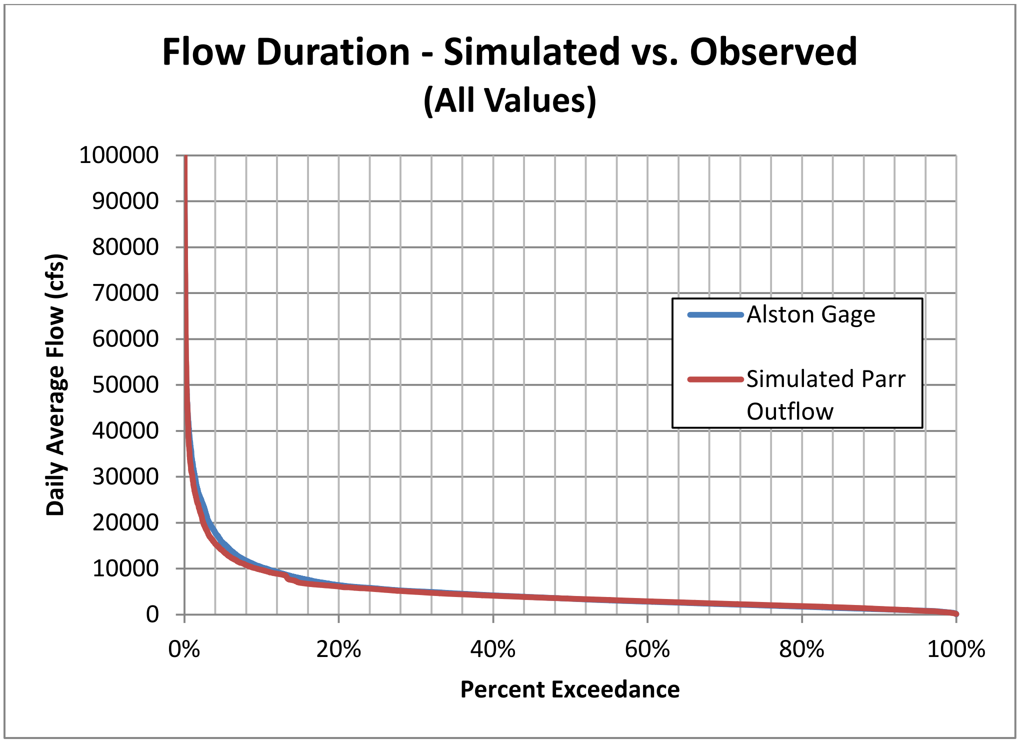

FIGURE 6-4 FLOW DURATION – RESSIM VS ALSTON, ALL VALUES

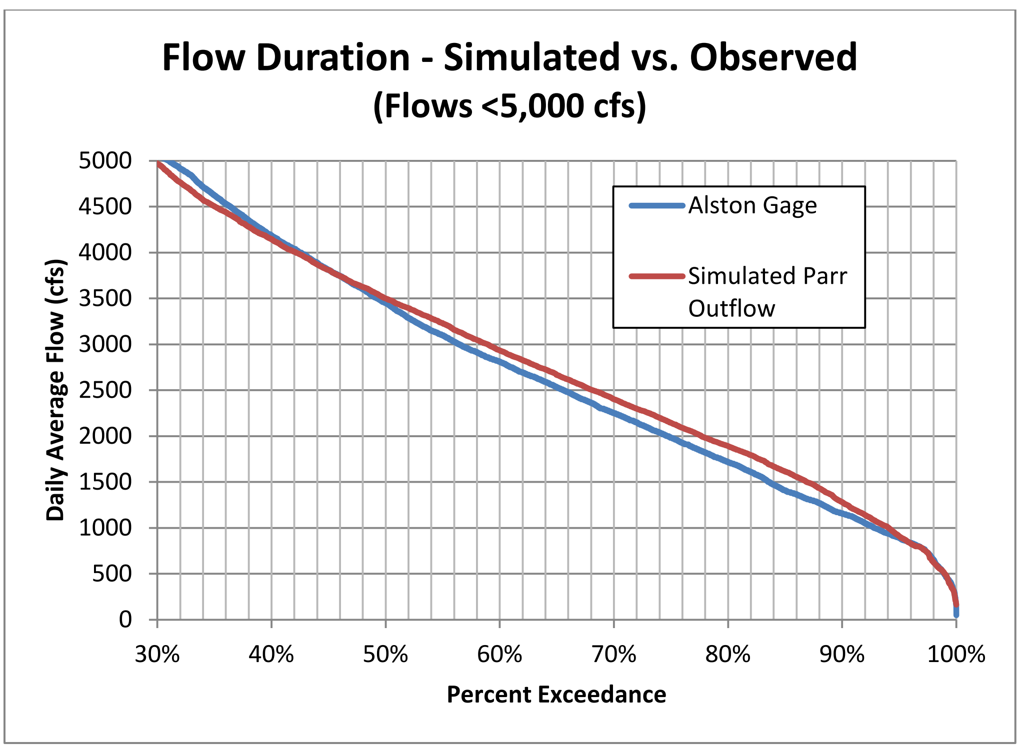

FIGURE 6-5 FLOW DURATION - RESSIM VS ALSTON, FLOWS < 5,000 CFS

6.3 River Routing Model

The river routing model (HEC-RAS) is generally referred to as a closed system, which performs mass balance checks as part of the simulation. The primary performance checks for the HEC-RAS model are essentially identical to the evaluations performed as part of the calibration of the model, which include a comparison of simulated flow and stage values at various locations along the river. The calibration comparisons are fully described in Sections 3-5 and 3-6.

APPENDIX A
CALIBRATION PLOTS

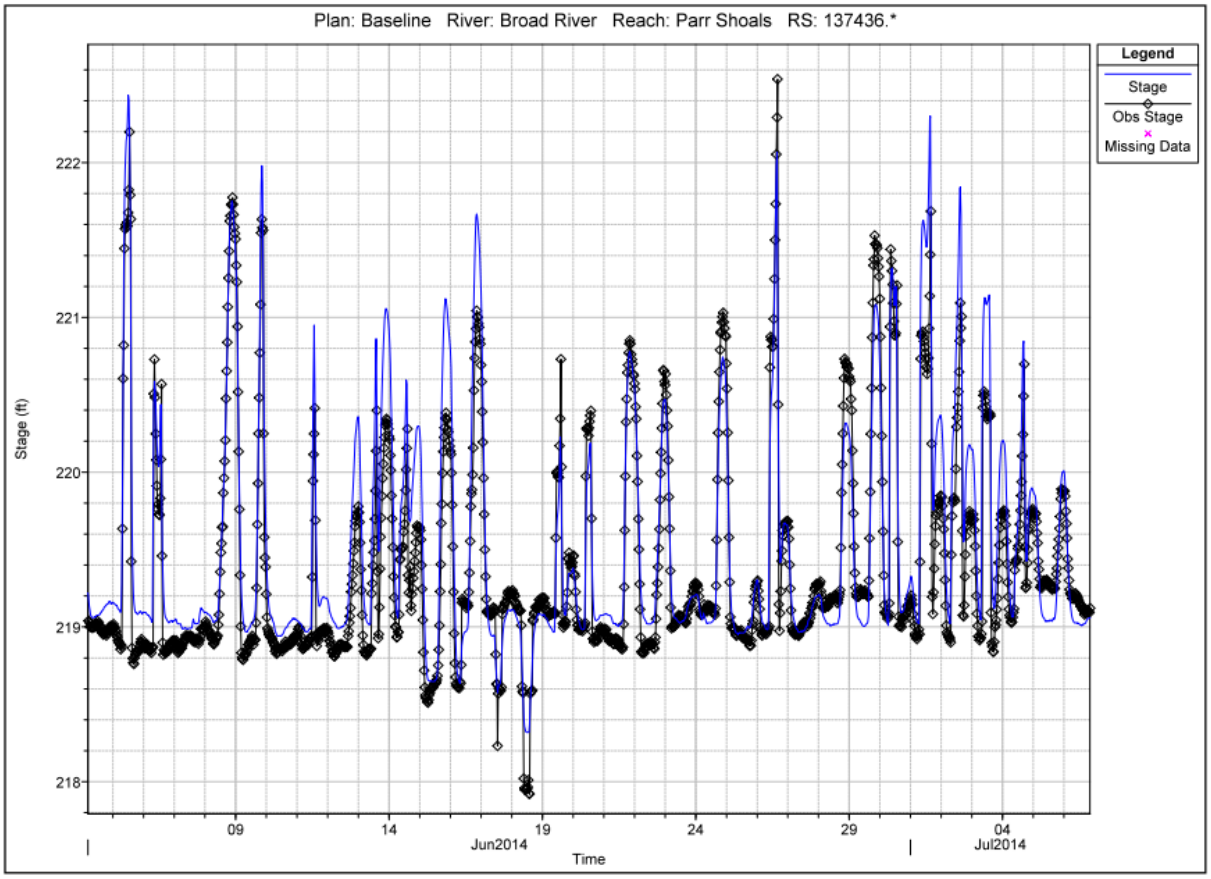

FIGURE A-6-6 CALIBRATION PLOT – SITE 1

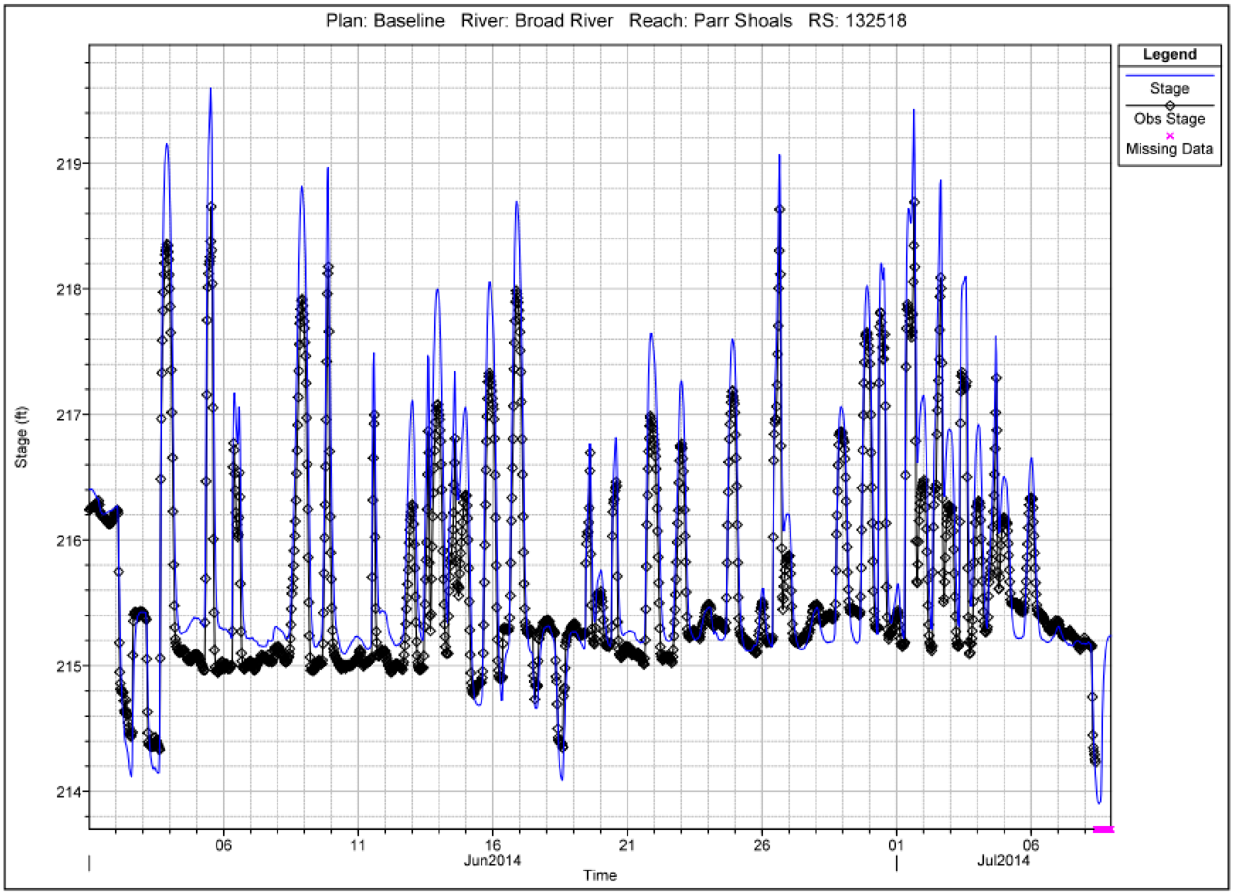

FIGURE A-6-7 CALIBRATION PLOT – SITE 2 / 3

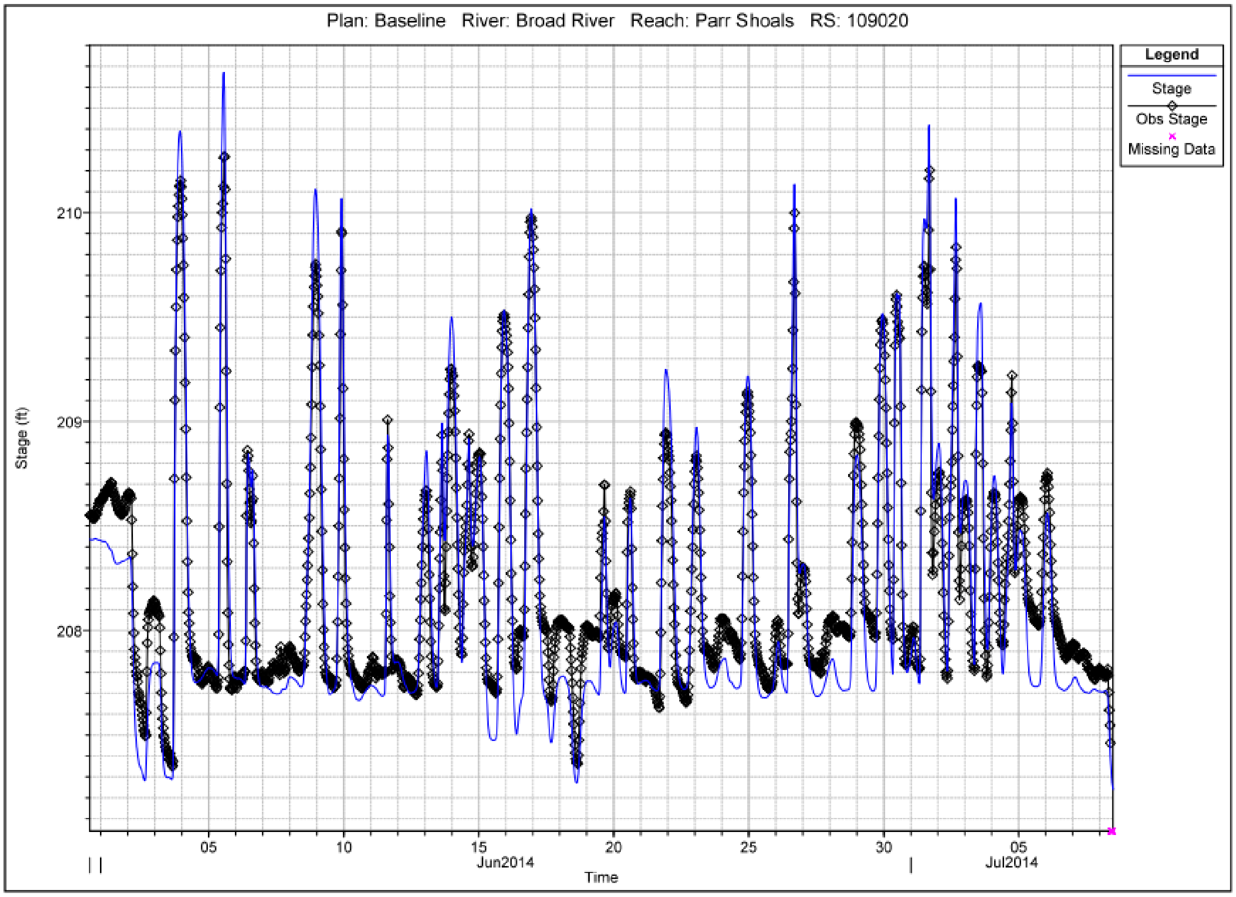

FIGURE A-6-8 CALIBRATION PLOT – SITE 4

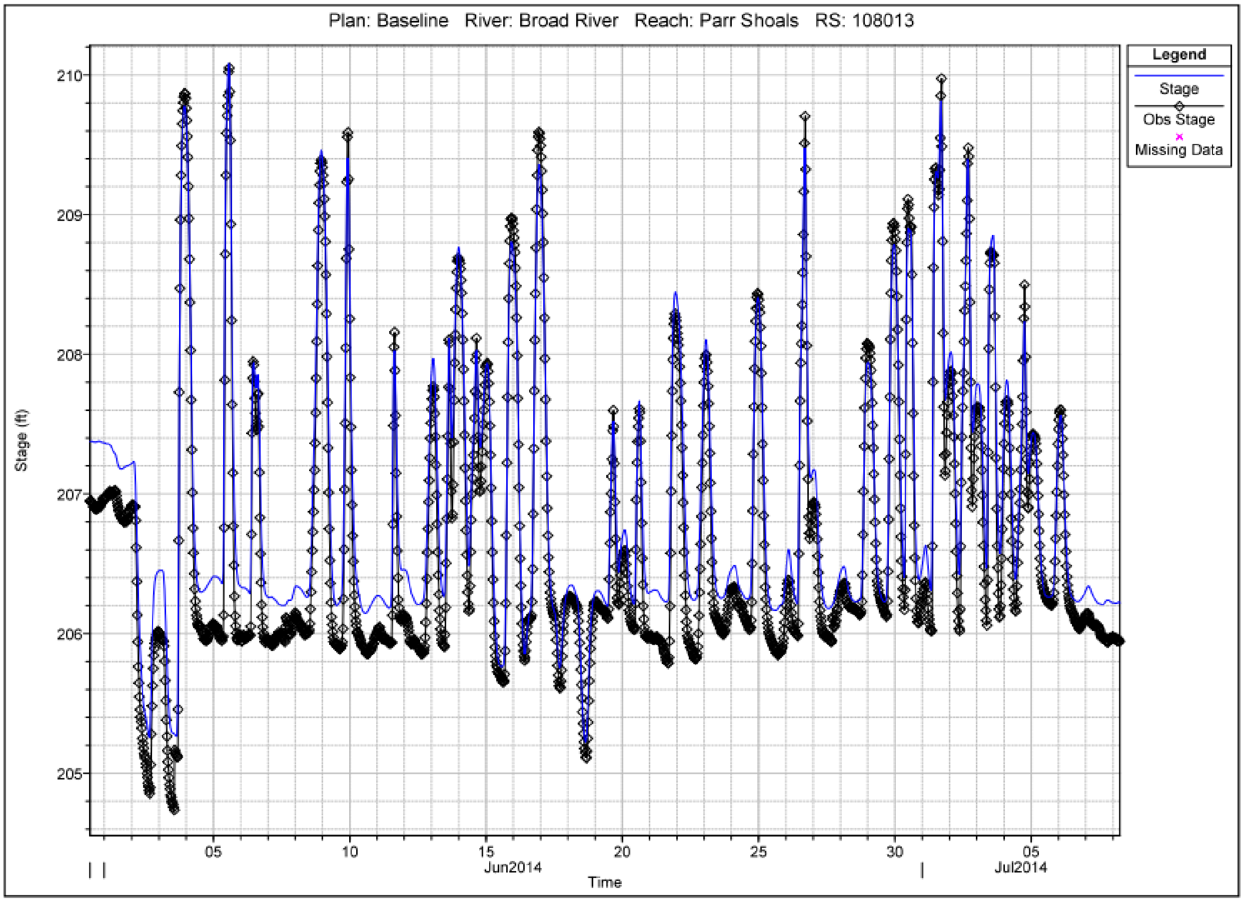

FIGURE A-6-9 CALIBRATION PLOT – SITE 5

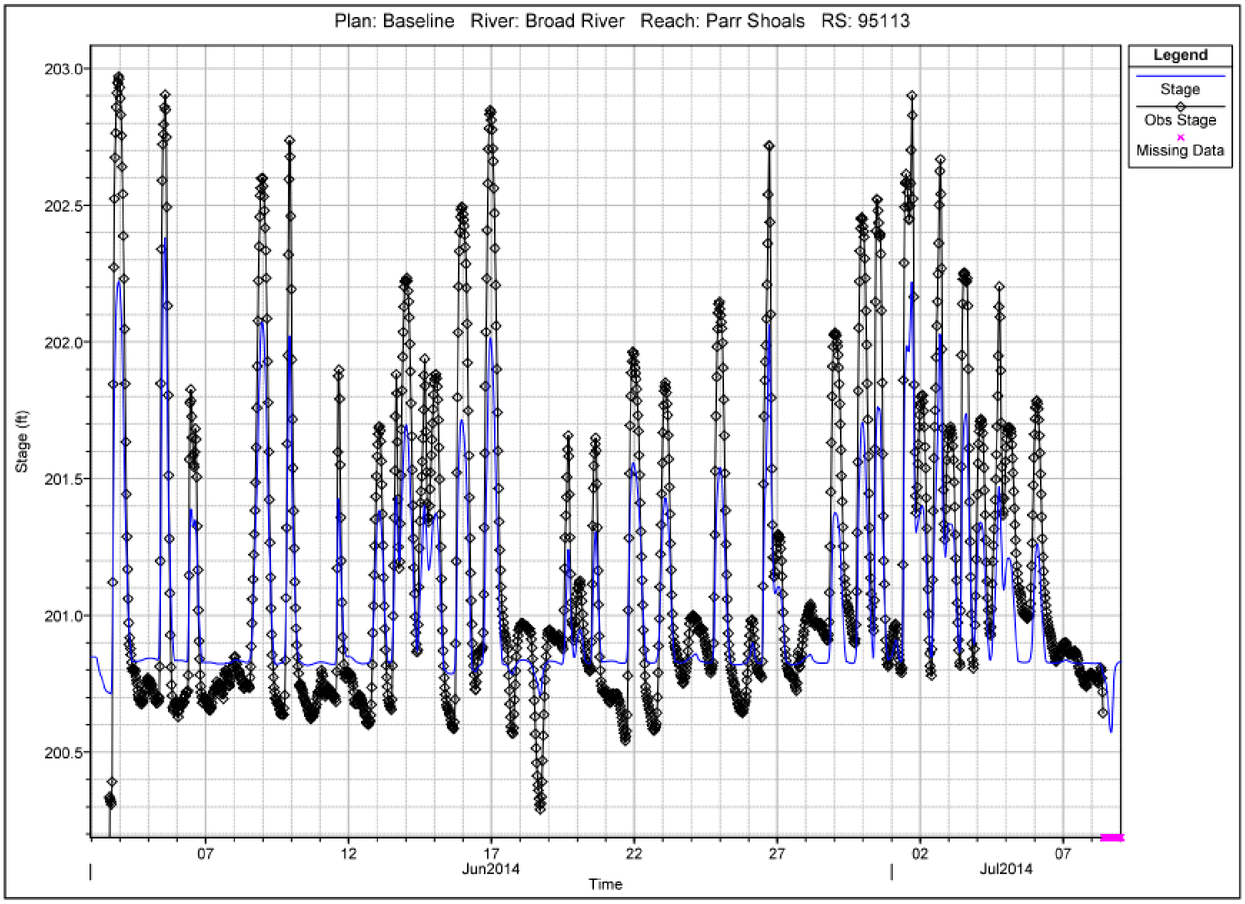

FIGURE A-6-10 CALIBRATION PLOT – SITES 6 / 7

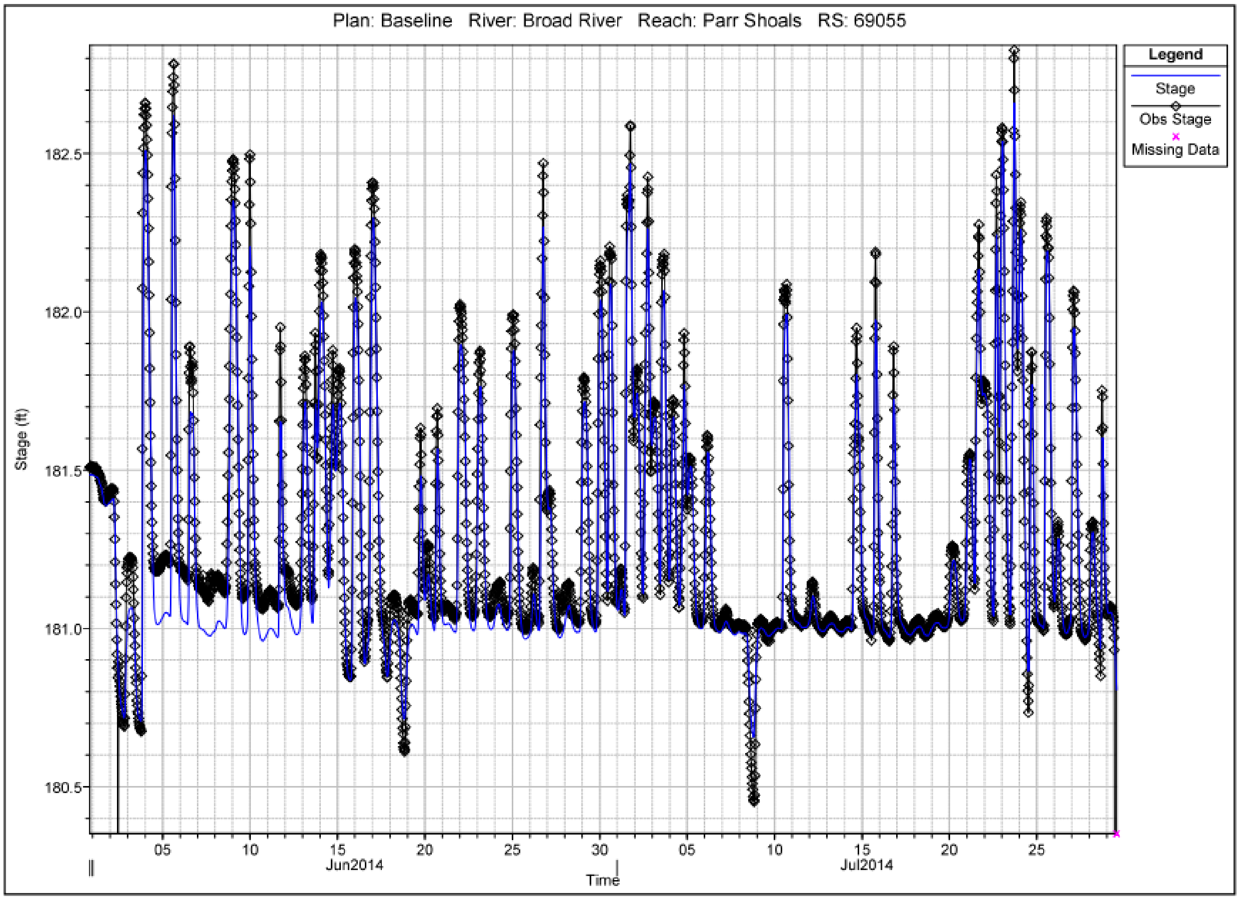

FIGURE A-6-11 CALIBRATION PLOT – SITES 8

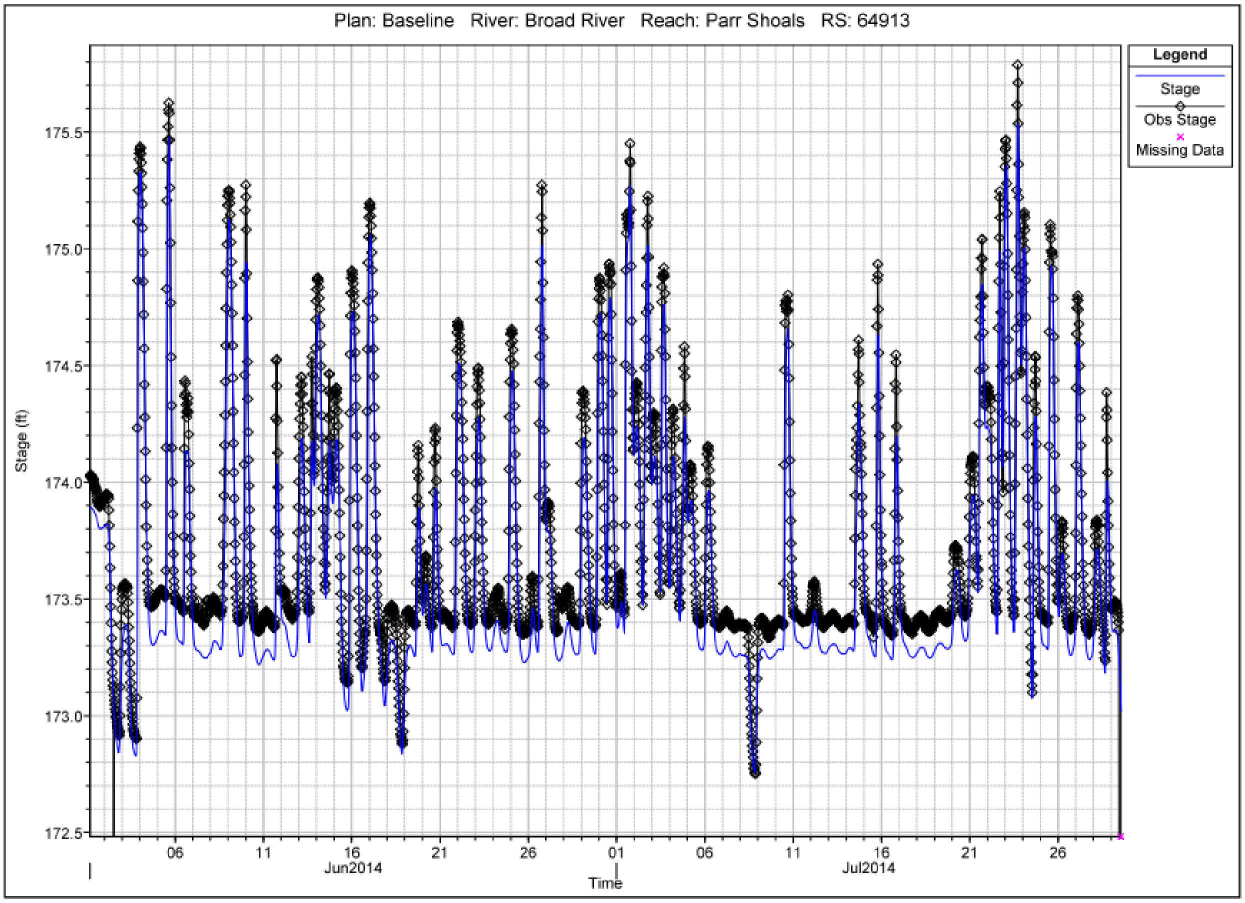

FIGURE A-6-12 CALIBRATION PLOT – SITES 9

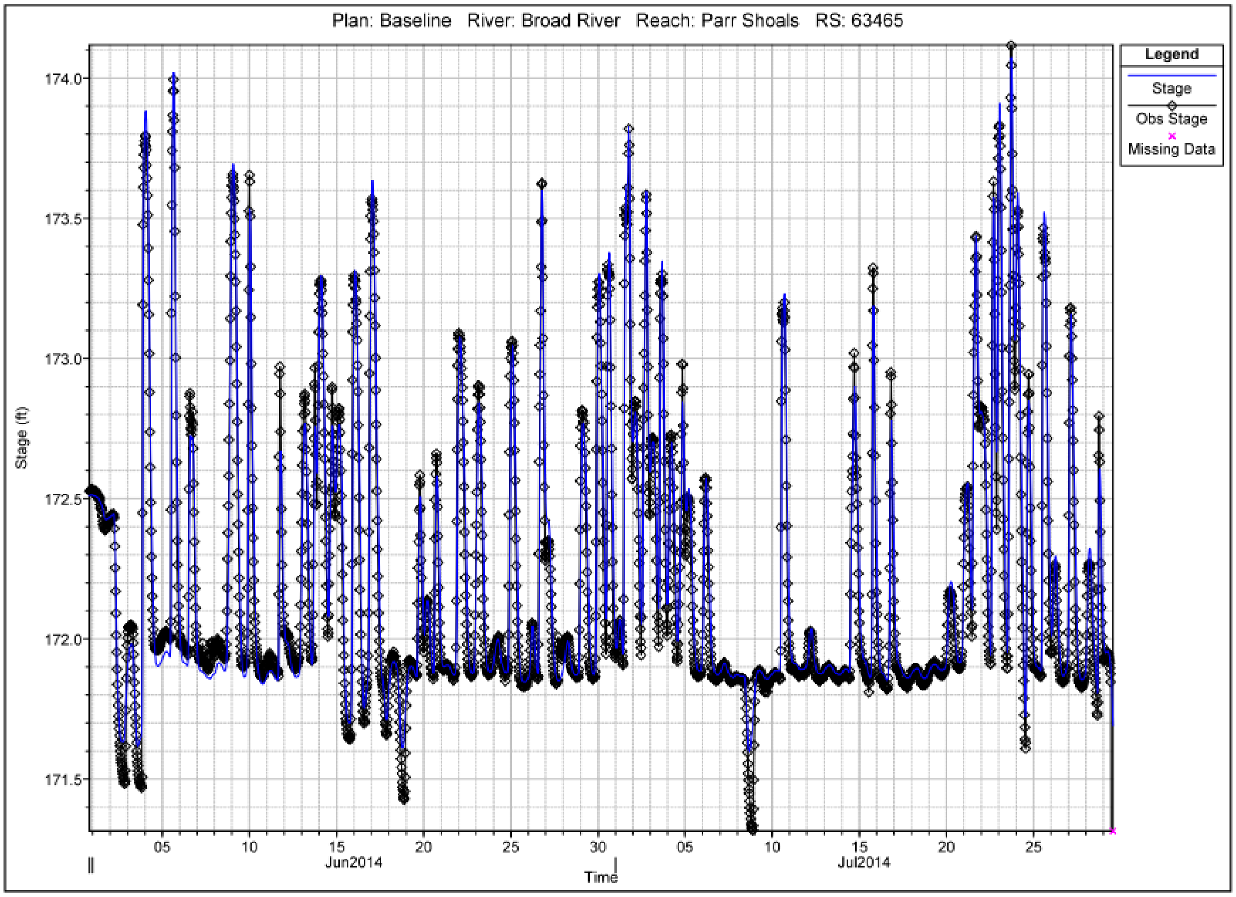

FIGURE A-6-13 CALIBRATION PLOT – SITE 10

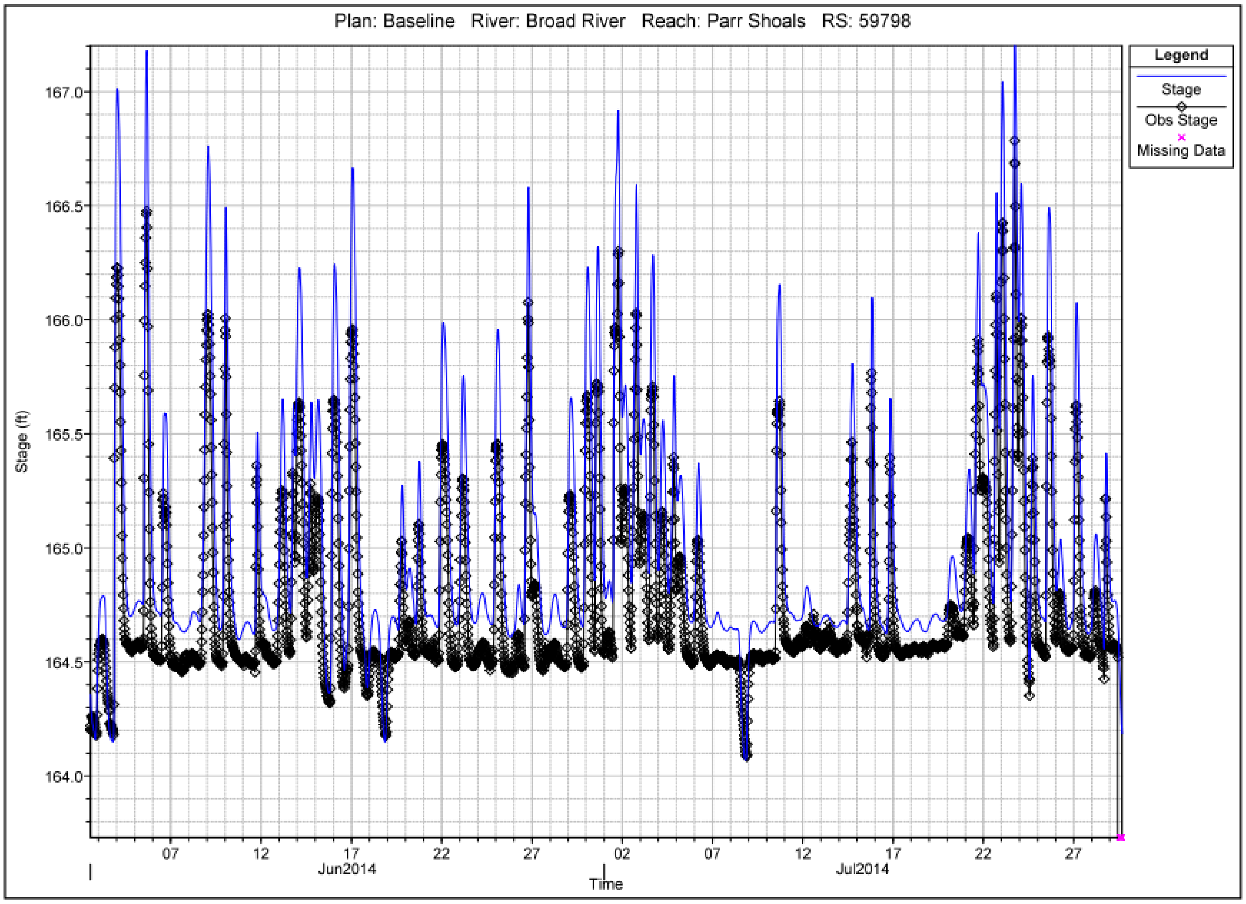

FIGURE A-6-14 CALIBRATION PLOT – SITE 11

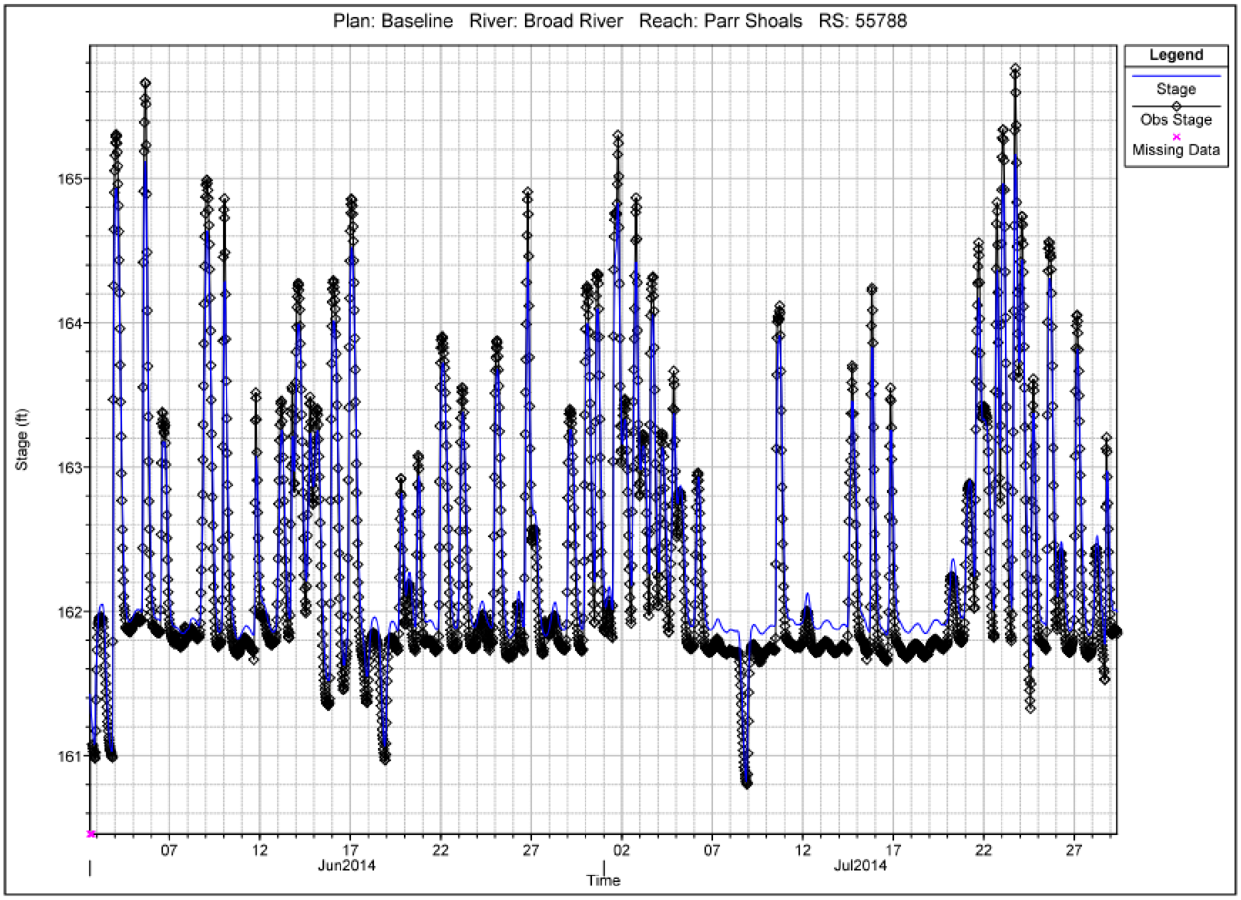

FIGURE A-6-15 CALIBRATION PLOT – SITE 12

APPENDIX B
HEC-RESSIM DATA INDEX

Data Set	Units	HEC-DSS Pathname
Parr - upstream inflow	cfs	/PARR RESERVOIR/TOTAL/FLOW//1DAY//
Parr – evaporation loss	cfs	//PARR-POOL/FLOW-EVAP//1HOUR/BASELINE1-0/
Parr - spill	cfs	//PARR-CONTROLLED OUTLET/FLOW//1HOUR/BASELINE1-0/
Parr - powerhouse outflow	cfs	//PARR-POWER PLANT/FLOW//1HOUR/BASELINE1-0/
Parr - total outflow	cfs	//PARR-POOL/FLOW-OUT//1HOUR/BASELINE1-0/
Parr - power	MW	//PARR-POWER PLANT/POWER//1HOUR/BASELINE1-0/
Parr - generation	MWh	//PARR-POWER PLANT/ENERGY//1HOUR/BASELINE1-0/
Parr - stage	feet	//PARR-POOL/ELEV//1HOUR/BASELINE1-0/
Parr - volume	ac-ft	//PARR-POOL/STOR//1HOUR/BASELINE1-0/
Parr - target max stage	feet	//PARR-CONSERVATION/ELEV-ZONE//1HOUR/BASELINE1-0/
Parr - target min stage	feet	//PARR-MINIMUM POND/ELEV-ZONE//1HOUR/BASELINE1-0/
Fairfield – power	MW	//MONTICELLO-POWER PLANT/POWER//1HOUR/BASELINE1-0/
Fairfield – generation	MWh	//MONTICELLO-POWER PLANT/ENERGY//1HOUR/BASELINE1-0/
Fairfield - powerhouse outflow	cfs	//MONTICELLO-POWER PLANT/FLOW//1HOUR/BASELINE1-0/
Fairfield – pumping	cfs	//MONTICELLO-PUMP-PUMP0/FLOW-PUMP-AVG//1HOUR/BASELINE1-0/
Monticello – stage	feet	//MONTICELLO-POOL/ELEV//1HOUR/BASELINE1-0/
Monticello – volume	ac-ft	//MONTICELLO-POOL/STOR//1HOUR/BASELINE1-0/
Monticello - target max stage	feet	//MONTICELLO-POWER POOL/ELEV-ZONE//1HOUR/BASELINE1-0/
Monticello - target min stage	feet	//MONTICELLO-CONSERVATION/ELEV-ZONE//1HOUR/BASELINE1-0/
Monticello - evaporation loss	cfs	//MONTICELLO-POOL/FLOW-EVAP//1HOUR/BASELINE1-0/
VC Summer - eq. evaporation loss	cfs	//MONTICELLO-VC SUMMER TAILWATER/FLOW//1HOUR/BASELINE1-0/