FINAL STUDY PLAN HYDRAULIC & PROJECT OPERATIONS MODEL

PARR HYDROELECTRIC PROJECT

FERC NO. 1894

Prepared for:

South Carolina Electric & Gas Company
Cayce, South Carolina

Prepared by:

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SOUTH CAROLINA ELECTRIC & GAS COMPANY

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 Hydro 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 detailed outline of the process proposed to complete a Hydrologic and Project Operations Model as part of the Parr and Fairfield relicensing project. These models will be used to assess ability to provide potential changes to project operations, and the resulting effects of potential modifications to operations of the projects. These models will primarily focus on the effects that may result from proposed changes in project operation on energy, capacity, water budget, and flood control. The intent of this effort is to develop a series of high-level fully functional modeling tools, which can be used to incorporate stakeholder requests as parameters to provide outputs and results that can be easily interpreted.

2.0 STUDY OBJECTIVES

2.1 HISTORIC INFLOW HYDROGRAPH DEVELOPMENT

Critical to the operations of hydroelectric projects is the hydrology, which generally requires using the best available gage data to determine local contributing flows. Unless there is a gage immediately upstream of the project headpond, the inflows can be derived by pro-rating available gages, to account for any ungaged drainage area between the respective gages and the site, and then summing the values. Alternatively, a downstream gage can be used to back-calculate inflow using the respective daily reservoir level and evaporation estimates. The goal of this task is to create the best available historic inflow series, which will form the input to the operations models, energy models, and habit and recreational studies.

2.2 HYDRAULIC MODELING

The operations of Parr and Fairfield may affect recreational or habitat interests on the downstream reach of the river. Rapid changes in flow result in a wave (either positive or negative) that propagates downstream, potentially affecting habitat, stream channel stability, and recreational opportunities. The hydraulics of this wave are affected by both translation and attenuation as it progresses downstream. The impacts of existing and proposed modifications to operations (if any) can best be evaluated with a 1-D hydraulic model, which will allow the evaluation of the unsteady flow wave along the downstream reach under several different operating conditions. The goal of this study is to either construct a model (or utilize an existing model) that will evaluate stage (water level), discharge, and velocity with time, along the Broad River downstream of the Parr Dam.

2.3 OPERATIONS MODEL

The Parr-Fairfield project includes several components that need to be included in an operational model. These include the Parr Dam and powerhouse hydraulic capacities, the Fairfield Pumped Storage project operational parameters (for both pumping and generating), the Monticello Reservoir, and the Parr Reservoir. The operations of this system have historically been closely coordinated for the primary purpose of supporting the electrical grid (both demand and stability). SCE&G will need to maintain this coordination during future operating conditions. Additionally, any potential changes to operations in the future will need to be evaluated for effects on dam safety, and operating rules or limitations. This is best accomplished by developing a comprehensive operation model. The goal of this task is to assess and quantify historic operations and limits, and to incorporate these rules into a comprehensive and flexible operations model that can be easily modified to simulate proposed future operations. We propose using the HEC-Res Sim model to investigate headpond fluctuations and associated hydro generation hours that SCE&G could have.

2.4 SCENARIO COMPARISON

SCE&G will develop a process for Technical Working Committees/Resource Conservation Groups (TWCs/RCGs) and stakeholders to submit scenarios to be analyzed and compared to evaluate potential future operations and their effects. The operations model will be used to run submitted scenarios. Results will be reviewed by the TWCs/RCGs during a series of meetings. Model results will be summarized and integrated into the final recommendations presented in the license application.

2.5 SUMMARY STATISTICS

With several integrated modeling efforts, each including possibly several different scenarios, it is critical to develop summary tables and/or summary metrics for each scenario. The goal of this task is to consider each of the studies, and the potential set of results, and develop a standardized means of summarizing and quantifying the results. As an example, it may include the number or percent of flood days changed from baseline conditions, the change in habitat area, the change in streamflow variance, or the increase/decrease in potential MWh. Using the summary statistics, stakeholders and TWC members can prioritize their requests and work to minimize the negative aspects of operational changes.

3.0 STUDY DOMAIN

The focus of this study includes the Parr Reservoir (defined as the elevation of the top of the crest gates, or El. 266.0'), the Fairfield Pumped Storage facility and the Monticello Reservoir, and the Broad River downstream of Parr Shoals Dam extending to and including Frost Shoals, near Boatwright Island.

Members of the Operations RCG expressed an interest in the Project's potential effects on the Congaree National Park (CNP). However, due to the complexities associated with the confluence of the Saluda and Broad Rivers upstream of the CNP, both of which are independently regulated by other hydro projects, the proposed operations model will not extend to the CNP. Rather, the Parr Project's potential to alter flows at the CNP will be statistically determined for specific flows or seasons of interest that are submitted from the TWCs or RCGs.

4.0 METHODOLOGY

4.1 INFLOW HYDROGRAPH DEVELOPMENT

Development of the inflow hydrograph can be accomplished by two methods: the use of upstream gages prorated to the dam's drainage area, or the use of the gage immediately downstream with detailed information of the project's past operations. In the case of the Parr model, the upstream gage proration method will be used, due to the limited availability of detailed Project operation data. Historic data will be reviewed to determine the period of record and time increment to be used to represent project inflow. The proposed inflow data will be reviewed by the Operations RCG for agreement.

4.1.1 UPSTREAM GAGE PRORATION

Proration of streamflow gages, in order to account for ungaged drainage area, is not necessarily a linear relationship. In order to evaluate the regional relationship between runoff and drainage area, two unregulated stream gages on the same river with overlapping records is required. The only gages that meet this in the immediate Parr Dam watershed are two gages on the Enoree River. These two gages will be used to assess an appropriate proration coefficient (α) and exponent (γ), which may be used to regionally prorate all of the gages required in construction of an historic inflow series.

An equation that may be used with the fitted regional coefficients to determine inflow to Parr is below, where the values are the ratios of the total area to gaged area for each gage location. Additionally, these gages are at different distances from the Parr Reservoir, and drain through different channels, thus the arrival times should be adjusted accordingly. The angled brackets denote a routed hydrograph series.

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

where,

BRC – Broad River at Carlisle
TRD – Tyger River near Delta
ERW – Enoree River at Whitmire
α – Fitted Regional Coefficient
γ – Fitted Regional Exponent
⟨...⟩ - Routed Translation

Routing will be completed using a simplified Muskingum approach, and will allow for wave attenuation and travel time, which are more critical for shorter period flows. Daily flow rates would not require this routing, as the average daily flows can simply be summed.

During the development of the hydrologic dataset, the statistical modeling approach and individual gage coefficients may be adjusted to increase data correlation. This has the potential to increase the accuracy of model simulations for inflow conditions that are of greater interest to stakeholders. Details of potential adjustments will be presented to the RCG for comment via memo, with a solicitation for flows (or ranges of flow) of interest. The dataset will be finalized by maximizing correlation across the target range of flows submitted by the RCG.

TABLE 1 SUMMARY OF AVAILABLE HYDROLOGIC DATA

DATA SOURCE	PERIOD OF RECORD	DATA TYPE
Parr Reservoir (#02160990)	10-1-1984 to Current	Stage
Broad R. at Alston (#02161000)	10-1-1896 to Current	Stage & Discharge
Congaree R. at Congaree NP (#02169625)	10-1-1984 to 8-9-2013	Stage
Broad River at Blair (#02160750)	9-11-2010 to 3-7-2013	Discharge
Broad River near Carlisle (#02156500)	10-1-1938 to Current	Stage & Discharge
Broad River below Neal Shoals (#021564493)	3-27-2012 to 9-26-2013	Stage & Discharge
Broad River at Diversion Dam (#02162100)	10-1-1987 to 9-24-2012	Stage
Enoree River at Whitmire (#02160700)	10-1-1973 to Current	Stage & Discharge
Enoree River near Woodruff (#02160390)	2-9-1993 to Current	Stage & Discharge
Tyger River near Delta (#02160105)	10-1-1973 to Current	Stage & Discharge
Fairfield Pumped Storage Generation/Flow	TBD	Discharge
Monticello Reservoir	TBD	Stage

4.2 HYDRAULIC MODELING

The downstream reach of the Broad River below Parr Shoals Dam will be modeled using the Army Corps of Engineers' HEC-RAS v4.1, which is a 1-dimensional model that will allow correlation between flow releases from Parr Reservoir and 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. Readily available data will be used for developing the model. The model will be developed to include the hydraulic affects of flow releases down to the Frost Shoals area near Boatwright Island (approximately 20 miles downstream of the Parr Shoals Dam). The results of the model will be used to determine flow estimates for other interests in the project, such as navigation, recreation, or habitat benefits.

4.3 OPERATIONS MODEL

Development of the operations model includes two major tasks: develop the rules and patterns from historical operations, and secondly use these rules to construct a model for testing alternative scenarios. Success of this task can be measured by the ability of the model to replicate historical operations, but can also be measured by the ease and flexibility of testing future scenarios that produce easily interpreted results by stakeholders and TWC members (i.e., important information is not lost in modeling details). The operations model can become quite complicated very quickly, thus to successfully accomplish both of these goals, an appropriate model framework using the best available data is required early in the process.

4.3.1 OPERATION RULES & REGULATIONS

Not only is hydrology a stochastic process, but operating history and generation (pumping/generating) can also be stochastic as a response to weather patterns, random outages, increased grid demand, changes to grid support via addition of other generators, low flow periods, or even differences in decisions between operators using forecast data. Therefore, it is impossible to state explicit rules that define the operating regime for any of the projects, but both extreme limits (i.e., minimum/maximum pond levels, or minimum/maximum flow rates, rates of change, etc.) may be extracted from specified rules, curves, or observations of the system. Additionally, subjective operational patterns may be inferred from historic operations (i.e., typical pumping volumes in June are a certain amount, generating is typically highest during a given period of the week, etc.). Both the hard and soft rules are important for developing an understanding of conjunctive project operations. Although the rules may not exactly depict the operations at any given point in time, from either the past or the future, they should be able to depict the expected system response.

Several key components of data will be concurrently analyzed:

- pond operating levels (Parr Dam & Monticello Reservoir)
- spillway gate operating guidelines
- pumping rates (Fairfield)
- generation rates (Parr & Fairfield)
- rates of change from generation flows
- typical generation periods (time of day, weekday, months)
- seasonal influences
- influence of low river flow conditions boundary
- influence of high river flow conditions boundary
- influence of water withdrawals from Monticello Reservoir
- potential impacts of future upstream and downstream water withdrawals on project inflow and downstream effects.

In order to appropriately define typical system responses, detailed historic information is required. This includes as available:

- hourly (or finer) generation records for Parr & Fairfield
- Parr and Monticello Reservoir stage records
- meteorological data (precipitation, temperature)
- river flow gage records

These records will be reviewed, plotted, regressed, and inferred upon to develop an understanding of 'typical' system responses. Again, exact operations for a complicated system are impossible due to the stochastic nature of all influences, but typical rules may be inferred.

4.3.2 OPERATIONS MODEL FRAMEWORK

Once a comprehensive understanding and documentation of typical operating rules has been developed, they may be used within a modeling framework to replicate historic operations (validation process), and then test future or altered operating conditions.

The model will be constructed at hourly time steps to allow testing of different release rates and spilling events from the Parr Dam, and/or operating conditions at Fairfield. Longer durations may miss critical operating responses, and unnecessarily short time steps would be excessive and not add additional value. The duration of the validation period will vary based on the available data, but should cover as many sequential years as manageable.

The operations model will be developed using the Army Corps of Engineers HEC-Res Sim software package. This package is freely available, easily integrates with other models (such as HEC-RAS), and has the capacity to model multiple projects (including the Fairfield pumped-storage) with a range of complex and even contradictory operating rules. Results of the model are easily viewed either within HEC-Res Sim, or externally using the HEC-DSSVue software package.

4.4 Scenario Comparison

From the early development of the study plan, model runs should be sufficiently detailed to outline how the projects' operations will be tested. For example, what river flows are critical (low flows to high flows) and should be emphasized? What rates of generation are important, and how quickly can they be changed? A matrix defining each scenario, and how each component of the project is being operated, should be developed. This will naturally confine modeling efforts, and maintain focused efforts for comparison by the TWC members and stakeholders.

4.4.1 Statistics

Statistics are valuable for concisely summarizing the nature or property of a random or stochastic variable. For example, the sample mean is commonly used to describe a set of data, but additional information may be obtained from higher order moments (variance, skew, kurtosis). The critical statistic (metric) should be determined early in the study process for each study or model output. For example, the total habitat area may be critical, the average generating rate, the 1% exceedance flow rate, the variance in water levels during a critical period, the maximum headpond level, the 7Q10 flow rate, etc. are all examples of summary statistics. These should be discussed early, and concurrence with working groups or stakeholders should be achieved early in the process to determine what is considered critical.

Additional examples of potential flow statistics include:

- rise-fall rates
- mean, median, quartile flow rates
- variance, skew, kurtosis
- autocorrelation function & partial autocorrelation function lags
- flow-duration curves
- excess distribution functions and conditional excess distribution functions
- 7Q10 flow
- 5, 10, 50, 100-year peak flows
- stage-duration curves (Parr Reservoir)

5.0 REPORTING

A preliminary report documenting the development of the operations model will be provided to the RCG for review prior to the completion of the model. This preliminary report will include the methods and information as follows:

- discussion of model data acquisition
- inflow hydrograph development
- development of future inflow hydrograph(s)
- hydraulic 1D model development & calibration
- operations model development & verification
  - Parr Operations
  - Fairfield Pumping/Generating

Following a comment period, a demonstration session will be conducted to familiarize interested stakeholders with the implementation of the HEC-Res Sim and HEC RAS models for this Project. During this session, the input data and Project parameters will be reviewed, and a "hands-on" session can be conducted to allow stakeholders to learn how to run the model. After the demonstration session is conducted, the final model will be developed and used to analyze operations scenarios.

A final report will document methods and results as encountered in the modeling effort, including:

- scenario results
- hydraulic routing model
- operations model
- energy modeling
- scenario comparison matrices & statistics

6.0 SCHEDULE

Data collection and model development will begin no later than the spring of 2015, with a preliminary report documenting the development of the model completed by the end of 2015. The methodology for this modeling effort may be revised or supplemented based on consultation with TWCs and other interested stakeholders. Model results will be used as an information resource during discussion of relicensing issues and developing potential Protection, Mitigation and Enhancement measures with the SCDNR, USFWS, TWCs/RCGs and other relicensing stakeholders. The final report, which will include the scenario results, will be completed for filing with the final license application.