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# Hydroelectric Power Generation from Reservoirs in Savannah River Basin

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**Abstract:** Hydropower is generated from three reservoirs in the United States Army Corps of Engineers's Savannah District. These reservoirs include J. Strom Thurmond, Richard B. Russell, and Hartwell. Currently, a contract in place specifies that a certain amount of energy must be provided to the region. Analysis of 25 years of operational data has shown that a 90% reliable yield is about 40% less than the current contract. Moreover, the weekly restraints on generation requirements are often set too high as the frequency of meeting the contract amount is only 30% for most months. These inconsistencies result in a cost variation that affects consumers. Statistical analysis of historic energy generation provides procedures to determine a reliable energy yield by observing generation amounts that occur within an acceptable amount of risk. The average reliable amount of energy available 90% of the time was found to be about 15,500 MWh per week for the Savannah Reservoir network.

**Keywords:** Reservoir Management, Hydroelectric Power Generation, Reservoir Network

## Introduction

The appropriate management and allocation of the Earth’s natural resources is paramount for current and future generations. Water is one of the most naturally abundant resources on the globe, from sustaining botanical ecosystems to generating billions of megawatts of energy. Water is a critical crutch for the domestic and global community. Reservoirs provide access to clean energy through hydroelectric generation, while also providing a source for public water supply, meeting environmental constraints and recreation opportunities.

Most reservoirs are allocated to address multiple benefits of society, from hydroelectric generation and water supply to recreation and flood control. These allocations often compete for water usage. A priority structure is therefore necessary to establish specific reservoir operational strategies.

Currently, a priority structure for the Savannah River Basin reservoir operation is primarily organized from highest to lowest importance as flood control, water supply, ecosystem sustainability, power generation, and recreation. Additionally, the reservoirs are used to maintain minimum stream flows in the Savannah River Basin downstream to ensure sufficient water supply as well as mitigate saltwater intrusion at the estuary in Savannah, Georgia. The streamflow requirement creates competing uses as well as regional discrepancies between reservoir and downstream residents.

### *Agency Involvement*

Beyond the physical allocation of reservoir resources, there are many federal, state, and local agencies that influence the operation of the reservoir network. The United States Army Corp of Engineers (USACE) operates and maintains the reservoir network, while the Southeastern Power Administration (SEPA) markets and sells the hydroelectricity generated from the reservoirs. Additional involvement includes the Department of Natural Resources (DNR) and the Department of Health and Environmental Control (DHEC). Both South Carolina and Georgia DNR offices police the lakes and surrounding property for fishing and hunting permitting as well as effectively managing the sensitive wildlife in and around the basin. DHEC is primarily concerned with the water quality of the basin to suit wildlife and other users through monitoring chemical and biological levels. Weather projections are handled by a variety of federal agencies to achieve the most accurate drought and weather forecasts. Public groups and committees also influence the management of the basin.

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### *Hydroelectric Generation Consideration*

Electricity is generated from the three USACE reservoirs in the Savannah Basin including Hartwell, Richard B. Russell, and J. Strom Thurmond reservoir power plants. The USACE reservoirs are "peaking plants" which typically only operate during peak consumer energy demands. Usually, this is during the workday Monday through Friday; however, Strom Thurmond operates more continuously to meet the minimum stream flow requirements. Strom Thurmond is the farthest downstream reservoir and releases make up a substantial portion of the Savannah River. The three reservoirs are considered one network operating together to meet energy objectives. This objective is defined as a specified amount of energy in Megawatt-hours per week (MWh/week) that is to be achieved at the end of a seven-day period. Moreover, the objective value varies by month allowing for flexibility and other operational objectives to be met. Seasonal weather patterns, fish spawning, and regional energy demands are just some of the considerations with the operation of the reservoirs and energy objectives.

SEPA is the federal agency that is tasked with marketing and selling the power and energy from the Army Corps-operated reservoirs in the region. Hydroelectricity makes up approximately 2% of the region's electric demand. Market energy from private companies often varies between \$80/MWh and \$160/MWh depending on the seasonal and daily demand. SEPA rates, however, are calculated to balance the operation, maintenance, and construction loan costs, not economic demand. Therefore, SEPA rates are static, currently \$9.32/MWh, and recalculated about every five years. Figure 1 shows the variability in monthly pricing between SEPA and market rates. The difference in pricing between market and SEPA rates acts as a government subsidy which helps reduce the energy costs to the regional consumers. If the amount of energy contracted is not able to be generated through hydropower, then the remaining energy needed to fill the contract is purchased at market rates to fulfill the contract. This creates variable rates that can be significantly higher than the intended SEPA rates and are simply passed on to the regional residents.

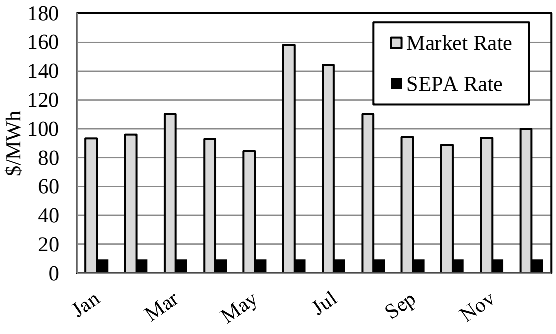

**Fig. 1:** Comparison between SEPA and market energy rates

### *Past Work*

Hydroelectricity is a function of the physical characteristics of the dam, power station, and drainage basin. Basin Characteristics can be seen in Table 1. Of course, water is also necessary in hydroelectric production; so rainfall, runoff, and droughts certainly affect the reliability of energy generation. A dependable energy yield for hydroelectricity exhibits consistent energy values that can be expected despite mild droughts (Cramton and Stoft, 2007). Lavender and Donnelly (2003) addressed hydropower risks with reservoir management. Sufficient risks of 1:10 and 1:20 years (90 and 95% reliable) were evaluated as normal operating risks. Christofides *et al.* (2005) focused on a 90% inflow reliability factor when showing the effects of lake levels and reservoir health. In this case, health included many uses such as power generation, water supply, tourism, and irrigation. Ramachandra *et al.* (2000) discussed the process of planning for hydropower development in India and described the procedure to establish a 90% accurate annual "water availability" utilizing 10-day weather forecasts. Finally, Wurbs (2005) stated that "Reliabilities are also highly dependent on reservoir storage capacity and multiple-reservoir or river system operating rules."

**Table 1:** Basin Characteristics

| | Unit | Hartwell | Russell | Thurmond |
|---|---|---|---|---|
| Reservoir area | Acre | 56000.0 | 26500.0 | 71100.0 |
| Local drainage area | Square miles | 2088.0 | 802.0 | 3244.0 |
| Shoreline | Miles | 962.0 | 540.0 | 1200.0 |
| Summer full pool elevation* | FT | 660.0 | 475.0 | 330.0 |
| Average pool elevation | FT | 652.0 | 473.0 | 327.5 |
| Average tailwater elevation | FT | 481.6 | 327.5 | 191.0 |
| Depth behind dam | FT | 180.0 | 165.0 | 180.0 |
| Dam length | FT | 1900.0 | 1904.0 | 2282.0 |
| Dam height | FT | 204.0 | 210.0 | 200.0 |
| Average operating head | FT | 171.0 | 144.0 | 136.0 |
| Power capacity | MW | 264.0 | 600.0 | 380.0 |
| Generator units | # | 5.0 | 8.0 | 7.0 |
| Average annual energy | MWh/year | 453,000.0 | 464,500.0 | 698,000.0 |

## Materials and Methods

To compare the reservoir operational strategies with hydro energy production goals, actual energy produced was evaluated instead of hypothetical values from inflow estimates. Often synthetic hydrologic data, such as reservoir inflow, is used to help establish new operating rules or priorities from perceived weather conditions. Here, the historical data is used to establish a reliable energy amount with current operating goals. The data was retrieved from the USACE Savannah District website's Data Retrieval Interface (DRI). Daily energy production from each of the three reservoirs was compiled over each week and compared to the energy objective of that week. Over 25 years weekly data was compiled, providing over 100 data points per month. This was deemed important because while the energy targets are weekly, they vary monthly. Additionally, the current reservoir network was completed with the christening of the Richard B. Russell Reservoir in 1984. Operational strategies would be most current following the completion of the current network and the energy contracts are issued every 30 years, thus the operational strategies over the past two and a half decades are most consistent.

Statistical analysis with respect to percentile, median, and average procedures was used to assess the appropriateness of the energy contract values. The percentile and average procedures give a comprehensive view of the frequency of meeting the energy targets.

Even though the SEPA rates are constant, if the contract amount is not met then it must be bought at the higher market rates creating an effective rate for the consumer. If the energy produced meets or exceeds the contract, the effective rate is simply equal to the SEPA rate ($9.32/MWh) as given by Eq. (1). If the energy produced is less than the contract, then the effective energy rate can be calculated by Eq. (2):

$$\frac{\$}{MWH} = SEPA\ Rate \tag{1}$$

$$\frac{\$}{MWH} = \frac{(Actual\ Generation * SEPA\ Rate) + (Contract - Actual\ Generation) * Market\ Rate}{Contract\ Genertaion} \tag{2}$$

## Results and Discussion

Figure 2, the frequency of meeting the energy contract is clearly not very high, let alone consistent. The frequency of meeting the energy contract is not a priority in the operation of the basin. The highest frequencies of meeting the energy target are about 50% of the time with the majority of the months being significantly less. Spring months have the highest frequency of meeting the contract and this is most likely because the amount of energy contracted is the lowest during this time. This also provides an opportunity to raise the reservoirs from winter to summer pool elevations. The thousands of acre-feet of reservoir storage available provide capacity for spring floods that help raise the reservoir elevations without jeopardizing damage to the dam, reservoir, or surrounding area.

Figure 3 shows the average and median energy values with respect to the contract amount from 1984-2008. The average values, by definition, are more susceptible to outliers skewing the data. The median offers the 50th percentile value, where half of the values are above and half are below. This also gives the energy that is reliable 50% of the time. For six out of 12 months, both the average and median values are below the contract value. This could suggest that the energy contract does not exhibit a reasonably attainable value and not a dependable yield for the reservoir system.

Figure 4 displays the current contract amount along with a suggested dependable yield for each month. The 90% reliable values have a hydrologic risk of 1:10, which was found to be an appropriate level of risk by past experts for reservoir operation. This also displays observed strategies with current allocation. Table 2 shows similar information as Fig. 4 with the reduced amount of energy between the 90th percentile and the current energy contract.

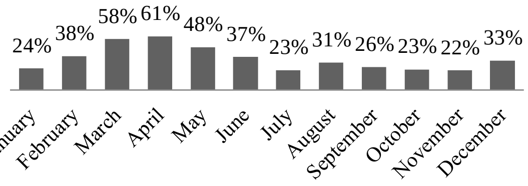

**Fig. 2:** Frequency of meeting the weekly energy contract

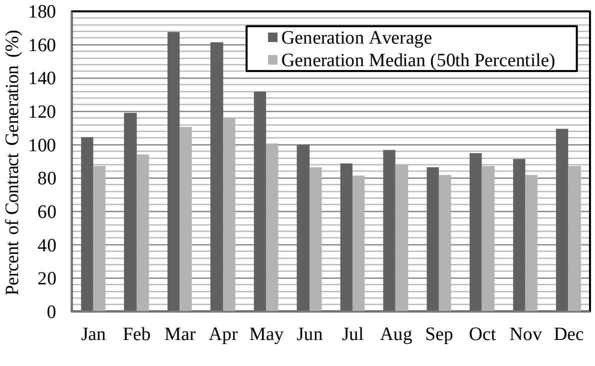

**Fig. 3:** Weekly averaged and median generation as a percent of contract generation

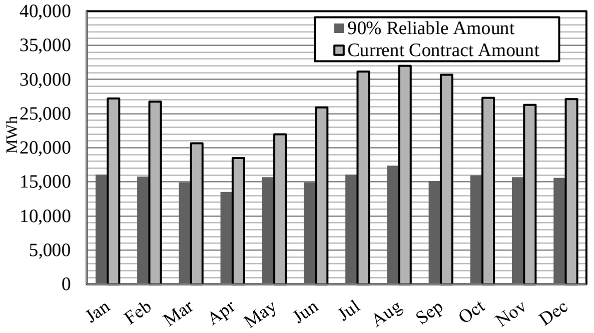

**Fig. 4:** 90% reliable energy yield displayed with the current energy contract

**Table 2:** 90th percentile energy value with contract reduction

| | Current contract (MWH) | 90th percentile (MWH) | % Reduction |
|---|---|---|---|
| January | 27233 | 16032 | 41 |
| February | 26714 | 15756 | 41 |
| March | 20669 | 14948 | 28 |
| April | 18504 | 13511 | 27 |
| May | 21948 | 15655 | 29 |
| June | 25935 | 14932 | 42 |
| July | 31195 | 16014 | 49 |
| August | 32035 | 17413 | 46 |
| September | 30685 | 15129 | 51 |
| October | 27304 | 15959 | 42 |
| November | 26284 | 15652 | 40 |
| December | 27104 | 15608 | 42 |
| Average | 26301 | 15551 | 40 |

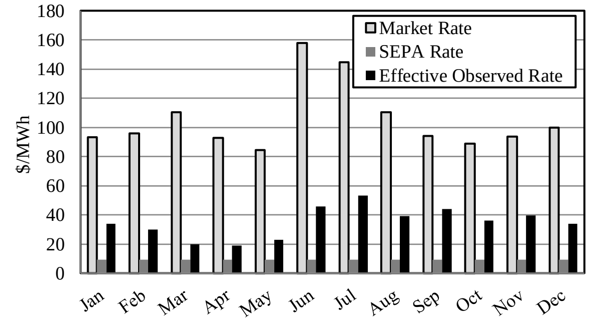

**Fig. 5:** Energy rate comparison between the 2008 market, SEPA, and effective observed historic values

The monthly variation between market and SEPA energy rates is shown in Fig. 5. In addition, the effective rate that was witnessed by the consumer for the contracted energy is also displayed. The effective rate is the weighted average between the SEPA and market rates over a 25-year period. While still significantly less than the market rates, the effective rates are much higher than SEPA and offer large variation creating price fluctuations for residents and commercial consumers in the region.

## Conclusion

It is clear from the energy analysis that the current energy contract does not reflect dependable energy for the Savannah River Basin reservoirs. Considering the dependable energy yield suggested by Lavender and Donnelly (2003) and a risk of 1:10, the weekly energy targets on average would need to be reduced by approximately 40% of their current value. This reduction would give reliability approaching 90%. Additionally, the contract targets are currently met only between 20-60% of the time. This illustrates the fact that in the last 25 years, more than half the observations have been below contract for most months. Due to the absence of penalties for SEPA and USACE, if the contract is not met, there is no incentive to meet the energy contract over other allocations. While hydropower generation is one of the founding reasons for the construction of dams and reservoirs, the hydropower priority compared to other uses is rather insignificant. Essentially, energy generation is a secondary consequence of managing the Savannah River Basin. It is a byproduct of managing the reservoirs to achieve other goals such as Municipal water supply, flood and drought control, and water quality for fish and wildlife. The use of "energy target" instead of "energy contract" more accurately represents the objects and priority of hydroelectric power in the Savannah River Basin. The integrity of the dam and ecosystem is important because irreparable damage could result if the reservoir network was operated to achieve other priorities such as energy demand or recreation.

The analysis shows a dependable energy yield that is influenced by reservoir and basin operation as described by Wurbs (2005). The critical period of drought has been eclipsed since the time of the energy contract. However, it is believed that the energy contract was not based solely on the dependable yield of the basin but rather on a loftier target. The definition of firm yield described by Cramton and Stoft (2007) with the ability to maintain yield with dry conditions should be considered in new contract targets. This could be quantified by a 90% reliable system such as presented here. A new energy contract is scheduled to be negotiated in 2016 and lower targets could surely be justified. New operating strategies and inflow projections should be considered regularly to ensure that current strategies reflect regional needs and expectations while maximizing the full benefit of the reservoirs.

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## Author's Contributions

**Travis Michael Yates:** Engaged comprehensively in all facets of the study.

**Abdul Aziz Khan:** Provided supervision to the student and actively contributed to the project.

## Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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