A CONTROL MODEL FOR THE SAVANNAH RIVER SYSTEM

Aris P. Georgakakos

AUTHOR: Aris P. Georgakakos, School of Civil Engineering, Georgia Institute of Technology, Atlanta, Georgia 30342.

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INTRODUCTION

Reservoir operation certainly provides ample opportunity to use computer-aided management tools. Except for simple systems, namely, small, single objective reservoirs, where optimal decisions are obvious, the decision making process must take into account a plethora of complicating factors. Uncertain inflows, reservoir and river dynamics, hydroelectric plant characteristics, flood and drought concerns, water supply, energy generation commitments and economics, water quality standards, recreational activities, local and regional water use conflicts and legislation, and public opinion are but a few of the parameters influencing reservoir management decisions.

Recent reservoir control research advances combined with fascinating developments in the computer industry provide new opportunities for model use in real time reservoir management. Modern reservoir control methods can now handle dimensionally large systems with both multiple objectives and operational constraints. And, of equal importance, control models can now be implemented on readily accessible microcomputers which encourages potential widespread use and numerous practical applications. Combined with interactive input-output graphics interfaces, management models can be designed to maximize user involvement and provide intuitive understanding of the computations in progress.

This paper reports on a state-of-the-art reservoir control model for the regulation of the Savannah River System. Except for model features, emphasis is also placed on how model usage can be maximized within the current organizational decision framework.

MANAGEMENT PRACTICES

The real-time operation of the Savannah Reservoir System requires the close collaboration of several agencies. The operational schedules are first tentatively decided on a weekly basis by the U.S. Army Corps of Engineers District in Savannah. These schedules include hydropower energy and capacity declarations, water releases, and end-of-the-week predicted storages for each system reservoir. The schedules are announced on Wednesday and apply for the week beginning Saturday. In these determinations, the Districts take into consideration current storage levels and turbine availability, and plan on energy generation and capacity amounts based on previous operational experience and the specific water release requirements authorized for each reservoir. The decision process is assisted by simple water balance computations incorporating the energy generation characteristics of each hydroelectric facility. The above reservoir release and energy generation schedules are then provided to the Corps' South Atlantic Division (SAD) office.

The role of SAD is to insure that the energy and capacity declarations satisfy the contracts of the Southeastern Power Administration (SEPA) with various electric cooperatives and municipalities. If the declarations fall short of these commitments, SAD negotiates with the Savannah and Mobile Districts in an effort to revise their schedules within the other water release constraints. In these revisions, SAD considers the seasonal as well as the over-year storage and energy generation potential of each project. Namely, during above-normal flows, energy is principally drawn from the smaller reservoirs in the Apalachicola and Alabama-Coosa basins which have limited over-year storage capability. During dry years, the large Savannah River projects pick up most of the power demand.

SEPA markets the energy and power capacity available by the Corps projects to electric cooperatives and municipalities (consumers). Such contracts are usually established with the consumers for a period of ten years. SEPA also has contracts with power companies (e.g., Georgia, Alabama, and Duke Power) which own the transmission lines and "wheel" energy to consumers. In practice, the consumers buy energy and capacity from the power companies and receive credit for the amounts produced by the Corps projects. The contracts stipulate that federal energy and capacity be used to cover the peak power demand period. The consumers would prefer to maximize SEPA's contractual commitments due to the relatively low rates of the federal energy. However, if SEPA contracts exceed the amounts actually produced by the Corps projects, SEPA is obligated to buy the contractual deficit from the open energy markets at 3 to 5 times higher rates. This cost is eventually transferred to the consumers in the form of rate increases. If, on the other hand, SEPA under-estimates federal energy production, excess energy may reach the consumers at higher cost. Thus from the standpoint of SEPA and its customers, the contracted and actually available energy and power amounts must be in close agreement.

SEPA determines the energy contracts based on system simulations with historical inflow sequences (1925 through present). The power capacity availability is based on simulations with the drought of 1981 (3rd worst drought on record as of 1985) and is taken as the minimum power capacity of each reservoir during this period. As mentioned, the weekly energy and power amounts thus contracted remain in effect for the next ten years. However, SEPA energy and capacity rates to the consumers may change every five years or less to recover the cost of energy purchases.

The power companies complete the decision making process by scheduling the energy generation and capacity availability at each system reservoir in accordance with the contractual commitments. In effect, the power companies are authorized to take the energy and capacity amounts stipulated in the SEPA contracts to meet the power demand of their customers. However, the SEPA consumers receive credit for the contracted energy and capacity amounts which must be applied to the hours of peak power demand. (From the power companies standpoint, a unit of energy or capacity sold by SEPA is a unit taken from their own sales, and, therefore, it is to their benefit to discourage high SEPA contractual commitments.) The power companies determine their rates by an economic model that takes into account outages and operational costs and performs dispatching of all power plants in their system. The power companies schedule the contracted energy generation and capacity availability on an hourly basis so as to minimize their operational costs. The hourly schedules are simply the weekly amounts divided by five and applied over the peak generation period of each day. (Weekends are not peak power demand periods.) These schedules are communicated to the operators of the Corps projects every Friday.

ELQG CONTROL SOFTWARE

This section describes a control software that is presently being implemented for the Savannah River system and is sponsored by the Savannah Corps District.

The software is based on the ELQG control method [*Georgakakos, 1984, Georgakakos and Marks, 1987, and Georgakakos 1989a, 1990*] and is organized as follows: The model includes three control levels N, F, and D (Figure 1) to guide the system during normal, flood, or drought periods respectively. The search for the optimal release and energy generation sequences starts at control level N. This level seeks to optimize the releases over the established horizon such that (a) the minimum release requirements are met, (b) energy generation and available power capacity levels are in accordance with contractual commitments, (c) the likelihoods of spillage or storage depletion are insignificant over the control horizon, and (d) the available turbines "run" at best efficiency or at specified overload levels depending on the power capacity commitments. Reservoir storage constraints are stated in a probabilistic format based on user-defined constraint violation tolerance levels. For example, the constraint relating to storage depletion requires that the probability that the reservoir storage falls below the conservation storage zone be less than or equal to a user-defined risk level (e.g., 2.5%).

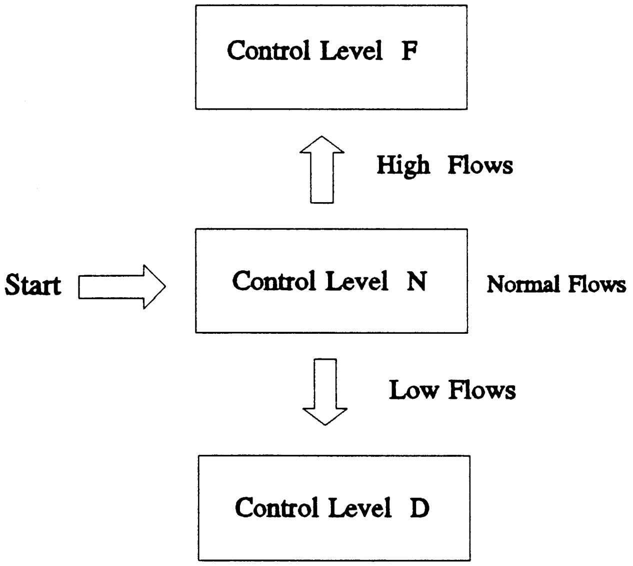

Figure 1: A Multilevel Control Model

ELQG determines the optimal sequences using the two-module optimization scheme shown on Figure 2. Module I in this scheme is concerned with the optimization of the release sequences over time. Module II specifies the each turbine's power load based on its characteristics and the forebay and tailwater reservoir elevations. (Although it is desirable that turbines "run" at best efficiency to maximize energy output for a given release volume, power commitments may require that turbines are overloaded by 20 to 25% above their nominal capacity rating.) The above scheme can utilize inflow forecasts from any available forecasting model. The forecasts are used together with a given release sequence to generate the probability density of the reservoir storage at each week of the control horizon. The goal of the control algorithm is to find that release sequence which gives rise to the most desirable probabilistic storage sequence. As discussed by *Georgakakos, 1989b*, the better the forecasting model, the less reluctant the controller is to let the reservoir approach the constraint levels. If this optimization process identifies a release sequence that does not violate any of the afore-mentioned constraints, then ELQG terminates. This week's optimal release and energy generation schedules are recommended for implementation, and the process is re-initiated at the beginning of the next week. If, however, the optimization process is unable to determine a feasible release sequence preventing violation of the upper or lower probabilistic storage bounds over the foreseeable future, then ELQG respectively activates its F (flood) or D (drought) control level.

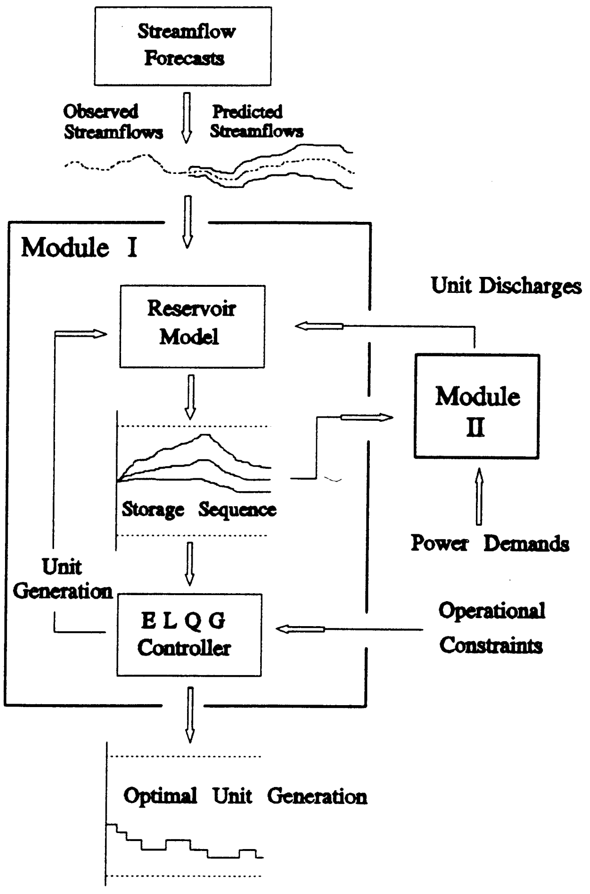

Figure 2: A Two-Module Optimization Process

The purpose of the F Control Level is to (**a**) prevent excessive releases, and (**b**) generate as much energy as possible. Since the objective now is to release as much water as possible through the system turbines, this level "runs" the turbines at maximum energy output.

The purpose of the Control Level D is to minimize the impacts of low flows during the anticipated drought period. Drought period operations are initiated if at any time of the control horizon the storage probability densities violate a user-defined lower storage threshold (e.g., the bottom of the conservation pool) with significant probability (e.g., more than 2.5%). In a situation like this, it may be more beneficial to start conserving water in advance, with moderate release deficits, than to implement severe rationing at some later time. During the drought operational mode, the energy generation proceeds at best turbine efficiency to maximize energy output. One must realize that even if the storage probability density violates the drought threshold, deficits will not necessarily take place. Even if one continues to release the normal amounts, it is only *possible* that deficits will eventually become mandatory. Thus, it is up to the management authority to determine the risk level which they feel is tolerable. This is one example of the various operational trade-offs that the management authority has to resolve in real time. As discussed next, ELQG is programmed to generate such trade-offs and solicit the involvement of the system operators.

A key feature of the ELQG control scheme is its ability to meet reliability constraints. The tolerance level for each constraint and time period is specified by the user and can be varied to explore the Pareto Optimal Surface among the system objectives. (In an application with the Savannah three-reservoir system, *Georgakakos, 1989a*, demonstrated that the ELQG user-specified tolerance levels are actually realized in practice, a feature which is presently unique among reservoir control methods.) The previous ELQG multilevel control structure is also convenient to segregate the trade-offs pertinent to each operational mode.

During normal operations, one may consider increasing the firm or the total energy generation, especially during periods of above average inflows, at the expense of having a lower end storage. ELQG quantifies this trade-off in real time by incrementing the firm or total energy target, performing the optimizations, and recording the end-of-the-year storage levels. If desired, this investigation may also be conducted for a multi-year period. The trade-off is expressed in terms of the mean firm or total energy output versus the mean terminal storage, or in terms of any percentile from the associated probability distributions. The program then prompts the user for his most preferable operational choice and proceeds to identify the associated release and energy generation schedules to realize this selection. Rather than specifying the weekly energy targets, a separate option allows the user to input predicted energy prices, and it determines the energy generation sequence that maximizes the associated economic gains of their customers as a function of the end reservoir storage. (As previously mentioned, every kilowatt hour (KWH) purchased by the Corps Projects is a KWH of lost sales to the power companies.) By varying the end storage, the program also generates the associated trade-off. These features are especially convenient if the Corps wishes to investigate various energy generation scenarios from each system reservoir or clusters of reservoirs.

During floods, a trade-off exists between energy generation and the downstream release level. Namely, energy generation may be increased if the releases are allowed to exceed the flood control thresholds. One must weigh the value of the additional energy generation (or the savings from the equivalent thermal energy) versus the risk of flood damages.

During droughts the issue is to determine the time distribution of low flows which minimize the downstream drought impacts. The implied trade-off involves deferring rationing versus the risk of a major shortage.

In view of the changing operational conditions, the ability to generate operational trade-offs is pivotal in the real-time management of any multipurpose reservoir system.

This ELQG implementation is developed on microcomputers. The program "runs" on 286, 386, or 486 machines under the DOS operating system and is integrated with extensive graphics routines based on the GSS*GKS graphics software. This software is able to generate, at "run time", screen and hard copy plots of the reservoir storage, release, and energy generation probabilistic sequences as well as of the afore-mentioned operational trade-offs. The program is driven by menus to facilitate the input process and provide the user with intuitive understanding of the computations in progress. The control software without the graphics interface but with extensive output files also "runs" on main frames or workstations. The user may then utilize the output files in connection with any graphics software at his disposal to generate plots. A more extensive discussion of the control model and its application is provided by *Georgakakos, 1991.*

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