Optimizing the TVA Reservoir System Using RiverWare

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Abstract

For the past several years, the Tennessee Valley Authority (TVA), U. S. Bureau of Reclamation (USBR), and the University of Colorado's Center for Advanced Decision Support for Water and Environmental Systems (CADSWES) have partnered to develop a software package called RiverWare for use in modeling multipurpose reservoir systems. RiverWare now offers three different modeling approaches: interactive simulation, rulebased simulation, and optimization. TVA implemented the interactive simulation software in April 1996 for scheduling both power and nonpower reservoirs in the TVA system. In May 2000, TVA implemented optimization modeling for scheduling the reservoir system. Prior to this, optimization modeling had been used in parallel with interactive simulation modeling in scheduling the system for about two years.

The optimization modeling approach takes into account not only the power economics of the hydro system, but also other demands placed on the reservoir system. These demands, which include flood control, navigation, recreation, and water quality, as well as special operations for maintenance and community events, are defined in RiverWare as prioritized constraints. The optimization routine uses goal programming to satisfy all of the constraints in order of priority to the extent possible, and then with any remaining flexibility, optimizes hydropower operations to reduce the total integrated system power supply cost. Hydropower operations are optimized by maximizing the combined value of energy generated during the forecast period and water reserved in storage for future generation.

TVA's RiverWare optimization model is typically run using 6 hour timesteps for a forecast period of one week. The optimization model can be run several times per day as forecasts of power demands or operational constraints change.

There are several advantages to using RiverWare for optimizing TVA's reservoir system. First, the optimization model ensures that all of the operational objectives of the reservoir system are met to the extent possible. Then, with the physical and policy constraints satisfied, the timing of hydro generation can be improved to maximize the dollar value of the hydro system to TVA. Finally, RiverWare allows the user great flexibility in scheduling the system. The user can interactively define operating policy in the form of constraints, quickly and easily manipulate input data, and use the objective function value to compare the cost difference of various operating scenarios.

Introduction

As demands increase on TVA's multipurpose reservoir system, and with impending deregulation of the electric utility industry, increased competition, and volatile market prices, one of the best ways for TVA to remain competitive is through optimization of the hydro system. Hydropower is one of the least expensive sources of energy generation, but it is also fuel limited. In order for TVA to optimize this limited resource, hydropower must be run when it is most beneficial to the power system, i.e. when it offsets other higher cost resources. TVA's hydro system comprises approximately 14% of the 29,000 MW capacity of the total TVA power system. Although not a large percentage, hydro plants are most beneficial when run to reduce the use of more expensive generation sources or purchases. This means running hydro plants on peak load hours. However, the many other operational objectives of the reservoir system must still be met. These operational objectives come in many forms. Maintaining flood storage availability as well as minimum depths for navigation are mandated by the TVA Act. Other objectives include minimum flow requirements for water quality and water supply, minimum pool elevations for recreation, and numerous special operations requests.

To satisfy these multiple objectives, TVA's reservoir operations personnel use a river and reservoir modeling package called RiverWare, which is a general river basin modeling tool developed through a collaboration between TVA, the U.S. Bureau of Reclamation (USBR), and the University of Colorado's Center for Advanced Decision Support for Water and Environmental Systems (CADSWES). TVA has been involved in the development of RiverWare for several years. The interactive simulation modeling feature of RiverWare has been used in daily operation of the reservoir system since 1996. Beginning in May 2000, TVA implemented the optimization modeling feature of RiverWare into daily operations.

Modeling the TVA Hydro System

The RiverWare model used for optimization and simulation of the TVA reservoir system is made up of 35 objects representing each of the reservoirs in the Tennessee Valley. Each reservoir object is linked to form a topology of the river basin. This topology also includes free flowing stream reaches, confluences, and canals. The links allow information to be propagated from one object to another. For example, the outflow from an upstream reservoir can be linked to either the inflow of the downstream reservoir or the inflow of a free flowing stream reach or confluence. Each reservoir object contains data characterizing that reservoir and hydro plant. One object, called the thermal object, is linked to each reservoir object. The thermal object contains data required for optimization of the hydro system. There is also one data object for each reservoir in the TVA system. These data objects contain policy data such as operating guide curves and required minimum flows. Figure 1 shows a RiverWare workspace with the thermal object, stream reaches, a confluence, canals, and reservoir objects representing each of the 35 hydro plants in the TVA region.

The optimization modeling approach takes into account not only the power economics of the hydro system, but also other demands placed on the reservoir system. These demands are defined in RiverWare as prioritized constraints. These constraints can be activated, deactivated, or reprioritized through a graphical user interface. Because all of these constraints are written through this graphical interface, adding, removing, or editing constraints does not require a computer programmer or optimization expert. Currently, TVA's optimization model contains over 800 user specified constraints. While all of these constraints are not necessarily active at the same time, constraints have been written to cover a wide range of possible operating scenarios. Therefore, reservoir operations personnel are not frequently required to write new constraints as situations arise. Each active constraint is modeled as an objective. These prioritized objectives

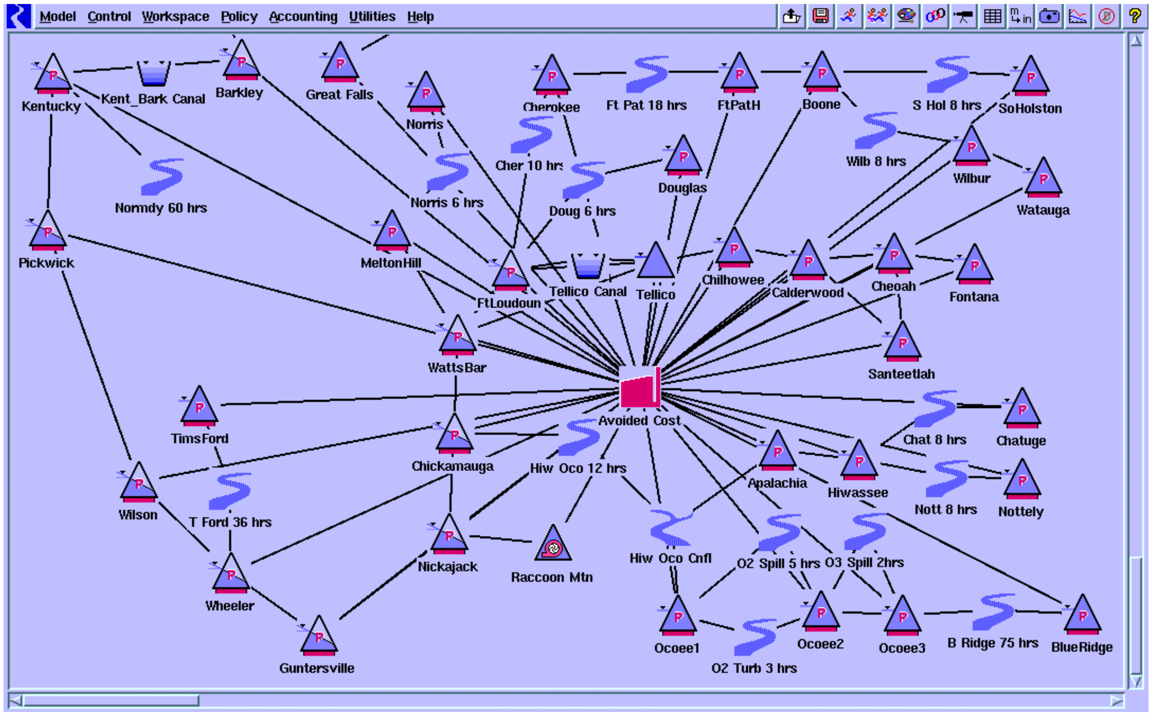

Figure 1. RiverWare workspace showing objects representing reservoirs in the Tennessee Valley.

are satisfied, to the extent possible, in order of priority. A high priority constraint cannot be violated in order to satisfy a constraint of lower priority.

Physical characteristics of each reservoir and hydro plant are defined as the highest priority constraints in a model. The characteristics contained in reservoir objects are used to define physical constraints. These physical constraints are followed by user specified constraints. The policy information contained in data objects are used to define user specified constraints. After all user specified constraints are satisfied to the extent possible, an economic objective function is maximized.

The economic objective function in TVA's RiverWare optimization model seeks to maximize the value of the hydro system to TVA. This is done by maximizing the value of the combination of energy generated during the current period and the value of water stored for generation in the future. The expected future value of stored water is computed by an external program and provided as input to the optimization model. The future time horizon can encompass a time period from two weeks to several months, depending on the time of year. An hourly incremental cost forecast is used to compute the expected future value of stored water. This same forecast is also provided as input to the optimization model.

An initial optimization model is run using the expected future value of stored water and the incremental cost forecast as inputs, in addition to physical and user supplied constraints. This initial optimization model run is used to determine the volume of water allocated for generation during the model time period. The incremental cost forecast used in this model assumes that each megawatt generated during a given hour has the same value. Therefore, there is no depth associated with the incremental cost forecast.

After the water allocation has been determined, a second optimization model is run with a second set of cost forecast data. This data is sensitive to the amount of energy generated during a given time period. Therefore, the depth of the energy market is reflected. The capacity of the hydro system is divided into 50 megawatt blocks, with each block being assigned a unique dollar value for a given time period. The water allocation decision from the first optimization model run must be maintained. However, the hours during which energy is generated is based on these block cost data reflecting depth of the energy market.

RiverWare uses pre-emptive goal programming as the optimization method. Policy expressions as well as physical constraints, which are often non-linear functions, are automatically linearized. Therefore, an approximate solution is returned. Post optimization simulation removes all approximations and computes energy generated at each hydro plant as well as performing routing computations and solving all other mass balance variables. TVA reservoir operations personnel can make adjustments to the optimization model output using interactive simulation.

TVA's RiverWare optimization model can be run multiple times per day, depending on changes in reservoir system status or load forecast. TVA uses a 6 hour modeling timestep for a forecast period of one week. Each optimization model run takes about five minutes. The majority of time and effort spent by reservoir operations personnel is in preparing a model for this five minute run. Initial conditions such as observed pool elevations and discharges are loaded into an optimization model from a TVA database. An inflow forecast is derived from a separate rainfall-runoff model. An hourly cost forecast is also derived from a separate model and provided as input to the optimization model as well as the external program that computes the future value of stored water. This program is then run with results being provided as input to the optimization model. Finally, a review of policy decisions and special operations considerations is made prior to running an optimization model. Based on this review, user specified constraints can be activated, deactivated, or reprioritized by the user.

Typically, the current day operating schedule is considered fixed and is not subject to change during the optimization model process. Any changes that are made to the current day operating schedule are made manually in response to reservoir system changes or load fluctuations. Situations that could result in current day operating schedule changes include higher or lower than expected loads, unexpected unit availability variations, weather changes, or other special circumstances that may arise. However, the model is capable of analyzing these changes if desired.

Hourly Optimization of the TVA Hydro System

Development of a RiverWare optimization model using an hourly timestep is currently under way. This model will replace the existing software used to produce an hourly schedule of hydro generation at each plant. This hourly optimization model will be run for a period of two to three days. Reservoir and power plant characteristics used in the hourly optimization model will be the same as those used in the 6 hour model. User supplied policy constraints will be very similar. The user supplied constraint of highest priority will require the daily volume from the 6 hour model to be maintained. Other constraints such as minimum flow requirements and pool elevation operating boundaries will follow. The future value of stored water does not play a role in the hourly optimization model since the daily water allocation has already been determined and is provided as input through a constraint to the hourly model. Finally, the economic objective function will again be to maximize the dollar value of the hydro system to TVA. This is done by maximizing the avoided operating cost, which means that expensive forms of generation, such as market purchases and fossil fuels, are replaced by less expensive hydropower.

Using a RiverWare optimization model to produce an hourly hydro schedule will ensure that hydro generation is run at the most cost effective times while still meeting reservoir operating constraints. Although optimization model results may require some manual adjustments using interactive simulation, this process will be an improvement over the current process, which requires a great deal of manual scheduling.

Hardware

TVA reservoir operations personnel run RiverWare on a Sun Ultra Sparc server, which contains 8 (333 MHz) processors, 2 gigabytes of RAM, and 36 gigabytes of disk space. The Sun server is networked to a series of HP9000 servers, which maintain databases and many other TVA reservoir operations applications. RiverWare is accessed through Hewlett Packard workstations as well as an X windows environment on personal computers.

Conclusion

TVA reservoir operations personnel expect to realize several advantages from using RiverWare for optimizing TVA's hydro system. The optimization model ensures that all of the operational objectives of the reservoir system are met to the extent possible. Prior to optimization modeling, the user had to manually schedule minimum flows, special operations, and other operating constraints. Now, the user can interactively define operating policy in the form of constraints, easily manipulate constraints as well as input data, and use the economic objective function value to compare the cost difference of various operating scenarios. As the experience level of users increases, all of these variables can be changed quickly so that multiple scenarios can be modeled. This should greatly improve the efficiency of evaluating potential operating schedules and help reservoir operations personnel determine the most effective operating plan. Also, with the physical and policy constraints satisfied, the timing of hydro generation can be improved to maximize the dollar value of the hydro system to TVA. Prior to optimization modeling, hydropower generation was scheduled based on a load forecast rather than a forecast of market prices. With RiverWare optimization models, particularly the hourly timestep model, the timing of hydro generation can be scheduled on the highest cost hours, which should closely correlate to but not necessarily exactly correspond to the highest load hours, to help TVA reduce the overall system cost of generation.

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