DEATH TO RULE CURVES

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ABSTRACT

The purpose of this paper is to focus attention on the potential for increasing the benefits from existing dams. Some reservoirs are operated by controlling releases to maintain reservoir water levels within established bounds that depend on the time of year. These time dependant bounds, or "rule curves", are determined by office studies that may have evolved many years ago during the design of the dam. Rule curves have one advantage - simplicity for the operator of the dam. They can have two disadvantages - disregard for present circumstances of weather and watershed conditions, and lack of a clearly defined objective function.

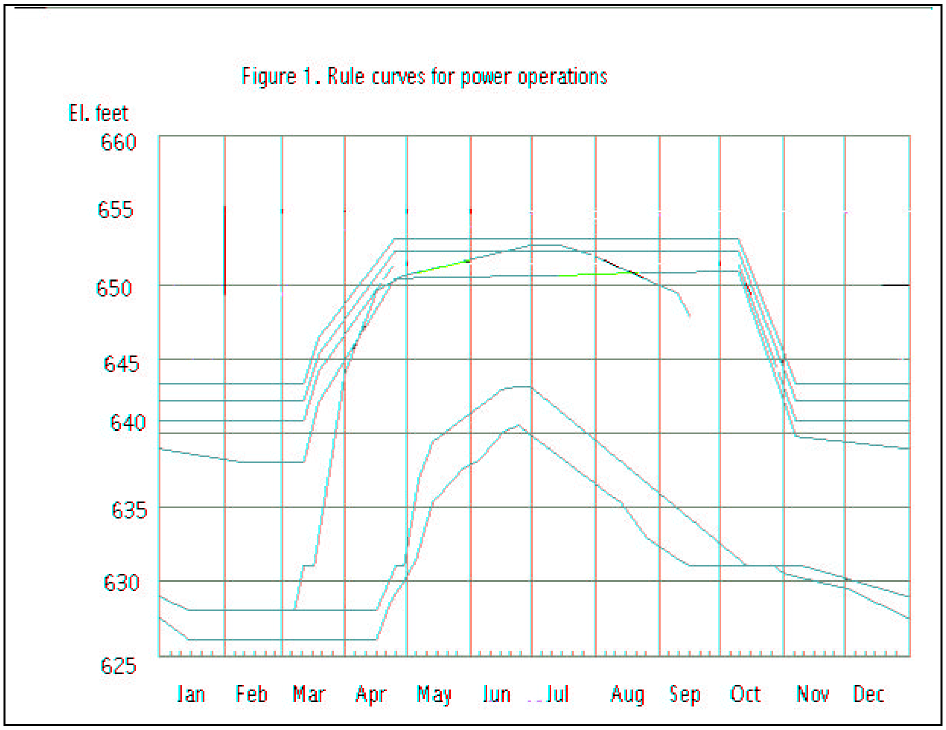
In general, rule curves displace opportunities for optimization with a blind constraint. In specific cases, rule curves can be arrogant artifacts that restrict discretion, wisdom, experience, and effective use of real-time data. The alternative is to provide operators of river systems with decision support systems that recommend current reservoir releases based on currently observed data and computer models that will satisfy constraints and maximize an objective function. This paper describes how such models are developed and two of the applications where they have been implemented.

INTRODUCTION

Rule curves are time dependant bounds that limit the maximum and minimum water levels of reservoirs. For some dams the rule curves define water surface elevation zones within which the operator is free to use his discretion when deciding how much water to store or release. In other cases the rule curves determine maximum levels (for dam safety during flood operations) or minimum levels (for providing reliable water supplies in the future) or defining maximum or minimum releases as a function of the date and the reservoir level.

Rule curves are usually determined from office studies based on historical stream flow records. In some cases only a short period of record was available for the studies and the method for determining reservoir operations has not been updated for 25 years or more. In some cases an administrative decision may determine the rule curves.

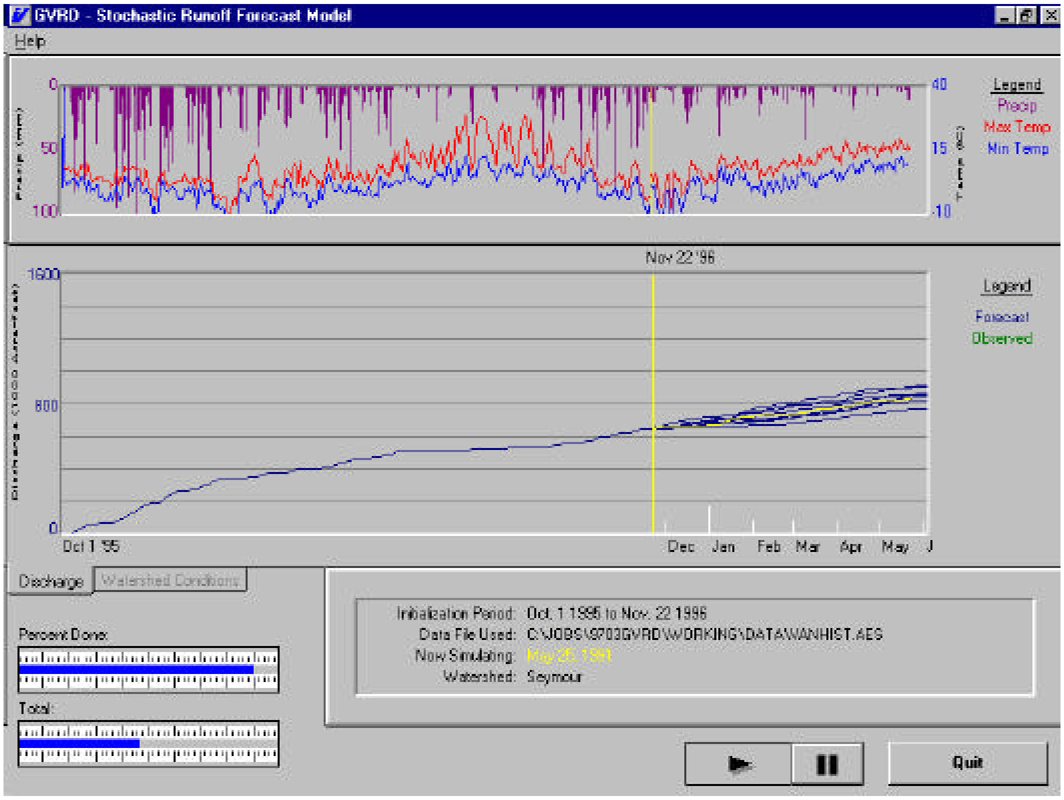
Figure 1 is an example of a fairly complex set of rule curves for a reservoir in North Carolina - as the level reaches each lower curve the utility must reduce the maximum amount of hydroelectric power that can be generated. The purpose of the curves in Figure 1 is indirectly to encourage the power utility to maintain a stable reservoir level for recreation. In response to a forecast of high inflows the utilty can increase generation to minimize spill, but generation must be reduced as the level drops below the various rule curves. The operator's discretion is crucial in determining the impact on energy revenues, and water levels upstream and downstream.



In some basins the rule curves may be conditional on the seasonal runoff forecast. Curves for reservoirs on the upper Columbia River in Canada are constructed from simulation studies based on prorating the current seasonal runoff forecast to monthly inflows for each year in a selected period of record. The rule curves are updated each month on the basis of the updated water supply forecasts. The goal is to provide "assured refill" if the volume of runoff occurs according to any pattern of monthly timing in the selected period of record. There are two obvious limitations of this approach. First, from a physical point of view, the actual pattern of runoff for the current year is almost certain to differ from all patterns that were used in the year by year simulations. Second, from an optimization point of view, the concept of "assured" is missing some statement of probability and confidence limits, which depend on some undefined dependancy between the selected period of record and the seasonal runoff forecast.

Decision support systems are highly interactive and graphically informative. They consist of a database and water management modules. The database includes the data and the methods for acquiring, editing, storing, and retrieving it. The water management modules optimize the use of storage based on continuously updated deterministic short-term inflow forecasts, and probabilistic long-term inflow forecasts. The optimization is constrained by the physical limitations of the facilities and the license conditions for their operation. A set of prioritized objective functions quickly guide the analysis to the appropriate recommendations for using the storage. Rule curves are not used in this process. Such decision support systems are routinely used for individual reservoirs (Van Do and Howard), cascades of reservoirs (Hartsock, Ott and Allen), and for river basins (Howard).

Figure 2 illustrate how a conditional probability distribution can be developed from a



hydrologic simulation. This is an important step in a decision support system. The goal is to account for the actual current conditions on the watershed (soil and soil moisture) as a first step to customizing the operating decision for the current day. Each time the hydrologic conditions change, the probability distribution is recalculated. The result is a narrower range of inflow possibilities than would be indicated by the historical stream flow record. With this information the optimization of operating decisions has an opportunity to capture increased energy and water supply benefits from the use of the storage.

The purpose of decision support systems is to ensure that the best available data are used in an objective comprehensive analysis that captures the maximum benefit from the investment in the reservoir system. With a properly designed decision support system this goal can be achieved with little effort during routine day to day operations.

For planning studies, decision support systems open a very broad avenue for investigating how a proposed project or license condition will actually affect operations. A decision support system exactly replicates the actual day to day decision process that deals with uncertainty. Continuously updated day to day operating decisions are based on continuously updated probabilities, and as the simulation (or optimization) moves ahead, the day to day outcomes are determined from actual recorded inflows. Rule curves provide a simpler but unrealistic guide for planning because uncertainty is embodied only in the rule curves and not in the day to day simulated operating decisions. This may help to explain the observed communications difficulties between operating and planning departments of hydroelectric utilities.

CASE STUDIES

There are many examples of water resource systems that do not depend on rule curves for operation. The two mentioned here illustrate the experience from over ten years of continuous operation, and how considerations for the Probable Maximum Flood can be recalculated each day.

Since 1986 Pacifica Papers (formerly McMillan-Bloedel, Powell River Divisions) has used a decision support system for optimizing monthly commitments to purchase electricity from the grid. Since the paper mill's electricity requirements normally exceed the capability of Pacifica Papers' two hydroelectric plants, the objective is to minimize the cost of purchases.

The decision support system consists of a probabilistic hydrologic forecast model, a probabilistic optimization model of reservoir operations, and an optimal model for generator unit commitments. Since 1986 this software has been used to guide weekly reservoir operating decisions without the need for rule curves. In fact, annual updates to studies of past operations have shown that if the old rule curves are followed the spill would be greater, the heads lower, and the average annual energy generation would be reduced.

BC Hydro's John Hart project on Campbell River in British Columbia consists of three reservoirs and power plants in a cascade. Downstream in the town the river can reach flood stage if high powerhouse releases coincide with high tides. The goal is to avoid operations which cause unnecessary flooding of the town downstream and the lake side residents upstream. The decision support system here consists of a set of integrated models for deterministic hourly hydrologic forecasting, tide forecasting, reservoir and spillway gate operation optimization, and economic generation scheduling. The system operates over a time horizon of 72 hours, and has been in use since 1992.

The John Hart software can be used each day with the probable maximum precipitation to recalculate the probable maximum flood as the snow and soil moisture conditions change on the watershed. This calculation establishes the currently safe limits for storage and avoids the need to reserve storage space unnecessarily for a PMF which is impossible under current conditions.

CONCLUSIONS

Decision support systems have proven their merit in water control centres, and without the aid of rule curves developed by office studies. The following observations may be made:

1. Data acquisition, quality control, storage and retrieval systems provide reliable timely information that can be used to keep decision support systems current.

2. Computers and decision support systems are inexpensive and readily available.

3. Decision support systems provide information for unanticipated contingencies.

4. The present generation of reservoir operators can use decision support systems.

5. Rule curves can lead to lost benefits and flood damage.

It may be concluded that rule curves are unnecessary and often wasteful.

References

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