OPTIMUM STORAGE REALLOCATION AND GATE OPERATION IN MULTIPURPOSE RESERVOIRS

Hamid Moradkhani[1]
Water Resources Research Cente, DPRI, Kyoto University, Japan

Abstract: This research is intended to integrate long-term operation rules and real time operation policy for conservation & flood control in a reservoir. The familiar Yield model has been modified and used to provide long-term rule curves. The model employs linear programming technique under given physical conditions, i.e., total capacity, dead storage, spillways, outlet capacity and their respective elevations to find required and desired minimum storage for different demands.

To investigate the system behavior resulting from the above-mentioned operating policy, i.e., the rule curves, the simulation model was used. Results of the simulation model show that the results of the optimization model are indeed valid.

After confirmation of the above mentioned rule curves by the simulation models, gate operation procedure was merged with the long term operation rules to determine the optimum reservoir operating policy.

In the gate operation procedure, operating policy in downstream flood plain, i.e., determination of damaging and non-damaging discharges in flood plain, peak floods, which could be routed by reservoir, are determined. Also outflow hydrograph and variations of water surface levels for two known hydrographs are determined. To examine efficiency of the above-mentioned models and their ability in determining the optimum operation policy, Esteghlal reservoir in Iran was analyzed as a case study.

A numerical model for the solution of two-dimensional dam break problems using fractional step method is developed on unstructured grid. The model is based on second-order Weighted Averaged Flux(WAF) scheme with HLLC approximate Riemann solver. To control the nonphysical oscillations associated with second-order accuracy, TVD scheme with SUPERBEE limiter is used. The developed model is verified by comparing the computational solutions with analytic solutions in idealized test cases. Very good agreements have been achieved in the verifications.

Key Words: reservoir operation, flood control, gate operation, optimization, simulation

1. INTRODUCTION

During the last three decades, optimum operation of multipurpose reservoirs, have received increasing attention among water resource planners. Various mathematical techniques, with goals of long term, as well as, real time operation of these reservoirs have developed and implemented.

Reallocation of storage capacity between flood control and conservation purposes could be physically implemented by lowering or raising the designated top of conservation pool elevation. Johnson et at. (1990), examined opportunities for reservoir storage reallocation by reviewing available reallocation studies. Ford. (1990), developed a Pc-based reservoir operation simulator to provide trade-off between water supply and flood control objectives. Another related strategy for modifying reservoir release policies is to alter the allowable flood control release rate without changing the designated storage capacity. This strategy can be implemented by developing a suitable gate operation rule.

Reallocation of a portion of the flood control storage to conservation purpose might be warranted under suitable condition. Increasing irrigation and domestic demands could justify storage reallocation in cases where new reservoirs are not compensating for the reduction in flood control capacity. On the other hand reallocation of the portion of the conservation storage to flood control, especially in flood season, might also be justified where flooding damage is high and/or reduction in conservation volume is not significant.

2. RESERVOIR REALLOCATION MODEL

Combined use of optimization and simulation models is a suitable analysis strategy for reservoir operation problem addressed in this research. With an optimization model a manageable range of alternative operation policies may be developed for further detail analysis with a simulation model. Here an optimization model is employed for preliminary development of reservoir operation rule. The optimization model is linked with two simulation models; namely reservoir simulation and gate operation.

3. MODIFIED YIELD MODEL

The reallocation between storage capacity, yield, and reliability is a fundamental and extremely important aspect of the planning, design and operation of a conservation reservoir. Yield is the amount of water, which can be supplied, in a specific period of time. The yield model, which explained in detail by Lucks. et al. (1981), has been modified to find the minimum required within year storage which is enough to satisfy the defined demand with specific reliability:

$$Min \quad \sum_{t=1}^{12} S_{y,t} \quad for \quad y = Critical \quad year \tag{1}$$

$$S_{y+1} = S_y + Q_y - \alpha_y ID_y - DD_y - SS_y - EV_y - SP_y \tag{2}$$

$$S_y \le Kao \tag{3}$$

$$S_{y,t+1} = S_{y,t} + Q_{y,t} - SS_t - \alpha_y ID_t - DD_t - SP_{y,t} - EV_{y,t} \tag{4}$$

$$S_{y,t} + Kd + KF_{y,t} + K_{ao} \le K \tag{5}$$

$$SP_y = \sum_{t=1}^{12} SP_{y,t} \qquad \forall_y \tag{6}$$

where, S = Storage, Q = Inflow, ID = Irrigation demand, DD = Domestic demand, SS = Seepage, EV = Evaporation, Sp = Spilled water, α =Irrigation supply reliability, Kao = Active over-year storage, Kd = Dead storage, KF = flood control capacity, and K = total reservoir capacity. Subscripts of t and y refer to month and year respectively. In objective function, the critical year refers to that year in which the total annual flow is less than the annual yield.

4 GATE OPERATION MODEL

A simple gate operation rule has been developed which pays attention to the paramount importance of the dam safety. The basic idea has been extracted from Sinske's paper (1985). While operating the gates, the release is to be limited to an amount not exceeding from the peak inflow. This means that outflow peak is always smaller than inflow peak and any increase in outflow is gradual, not endangering downstream activities. Gate operation model developed employs three control discharges with no, little, and acceptable damage in downstream and finds three control reservoir levels within flood control stages. By means of reservoir level observation and monitoring flood inflow, the decision whether to maintain the present control stage or to gradually increase it to the next control release is made.

5. APPLICATION OF THE MODELS

To illustrate the applicability of the models, Esteghlal reservoir operation was used as a real case. The reservoir is located in southern part of Iran with total capacity of 350 MCM from which 80 MCM is allocated to dead storage.

Irrigation and domestic demands at year 2010 are anticipated as 62.2 and 117 MCM/year, respectively.

The modified yield model, as formulated, was applied for domestic reliability of 100 percent and different reliabilities ranging from 60 to 100 percent for irrigation supply. Minimum storage required to satisfy different percents of irrigation demand (i.e., 60,70, 80, 90, and 100) is illustrated in Fig. 1.

For example, when the storage in any month lies between two rule curves labeled with 0.8 and 0.7, only 80 percent of irrigation demand must be released. In another word, in such a

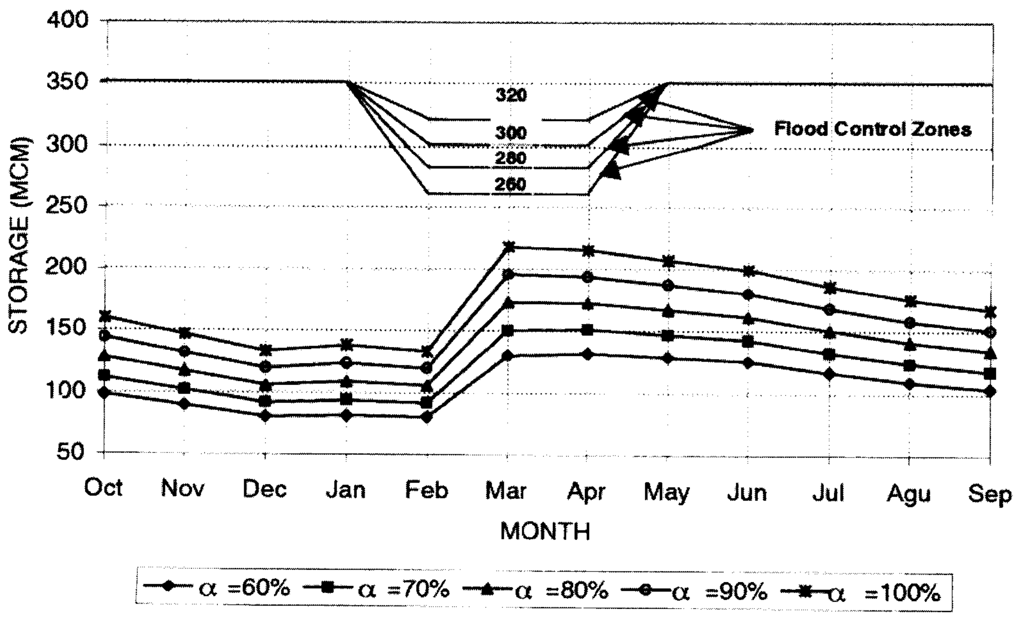

Fig. 1. Monthly Rule Curves Obtained by Modified Yield Model

Table 1. Results of the Simulation Model

Normal Water level (m)	Reservoir Storage (MCM)	Flood Control Capacity (MCM)	Average Annual Deficit (MCM)	Average Annual Spill (MCM)	Reliability (%)
94.4	260	90	4.2	77.25	78
95.5	280	70	3.17	74.45	83
96.6	300	50	2.28	72.08	88
97.6	320	30	1.84	69.92	89

situation, irrigation release must be cut back by 20 percent.

In order to make best use of available storage for flood control, different top of conservation pool level for flood seasons are defined. To test the sensitivity of the reservoir performance to the top of conservation pool level in floody season, i.e., Feb., March, and April, four discrete storages were used. In another word, for floody months, different alternatives with 90, 70, 50, and 30 MCM flood control volume were analyzed. For these alternatives, flood control simulation model were run by utilizing the previously derived operation rules. Simulation results are summarized in Table 1. It is shown that increasing top of conservation pool level in floody season from 260 to 320 (i.e., reducing flood control volume from 90 to 30 MCM) results in 2.36 MCM reduction in average annual deficit which causes 11 percent increase in monthly reliability (i.e., 78 to 89 percent). Reduction in average annual deficit, on the other hand, reduces the flood control capacity of the system.

By defining three control discharges as Q_{B1} = 3500, Q_{B2} = 4500, Q_{B3} = 6000 cms, the results of the gate operation model for different top of conservation level in floody season are given in table 2. As illustrated, it is possible to control a flood with a peak of 5759 cms, comparing to one with a peak of 4658 cms without exceeding the first control discharge, while reducing the flood control volume from 90 to 30 MCM (i.e., reservoir normal storage from 260 to 320 MCM) For the same normal storages, by not exceeding the second and third control discharge, floods with peak ranging from 5517 to 7703 cms could be controlled. Simple comparison of table 1 and

Table 2. Maximum Attenuable Peak Flood with regard to Control Discharges

Q_{B1} = 3500 cms, Q_{B2} = 4500 cms, Q_{B3} = 6000 cms

Normal Water level (m)	Reservoir Storage (MCM)	Flood Control Capacity (MCM)	Q_{p1} (cms)	Q_{p2} (cms)	Q_{p3} (cms)
94.4	260	90	5759	6427	7703
95.5	280	70	5437	6165	7480
96.6	300	50	5065	5859	7217
97.6	320	30	4658	5517	6919

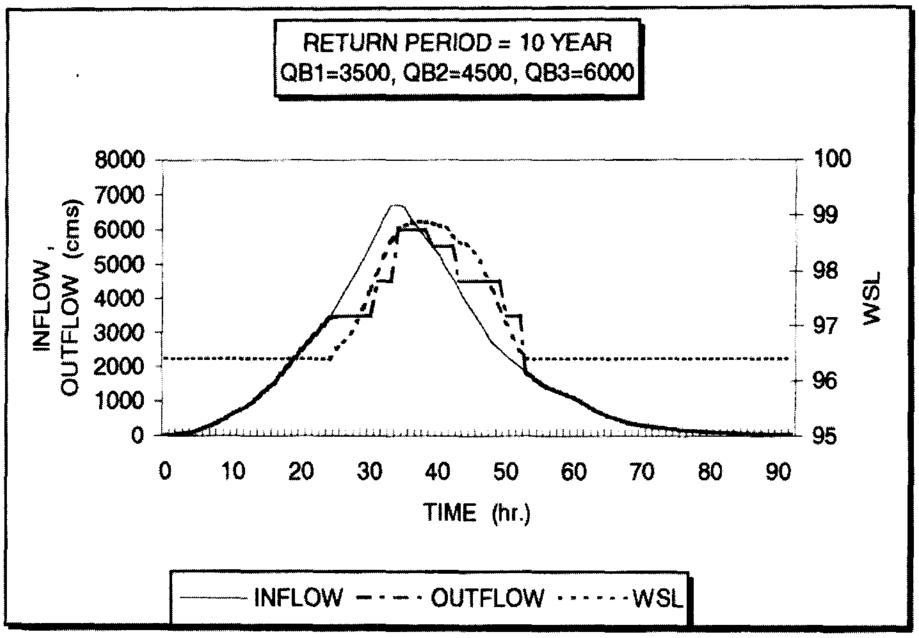

Fig. 2. Gate Operation analysis for a typical hydrograph

2 shows that increasing the flood control capability of the reservoir from 4658 to 5759 cms (1100 cms increase) may be achieved in cost of increasing the average annual deficit by 2.36 MCM. Availability of reliable flood damage cost function will make the economic analysis very simple and useful. A typical inflow hydrograph with return period of 10 years was analyzed and outflow hydrograph as well as top of conservation pool levels presented in Fig. 2.

6. CONCLUSION

As illustrated, three models were utilized to develop an optimum storage reallocation and real time gate operation in a multi-purposes reservoir. Modified Yield model was used to develop monthly operation rule, which was verified by a simulation model. Flood release simulation was done with the gate operation model. Reallocating the available storage and using different top of conservation pool level in dry and floody seasons increased flood control capacity of the system. It was shown that probable reduction in reliability is not very significant accordingly lowering the normal water level to provide more capacity for flood control can be a good solution, nevertheless, availability of reliable damage cost function in downstream and benefit-cost analysis will make the storage reallocation more sensible.

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Currently PhD Student, Department of Hydrology and Water Resources, University of Arizona, Tucson, Arizona, 85721