CSUDP를 이용한 홍수기 댐운영
Flood Control Operation Model of Reservoir Using CSUDP

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Abstract

The purpose of this study is development of operation model for flood control of multi-reservoir in river basin, which can provide the best decision of reservoir release in timely and appropriately manner using CSUDP. For verification and validation of the developed system, the Gum River Basin was selected, which has 82 rainfall gauging stations, 28 water level gauging and 2 multi-purpose reservoirs which can control flood. There was a successful simulation of the developed model and system, using the real-time data from the Han River Basin Flood Forecast Center. Specially, case study for '1995 flood was performed.

Key words: Flood control, Reservoir Operation, Optimization, Dynamic Programming

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1. Introduction

In order to control the flood through the reservoir operation, it is not only required to secure the enough reservoir capacity for flood control but the fast and exact information on the hydrologic state of whole watershed, the correct prediction of flood runoff couple of hours or days ahead and the proper methodologies for the reservoir operation are also required.

The purpose of this study is to operate Colorado State University Dynamic Programming (CSUDP) as a tool for fulfilling the above requirements that can forecast the reservoir inflow and downstream flood flows following the reservoir operation alternatives by the decision maker and lateral inflow from the downstream tributaries.

2. Flood control in Gum Rivver Basin, South Korea

One of the basins to which CSUDP is being applied to is the Gum River Basin. As the Gum River Basin has relatively small ratio of basin area vs. reservoir volume capacity ($14.9 \times 108 m^3 / 4{,}143 km^2$), the reservoir level rises so steeply by the medium or large-sized storm. Also, the basin has YongDam dam ($930 km^2$, completed in 2001), as shown in Fig 1. Two flood control points at the downstream of DaeChung dam, which attract lots of the attentions due to the frequent flooding, are GongJu and KyuAm. As a multipurpose dam, the DaeChung

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dam is operated mainly for flood control, water supply, and energy generation. The flood events selected for applying CSUDP during flood are one between of Aug.30 01:00 ~ Sep.5 24:00. During the selected floods above Hydrological conditions are total rainfall(204mm), maximum inflow (5,890m^3/sec), Highest reservoir stage (77.15EL.m), and maxium release (1,700m^3/sec).

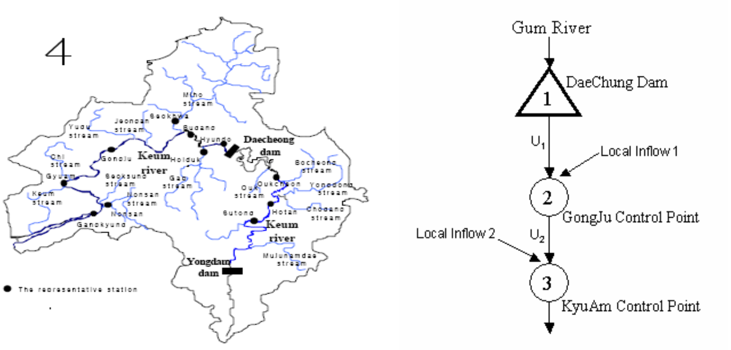

Fig 1. Location map and schematic layout of Gum River Basin in Korea

3. Reservoir optimization

3.1 Formulation of Reservoir System Operational Problem

The collected natural inflows of the upstream reservoirs in the Gum River Basin are represented in Fig. 2 and also illustrates actual local inflows of control points. Use of the CSUDP is illustrated here with a subsystem of the Gum River. The subsystem, shown in Fig. 1, includes one flood control storage reservoir which is DaeChung dam and two flood control points of downstream. These are considered as the state variables to develop the operation model for flood control in the Gum River Basin.

For the operation of reservoir for flood control problem, the proposed Dynamic Programming (DP) model considers the following two objectives: We now quantify each of the two objectives considered in the DP model. The objective functions and restrictions on the variables include continuity or mass balance and upper and lower bounds on release are expressed as follows:

· Objective 1 minimizes the downstream flooding effects; $\min f_1 = \sum_{t=1}^{T}\sum_{i=1}^{N}(Q_{it} - DF_i)^2$.

· Objective 2 minimizes the assuring optimal policies within the actual possible release, and can be represented by the following way; $\min f_2 = \sum_{t=1}^{T}\sum_{i=1}^{N}(u_{it} - u_{it,\max})^2$.

where Q_{it} = release from node i (decision variable) during the time interval t in(m^3/s) and DF_i = maximum experience (known) flood for design flood (m^3/s), u_{it} = node release at the end of time interval t, $u_{it,\max}$ = maximum node release at the end of time interval t.

We now formulate the composite objective function as follows; $\min Z = w_1 f_1 + w_2 f_2$. Where w_1 = penalty value for design flood and w_2 = penalty value for spill capacity. The weighting coefficients reflect the priority of these objectives, and a judicious selection of their values is crucial to achieving a balance.

Certain combinations of the objectives are neither desirable nor infeasible, and some of the objectives can be treated as hard constraints (Barros, Tsai et al. 2003). The constraint set includes the flow continuity, maximum storage variation, and maximum and minimum allowable release. Specially, the following types of constraints are considered;

$$x_{i,t+1} = x + I - u,\ x_{i,\min} \le x \le x_{i,\max},\ u_{i,\min} \le u \le u_{i,\max},\ \text{and}\ Q_{it} \le DF_i \qquad (1)$$

where $x_{it} = i^{th}$ node storage levels at the beginning of time interval t; $x_{i,t+1} = i^{th}$ node storage levels at the end of time interval t; I_{it} =unregulated local flows during time period t; T = total number of time intervals; and N = total number of nodes.

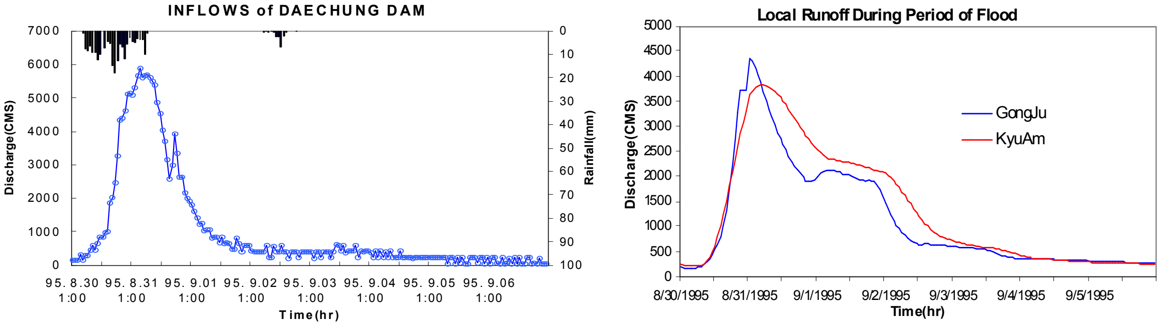

Fig 2. The collected natural inflows of the upstream reservoir and Control point

The system variables are bounded from above and below (Equation 1) due to various physical restrictions and capacities, and the individual objective functions may be nonlinear and reflect differing dynamic characteristics (Ko, Fontane et al. 1992). A hypothetical loss function which is objective function defining the loss due to non ideal reservoir operation is assumed to exist (Karamouz and Houck 1987). In the objective function, the various weighting factors are involved. For example, in the first objective node 1 has zero value of weighting factor because this term should not be considered at these nodes. But node 2 and 3 has weighting factor which value totally depends on the decision maker's judgment. Thus the weighting factors of objective and state variable were involved to flexibly implement under given hydrologic conditions or ranking of priorities (Shim, Fontane et al. 2002). The second terms of the objective function restricts derived release to the actual possible release. The Korea Water Resources Corporation (KOWACO) provided water level-storage volume relationship and water level maximum spill relationship. The simple curve fitting analysis was performed based on these data. The results is that

$$u_{i,\max} = 0.0029 * \left(\frac{x_i + x_{i+1}}{2}\right)^2 + 5.3297 * \left(\frac{x_i + x_{i+1}}{2}\right) - 4{,}520.4.$$

The DP problem was solved using a backward moving procedure, starting at the last stage and finding the optimal operating policy at each stage until a stationary solution was obtained.

3.2 The Operation of DaeChung Reservoir System for Flood Control

The Muskingum method is a commonly used hydrologic routing method for handling a variable discharge-storage relationship.

$$O_{j+1} = C_0 I_{j+1} + C_1 I_j + C_2 O_j \qquad (6a)$$

where,

$$C_0 = \frac{-(KX - 0.5\Delta t)}{K - KX + 0.5\Delta t}, C_1 = \frac{KX + 0.5\Delta t}{K - KX + 0.5\Delta t}, C_2 = \frac{K - KX - 0.5\Delta t}{K - KX + 0.5\Delta t},\ C_{0+} C_{1+} C_2 = 1 \qquad (6b)$$

According to the method of state dynamic of real time flood forecasting by Labadie (1988) and Shim (Shim, Fontane et al. 2002). The routing coefficients are successively calculated at current iteration k as $\alpha_{l,t}(u^{(k-1)}, QO^{(k-1)}) = u_t^{i,(k)} / QO_{l,t}^{(k)}$ $(\text{for}\, i = 1,\ldots,N; t = 1,\ldots,T; l = 1,\ldots,L)$. where, flow rates at the upstream and downstream of reach $l(u_t^{i,(k)}, QO_{l,t}^{(k)}, respectively)$ are obtained directly from the hydrologic flood routing model that simulates water discharges based on given status of system, $u^{(k-1)}$ and $QO^{(k-1)}$which are calculated from the optimization model in the previous iteration, $k-1$ (Shim, Fontane et al. 2002)

Gross storage in the main reservoir is 1,490MCM with 450MCM of inactive storage. A volume of 250MCM is allocated for flood control during the rainy season and 790MCM is allocated for conservation purposes. Selection of $delx$ in CSUDP is extremely important since it affects execution time, computer storage requirements, and solution accuracy. Current array dimensioning in CSUDP requires that for one-dimensional problems, $delx$ and the bounds must be selected by the user (Labadie 1999). Based on the criterion above, the $delxi$, $delxf$, and $delu$ were selected as 50, 0.01, and 0.001 respectively. The splicing option is also available whereby the user can specify an initial coarse interval $delxi$ and a final desired interval $delxf < delxi$. The use of the splicing option can significantly reduce execution time, but there is danger in missing the global optimal solution unless care is taken (Labadie 1999). In this study, the value of the splicing factor was 5.

The '95 flood event was simulated using the water level of reservoir according to the pre-release of flood control release. The comparison charts of recorded results and the simulation results are shown in Fig. 3. The peak release in DaeChung dam can be reduced from the actual operation result of 1,690CMS to 1,609CMS and the highest water level can be lowered from the actual operation result of EL. 82.55m to EL. 81.56m by using the CSUDP. Also, the effect of CSUDP in GongJu and KyuAm control points were similar to above results, that is the maximum discharge could be reduced from the actual operation result of 4,166CMS to 3,824CMS and the highest water level can be lowered from the actual operation result of EL. 7.3m to EL. 6.9m in case of KyuAm. The case study showed that by using CSUDP, possible catastrophic floods could be prevented by reducing the peak releases of each dam and lowering the highest reservoir water levels and minimizing the downstream flood flow. The maximum utilization of the reservoir common capacity can be extremely difficult decision for dam operator to make considering its urgent situation during a severe flood.

Thus, it is necessary to develop more reliable hydrologic prediction techniques and to apply them to actual situations in real-time. Also, another study, which can validate the useful application of this system, will be continued research and further experiments.

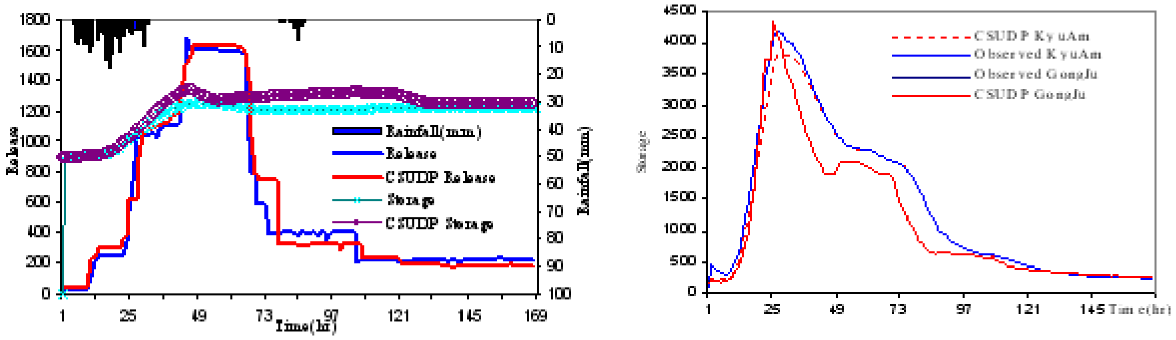

Fig 3. The release and storage of DaeChung dam and the flood flow at Gonju and Kyuam

3. Conclusions

Based on the test cases and hypothetical objective function, the CSUDP model performed better than actual operation. The results were successful, however, it is recommend that further research and experiments should be conducted to ensure its flexibility and robustness. It is believed that such a system could enable the water managers or operators to make more reliable and efficient decision for reservoir operation. It is a difficult task to efficiently and reliably manage reservoirs that are subject to natural uncertainties and multi-purpose operational requirements. CSUDP enables the decision makers to evaluate operational alternatives conveniently by calculated data. The results of study for ‘1995 flood event in the Gum River Basin have shown that CSUDP can work better than actual operation to minimize downstream flood impacts and to find optimal release amount of DaeChung dam.

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