Integrated Approach for Basin Reservoirs System Operation
(유역 저수지 시스템의 통합적 운영기법)

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1. Introduction

The importance of water quality issues has grown in parallel with industrialization and population growth in past decades. Water quantity and quality problems should be attacked simultaneously to cope with shortages in water quantity due to the limited availability of water resources, diversification of the sources of pollutants, and higher pollutant concentrations.

The complexity of modern water resources planning and management requires broad consideration of multiple objectives, tradeoffs, and a variety of noncommensurable benefits. Since most large scale reservoir systems serve multiple purposes, multiple goals and objectives are required in planning and evaluation of the system. In order to plan and operate these systems in a truly multipurpose fashion, comprehensive reevaluation of the management of existing water projects as well as systematic integrated planning for new storage projects is required.

The need for integrated operational strategies confronts the system manager with a difficult task. Expanding the scope of the system for more integrated analysis greatly multiplies the potential number of alternative operational policies. This is further complicated by conflicting objectives, stochastic hydrology, and uncertain consumptive water use. Optimal coordination of the many facets of such a system requires the assistance of computer modeling tools to provide information on which to base rational operational decisions. These tools should be adaptable enough for both operational planning uses, as well as actual real-time decision support (Labadie, 1989).

Due to the differing objectives for the operation of river basin water resources systems, difficult problems may arise for water resources managers since multiobjectives may be in direct conflict or competition with each other. Development of

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general methodologies for basin-wide water resources system planning and operation which consider both water quantity and water quality control are important issues for water and environmental managers and engineers.

2. Methodology Proposed in This Study

Two fundamental questions which should be raised for integrated basin water quantity and quality control problems are:

1) How much water should be released from each upstream reservoir for each time period to meet the downstream water quality objectives based on the concept of dilution effect while simultaneously maximizing water quantity objectives?
2) To what degree should the wastewater be treated for the areas between the headwater storages and the downstream water quality control point based on the optimal waste load allocation (WLA) strategies?

This research provides a methodology in order for answering the first question. A basin-wide reservoir system optimization model, H3DP, which simultaneously considers the downstream river water quality objectives has been developed. CSUDP, a generalized dynamic programming model (Labadie, 1990), was selected to develop this multipurpose, multi-reservoir system optimization model based on the incremental dynamic programming (IDP) algorithm.

QUAL2E-UNCAS, a generalized streamflow water quality model developed by US EPA(1987), was utilized to initially develop a basin stream water quality prediction model, Q2LF, and then, to develop a water quality computation subroutine at the downstream target control points as functions of headwater releases. The developed subroutine, QUAL, is a component of the water quantity and quality module, incorporated into the reservoir system operation model.

A case study was used to demonstrate the integrated basin water resources and water quality planning and operation for the Han river basin.

3. Reservoir System in the Han River Basin

The Han river basin has a drainage area of 26,200 km2 and discharges about 18,000 million (MCM) annually. The river consists of two main branches, the North Han and the South Han that confluence about 35 km upstream from the capital city of Seoul.

There are nine reservoirs with hydropower plants in the basin. Twe multipurpose storage reservoirs including Soyang and Chungju Main and one flow-through reservoir, Chungju R/R are managed by Korea Water Resources Corporation. The other storage reservoir, Hwachon, and five other small-scale flow-through reservoirs are managed by Korea Electric Power Corporation for the single purpose of hydro-energy generation.

The main objectives of the existing multipurpose reservoir system in the basin include flood control, low flow augmentation for water supply, hydropower generation, water quality enhancement, and recreation. Especially, the operation of the three headwater storage projects, Hwachon, Soyang, and Chungju system, is fundamental to meet the municipal and industrial water supply of the Seoul metropolitan area. Releases from these three reservoirs in the basin also have a direct impact on water quality throughout the basin. These releases are major variables as inputs to the water quality models.

4. Development of the H3DP Model

A deterministic, three-dimensional discrete incremental dynamic programming approach was used to develop the Han river reservoir system optimization model, H3DP. The Weighting Method (Zadeh, 1963) is used for the problem formulation to combine the following seven objectives into a single scalar function. To convert all objectives into summation type objective(F1), the six max(min) and min(max) objectives were transformed into summation type objectives by minimizing the squared sum of deviations from targets of firm flow or water quality standards. By this conversion, essentially a goal programming problem (Ignizio, 1976) is created. The seven principal objectives considered in the formulation of the system are based on current needs in the basin considering downstream water quality control objectives:

F1 = Maximization of the total annual energy from all the hydro-power plants considered in the system.
F2 = Maximization of monthly firm water supply from Hwachon reservoir.
F3 = Maximization of monthly firm water supply from Soyang reservoir.
F4 = Maximization of monthly firm water supply from Chungju reservoir.
F5 = Maximization of monthly firm basin water supply at the downstream control point (Paldang reservoir).

F6 = Minimization of the maximum BOD violation from its target standard at the entrance of Paldang reservoir from the North Han river.

F7 = Minimization of the maximum BOD violation from its target standard at the entrance of Paldang reservoir from the South Han river.

Then the model for the Han river basin, H3DP, can be expressed as the following vector optimization problem subject to system state equations and corresponding system boundary constraints:

$$F = Max[w_1F_1 + w_2F_2 + w_3F_3 + w_4F_4 + w_5F_5 + w_6F_6 + w_7F_7] \tag{1}$$

Subject to,

$$u_{it} = X_{it} - X_{i,t+1} + I_{it} - E_t(X_{it}, X_{i,t+1}) - D_{it} + R_{ij}u_{it} \quad ;\text{for} \quad t = 1, \ldots, T, \quad i = 1,2,3 \tag{2}$$

$$u_{4t} = I_{4t} + u_{3t} - E_t(X_{3t}) - D_{4t} \quad ;\text{for} \quad t = 1, \ldots, T, \quad i = 4 \tag{3}$$

$$X_{it} \text{ min} \leq X_{it} \leq X_{it} \text{ max} \quad ;\text{ for} \quad t = 1, \ldots, T+1, \quad i = 1,2,3,4 \tag{4}$$

$$u_{it} \text{ min} \leq u_{it} \leq u_{it} \text{ max} \quad ;\text{ for} \quad t = 1, \ldots\ldots, T, \quad i = 1,2,3,4 \tag{5}$$

Where,

I_{it} = Reservoir inflow to i-th reservoir during period t ;

$E_t(X_{it},\ X_{i,t+1})$ = Volume of evaporation loss from i-th reservoir during period t as a function of average surface area of the i-th reservoir during the period ;

D_{it} = Water depletion from upstream of the i-th reservoir during period t ;

R_{ij} = System configuration matrix (N*N vector) ;

w_k = Weightig factor for k-th objective, k=1,2,3,4,5 ;

The developed model optimizes the monthly operation of the Hwachon and Soyang Projects on the North Han river and Chungju Main Project on the South Han river. Since the Chungju Re-regulation reservoir is considered as a flow-through reservoir, its storage level is assumed to be constant. Objectives of flood control and direct depletion for diversion are considered as fixed constraints in the model. The other flow-through reservoir, Paldang, which is located at the confluence of the North and the South Han rivers, is considered as a water quantity (basin firm water supply) and water quality control point due to its important functions as a principal water depletion site for the downstream lower Han river basin where the Seoul metropolitan area is located.

4. Model Calibration and Verification

Based on the problem formulation for the Han river reservoir system optimization and the corresponding input data files, calibration and verification of the H3DP verified that the model had the ability to closely represent the physical processes.

Two years (1992 and 1993) of monthly historic reservoir inflow data, reservoir and hydro-power plant operation data were chosen for this work. Calibration was initiated using 1993 inflow data together with the reservoir and power plant operation record. Verification was performed using a different set of flow and operational records for 1992. Incremental local flow between three upstream reservoirs and the downstream control point (Paldang) was calculated by subtracting upstream reservoir release records (Hwachon, Soyang, and Chungju R/R) from historic inflow records at Paldang. Initial and final storages of each reservoir were adopted as boundary conditions of the system based on their historic record and each reservoir's beginning of the month storage was input as initial storage trajectories.

5. Case Study

In terms of integrated river basin water quantity and quality management, it is important to analyze the possibility of downstream water quality management through the systematic operation of the upstream reservoirs. In addition, tradeoff analysis between the reservoirs system benefits and the water quality improvement should be confirmed.

Utilizing the integrated river-reservoir system operation model, the following example applications were carried out for performance evaluation of the developed system:

(1) Comparative analysis of alternatives for system objectives ;

(2) Tradeoff analysis between water quantity and water quality objectives.

For this case study, a monthly time step for a one year operation period was selected. All the alternative analysis is based on 1993 hydrologic conditions.

6. Summary

One of the major concerns in this research, especially with environmentally related objectives, is how to plan and operate large-scale upstream reservoir systems within a river basin such that water quality problems at the downstream area are not induced, while still satisfying other system objectives.

This study presents performance analysis considering both water quantity and quality objectives to examine the possibility of water quality management through upstream storage project operation and to assess the variability of system benefit from multi-reservoir system operation against the degree of the improvement of downstream water quality.

The results of the research reveal the practical possibility of deriving optimal integrated multi-reservoir system operational strategies which simultaneously consider downstream water quality control. Nondominated solutions for further tradeoff analysis to assess the variability of system benefit from a multi-reservoir system against the improvement of downstream water quality can be derived with ease by parametrically changing the assigned weights for water quality objectives (w_6 and w_7) and running H3DP model.

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