Ⅱ-44 OPTIMAL REAL-TIME RESERVOIR OPERATION USING GENETIC ALGORITHMS

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1. INTRODUCTION

In this study, *genetic algorithms* (GAs) are used to solve an optimization model for the operation of the system that provides the water supply of Matsuyama City, capital of Ehime Prefecture. The system consists of a multipurpose reservoir named Ishite River Dam and a set of 26 wells located around the Shigenobu River (Fig. 1). The reservoir controls the over flow of Ishite River and provides half of the water supply of Matsuyama while the underground water of Shigenobu River provides the other half. The dam is also used for irrigation of the northern area of Ishite River. The aim is to determine the best allocation of water from the reservoir and the set of wells that attend to the greatest extent possible the demands for city supply and irrigation. Another objective is to maintain the reservoir storage as close as possible to a given target storage in order to not let it decrease considerably. Besides, the allocation of water should not compromise the operation of the system violating its constraints and leading it to a collapse.

2. MATERIALS AND METHODS

The three main decision variables of the model are shown in Fig. 1: Q_{rel} allocation of water from the dam for city supply; Q_{well} allocation of water from the wells for city supply; and Q_{irr} allocation of water from the dam for irrigation.

According to the objectives, the mathematical model for the operation over an operating horizon of N days may be written as shown by the expressions (1) (7). The objective function is formed by the sum of deviations of releases and storage volumes from their targets (T_{dem}, T_{irr}, and T_{stor} for city supply, irrigation and storage, respectively). Constraints are composed by continuity equation, limitations of the components of the system, etc.

$$\textit{minimize} \quad \sum_{t=1}^{N} \left\{ \left(\frac{Q_{rel}^{t} + Q_{well}^{t} - T_{dem}^{t}}{T_{dem}^{t}} \right)^2 + \left(\frac{Q_{irr}^{t} - T_{irr}^{t}}{T_{irr}^{t}} \right)^2 + \left(\frac{V_{stor}^{t} - T_{stor}}{T_{stor}} \right)^2 \right\} \quad (1)$$

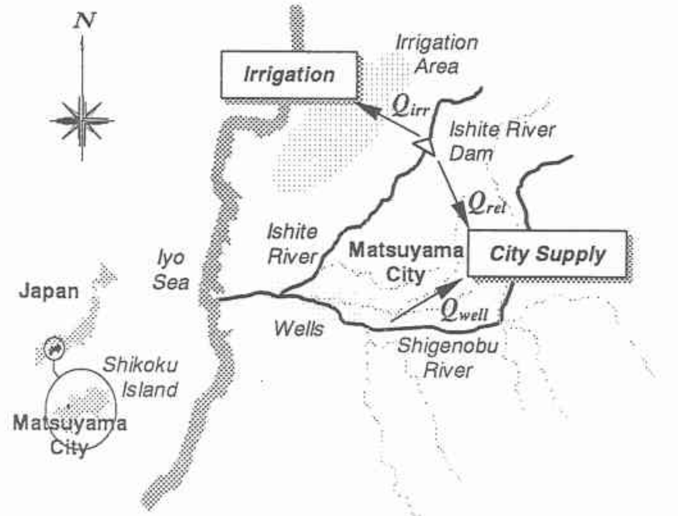

Figure 1. Location and layout of the system.

subject to

a) Continuity equation for the reservoir:

$$V_{stor}^{t+1} = V_{stor}^{t} + V_{inf}^{t} - Q_{rel}^{t} - Q_{irr}^{t} - V_{spill}^{t}, \; t = 1,\ldots,N \quad (2)$$

$$(t: \text{day}; V_{inf}: \text{inflow}; V_{spill}: \text{spill})$$

b) Storage volume (V_{stor}) can vary only between maximum ($V_{stor}^{\max}$) and dead storage of the reservoir (V_{stor}^{dead}):

$$V_{stor}^{\text{dead}} \le V_{stor}^{t} \le V_{stor}^{\max}, \; t = 1,\ldots,N \quad (3)$$

c) Water provided by the wells depends on the precipitation (P) and cannot be greater than the capacity of the underground water purification plants ($Q_{well}^{\max}$):

$$Q_{well}^{t} \le f(P^{t}), \; t = 1,\ldots,N \quad (4)$$

$$Q_{well}^{t} \le Q_{well}^{\max}, \; t = 1,\ldots,N \quad (5)$$

d) Water released from the reservoir cannot be greater than the capacity of the surface water purification plants ($Q_{rel}^{\max}$):

$$Q_{rel}^{t} \le Q_{rel}^{\max}, \; t = 1,\ldots,N \quad (6)$$

e) Nonnegativity constraints:

$$Q_{rel}^{t} \ge 0; Q_{well}^{t} \ge 0; Q_{irr}^{t} \ge 0, \; t = 1,\ldots,N \quad (7)$$

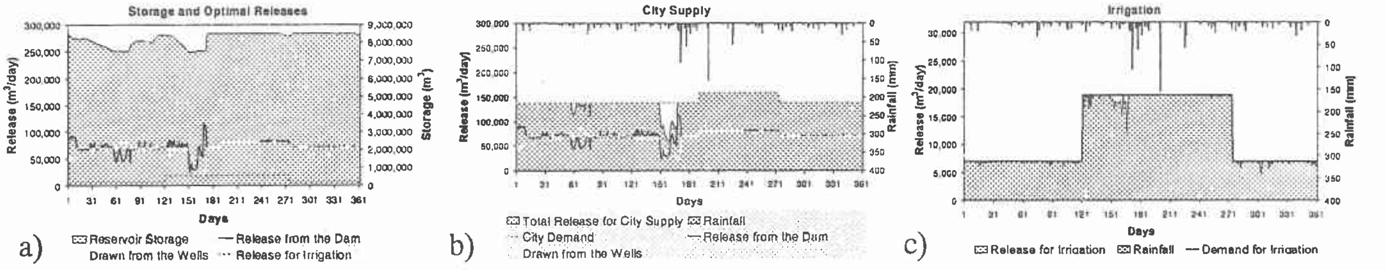

Figure 2. Optimal operation by the SQP method.

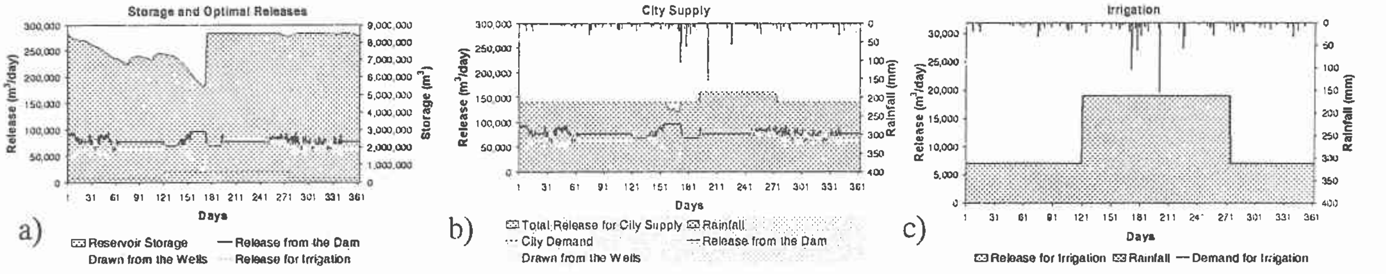

Figure 3. Optimal operation by the SCE–UA method.

Considering T the index of the current operating day, T_{tot} the total number of days of operation, and N the number of days in the operating horizon, the steps of the simulation process in real–time are as follows: 1. Set $T = 1$ ($T = 1, 2, \quad , T_{tot}$) and specify the initial reservoir storage (e.g., target storage); 2. Forecast the rainfall for the next N days. Use the forecasted rainfall to estimate the inflows to the reservoir and the amount of water available in the wells for the next N days; 3. Use the GA–based optimization technique to solve problem (1)–(7) and obtain the optimal reservoir releases and amount of water to be drawn from the wells during the next N days; 4. Implement the first day s releases/drawn; 5. Update the reservoir storage using the actual reservoir inflow and the selected releases. Set $T = T + 1$; 6. If $T > T_{tot}$ stop, otherwise go to step 2.

To solve the optimization model (1)–(7) the *Shuffled Complex Evolution Algorithm* (SCE–UA) [1] was used. In this method, the population of points is partitioned into complexes that evolve separately and are periodically shuffled to ensure information sharing. As the search progresses, the entire population tends to converge towards the neighborhood of the global optimum.

The same operation problem was solved by using a calculus–based procedure, which belongs to the *MATLAB Optimization Toolbox* and uses a *Sequential Quadratic Programming* (SQP) method. In this method, a *Quadratic Programming* (QP) subproblem is solved at each major iteration. A full description of this procedure is found in the toolbox manual [2].

3. RESULTS AND DISCUSSION

Figures 2 and 3 show the results from one operation using the observed rainfall data of the year of 1996 as perfectly forecasted rainfall. Fig. 2 displays the results obtained using the SQP method and Fig. 3 presents the optimal results by the SCE–UA.

It is observed that the method based on genetic algorithm produced better results than the calculus–based technique. The SQP approach has decided not to release enough water to attend the demands during certain days (e.g., days 58 to 78 for city supply) while the SCE–UA found that the demands could still be attended on those days without compromising the system. That means that the genetic algorithm has found values of the objective function lower than the minima found by SQP during those periods.

4. CONCLUSION

The SCE–UA algorithm was used to solve an optimization model for the operation of a multipurpose water resource system in real–time. The genetic algorithm was found to outperform a calculus–based approach and showed to be efficient and robust for solving optimization problems of reservoir operation models.

REFERENCES

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2. *Optimization Toolbox user's guide –version 5.* (1996). The MathWorks Inc., Natick, Massachusetts.