II-17 OPERATION OF ISHITEGAWA DAM BY MATHEMATICAL PROGRAMMING

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1. INTRODUCTION

In regions where water is scarce and its demands are continuously increasing, a better management of the water resources is a must. The city of Matsuyama, in Ehime Prefecture, suffers periodically with problems originated from the scarcity of water. Matsuyama is supplied by a system composed of a reservoir named Ishitegawa Dam and a set of 26 wells located along the Shigenobu River as shown in Figure 1. Half of the total supply comes from the reservoir and the other half is from the underground water of Shigenobu River. In 2002, there was a lack of rainfall over the region and the water level of the reservoir reached 46.6% of the capacity in September, which was lower by 31.8% than that of the average year. Underground water was also measured more than one meter lower than the average year. The population of Matsuyama is constantly growing and therefore there is a necessity of a good development and management of the water resource systems in the region.

Mathematical models of optimization are common tools used for identifying the best set of plans and policies that provide a fair and economical distribution of the available water[1]. In this study, an optimization model is constructed in order to determine the optimal operation of Ishitegawa Dam so that the demands are met as much as possible and the system does not collapse in periods of shortage.

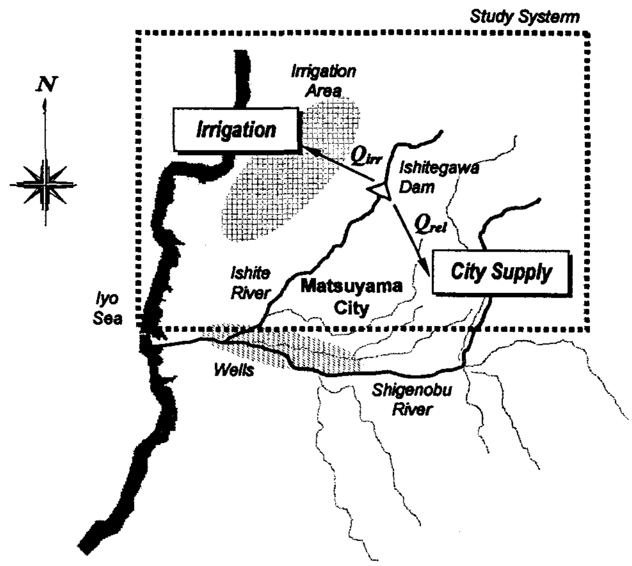

Figure 1. Location and layout of the system.

2. MATERIALS AND METHODS

The reservoir is used for the Matsuyama supply as well as the irrigation of the northern area (550 ha) of the Ishite River. The decision variables of the proposed model are thus the releases of water for city supply (Q_{rel}) and irrigation (Q_{irr}).

The objective of making the allocations meet the demands to the greatest extent possible can be accomplished by writing an objective function as the sum of deviations of releases from their targets. One more term is added to assure that the reservoir storage will not decrease significantly. Constraints are composed by continuity equation, limitations of the components of the system, etc:

$$\min \sum_{t=1}^{N} \left\{ \alpha_1 \left(\frac{Q_{rel}^t - T_{dem}^t}{T_{dem}^t} \right)^2 + \alpha_2 \left(\frac{Q_{irr}^t - T_{irr}^t}{T_{irr}^t} \right)^2 + \alpha_3 \left(\frac{V_{stor}^t - T_{stor}^t}{T_{stor}^t} \right)^2 \right\} \quad (1)$$

subject to

$$V_{stor}^1 = V_{stor}^0 + V_{inf}^1 - Q_{rel}^1 - Q_{irr}^1 - V_{spill}^1 ; \quad (2)$$

$$V_{stor}^{t+1} = V_{stor}^t + V_{inf}^{t+1} - Q_{rel}^{t+1} - Q_{irr}^{t+1} - V_{spill}^{t+1} ; \forall t \quad (3)$$

$$Q_{rel}^t \le T_{dem}^t ; \forall t \quad (4)$$

$$Q_{rel}^t \le Q_{rel}^{\max} ; \forall t \quad (5)$$

$$Q_{irr}^t \le T_{irr}^t ; \forall t \quad (6)$$

$$Q_{irr}^t \le Q_{irr}^{\max} ; \forall t \quad (7)$$

$$V_{stor}^{\text{dead}} \le V_{stor}^t \le V_{stor}^{\max} ; \forall t \quad (8)$$

$$Q_{rel}^t \ge 0; Q_{irr}^t \ge 0 ; \forall t \quad (9)$$

in which t is the time index; N is the operating horizon; α_1, α_2, α_3 are coefficients that measure the relative importance given to each of the reservoir operation purposes; Q_{rel}^t is the amount of water allocated for city supply from the reservoir; T_{dem}^t is the demand for city supply; Q_{irr}^t is the allocation for

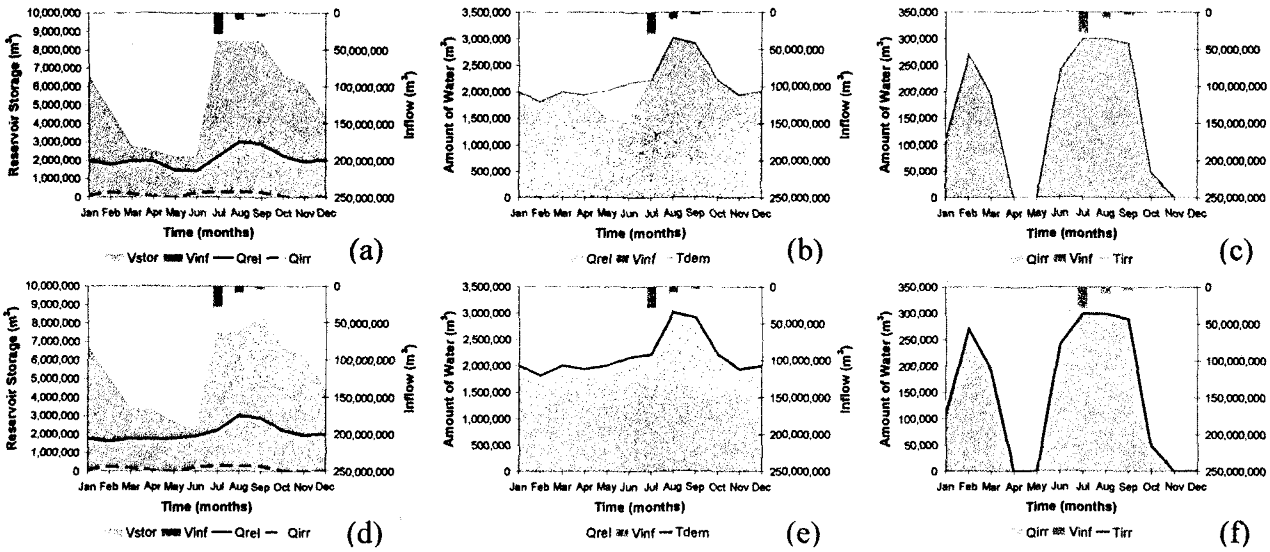

Figure 2. Results from simulation (a, b, c) and optimization (d, e, f).

irrigation from the reservoir; T_{irr}^{t} is the demand for irrigation; V_{stor}^{t} is the reservoir storage; T_{stor}^{t} is the target reservoir storage; V_{stor}^{0} is the initial storage; V_{inf}^{t} is the inflow to the reservoir; V_{spill}^{t} is the amount of water that might spill from the weir; $Q_{rel}^{\max}$ is the total capacity of the surface water treatment plants; $Q_{irr}^{\max}$ is the capacity of the irrigation system; V_{stor}^{dead} is the dead storage of the reservoir; and $V_{stor}^{\max}$ is the capacity of the reservoir.

3. RESULTS AND DISCUSSION

Figure 2 presents the results from the application of the optimization model (1)-(9) to the long-term (monthly) operation of Ishitegawa Dam. The average monthly data of inflows of 1997 were used for the operations ($N = 12$ months). For comparison purposes, fictitious simulations, where all the demands should be met when possible, were considered and compared with optimal operations for several scenarios. The model was solved by *Quadratic Programming* (QP). Figures on the left display the variation of the reservoir storage and the optimal releases along the year. Centered figures consider only the city supply and show how the allocations from the dam meet the target demands. Right-sided figures illustrate how the allocations from the dam for irrigation satisfy the demands.

The results from the fictitious simulations show that if the releases have to always meet the demands, the system will collapse if there is not enough rainfall. That is what happens in the city supply in May and June. During these periods the difference between demands and releases are very high and the situation would become critical if the operation of the dam was carried out to fulfill all the demands. The optimization process, on the other hand, does not let this occur. It tries to alleviate the difference between allocations and demands for city supply in the critical months by decreasing the releases for other months. During the months when the allocations are decreased the population could be encouraged to rationing.

4. CONCLUSIONS AND FURTHER STUDY

In this work, an optimization problem based on quadratic programming was applied to the long-term operation of Ishitegawa Dam in Matsuyama, Ehime. The results showed that the optimization model found more reasonable operating policies than simulations that tried to meet all the demands without taking the future situation into account. By using optimization models, the performance of the system can be analyzed for several scenarios and conditions. Reservoir operators can take advantage of this as screening tools in the decision making process. The proposed optimization model can be implemented for real-time operation by varying the value of the operating horizon (N). In real-time short-term operation, however, the operating horizon needs to be long which is not always possible due to the inaccuracy of the forecast information. Further research is thus needed to integrate short and long term information in real-time.

REFERENCES

1) Yeh, W. W-G. (1985). "Reservoir management and operations models: a state-of-the-art review". *Water Resour. Res.*, 21(12), 1797-1818.