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Extended Abstract

Optimal Operation Modeling of Reservoirs using Mixed Integer Linear Programming (MILP)

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Introduction

Floods, droughts, water scarcity, water contaminants, and optimal use of water resources including reservoirs and aquifers are some of the many water problems present today. These will be even more noticeable in the future. The optimal operation of reservoirs is one of the best ways in water resources management to deal with such problems and other unwanted temporal and spatial distributions of water. Optimization techniques have become increasingly important in the management and operation of complex reservoir systems over the past three decades. Some researches have provided an extensive literature review and evaluation of various optimization methods and their corresponding models. Each optimization method has its advantages and disadvantages that make them suitable for some problems. Selection of each method depends on the characteristics of the system being considered, data availability, optimization objectives, and the problem constraints.

Water resources allocation problems are mostly addressed using Linear Programming (LP) solvers. LP is applied to problems that can be formulated as a separable objective function with linear constraints. However in most of the practical water management applications neither the objective function nor the constraints are of a linear nature.

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On the other hand a common difficulty in linear programming formulations for reservoir operation and management problems is that the storage- continuity constraints cannot explicitly enforce controls on the spills. This may drive the solution of the optimization model to report a spill even if the reservoir is not full. Even though a spill term is included in the continuity equation, there are no constraints to control spills in relation to the reservoir capacity and storage. Results of other research such as Moy et al. (1986) and Shih and Revelle (1994) reported this problem in their work. This article applied the mixed integer linear programming technique based on a system approach to model the operation and management of the multiobjective multireservoir system of the Tehran-Karaj plane. As mentioned before there are some nonlinearities in the constraints. These have been changed into linear relations using piecewise linearization and then solved by MILP.

Methodology

The formulation of this research is based on the Mixed Integer Linear Programming (MILP) and includes the objective function and the constraints. The topology of the system is being considered based on the network flow optimization. The interconnected reservoir system is represented as a network of nodes and links. Nodes are storage- or non-storage points representing confluences, diversions, sinks or sources. Links symbolize reservoir releases, channels or pipes tunnels, spillways, water demands, carryover storages, and evaporation or other loses. All the nodes and links own a value and upper and lower bounds. In the network flow model with minimum cost, all the nodes and links hold a coefficient as penalty or priority which goes into the objective function.

The software designed for this study includes the GUI (graphical user interface), the database, and the solver. It has been developed for the optimized operation of the multiobjective multireservoir systems. GUI has been developed so that the system configuration and basic constraints can easily be defined and the desired results of the modeling can be reported. Using this GUI the user describes the physical system (reservoirs, channels, pumping plants, and consumers), the physical constraints (upper and lower bounds in reservoirs, channels, etc.), and the allocation priorities and penalties. The software then converts this user defined configuration into the mathematical formats and relations. Time series data are read from a separate database. Then the entire problem is passed to the solver. The MILP solver returns the results for the decision variables into the time series database. The model output can finally be viewed through the software user interface.

Case study

In this research, the developed model has been used for operation and management of the multiobjective mutireservoir of the Tehran plane. The graphical scheme of this system is shown in Fig. 1.

The trends of the water demands in this region are considered in the simulation based on the population growth through the historical period. The water supply system includes 5 dams (Lar, Latian, Karaj, Mamlu, and Taleghan), two tunnels, some agriculture regions and a few cities. Taleghan and Mamlu reservoir is under construction. The objective function for this system presented in Equation 1 consists of 5 types of principle decision variables; the storage in reservoirs, spillage from reservoirs, agricultural demand shortages, domestic demand shortages, and the flow in control channels.

$$\text{Minimize } OBJ : \sum_{1}^{n}\sum_{1}^{T} C_1.CH_{nT} + \sum_{1}^{n}\sum_{1}^{T} C_2.HO_{nT} + \sum_{1}^{n}\sum_{1}^{T} C_3.PL_{nT} + \sum_{1}^{n}\sum_{1}^{T} C_4.ST_{nT} + \sum_{1}^{n}\sum_{1}^{T} C_5.US_{nT} \quad (1)$$

The objective is to minimize the severe shortages during the period of study (usually the critical period) so that the safe yield is enhanced. The amount of the total outflow from the basin is very important to evaluate the performance of the conservation operation. Priorities are orderly given to the demand shortfall reduction, decreasing outflow from the basin, increasing hydroelectric production, and maintaining more storage.

Constraints in this model includes the continuity equation at each node, physical limitation of each reservoir in the system with zone segments for piecewise linearization, restriction of the bounds on releases, and restriction of the bounds on spillage constraints for up and downstream demand shortages.

Results and Discussion

The real operational behavior of the system is used to verify the results of the model.

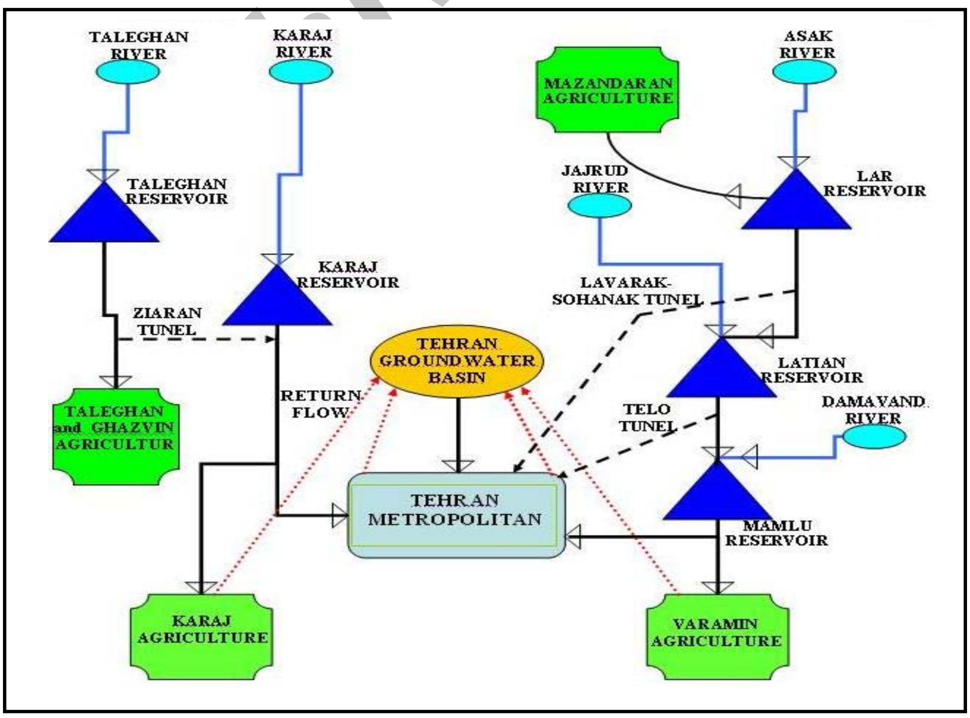

Figure 1- Schematic representation of the Multi-Reservoir System of the Tehran plane

This includes reservoir release and storage variations over time, and amount and time of spillage and shortfalls on demands from each individual dam. Fig. 2 shows a comparison of the total storage of Karaj reservoir calculated by the model against the historical data.

Results showed that the developed model by MILP have better performance compared to the LP model and also the historical operation. Based on MILP results the amount of spillway has reduced and the storage in and releases from the reservoirs have increased.

Conclusion

This optimization study was not directly focused on the economical efficiency but considered the optimized multiple reservoir operation from the perspective of the coordinated operation.

The inputs of the model are data that are readily available. Also the inputs and parameters are presented in the form of spreadsheet, which may be easily entered and edited through integrated graphical forms. Therefore, the model is easily modifiable and very flexible and the cost coefficients or priorities of objectives can always be changed by the will and need of the operator.

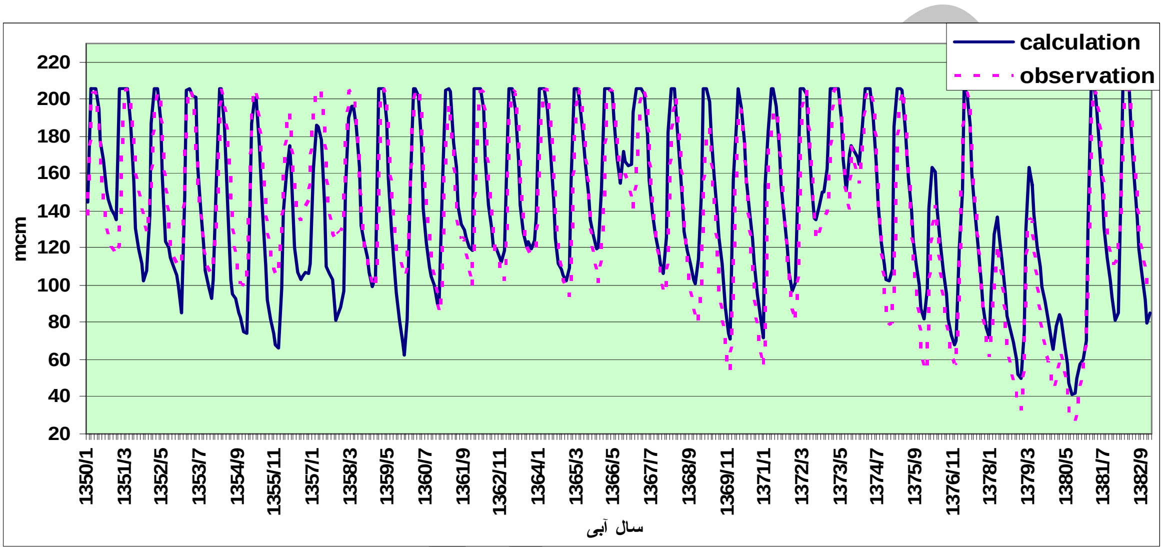

Figure 2- Comparisons of the observed and calculated storage in Karaj reservoir during the the historical period

***Keywords*:** Reservoir Operation, Mixed Integer Linear Programming (MILP), Tehran Plain, Modeling

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