AN APPLICATION OF MONTE CARLO OPTIMIZATION TO RESERVOIR OPERATION

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This paper investigates the determination of reservoir operating rules by Monte Carlo optimization or Implicit Stochastic Optimization (ISO). The basic principle of the ISO technique is to use a deterministic optimization model to find optimal reservoir releases over an operating horizon assuming a particular sequence of inputs (reservoir inflows). The ensemble of optimal releases is then examined in order to develop a release policy which can be used for practical operation.

In studies regarding the construction of reservoir operating policies via Monte Carlo optimization, linear and nonlinear regression is commonly used to delineate the rules from the data obtained by the deterministic optimization model. However, as was pointed out by Willis et al. (1984), examinations of release-storage-inflow relationships often reveal highly nonlinear trends and are not appropriate for simple regression analysis. In this study, the optimal releases are related to storage and inflow, as usual, but the selection of releases based on the two other variables is carried out by means of two-dimensional numerical interpolation instead of the frequently used least squares analysis.

The deterministic optimization model assumes that the main objective of the operation is to find the allocations of water that best satisfy the respective demands without compromising the system. Another aim is to keep the storage high whenever possible, i.e., every time there exists alternative optimal solutions for the releases.

The Monte Carlo procedure has three basic steps: 1) Generate M synthetic N-month sequences of inflow; 2) For each inflow realization, find the optimal releases for all N months by the deterministic optimization model; 3) Use the ensemble of optimal releases ($M \times N$ data) to develop operating rules for each month of the year.

The releases obtained by the optimization model are related to reservoir storage at the end of the previous time period and the inflow during the current time period. One relationship (rule) is determined for each month of the year. The relationships are established by surface graphs which are fitted to the data via numerical interpolation.

The ISO procedure was applied to the Ishitegawa Dam reservoir which supplies the city of Matsuyama, located in Ehime Prefecture, Japan. The Monte Carlo process was run under an operating horizon of 288 months (24 years). 100 sequences of synthetic monthly inflow data were generated by the non-stationary autoregressive model of Thomas-Fiering (Celeste et al., 2004). The first and last two years of data were rejected to avoid problems with boundary conditions. This provided 24,000 optimal monthly releases. The data of releases, initial storages and inflows for the months of January through December were grouped and plotted. This process generated 12 surfaces, one for each month.

After the definition of the release rules, they were applied to a new realization of 10 years of monthly inflows and compared to the results obtained from the utilization of the deterministic optimization model assuming the inflows as perfect forecasts. Simulations based on the so-called *Standard Linear Operating Policy* or SLOP, were also used for comparison. The correlation regarding water allocation between the results obtained by the release rules and optimization under perfect forecast was 90%. The correlation of the SLOP with optimization was only 65%. The results (Fig. 1) show us that the simulation using the ISO-generated rules tries to allocate water in a way very similar to the optimization. This indicates that the results from the derived release policies were quite satisfactory given the fact they have information only on the previous reservoir storage and current inflow whereas the optimization model has knowledge of inflows for the whole operating horizon and thus better means to define superior policies.

(a)

(b)

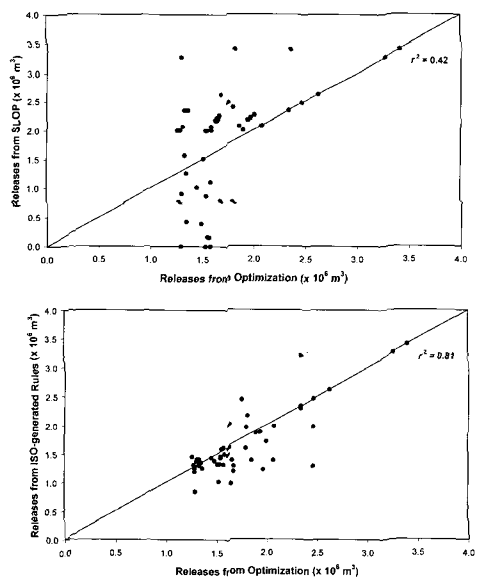

Fig. 1 Scatter graphs (release data) for (a) optimization × SLOP and (b) optimization × ISO-generated rules.

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