Optimal Operation of Water Resources of Storage Reservoirs by Controlling Seasonal Floods, Allavian Dam Case Study

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ABSTRACT

Optimal operation of storage reservoirs and estimation of flood volume in torrential seasons has an important role in flood control and can reduce additional costs. Inflexibility of flood warning systems and uncertainty of long-term and short-term hydrological phenomena prediction in real-time are major problems in the management of reservoirs in dams. In this study, flood routing in Allavian Dam in East Azerbaijan province in Iran is simulated. Based on the Standard Operation Policy (SOP), real time operating of the reservoir dam is obtained by flood routing and modeling with one of the optimization methods. The results of this study showed that simulated optimal model of dam reservoir for 300-years flood of the Sufichai River is estimated to be 25(MCM), which could be released according to the needs of downstream. Finally, for determining the input and output flow based on operation conditions at the beginning of each month, it is proposed to modify the operating rule curve of Allavian dam in flood seasons, which in this case volume of floods could be temporarily stored in reservoir.

KEYWORDS: Flood control, Flood routing, Operation management, Rule Curve, Sufichai River.

1. INTRODUCTION

In general, the evaluation and response to natural risks in urban areas and the circumstances of this science can be effective on the programming and process of integrated management of water resources. In flood management, this can have a significant effect on environment and prevention of damages resulting from outside city floods, which are often heavy with numerous disastrous casualties. Regarding this subject, extensive studies have been carried out on flood control in the world. Dams are not only the most important reservoirs to store water, but also they can be used as appropriate tools to control the flood.

Guang and Wang [1] used Rung-Kutta non-linear algorithm to solve the differential equation in flood control of dam reservoirs. In this method, time series in flood routing are considered in static points that are approximated by characteristics method between dependent variable errors in each time series. Its feedback can be calculated by the reverse Rung-Kutta method. In the study, Rung-Kutta method is used in the integrated system of flood control and it is applied to control the inflow flood to Huiling dam reservoir in Hunjiang basin in China Northeast whose results indicate this algorithm is more reliable and applicable in flood control and routing [1]. In evaluating the control and management methods of flood, Green et al. [2] have introduced the storage and delay dams to be used in flood control. Examining the delay reservoirs, annual report of American army (corps of engineering) has presented proofs on the decrease of peak discharge of flood because of storage dams’ operation [2]. Damal et al. [3] performing the best control system in one of sub basins of Athen city came to the conclusion that using a cavity and construction a dam in the upstream basin, so that a year flood could be controlled and these constructions will be the most efficient method to protect the city from economical, social and environmental issues [3].

In the previous researches, empirical hydrologic methods have been used to calculation of flood control. These methods are approximate methods and have significant errors. Therefore in this paper, characteristic method was used to reducing the error. This method has less error in comparison with empirical hydrologic methods.

The scientific contributions of this paper are: 1) Determine the optimum level of water delivery that will result in the most effective economic and physical use of available water supply. 2) Develop methods for measuring the economic impact that may be expected to result from shortages of water occurring in large water resource systems. 3) Modify existing optimization and simulation procedures as may be needed to provide minimum-cost optimization capabilities for any desired level of development.

The purpose of this study is the optimal operation of the reservoir of Alavian dam in order to control the flood and make optimum use of water resources in the studied area. In this paper, the Alavian dam is considered as the case study and studies have been done regarding flood routing and the use of target functions to optimum management of dam reservoirs allocation to demands of downstream by minimizing the target function and applying constraints such as reservoir volume, demands and outflow of downstream of dam over various months during the operation.

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MATERIALS AND METHODS

To control the flood in the area, it is needed that various methods of flood control be carefully examined and evaluated so that among various methods, the applicable method proportionate to various potentials of that area be finally applied. Examining the effective factors on dam operation represents the volume of inflow to dam reservoir. That is obtained from target function and a linear optimization model to control the flood.

**Target Function**

Mathematical programming models give an optimum resolution to system operation so that all of constrains of the system is estimated regarding maximization or minimization of the target function. Unlike simulation models, the optimization models determine the operation policy in a way that the specified aim or aims is/are optimized. In other words, optimization proceeds to all possible choices in determination [4]. A hydraulic system always contains a number of constraints which are able to the basis of the target function to achieve the optimum case [5]. In this paper, optimum operation of the dam, determination of curve role for operation of dam reservoir in normal condition and calculation of inflow volume in flood seasons of the reservoir are examined.

**Description of Major Parts of the Optimization Model**

A model using linear programming is presented for optimum management of the allocation of dam reservoir for downstream demands, in which the optimum model that has a minimization target function, calculates the monthly inadequacy by applying constrains such as reservoir volume, demands and outflows during various months in operation period. In this direction, the linear optimization model is extended by using the continuity equations and physical constrains of reservoir volume [6]. This model is run by using Maple-V software and the optimum answers along with other decision variable are calculated.

The continuity equation in the system according to regulated outflow variable, reservoir volume in the beginning, inflow to the reservoir and evaporation from lake level, is as follow [7]:

\[
S_{i+1} = (S_i + Q_i + P_i - R_i - EV_i), \quad i = 1, 2, ..., 12
\]  

In which, \(S_i\): Storage values in initial time, \(S_{i+1}\): Storage values in time \((i+1)\), \(Q_i\): Inflow in time \(i\), \(R_i\): Outflow in time \(i\), \(P_i\): Rainfall values on Reservoir Lake in time series \((i)\), \(EV_i\): Evaporation values of Reservoir Lake in time series \((i)\).

The monthly deficiency percent of system is followed:

\[
f_i = \left( \frac{D_i - R_i}{D_i} \right) \times 100
\]  

In which, \(D_i\): Water demands values in time \(i\), \(f_i\): Monthly deficiency percent in period \(i\). The Average annual deficiency \(K\) is followed:

\[
K = \frac{\sum_{i=1}^{12} f_i}{12}
\]  

Also for preventing of water wasting and over consuming, it is assumption that \(R_i \leq D_i\). Therefore, the target function may be written as:

\[
\text{Minimize } f_i
\]  

It is assumed that reservoir is empty in the initial period and reservoir dead volume is volume storage and on the other hand, due to annual management, storage volume of each year’s beginning is equal to the values of next year's first period; thus:

\[
S_i = S_{i+1}, \quad S_1 = 0
\]  

Therefore, monthly amount discharge per month should be always higher or equal to demanding water that is required for; thus:

\[R_i \geq (\text{Demanding water values per month})\]

In the mentioned model, relation 4is as the target function and other relations are considered as a limitation.

**Studied Storage Dam**

Alavian dam is an embankment dam with central clayey core and an elevation of 80 meters bed rock. The dam crest is 935 meters long, 10 meters wide and the total volume of dam body is 4.8(MCM). To improve the quality of bed
rock in foundation and sides of the dam, the diaphragm is constructed by drilling in a major row 49 meters deep and in two minor rows which are less deeper. References level of the spillway, dam crest, normal level of reservoir water and maximum possible level of water in reservoir are 1568, 1572.65, 1568 and 1572 meters above sea level, respectively. The reservoir volume at normal level, its efficient volume and dead storage are 60, 57 and 3(MCM) per year, respectively. The adjustable volume of water is about 123(MCM) per year. Figure 1 shows the position of Soufi Chai basin and Alavian Dam. Alavian Dam reservoir dimensions and other specifications are showed in Table 1.

![Figure 1. Location of Soufi Chai basin and Alavian dam in the study](image)

**Table 1.** Alavian Dam reservoir dimensions and other specifications

<table>
<thead>
<tr>
<th>General dimensions</th>
<th>Hydraulic specifications</th>
<th>Spill way specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of dam</td>
<td>Total volume of reservoir</td>
<td>Type of spillway</td>
</tr>
<tr>
<td>Embankment dam with central clayey core</td>
<td>60 (MCM)</td>
<td>Free side spillway with gate</td>
</tr>
<tr>
<td>Elevation from bed rock</td>
<td>80 meters</td>
<td>Efficient volume</td>
</tr>
<tr>
<td>Elevation from river bed</td>
<td>74 meters</td>
<td>Dead storage</td>
</tr>
<tr>
<td>Wide of dam crest</td>
<td>10 meters</td>
<td>Adjustable volume of water</td>
</tr>
<tr>
<td>Wide of dam in foundation (average)</td>
<td>410 meters</td>
<td>Level of dam crest</td>
</tr>
<tr>
<td>Long of dam crest</td>
<td>935 meters</td>
<td>Normal level of reservoir water</td>
</tr>
<tr>
<td>The total volume of dam body</td>
<td>4.8(MCM)</td>
<td>Maximum level of water</td>
</tr>
</tbody>
</table>

**RESULTS AND DISCUSSION**

Examining the monthly mean discharge regimes of Soufi Chai on the basis of recorded runoff statistics at the sight of Tazehkand station shows the long-term average of monthly discharge at the inlet of Alavian Dam during the statistical period from the year 1973 through 2007. According to Table 2, monthly mean discharge is equal to 3.9(m$^3$/s).

**Table 2.** Monthly mean, maximum and minimum values of discharge in Soufi Chai River at the dam during the statistical period from 1973 through 2007

<table>
<thead>
<tr>
<th>Month</th>
<th>Parameter (m$^3$/s)</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>Aug</th>
<th>Sep</th>
<th>monthly</th>
</tr>
</thead>
<tbody>
<tr>
<td>max</td>
<td></td>
<td>1.61</td>
<td>3.09</td>
<td>6.1</td>
<td>21.71</td>
<td>30.98</td>
<td>19.16</td>
<td>5.48</td>
<td>2.55</td>
<td>3.11</td>
<td>3.12</td>
<td>2.89</td>
<td>2.1</td>
<td>30.98</td>
</tr>
<tr>
<td>mean</td>
<td></td>
<td>1.21</td>
<td>1.43</td>
<td>1.39</td>
<td>1.368</td>
<td>1.46</td>
<td>2.56</td>
<td>8.96</td>
<td>13.69</td>
<td>9.62</td>
<td>2.68</td>
<td>1.25</td>
<td>0.98</td>
<td>3.9</td>
</tr>
<tr>
<td>min</td>
<td></td>
<td>0.45</td>
<td>0.36</td>
<td>0.72</td>
<td>1.918</td>
<td>4.93</td>
<td>4.49</td>
<td>0.69</td>
<td>0.69</td>
<td>0.74</td>
<td>0.75</td>
<td>0.68</td>
<td>0.61</td>
<td>0.36</td>
</tr>
</tbody>
</table>

To examine the method of operating Alavian Dam, needs accurate information of inflow values to the reservoir during the operating period of the dam. Monthly time series of inflow and outflow from the reservoir can be considered by using this information. The method of operation of the Alavian Dam can be seen from Figure 2. The following results can be extracted from this Figure:

- Present time delay between inflow and outflow shows that the dam has been able to perform its storage role effectively,
- Outflows have considerable values in the months during which inflow values to reservoir are little. This shows there is water demand during these months.
Based on the studies of USACE\textsuperscript{1}, suitable management of reservoir contains a set of operative processes, laws, programs or plans which supply the operation’s aims the best. In spite of the fact that numerous studies are done on the operation of a reservoir, the operation of reservoir in drought and flooding conditions have been less taken into consideration, and fewer researchers have engaged in this field. During operation time in normal conditions, when the inflow to reservoir is sufficient, the purposes of reservoir operation will not confront any difficulties. In this condition, the standard operation policy of reservoir is the SOP\textsuperscript{2} law. In this policy, the outflow is a function of available water \cite{8}. In Figure 3, restricting laws in various cases compared to SOP method are shown. According to this Figure, if available water is less than or equal to the target value, the total water will come out of the reservoir. If total available water is more than demand, the excess amount will be kept in the reservoir so that it spills after the reservoir is fully filled. In this study, to consider the restricting laws, the linear optimization model is used. Considering the restricting laws and role curve, the flood control (Upper curve), target volume (Middle curve) and constant storage (Lower curve) curves in Figure 4 are simultaneously used. These curves are used in programming stage as a guide to operate the dam reservoir. In fact, a balance is created between inadequacies, flood control and storage aims by using the restricting laws along with reservoir role curves. Figure 4 shows Role curves for a single reservoir system to flood control.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Fig2.png}
\caption{Figure 2. Monthly time series of inflow and outflow from of Alavian Dam.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Fig3.png}
\caption{Figure 3. Monthly Reservoir Release Rules \cite{8}}
\end{figure}

\begin{itemize}
\item\textsuperscript{1}United States Army Corps of Engineering
\item\textsuperscript{2}Standard Operation Policy
\end{itemize}
In this study, to present an optimum model for dam reservoir to control the flood and to maximize the available water downstream of the dam, the rule curve of the dam should be proportionate to the demand in operation periods. The rule curve was obtained on the basis of linear programming model and adjustable volume in order to fulfillment of downstream demands with considering boundary condition and input data such as discharge-scale curve of entering water and volume of reservoir (60 MCM) in normal level (122.4 m). In addition, the correction of curve of dam operation to control the flood and the optimal allocation of water on the basis of target functions are complied. Compiling the policy of operating the optimum model and considering the uncertainties in monthly inflows, improves the long-term system operation under the programming. In Figure 5, the operating curve rule of Alavian dam operation from 1997 through 2003 is compared.

It is concluded from the operating rule curve of the dam that the rule curve of basic dam designs below the curves of the operation period of dam reservoir, and practically the prediction of control space of reservoir flood is a combination of efficient volume and control volume of reservoir flood. This volume is little during the operation period relative to spring floods of the river and causes loss of a large amount of flood volume. By remodeling the reservoir operating rule curve, we can decrease the peak of the occurred flood hydrograph in downstream by keeping a volume of flood in reservoir and delay the time of peak. Since Souf Chay river floods every spring (approximately 70 percent of volume of river floods), it is proper to allocate some of the reservoir volume for the purpose of flood control during this season. In other word, with releasing of dam water in the short period of year and increasing volume of flood control, it can be performed controlling floods in the times of peak and operating the occurred flood in downstream of dam well. Indeed, time management of water storage in dam reservoir is performed with this scenario. Figure 6 shows the comparison of flood control operation (level) with operating rule curve’s flood draining time during the years of operation. These curves show disagreement between the flood occurrence time and downstream demands. Because the reservoir volume is full in the wet seasons, a portion of the volume is released without the downstream demand.
It is concluded from the above graph that during the operation years, because of the quantity of downstream demands, consumptions are less than the basic prediction and more than the simulated results from system, therefore to supply the demands in the long term, necessary plans such as controlling more storage volume of flood must be carried out.

CONCLUSION

In this paper, It have beeen tried to increase the volume of storage reservoir in Alavian Dam reservoir from 2.5 to 4(MCM) in order to control flood with using an optimization model, as far as it is possible to control the 300 years-flood (almost equal to 25 MCM). Therefore to obtain an optimum model in the reservoir operation with flood control and supply drinking and agricultural water, it is suggested that the following methods be used in the operation of Alavian Dam reservoir:

- Modifying the operation model of the dam according to operation time of reservoirs in which supplying the demands for 100 percent is essential in 80 percent of the cases, to obtain the monthly optimal operating rule curve.
- Using more percentage of flood volume to supply downstream demands, that is the daily or momentary operation of gates and flood control so that the release rate of 300-year floods according to the reservoir potential will be less than the inflow rate of the flood.
- Increasing the reservoir volume by breaching sediments to raise the storage volume of the flood.
- Increasing the spillway elevation by using gates to control flood and to raise the normal level of dam reservoir.
- Increasing the volume of downstream diversion dam to supply the demands in the long term in the duration of dam operation.
- To use a nonstructural package that contains snows survey stations, seasonal flood prediction, risk management and to apply the Remote Sensing (RS) and flood warning systems.

REFERENCES