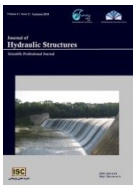
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Optimization of Reservoir Operation for Real-Time Flood Control with Emphasis on Forecast Uncertainty: A case study of Dez Reservoir

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Abstract

This study presents a novel approach for real-time flood control by optimizing operation of a dam reservoir during the flood. The real-time flood control (RTFC) with decision support systems (DSS) has recently received significant attention in flood management of reservoir dams, which results in the timely flood forecasts. However, the fundamental operational challenge of using this method is to determine optimized decisions of the reservoir management before the occurrence of flood, and optimal use of the pre-release to reduce the flood damages. In addition to this optimization challenge, since the timely forecasts are derived by employing the probabilistic methods, they would always associate with epistemic uncertainty. As a result, quantifying and considering these uncertainties in the flood control would result in reducing the risk of flood damage that can be evaluated by minimizing the expected value of the loss function represented in terms of flood damage. Timely and continuous forecasting of inflow and reservoir operation management will be implemented before the occurrence of flood until it ends. In order to address the above challenges, a novel simulation-optimization methodology, by taking into account uncertainty, is developed; and illustrated on a case study of Dez reservoir, as a highly important reservoir system in south-west of Iran, to optimize the performance of this reservoir, during the floods. Accordingly, a new water resource management has been proposed and tested. The results derived from the proposed method, indicate a significant reduction in the peak release from the reservoir, and the improved operation of the Dez reservoir in controlling the flood at real-time, which will reduce damages in the downstream area.

Keywords: Real-time flood control, Optimization of reservoir operation, Uncertainty quantification, Expected flood damage

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1. Introduction

Reservoir dams are considered as one of the most important infrastructures for flood control [1], and it is very important to use their maximum efficiency during floods. One of the most important challenges in the optimal management of floods in reservoirs is to timely react before occurrence of floods, and also manage floods in real-time when the floods is occurred. Real-time flood control is a newly developed method of flood management in reservoirs, which is based on the probabilistic forecasts, and use these forecasts for planning and managing reservoir operation/release. In the meantime, employing the hydrological forecasts and making optimal decisions to release the flow in order to reduce the risk of flood damage in the downstream is the decisive and considered as the most important issue [1].

Considering the history of dam construction and the importance of flood control in reservoir dams, optimizing the performance of reservoir dams in flood management is considered as one of the most important research challenges in this field. However, many of the recent studies have attempted to improve reservoir performance in flood control without employing the forecasts [2-6]. Since, the inflow flood to the reservoir was not known in advance, the authors of these studies have mainly used a single functional policy to operate the gated spillway of dams during the flood. As a result, the provided method was based on the inflow flood into the reservoir and the reservoir level [6]. In this regard, Sinske (1983) proposed a three-outflow for reservoir release including, without-damage, low-damage and acceptable-damage at downstream, and the flood control levels in the reservoir based on these outflows should be then determined [3,5]. This approach which is known as Sinske's method was further developed by Akanal et al. [2] and Hacktanir et al. [3]. They proposed fifteen-step policies to control and operate spillway gates of the reservoir in non-flood prediction systems. In this method, the volume of reservoir flood control is divided into a number of small storage volumes, and for each of these, the level of reservoir and opening of the gated spillway is determined based on the trial-and-error criteria. This approach that is also known as Multi Stage Method (MSM) has been further developed by several researchers in the last two decades [5, 6]. The developed method in these studies was implemented based on the water levels observations that can be used to operate the dam and reservoir release, without taking into account any inflow forecasts. Samani et al. [5] and Zargar et al. [6] have applied this method to the Karun water resources system.

In order to overcome the limitations of the above methods, various probabilistic approaches have been recently proposed in the field of water resources management, at which the future states of the system of interest can be efficiently predicted in a probabilistic manner by quantifying surrounding uncertainties. In particular, the probabilistic risk assessment methods for reservoir flood management have recently started to receive more attention by the researchers [7]. This could be due to this fact that the forecasts and estimates computed from the probabilistic methods can be reported with uncertainty. This could be very useful to amend the inaccurate assessments of the risk and consequences of flood damage at downstream, suggested by the conventional methods as discussed above. As a result, the forecasts and optimized reservoir decisions should be revised by taking into account the uncertainty in forecasts through determining the probabilities and including their impacts in the decisions to control the floods and reservoir management [7-18].

In many of these mechanisms, uncertainties in rainfall-runoff models have been investigated using various approaches, in particular the Monte Carlo (MC) methods. For instance, Yimeng Sun et al. [8] quantified flood uncertainties (by three grade levels, A, B, and C, at which each of them represents the different forecast accuracy level) using the MC method, then generated different occurrence modes based on tree-based probability functions, and finally optimized

reservoir operation. The optimization has been derived by maximizing the water level in the reservoir, in terms of the defined risk of reservoir overtopping. Bianusi et al. [16] developed an alternative method to obtain a reservoir flood control policy using calibration of model parameters based on the risk analysis method. In this method, the loss function in terms of reservoir water levels and volume was first developed, and optimization would be then performed using the linear programming. This methodology is structured in three steps: characterization, synthesis and comparison of the performance of the model for each parameter. Therefore, instead of using uncertain forecasts, they have used synthesis of the parameter. Juan Chen et al. [17] proposed another approach to control the floods in real-time based on risk analysis of the emergencies of the series reservoirs, in which the reservoir level control, dam overtopping and dam's failure were considered. The proposed methodology includes three components: emergency scenarios establishing, MC simulations, and risk analysis. The emergency scenarios include earthquakes, extreme floods and failure of spillways of a reservoir. For each emergency scenario, the MC simulations were conducted to predict the real-time flood control operation of reservoirs, considering the uncertainty of reservoir inflows. The risk analysis of the operation schedules was also carried out, and the risk of dam overtopping was finally assessed. They have illustrated the proposed methodology on a case study of the Daduhe River Basin in China. Malde et al. [19] developed a fully Bayesian probabilistic method by employing the Gaussian emulator (GPE) for coastal flood risk analysis in which the MC method was used to estimate the hyper-parameters of the GPE. The updated GPE by observing the data through Bayesian updating can be directly used for forecasting the future unseen scenarios and quantifying the forecasts' uncertainty [9-14].

Despite the improvement of techniques and methods in computing the hydrological forecasts in the recent years using the numerical and simulation-based methods, due to the probabilistic nature of these forecasts, they are mixed with some degrees of epistemic uncertainty (Daneshkhah et al., [10]; Daneshkhah and Bedford., [13]; Bedford et al., [11]; Daneshkhah et al., [14]). Consequently, the focus must shift from forecasting to assessing uncertainty, as realistically as possible, evaluating its implications to risk and exploring ways to prepare to face it. Therefore, it is very important to quantify uncertainty in the inflow forecasts computed from the probabilistic models, and take them into account in reservoir management of flow release. This could have great impact in maintaining stability of the dam and related facilities, and consequently mitigate the possible damages to the human lives and infrastructure at downstream. Myo Lin et al. [20] present a predictive model-based control scheme for real-time operation of a multi-reservoir system in the Sittaung river basin in Myanmar. The control objectives are to minimize the storage deviations in the reservoirs, to minimize flood risks at a downstream as a vulnerable place, and to maximize hydropower generation by using penalty coefficients to water levels and flows of the system in deviation from objectives. The focus of this study was to address the conflicting objectives in the reservoirs including two days horizon forecast, and longer horizon by taking into account uncertainty in the forecast that is very crucial in the decision-making. Victor Cuevas-Velasquez et al. [21] present a real-time flood control model for dams with gate-controlled spillways that brings together the advantages of an optimization model based on mixed integer linear programming (MILP) and a case-based learning scheme using Bayesian networks (BNs). A BN model was designed to reproduce the causal relationship between inflows; outflows and reservoir storage. The model was trained with synthetic events generated with the use of the MILP model. The BN produces a probabilistic description of recommended dam outflows over a time horizon of 1 to 5 h for the Talave reservoir in Spain. The inflow flood events estimated by applying a semi-distributed event-based hydro-

meteorological model that modeled the main physical processes from the rainfall generation to the estimation of the inflow floods (see also Smith and Daneshkhah, [23] for a Bayesian sensitivity/uncertainty analysis of BN models). However, the real-time forecasts with uncertainty have not been directly used in this study. In another relevant study, Zhang et al., [22] propose a human-machine interactive method, namely real-time optimization model enhanced by data assimilation (ROMEDA) for the reservoirs which have complex storage and stage relations (e.g., long and narrow reservoirs). This system is composed of an optimization model to search for optimal releases, reservoir operators' choices based on their experiences, knowledge, and behaviors, a reservoir storage-stage simulation and data assimilation schedule to update the storage based on real-time reservoir stage observations. The forecast horizon of the real-time flood control model for the reservoir is only 3 days.

In this study, a novel approach has been proposed to take into account the uncertainty in short-term flood forecasts, to make the optimal decision to reservoir release and flood control optimization. In order to achieve these objectives, a probabilistic approach is developed based on the simulation-optimization model. The proposed methodology provides timely and continuous inflow's forecasts, which can be used in reservoir operation management before the occurrence of the floods to its end. This process progresses with continuous forecasts (rolling-over horizon) and is updated to the end of the floods. In this study, risk mitigation of the flood damages is also evaluated by minimizing the Total Expected Value of Damages (TEVD). The proposed methodology is illustrated on the Dez reservoir where the real-time flood forecasts under uncertainty are first evaluated, and their impacts on the flood control optimization and reservoir operation management are then studied in details.

2. Methodology

2.1. Case study: Dez Reservoir Dam

The Dez River in the Iran has so many floods, and these floods have caused damages to the downstream area. Study of the history of floods in catchments leading to these area shows that the floods in Dez River has the highest frequency compared to other rivers. Dez reservoir dam, in south-west of Iran, is a two-arched concrete type and has been constructed in 1961 with 203m height and about 3300mcm volume. This dam has multi-purpose goals of flood control, water supply and hydropower generation and has two series of tunnel with gated spillway 3000CMS capacity, which in total can discharge flood capacity 6000cms. In addition to spillways, water valves are installed for the power plant and irrigation outflows in the body of the dam. Operation of the dam reservoir is done in the form of monthly normal and flood control rule curves. These rule curves show necessary reservoir leveling in different months of the year. This information in the short-term events conditions cannot guarantee the optimal operation of the reservoir and provide an order to maneuver the spillway gates during floods alone.

The hydrograph diagrams of the inflows to Dez reservoir show a steep shape with a high peak flow within 48 hours after the start of the flood. Therefore, the importance of optimal operation of reservoir volume and also to make optimal decisions to pre-release in the flood control process shows. Table1 shows some Characteristics of Dez reservoir dam.

Table 1. Characteristics of Dez reservoir dam.

Dam Height	203 m	Lake Area (In NWL)	75 km^2
Crest Length	212 m	Lake Area (In NWL)	60 km
Wide of Crest Dam	4.5 m	Max. inflow(10000Yr)	13166 cms
Reservoir Volume	3306 mcm	Base Flow	250 cms

Reservoir release and water level are two effective variables for flood control. Since these variables are a function of the reservoir inflows and on the other hand the inflows are uncertain, so any decision to release in reservoir management will be a probabilistic aspect. Therefore, in this approach, selected release from the reservoir before the flood occurs and to the end of flood, at the appropriate time and to the extent necessary, will be decided and optimized by risk analysis. Every decision to release from the reservoir has consequences, the impact of which is evaluated in risk analysis. Thus:

1) By quantifying the uncertainty in inflow forecast as probabilistic, it is possible to include it in the planning and reservoir release management.
2) By including of probabilistic inflow and risk analysis in the selection of reservoir release decisions, the performance of the reservoir dam in flood management will be improved by minimizing the expected value of damages (TED).

Figure 1 shows the flowchart of the proposal methodology for real-time optimal operation considering inflow forecast uncertainty. As presented in Figure1, this approach includes five main components: Initial information and probabilistic inflows forecast, hydrographs of probabilistic inflows production, simulation of flood routing and optimal based release under constrains, risk analysis by reliability optimization and select based release for reservoir operation. This framework has some loops in real-time flood control processing. The details of the proposed components of models are shown in following sections.

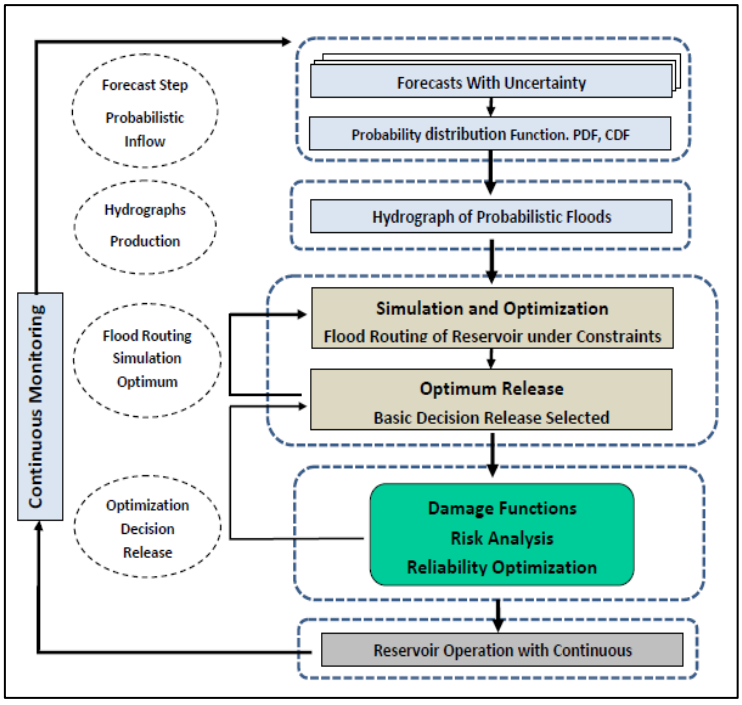


Figure 1.Flowchart of the proposed methodology for reservoir real-time optimal operation considering inflow forecast uncertainty.

2.2. Flood uncertainty and probabilistic inflow intervention in reservoir management

Suitable facilities for forecasting storms and short-term rainfalls are currently available. These forecasts have a 16-day horizon, and with the availability of rainfall-runoff models, flood forecasting up to a 16-day horizon is provided to the reservoir operation system. These forecasts have a probabilistic aspect, and occurrence during floods is always uncertain. Also, as time progresses and near the beginning of the flood, awareness and information on the ongoing flood is expected to increase, and in any case, the amount of uncertainty is changing. In other words, these probabilities will change in each steps of the forecast (for example, the 12 or 24-hour steps in forecasting inflows). Therefore, reservoir management is taking place in uncertain flood conditions, which will require determining the probabilities and including their impact in the decision to release from the reservoir. To investigate the effect of input uncertainty as different probabilities, it is necessary to consider the probability distribution function (PDF). In real time and at each step, the forecast value is assumed as the average probabilities, and its probability distribution function is obtained. This function, which is modified in real time and for each forecast step, is considered to represent the changing flood conditions occurring during the operation of the reservoir. Thus, the cumulative probability distribution function (CDF) is obtained for each step to distribute the reliability. (Similar diagrams as shown in figure 2).
In reservoir management, flood routing is performed for each reliability level and with latest reservoir data, the hydrographs calculated and the selected release decision. The real-time operation is not limited to the initial information, and the latest timely observations will be the basis for the decision by modifying the probability distribution function. Therefore, in this method, the decision for operation is not fixed and definite, and in realtime, based on probabilistic inflows, it searches for the optimal decision release.

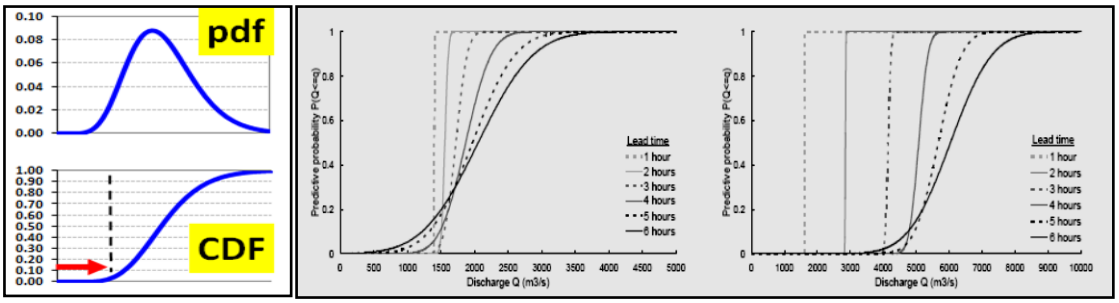


Figure 2. Type diagram for the forecast horizon in the cumulative probability distribution.

3. Simulation-Optimization Model For Reservoir Operation

A) Simulation model

To simulate reservoir operation against different inflows and different release decisions, a simulation model based on the Continuity Equation has been developed as follows:

$$I(t)_i - O(t)_i = dS(t)_i/dt \quad (1)$$

Where, $I(t)_i$ and $O(t)_i$ are inflow and outflow rate, $S(t)i$ is reservoir storage, $dS(t)_i/dt$ rate of reservoir storage change at time (t) and in reliability (i).
It is differential by using the finite difference method for each reliability level (i) as follows:

$$S_t = S_{t-1} + \frac{I_{t-1} + I_t}{2}\Delta t - \frac{O_{t-1} + O_t}{2}\Delta t \quad (2)$$

Since there are conditions and constraints for reservoir operation, the optimal releases are calculated by flood routing optimization.

B) Risk Analysis and Optimization model

The optimization model has been developed in combination with simulation model to making an optimal decision as a basis for release from the reservoir in different modes (with probable inflows). The solution space and limit states for decision making in this model are as follows:

- **Solution space**

To definition the response space, first, the decision limit states are defined in terms of the minimum and maximum possible inflows. Accordingly, the inflow that is selected as the basis and based on which the necessary reservoir release is calculated is called the decision-based flood or, the "base flood" and the similar release is called the "release base or release basis decision". According to the above definition, the limit operating conditions depending on the flood are as follows:

- **Pessimistic state**

In this case, the incoming base flood is assumed to be a flood with a very huge peak discharge (for example, 10,000-year flood) and the reservoir release is calculated based on it and has a large discharge. In this case, if this assumption is not met, the smaller the flood, the operation policy will move more away from optimal performance. In this case, the selected release decision causes to maximum damage in the downstream area.

- **Optimistic state**

In this case, the flood is assumed to be a small peak discharge flood and reservoir release based on it. If this assumption is not met, the larger the flood, the operation policy moves more away from optimal performance. Thus to compensate for less pre-discharge during the selected release period, additional outflow must be release as the flood control process.

- **Decision variable**

Therefore, in the case where the base flood is between the largest and smallest possible flood, the optimal decision can be sought. Comparison of limit operating conditions shows that each inflow that is selected as the based flood imposes two types of damage downstream, which is:

1- Deterministic damages resulting from based flood routing and peak discharge of reservoir release.
2- Probability damages resulting from the routing of probability inflows greater than the based flood.

As the cumulative probability increases, the deterministic damages increase and the Probability damages decrease, and vice versa. Therefore, to minimize the total expected damages (TED), the

sum of deterministic damages and probability damages should be minimized. This concept is shown in the following schematic diagram (Figure 3).

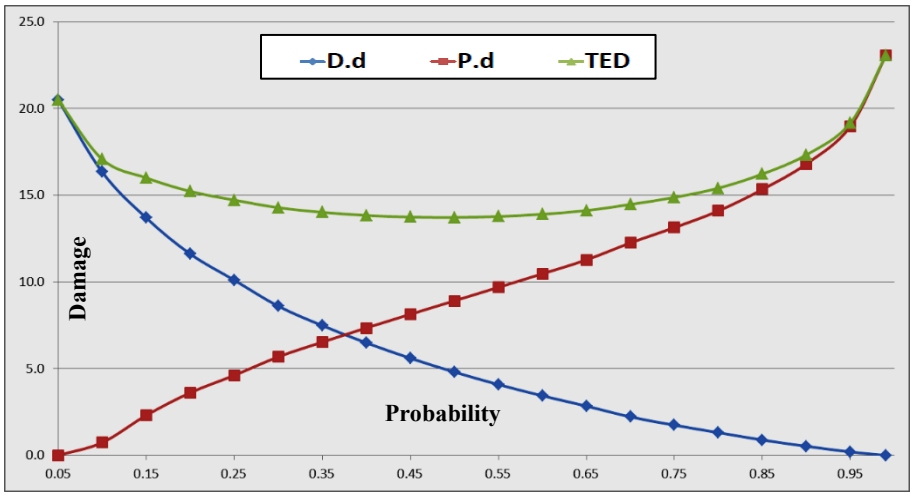


Figure 3. Schematic diagram of D.d, P.d and TED in different probability.

One of the important parts of the model is the calculation of downstream damages. The general form of the damage function versus discharge release from the reservoir is as follows:

$$Damage = fd(QR) \tag{3}$$

Where, QR is Reservoir release discharge and fd is damage function. However, Probability damages are defined as follows:

$$E[Damage] = \int_{-\infty}^{\infty} Damage(p) \times f(p) \times d(p) \tag{4}$$

Where, $E[Damage]$ is the expected damage that occurs with the probability of occurrence of Pi and $f(p)$ is related to the probability distribution function. In a more fragmented term, the damage functions in each step are used in the following simplified way:

$$E[Damage] = \left[\sum \frac{(\text{Damage}_{i+1} + \text{Damage}_i)}{2} \times (P_i - P_{i+1})\right] \tag{5}$$

- **Objective function**

According to these concepts, the objective function, which is formulated to minimize TED, can be summarized as follows:

$$Total\ Expected\ Damage(TED) = Deterministic\ Damage + Risk \quad (1)$$

$$Min\ TED = D(X_1) + ED\left\{\sum P_i \times D[X_i\ |f(i).X_1]\right\} \quad for \quad i > 1 \quad (2)$$

$$D(X_1) = fd(QR_1) \quad (3)$$

$$ED(X_i) = \sum\{(P_{i+1} - P_i) \times [fd(QR_{i+1}) + fd(QR_i) - 2 \times fd(QR_1)]/2\} \quad (4)$$

subject to

$Smin \ll SRi \ll Smax$

$0.05 \ll Pi \ll 0.99$

$QRi \ll QR_{allowable}$

$QR_{Outflow} \ll 350\ cms$

$REL0 \ll 350\ masl$

Where, P_i is cumulative probability (Reliability) for X_i , and X_1 is based decision release, $D(X_1)$ is deterministic downstream damage depended of based decision Release X_1, P_i is Residual risk of probabilistic flood, where: $\sum_1^m Pi = 1 - P_1$, for number of probabilistic floods (m) and P_1 is Reliability of X_1. $Smin$, $Smax$ are minimum and maximum storage of reservoir, respectively. QRi is the release from the reservoir depends on rating curves. $QR_{Outflow}$ is the other outflows (including outlets of hydropower and other gates), $REL0$ is the initial water level of operation for the reservoir.

- **Optimization constraints**

In the optimization model, the following basic criteria and constraints are considered:

- Operation rule curves and all hydraulic considerations and constraints, reservoir storage and hydraulic structures relationships of the dam are taken into account in the model.
- As a basic assumption, the maximum (temporary) storage volume is equal to or less than the available flood control capacity. As the storage, volume becomes less than the flood control capacity, the maximum release increases.
- In order to prepare for the management of future floods, the water level in the reservoir should reach a certain level (target water level) one week after the end of the present flood. For this purpose, at the end of each flood, the reservoir water level will be reduced in order to create a suitable volume for the next flood. The target water level at the end of the flood in this study assumed a maximum of 345masl.
- The initial water level of operation for the reservoir is 345masl.
- In the release from the reservoir, for other outflows (including outlets of hydropower and other gates) the maximum capacity is up to 350cms.
- The spillway Rating curve (Elevation-Discharge relationship) is considered as one of the hydraulic constraints in the simulation models.

4. Results and discussion

According to the described approach, for each flood forecast, a normal probability distribution function is assumed. Considering the index hydrograph, for each flood one hydrograph is

calculated for 16 days with the following assumptions:

1) The maximum Inflow forecast is assumed from 3000cms to 10,000cms.
2) The inflow forecast horizon is available for up to 16 days. This information is global and is provided by sources such as the Global Forecasting System (GFS) and the European Center for Medium-Range Weather Forecasts (ECMWF). Accordingly, with the availability of the maximum forecast inflow and the hydrograph of the basin index and considering the previous and subsequent conditions for it, the hourly flood hydrograph is obtained for each forecast with a base duration of 16 days.
3) In constructing the probabilistic hydrographs for each step, the inflow forecast was considered as an average of the events, and the Normal distribution was then used to compute the probability of each level. Thus, by fragmenting the derived CDF from 5% to 99% in 20 reliability levels, the 20 curves of hourly hydrographs (16-days) can be generated.
4) The start of reaction or the reservoir release for flood control begins 5 days before the start of inflow flood to the reservoir.
5) For the probability distribution function of inflow forecast, the peak of inflow forecasted was considered as the average of events and the standard deviation and coefficients of variation for them are assumed. The concept of maximum coefficient of variation is defined as follows:

- **Maximum coefficient of variation**

The role of probabilistic prediction is to cover errors at the desired reliability level. For this purpose, the flood probability distribution function can be selected so that the largest inflow flood in probability is 99.99% equivalent to 10,000-year of flood design of the dam about 13,000cms (for Dez reservoir) to be achieved. Therefore, the maximum coefficient of variation, the ratio of standard deviation to the mean of forecast, is a parameter in the probability distribution function that averages the probability of occurrence of 99.99% converts to figures close to 13,000cms (10,000-year flood peak). This coefficient is the final limit of the forecast error in this study. In other words, a larger coefficient of variation will lead to the forecast inflow larger than 10,000-year of flood in the reservoir, which is not be practical and is not considered in the present study. Table 2 presents the maximum coefficient of variation related to each of the supposed discharges.

Table 2.Maximum coefficient of variation for each forecast inflow discharge.

Discharge(cms)	3000	4000	5000	6000	7000	8000	9000
Max. C.V.	0.8	0.61	0.44	0.32	0.32	0.17	0.12

It is expected that with the approaching the flood time, the accuracy level of the forecast model will increase and the values will be closer to the real limit. Therefore, it can be expected that on the day of the flood, the coefficient of variation or standard deviation will be at least.

6) According to the previous studies on downstream floodplains, the flood damage function is considered as follows:

$$D = -(2e-06) \times QR^2 + 0.0345 \times \mathrm{QR} - 24.294 \quad (9)$$

Where, D is downstream flood damage and QR is discharge outflow from Dez reservoir.

Therefore, the performance of Dez Reservoir in flood management is investigated for different flood conditions. The results are summarized as follows:

The results are summarized in Table 3 and Table 4 for different forecast inflows. In these tables, the results of optimization and risk analysis are summarized, and finally the selection of the basis for decision making for the two cases 5 days and 2 days before the beginning of flood is presented. Also in Figure 4 and Figure 5 for some sample cases of flood, the changes of the maximum release of the reservoir versus the peak of inflow for different reliability coefficients and finally the decision of the optimal selected basis for release are shown.

Based on these results, in the 5 days before the flood, for different forecasts from 3000cms to 10,000cms, the optimal based release is varied from 756cms to 2156cms, respectively. This is an acceptable achievement for flood control by reservoir management. The results also show that the model tends to have higher reliability coefficients for lower forecast inflows and a decrease in this coefficient for larger forecast inflows. This means that the model has been affected by deterministic damages due to release for high forecast inflows.

The results are also compared with previous flood events of Dez reservoir as well as other recent research achievements. A summary of its comparison with the results of the present study is presented in Table 5 and Table 6.

As can be seen, in the November 1994 Dez dam flood, the peak of inflow and outflow is equal to 4400cms and 2900cms, respectively. The same input conditions are obtained with the approach of the present study with a basis release of 773cms to maximum release 914cms. These values were obtained in the flood of April 2016 with maximum inflow and outflow of 8000cms and 4500cms, equivalent to 1405cms and finally 1829cms.

The MSM method was also used in the recent studies including Zargar et al., [6], at which the maximum inflow from 4597cms to 9026cms and the maximum outflow from 1179cms to 4740cms were reported, respectively. According to the present approach, the maximum outflow of the release for the above inputs and from 5 days to the start of flood with the mentioned criteria, respectively, equivalent to 776cms to 1800cms have been obtained, which shows a significant reduction in outflow.

Also, in Malekmohammadi et al., [7]'s research, for maximum inflow from 3691cms to 4733cms, maximum outflow of 1239cms to 3160cms has been obtained. According to the method of the present study, the discharge of the release base for pre-release in order to control the mentioned floods is obtained from 758cms to 780cms, which has shown a significant decrease compared to the above values.

Table 3. Summary of optimization results and optimal basis release (5 days to start of flood).

Forecast inflow(cms)	3000	4000	5000	6000	7000	8000	9000	10,000
Basis Release(cms)	756	758	788	819	1076	1405	1791	2156

Opt.	Qf=3000cms(Cv=0.9) Qselect=756 cms			Qf=4000cms(Cv=0.61) Qselect=758 cms			Qf=5000cms(Cv=0.44) Qselect=788 cms			Qf=6000cms(Cv=0.32) Qselect=819 cms		
Flood Degree	Pi	IRi cms	QRi cms	Pi	IRi cms	QRi cms	Pi	IRi cms	QRi cms	Pi	IRi cms	QRi cms
1	0.25	1179	266	0.25	2355	498	0.25	3517	723	0.25	4705	954
2	0.5	3000	623	0.5	4000	817	0.5	5000	1011	0.5	6000	1239
3	0.75	4822	977	0.75	5646	1148	0.75	6484	1373	0.75	7296	1614
4	0.99	9282	2221	0.99	9677	2343	0.99	10118	2478	0.99	10467	2584
Opt.	Qf=7000cms(Cv=0.23) Qselect=1076 cms			Qf=8000cms(Cv=0.17) Qselect=1405 cms			Qf=9000cms(Cv=0.12) Qselect=788 cms			Qf=10,000cms(Cv=0.1) Qselect=819 cms		
Flood Degree	Pi	IRi cms	QRi cms	Pi	IRi cms	QRi cms	Pi	IRi cms	QRi cms	Pi	IRi cms	QRi cms
1	0.25	5915	1214	0.25	7083	1551	0.25	8272	1912	0.25	9393	2255
2	0.5	7000	1525	0.5	8000	1829	0.5	9000	2133	0.5	10000	2442
3	0.75	8086	1856	0.75	8918	2110	0.75	9729	2355	0.75	10608	2625
4	0.99	10746	2671	0.99	11164	2795	0.99	11513	2995	0.99	12094	3384

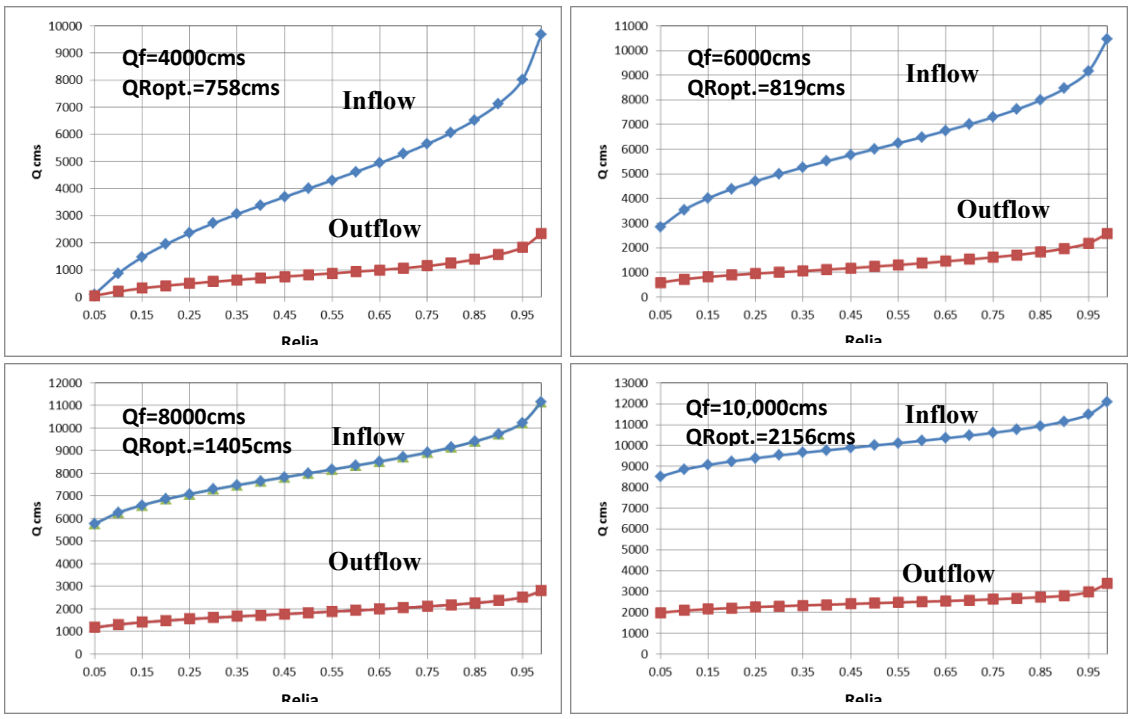


Figure 4. The Maximum Inflow forecast And Outflow for Reliabilities. (5 days to start of flood).

Table 4. Summary of optimization results and optimal basis release (2 days to start of flood).

Forecast inflow(cms)	3000	4000	5000	6000	7000	8000	9000
Basis Release(cms)	777	785	812	1082	1357	1637	1977

Opt.	Qf=3000cms(Cv=0.9) Qselect=777 cms			Qf=4000cms(Cv=0.61) Qselect=785 cms			Qf=5000cms(Cv=0.44) Qselect=812 cms			Qf=6000cms(Cv=0.32) Qselect=1082 cms		
Flood Degree	Pi	IRi cms	QRi cms	Pi	IRi cms	QRi cms	Pi	IRi cms	QRi cms	Pi	IRi cms	QRi cms
1	0.25	1179	286	0.25	2355	553	0.25	3517	812	0.25	4705	1082
2	0.5	3000	698	0.5	4000	925	0.5	5000	1152	0.5	6000	1379
3	0.75	4822	1111	0.75	5646	1295	0.75	6484	1487	0.75	7296	1697
4	0.99	9282	2277	0.99	9677	2395	0.99	10118	2527	0.99	10467	2632

Opt.	Qf=7000cms(Cv=0.23) Qselect=1357 cms			Qf=8000cms(Cv=0.17) Qselect=1637 cms			Qf=9000cms(Cv=0.12) Qselect=1977 cms			Qf=10,000cms(Cv=0.1) Qselect=2309 cms		
Flood Degree	Pi	IRi cms	QRi cms	Pi	IRi cms	QRi cms	Pi	IRi cms	QRi cms	Pi	IRi cms	QRi cms
1	0.25	5915	1356	0.25	7083	1637	0.25	8272	1977	0.25	9393	2309
2	0.5	7000	1616	0.5	8000	1897	0.5	9000	2189	0.5	10000	2491
3	0.75	8086	1920	0.75	8918	2168	0.75	9729	2412	0.75	10608	2674
4	0.99	10746	2717	0.99	11164	2933	0.99	11513	3157	0.99	12094	3554

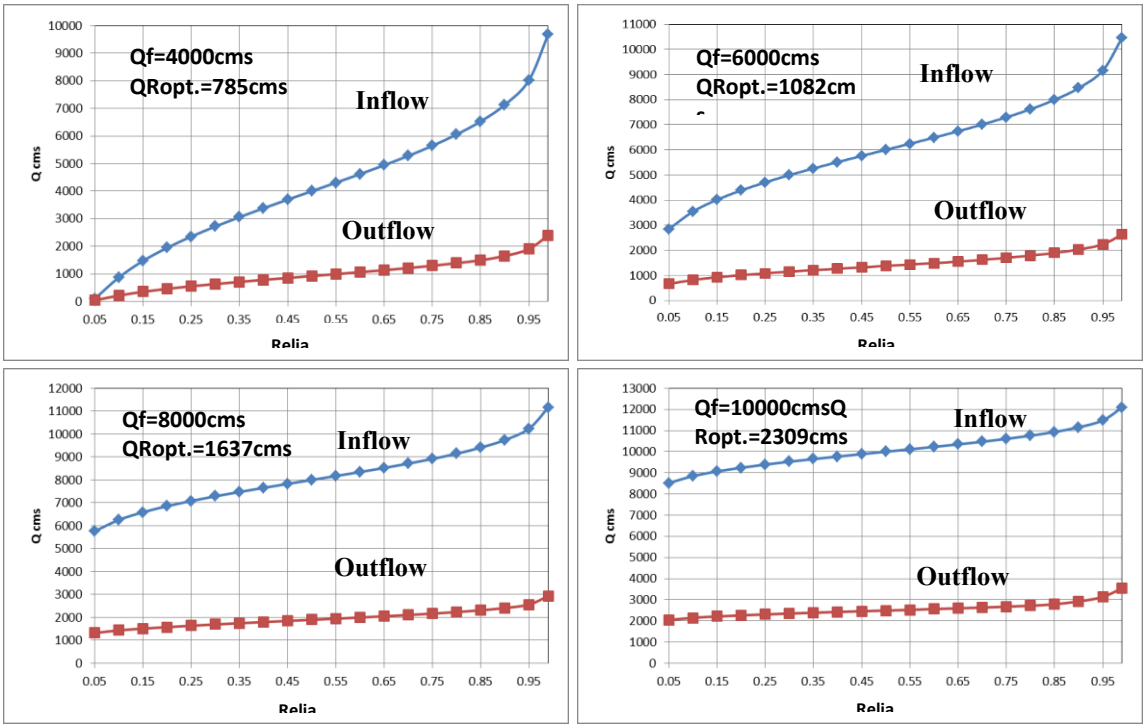


Figure 5. The Maximum Inflow forecast And Outflow for Reliabilities. (2 days to start of flood).

Table 5. Summary of comparison between results of the present study and historical reservoir operation of Dez reservoir.

Event	Inflow / Outflow	QR cms
Dez Dam Flood,	Maximum Inflow	3400
April 1994	Maximum Release	2400
Result of This Study	Selected Release	757
Dez Dam Flood,	Maximum Inflow	4400
Nov-94	Maximum Release	2900
Result of This Study	Selected Release	773-914
Dez Dam Flood	Maximum Inflow	8000
Apr-16	Maximum Release	4500
Result of This Study	Selected Release	1405-1829

Table 6. Summary of comparison between results of the present study with other researches.

Dez Dam Flood	Maximum Inflow	4597	5612	6223	9026
Zargar et al.,2016[6]	Maximum Release	1179	2407	2407	4740
Result of This Study	Selected Release	776-933	807-1151	876-1303	1800-2141
Dez Dam Flood	Maximum Inflow	3691	4490	4733	-
Malekmohammadi et al. 2006[7]	Maximum Release	1239	2420	3160	-
Result of This Study	Selected Release	758	773-912	780-960	-

6. Conclusion

Reservoir management by using inflow forecasting and timely action to select the pre-release in uncertain flood conditions is one of the new methods of reservoirs operation. Making an optimal decision in unreliability situations requires a systematic and probabilistic approach. In this research, by quantifying the probability distribution function for the inflow forecasts, developing a simulation-optimization model and performing risk analysis, the expected value damage is minimized. As a result, the optimal based release can be selected in a timely and continuous reservoir operation management before the occurrence until the end of flood. In this way, while making optimal decisions for reservoir releases, downstream damages are significantly reduced. This method solves the main concern of the operator for optimal decision-making in the reservoir operation in flood uncertainty conditions. The results of using this approach for the operation of Dez reservoir indicate a significant reduction in the peak release from the reservoir, and improved the operation of the Dez dam reservoir in real-time flood control in different conditions, which will reduce the total expected damage in the downstream area. This approach is provided only for a single reservoir system (e.g., Dez Dam) and can be developed for a multi-reservoir system, taking into account reliable storage volumes to supply downstream demands (at the end of the flood season) or by maximizing hydropower generation.

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