

Development and application of a decision support system for flood production and control using hydrological flow and reservoir simulation models

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ABSTRACT

This study employs HEC-HMS and HEC-RESSIM software to simulate flood events and optimize reservoir operations in the Dez River watershed, Iran. The HEC-HMS model was calibrated using 21 historical flood events, with key parameters—including rainfall losses, unit hydrograph methods, and flood routing (using the Muskingum method)—adjusted to minimize error between observed and simulated discharge. Results reveal significant variations in hydrological response across sub-basins: Dorood and Dorood 3 exhibit slow runoff due to large drainage areas (3449 km² and 2655 km²) and low infiltration rates (0.91–1.1 mm/hr), while Tang Panj basins show rapid response (lag times of 2.0–2.5 hr) and high infiltration (2.19–4.4 mm/hr), likely due to steep terrain and permeable soils. For reservoir management, HEC-RESSIM was used to simulate Dez Dam operations under current and elevated water level scenarios (352–362 masl), prioritizing downstream demands (irrigation, municipal supply, and ecological flows). Seasonal allocation patterns were identified, with peak diversions in June–July (320–324 MCM) for agriculture and minimal releases in winter (87–96 MCM). Raising the dam height by +8m (360 masl) optimally balanced flood control (22–25% storage increase) and drought resilience, though +10m required costly infrastructure upgrades. The study underscores the trade-offs between storage capacity, operational flexibility, and environmental needs, providing a framework for adaptive water resource management in semi-arid regions.

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1. Introduction

Flooding is a sudden event involving an excessive and unnatural flow of water, typically caused by heavy rainfall in a short period of rapid snowmelt. Among its devastating consequences are dam breaches and the overflow of floodwaters into cities and villages, leading to loss of life and property damage. In our country, despite the generally low average rainfall, the occurrence of floods—whether due to human-made or natural causes—is common, given the complex orography and numerous flowing rivers (Kundzewicz et al., 2014; IPCC, 2021, Nazeri Tahroudi, 2025). On the other hand, one of the effects of climate change is the increased frequency of extreme weather events. Climatic extremes occur under conditions of extreme

essential. One of the key indicators of climate change is the alteration in extreme climatic phenomena, including the intensification of the hydrological cycle, changes in the frequency of droughts and floods, and the expansion of flood and drought-affected areas into new regions (Milly et al., 2008). Studies conducted so far highlight the importance of reservoir operations in water management systems, not only for current needs but also for future demands. Physics-based models, sometimes referred to as deterministic, comprehensive, or process-based models, aim to represent observed physical processes in the real world. Typically, these models include representations of surface runoff, subsurface flow, evapotranspiration, and



channel flow, though they can be far more complex (Klipsch and Hurst, 2007). Several studies have examined hydrological modeling and watershed management, highlighting critical challenges in precipitation data accuracy. Todini et al. (2017) emphasized that rainfall data is a fundamental input for hydrological modeling, contributing to 70-80% of simulation uncertainties due to inherent data variability.

Recent studies by Wang et al. (2020) and Mekonnen et al. (2021) have demonstrated that satellite remote sensing technologies offer innovative approaches for precipitation monitoring, providing extensive spatial coverage that compensates for the uneven and insufficient distribution of ground-based rainfall observations, particularly in ungauged basins. Since precipitation amounts constitute the most critical component in hydrological and flood simulations, their accurate selection can significantly enhance the reliability of modeling results. In this context, Nguyen et al. (2015) employed the HiResFlood-UCI hydrologic-hydraulic model to simulate historical floods in Iowa, utilizing both PERSIANN-CCS and NEXRAD rainfall data as model inputs. Their findings revealed that hydrographs simulated using PERSIANN-CCS data showed closer agreement with observed hydrographs compared to those generated with NEXRAD data, highlighting the potential advantages of satellite-based precipitation products in flood modeling applications.

Li et al. (2018) conducted a comparative study evaluating TRMM satellite products versus ground-based rain gauge data for flood simulation in Lake Taihu basin using the SWAT model. Their research demonstrated that the SWAT model produced satisfactory results when using satellite-derived precipitation data as input. Statistical performance metrics (including the Nash-Sutcliffe efficiency index) further revealed that TRMM precipitation data performed well for daily streamflow simulation in this region. These findings suggest that such satellite-based datasets can serve as viable alternatives for model inputs in data-scarce areas of the basin, particularly where ground observations are unavailable.

The management of dam reservoirs has become increasingly critical due to the dual challenges of climate change and urbanization, which intensify the risks associated with flooding and

water resource allocation. Recent advancements in hydrological modeling, particularly with tools like HEC-HMS and HEC-ResSim, provide robust frameworks for simulating and managing water resources effectively=

The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) and Reservoir Simulation Model (HEC-ResSim) have been extensively utilized in both urban and rural settings for flood hazard assessment and water resource management. HEC-HMS is particularly adept at simulating rainfall-runoff processes and has been applied in various contexts, including the Deduru Oya river basin in Sri Lanka, where it demonstrated high accuracy in streamflow reproduction (Sampath et al., 2015). This effectiveness is pivotal for optimizing water allocations, particularly in regions experiencing complex water use scenarios (Fernando et al., 2022).

In contrast, HEC-ResSim is designed for modeling the operation of reservoirs in response to varying inflow conditions and management objectives. It serves as a decision-support tool that integrates real-time data for optimal reservoir operation (Uysal et al., 2018). The combination of these models facilitates a comprehensive approach to reservoir management by addressing both hydrological simulations and operational decision-making. Recent studies have underscored the importance of integrating advanced modeling techniques with high-resolution data to enhance flood simulations. For instance, the multicriteria approach employed by Psomiadis et al. (2021) utilized HEC-RAS alongside remote sensing data to assess potential dam breach scenarios, emphasizing the necessity for accurate flood wave risk assessments in dam management. This reflects a growing body of literature that emphasizes the significance of understanding flood wave propagation and the influence of stored water volume on downstream areas (Zhang et al., 2013).

Furthermore, the incorporation of future climate scenarios into hydrological models has emerged as a critical aspect of reservoir management. Research by Deb et al. (2018) showcased a multi-GCM approach for assessing climate change impacts on water resources in Thailand, which could be instrumental for proactive reservoir management strategies. Such studies highlight the necessity of preparing reservoir systems for

future uncertainties, a theme prevalent in current research (Tramblay et al., 2018). Despite the advancements in modeling, challenges remain, particularly in data collection and model calibration. The lack of high-resolution data often complicates flood management efforts (Manandhar et al., 2023). Recent literature suggests that improved data collection methods and calibration techniques are essential for enhancing the accuracy of models like HEC-HMS and HEC-ResSim (Lin et al., 2023).

This gap underscores the need for ongoing research into innovative data acquisition technologies, which could significantly improve model performance and reliability. Effective dam reservoir management necessitates a combination of structural and non-structural measures. The literature indicates that urban flood management, for example, benefits from integrating hydraulic and hydrological models for comprehensive hazard assessments (Pathan et al., 2021; Lee et al., 2022; Zhao et al., 2025; AL-Hudaib et al., 2025).

This dual approach not only aids in flood risk mitigation but also enhances the overall resilience of water management systems against climate variability. Tanhapour et al. (2025) first investigated the potential of sequential long short-term memory (LSTM) networks for predicting group inflow floods one day in advance, based on numerical weather prediction data. Next, they developed a novel framework to incorporate group inflow forecasts into multi-objective reservoir operation optimization using a grid search-based genetic algorithm.

Finally, they implemented their proposed group-based inflow operation method on the Dez Dam basin in Iran. Their findings indicated that applying a skillful group-based scheme in reservoir flood control operations can be effective in reducing flood damage and water shortages. Effective water resources management and prevention of unforeseen hydrological risks – including reservoir operation optimization – can only be achieved through the integration of accurate inflow forecasting and advanced optimization technologies. This necessitates combining two critical components: 1) coupled hydrological-hydraulic simulation models, and 2) numerical optimization algorithms, representing an innovative approach for multi-objective

reservoir management. Reservoir modeling constitutes an integral part of comprehensive water flow simulation systems, beginning with rainfall-runoff processes at the watershed scale, continuing through river network routing, and concluding with storage operations in reservoirs followed by controlled releases through hydro-mechanical structures and hydropower plants. The present study specifically aims to model rainfall-runoff processes in reservoir watersheds, develop reservoir storage simulation capabilities, and establish flood control mechanisms through integrated modeling frameworks. This integrated approach addresses the complete water cycle from precipitation to controlled release, enabling balanced decision-making between flood mitigation, water supply, and energy production objectives. The methodology particularly focuses on reservoir systems where operational decisions must simultaneously consider hydrological inputs, storage dynamics, and downstream safety requirements.

2. Material and methods

2.1. Study area

The Dez Dam watershed is a sub-basin of the larger Karun River basin, located in the semi-arid mountainous region of southwestern Iran. It lies within the upper Karun basin between 48°9'15"E to 50°18'37"E longitude and 31°35'51"N to 34°7'46"N latitude. The watershed is fed by two principal tributaries the Sazdar and Bakhtiari rivers — which converge at Tang-e Panj to form the Dez River. The multi-purpose Dez Reservoir Dam, situated downstream of Tang-e Panj, provides water for drinking, industrial, and agricultural uses, as well as hydroelectric power generation. Fig. 1 illustrates the geographical location of the study area.

This study aims to develop and implement a decision support system (DSS) for flood generation and control using hydrological flow and reservoir simulation models. The study area covers the Dez River Basin, extending from the Bakhtiari Dam on the Bakhtiari River branch and the Sazar Tunnel on the Sazar River branch in the upstream, to the Dez Dam reservoir and further downstream until its confluence with the Karun River within the Greater Karun Basin. The proposed DSS integrates watershed-

scale hydrological modeling with reservoir operation simulations to optimize flood

management across this strategically important water system.

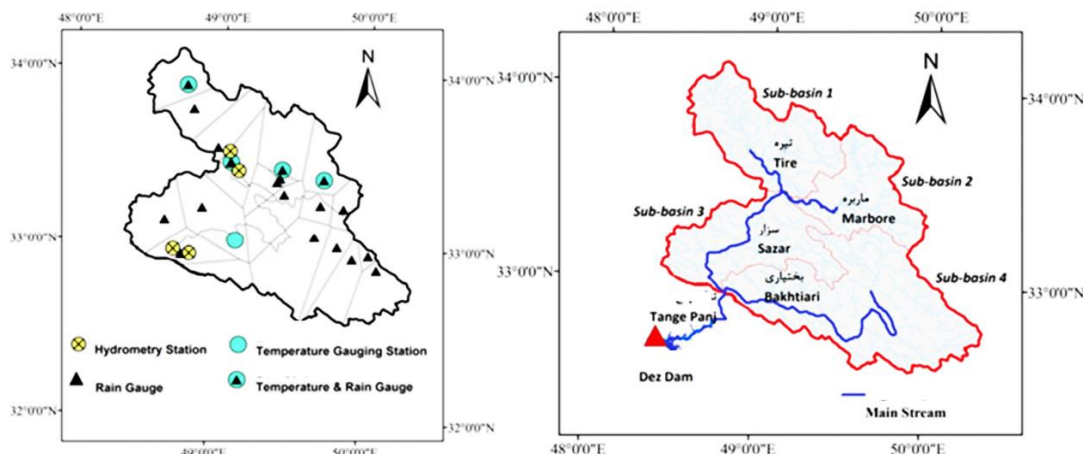


Fig. 1. Location of studied area.

This study utilizes the following datasets: Daily and hourly discharge data from downstream sub-basins of the Dez Dam watershed were obtained from the Iran Water Resources Management Company and Khuzestan Water & Power Authority. Temperature, precipitation, and evaporation data, scaled to match the hydrometric records, were collected over a 54-year statistical period from synoptic and climatological stations operated by the Iranian Meteorological Organization and stations managed by the Iran Water Resources Management Company. A key challenge in this research involves the inadequate spatial

distribution of monitoring stations and potential data gaps at some stations, which may affect the comprehensiveness of the analysis. The study period covers hydrological records, with particular attention given to data quality control and consistency checks across different sources. Based on the latest available data and most recent studies, the required specifications of the reservoir system under investigation have been prepared and are presented in Table 1. These specifications incorporate findings from current research, including data from the Dez Dam height-raising project.

Table 1. Presents the detailed characteristics of the reservoirs and hydropower plants within the study area, including.

	Parameter	Unit	Dez	Bakhtiari	Gotvand	Godar-e-Lander	Shahid Abbaspour	Karun 2	Karun 3	Karun 4	Khersan 3
Reservoir	Normal Water Level	masl	352	830	230	372	532.5	660	845	1028	1432
	Minimum Operating Level	masl	310	785	185	363	490	655	800	996	1400
	Total Storage Capacity	MCM	2698.5	4845	4671	261.6	2438.6	197	2718.6	2279.7	1037.4
	Active Storage Capacity	MCM	1868.9	2122.6	3050.5	60.7	1614.4	27	1624.5	834.2	618.5
Power Plant	Installed Capacity	MW	520	1500	2000	2000	2000	642	2000	1000	400
	Number of Units		8	6	8	8	8	4	8	4	4
	Design Discharge	cms	357	613.6	1686.3	1605.8	1471	799.7	1370.5	684	319.4
	Design Head	M	165	270	130	138	154	88	161	162	140
	Efficiency	%	90	92.1	93	92	90	93	92.4	92	91.2
	Average Tailwater Level	Masl	175.5	537	88.5	232	370	570	668	845	1267
	Average Head Loss	M	3	4	4.5	4	8	2.25	4.5	3	2.3

2.2. Water demands and consumptive uses

As previously mentioned, the Karun-Dez water resource system—encompassing both the Karun and Dez river basins—represents a highly complex system with numerous water supply and demand components. While numerous studies have been conducted on this basin, the current research utilizes the latest verified studies and acquired data to accurately quantify water demands within the study area. The following sections first describe the upstream inter-basin water transfer projects affecting the study area, including their current abstraction volumes and future water allocations. Subsequently, the local water demands and requirements within the study area itself are analyzed and presented. [Table 2](#)

shows the monthly and annual water withdrawals and interbasin transfers (million cubic meters, MCM) for the upstream Dez and Karun sub-basins.

As previously outlined, the study area extends from the Karun-4 and Khersan-3 dams on the Karun River, and the Bakhtiari Dam and Sazar Tunnel on the Dez River, downstream to the terminus of the Greater Karun River system. The primary water demands in this region consist of:

- Agricultural needs for the Khuzestan Plain
- Municipal and industrial demands for major urban centers including:
 - Ahvaz
 - Abadan
 - Khorramshahr
 - And other key cities

Table 2. The monthly and annual water withdrawals and inter-basin transfers (million cubic meters, MCM) for the upstream Dez and Karun sub-basins.

Plan	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Ann (MCM)
Koohrang 1	13.70	13.70	13.20	11.70	13.20	19.80	44.20	53.30	50.60	41.80	29.50	18.20	322.90
Koohrang 2	8.30	11.40	12.40	12.40	15.60	23.60	49.30	67.80	56.20	38.00	19.30	11.00	325.30
Koohrang 3	8.00	11.40	12.20	11.40	13.00	22.60	43.90	51.70	32.70	20.10	13.40	9.40	249.80
Beheshtabad	33.80	30.80	32.50	36.70	39.10	44.10	58.90	69.10	74.50	66.80	53.80	40.00	580.10
Solgan	8.00	11.90	17.90	17.10	21.00	32.10	39.90	32.90	20.90	13.10	9.10	8.00	231.90
Upstream of Karun-4 Dam	71.80	79.20	88.20	89.30	101.90	142.20	236.20	274.80	234.90	179.80	125.10	86.60	1710.00
Shahid	1.80	2.10	1.80	1.80	2.30	4.30	7.80	10.40	12.30	7.80	4.60	3.20	60.20
Bideh	19.20	19.20	19.20	19.20	19.20	19.00	19.30	19.30	19.30	19.30	19.30	19.30	230.80
Upstream of Khersan-3 Dam	21.00	21.30	21.00	21.00	21.50	23.30	27.10	29.70	31.60	27.10	23.90	22.50	291.00
Dez to Qomrud	6.20	10.10	13.20	12.70	15.80	21.50	35.10	31.10	14.70	8.30	7.00	5.40	181.10
Cheshmeh Langan	0.80	1.60	3.10	3.90	8.60	15.00	31.60	30.00	15.30	6.20	2.40	1.10	119.60
Khodnegstan	1.30	1.80	2.90	1.80	2.30	6.50	22.00	24.10	12.10	5.40	2.40	1.30	83.90
Bakhtiari upstream transfers	8.30	13.50	19.20	18.40	26.70	43.00	88.70	85.20	42.10	19.90	11.80	7.80	384.60
Kamal Saleh	5.20	5.70	5.20	5.20	5.20	5.50	5.10	5.40	5.40	5.60	6.20	5.60	65.30
Sazar upstream transfers	5.20	5.70	5.20	5.20	5.20	5.50	5.10	5.40	5.40	5.60	6.20	5.60	65.30

The study area's total water demands are estimated at 27.5 billion cubic meters (BCM) annually, comprising 21.5 BCM for agricultural irrigation, 4 BCM for municipal and industrial uses, and 2 BCM for aquaculture operations. Additionally, two critical environmental flow requirements have been established: the Ahvaz control point requiring 200 m³/s (~6.3 BCM/year) to

maintain urban river ecosystems, and the Persian Gulf inlet needing 120 m³/s (~3.8 BCM/year) to prevent saltwater intrusion and sustain the delta's biodiversity. These combined demands highlight the challenging balance between consumptive water use (78% for agriculture) and ecological preservation in this strategically important basin.

HEC-ResSim Model: HEC-ResSim (Hydrologic Engineering Center's Reservoir System Simulation) is a software developed by the U.S. Army Corps of Engineers (USACE) for modeling reservoir operations, water allocation, and flood control. It is widely used for:

- Simulating reservoir system behavior under different hydrologic conditions.
- Evaluating flood risk mitigation strategies.
- Optimizing water release policies for hydropower, irrigation, and environmental flows.

The fundamental equation governing reservoir operations is Eq. 1:

$$\frac{dS}{dt} = I(t) - Q(t) - E(t) - L(t) \quad (1)$$

Where:

- S = Storage volume (m^3)
- $I(t)$ = Inflow rate (m^3/s)
- $Q(t)$ = Outflow (controlled release) (m^3/s)
- $E(t)$ = Evaporation loss (m^3/s)
- $L(t)$ = Leakage/seepage losses (m^3/s)

Storage-Indication (Modified Puls) Routing Method used for flood routing in reservoirs (Klupsch and Hurst, 2007) (Eq. 2):

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

Where:

- S_t, S_{t+1} = Storage at time t and $t+1$
- I_t, I_{t+1} = Inflow at time t and $t+1$
- Q_t, Q_{t+1} = Outflow at time t and $t+1$
- Δt = Time step

HEC-ResSim requires hydrologic, topographic, operational, and meteorological data to simulate reservoir behavior accurately.

HEC-HMS Model: HEC-HMS is a widely used rainfall-runoff simulation model developed by the U.S. Army Corps of Engineers (USACE). It is designed to simulate:

- Watershed hydrology (precipitation, infiltration, runoff).
- Flood forecasting and stormwater management.
- Climate change impact assessment on hydrologic cycles.

Mathematical Foundations of HEC-HMS: 1. Precipitation Loss Methods (Infiltration Models) using SCS Curve Number (CN) Method (Peters, 1998) (Eq. 3):

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}, \text{ where } S = \frac{25400}{CN} - 254 \quad (3)$$

Where Q is Runoff depth (mm), P is Precipitation (mm), and S is Potential retention (mm).

Green-Ampt Method: Eq. 4.

$$f(t) = K_e \left(1 + \frac{\psi \Delta \theta}{F(t)} \right) \quad (4)$$

Where $f(t)$ is Infiltration rate (mm/hr), K_e is Effective hydraulic conductivity, and ψ is Soil suction head.

Transform Methods (Runoff to Hydrograph), Unit Hydrograph (UH): Eq. 5.

$$Q(t) = \int_0^t P(\tau) UH(t - \tau) d\tau \quad (5)$$

Where UH is Unit hydrograph ordinates.

Kinematic Wave Routing: Eq. 6.

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q, \text{ where } Q = \alpha A^m \quad (6)$$

A : Flow cross-section area.

Channel Routing (Muskingum Method): Eq. 7.

$$Q_{t+1} = C_1 I_{t+1} + C_2 I_t + C_3 Q_t \\ C_1 = \frac{\Delta t - 2KX}{2K(1-X) + \Delta t}, C_2 = \frac{\Delta t + 2KX}{2K(1-X) + \Delta t}, C_3 = \frac{2K(1-X) - \Delta t}{2K(1-X) + \Delta t} \quad (7)$$

Where K is Travel time and X is Weighting factor (0–0.5). To calibrate and validate the HEC-HMS hydrological model, diverse input datasets including hydrological, meteorological, and geospatial data—such as discharge, precipitation, land use, DEM, and soil data—were required. The observed meteorological and hydrological data were collected from multiple sources.

Daily-scale meteorological datasets—including precipitation, maximum/minimum temperatures, wind speed, and relative humidity—were obtained from the Ethiopian National Meteorological Agency (NMA) for the study's statistical period. Precipitation data used for HEC-HMS simulations were derived

Annual	1709.9	290.9	384.6	65.3	18.4	4.8	4.8	1.6	109.2	20.4	3.3	8.4	20.4	120.6	9.6
April	86.6	22.5	7.8	5.6	2.3	0.4	0.4	0.2	9.1	1.7	0.4	0.7	1.7	24.3	0.8
May	125	23.8	11.8	6.2	2.8	0.4	0.4	0.2	9.1	1.7	0.4	0.7	1.7	17.5	0.8
June	179.8	27.1	19.8	5.6	3	0.4	0.4	0.2	9.1	1.7	0.4	0.7	1.7	10.4	0.8
July	234.9	31.6	42.1	5.4	3.3	0.4	0.4	0.2	9.1	1.7	0.4	0.7	1.7	9.4	0.8
August	274.8	29.7	85.2	5.4	2.3	0.4	0.4	0.2	9.1	1.7	0.4	0.7	1.7	14.7	0.8
September	236.2	27.1	88.7	5.1	1.8	0.4	0.4	0.2	9.1	1.7	0.4	0.7	1.7	12.3	0.8
October	142.1	23.3	43.1	5.5	0.1	0.4	0.4	0.1	9.1	1.7	0.2	0.7	1.7	4.3	0.8
November	101.8	21.5	26.7	5.2	0	0.4	0.4	0	9.1	1.7	0.1	0.7	1.7	0.7	0.8
November	89.3	21	18.4	5.2	0	0.4	0.4	0	9.1	1.7	0	0.7	1.7	1.2	0.8
January	88.2	21	19.2	5.2	0	0.4	0.4	0	9.1	1.7	0.1	0.7	1.7	1.4	0.8
February	79.3	21.3	13.5	5.7	0.6	0.4	0.4	0.1	9.1	1.7	0.2	0.7	1.7	7	0.8
March	71.9	21	8.3	5.2	2.2	0.4	0.4	0.2	9.1	1.7	0.3	0.7	1.7	17.4	0.8

Table 3. Continue...

Uses and demands	Fish farming between Karun 1 and Godar-e-Lander	Agriculture between Godar-e-Lander and Gotvand	Domestic & industrial use between Godar-e-Lander and Gotvand	Fish farming between Godar-e-Lander and Gotvand	Agriculture between Gotvand and Qir with downstream return flow	Agriculture between Gotvand and Qir with return flow to Dez	Agriculture between Gotvand and Qir without return flow	Domestic & industrial use between Gotvand and Qir	Fish farming between Gotvand and Qir	Agriculture between Bakhtiari and Dez	Domestic & industrial use between Bakhtiari and Dez	Fish farming between Bakhtiari and Dez	Ghadeer Project (a specific water management/development plan)	Agriculture between Dez and Qir
Long-Term Shortage Percentage	0	0	0	0	40.4	35.3	36.8	0.6	0	0	0	0	0.6	40.3
Annual	38.4	93.9	90	0	2162.7	119.4	303.1	138.2	201.6	27.2	12	19.2	495.2	3660.6
April	3.2	15.4	7.5	0	135.7	5.2	20.3	11.4	16.8	4.1	1	1.6	40.9	236.9
May	3.2	12.8	7.5	0	238.3	12.2	26.9	11.5	16.8	3.4	1	1.6	41.3	377.1
June	3.2	9.7	7.5	0	298.7	15	27.8	11.6	16.8	2.8	1	1.6	41.5	455.8
July	3.2	8.6	7.5	0	305.1	12.1	29.9	11.6	16.8	2.7	1	1.6	41.5	522.5
August	3.2	11.8	7.5	0	331.3	18.2	54.4	11.6	16.8	3.6	1	1.6	41.5	685.6
September	3.2	11.3	7.5	0	298.2	17.2	60.1	11.6	16.8	3.3	1	1.6	41.5	387
October	3.2	6.8	7.5	0	185.4	12.8	40.1	11.6	16.8	2.8	1	1.6	41.5	321
November	3.2	0.7	7.5	0	86.2	8.4	10.3	11.6	16.8	0.4	1	1.6	41.5	163.3
November	3.2	1.2	7.5	0	55.6	7.1	9.5	11.6	16.8	0.8	1	1.6	41.5	82.8
January	3.2	2.8	7.5	0	65.9	6	8.5	11.5	16.8	0.9	1	1.6	41.3	158.1
February	3.2	3.7	7.5	0	79.4	2.7	8.1	11.3	16.8	1.1	1	1.6	40.6	134
March	3.2	9.1	7.5	0	82.9	2.5	7.2	11.3	16.8	1.3	1	1.6	40.6	136.5

Table 3. Continue...

Uses and demands	Domestic & industrial use between Dez and Qir	Fish farming between Dez and Qir	Agriculture between Qir and Ahvaz	Domestic & industrial use between Qir and Ahvaz	Fish farming between Qir and Ahvaz	Agriculture between Ahvaz and Abadan	Domestic & industrial use between Ahvaz and Abadan	Fish farming between Ahvaz and Abadan	Agriculture between Abadan and Persian Gulf	Domestic & industrial use between Abadan and Persian Gulf	Fish farming between Abadan and Persian Gulf	Environmental flow requirement for Ahvaz	Environmental flow requirement for Persian Gulf
Long-Term Shortage Percentage	0.6	0.1	40	0	35.6	38.1	0	35.7	37.9	0	35.7	0.2	0.6
Annual	72.9	39.6	865.1	228	16.2	4152.5	2203.2	920	1613.8	662.4	167.4	6294.5	3762
April	6	3.3	55.6	19	0.6	240.1	183.6	34.8	89.4	55.2	6.3	532.5	316.9
May	6.1	3.3	104.3	19	1	444.1	183.6	57.9	165.2	55.2	10.5	534.4	319.7
June	6.1	3.3	136	19	1.3	571.1	183.6	75	217	55.2	13.7	535.7	321.1
July	6.1	3.3	122.6	19	1.5	566.8	183.6	84	243.5	55.2	15.3	535.7	321.4
August	6.1	3.3	111.9	19	1.7	534.3	183.6	99.1	269.1	55.2	18	535.7	321.4
September	6.1	3.3	93.7	19	1.8	548.6	183.6	104.8	208	55.2	19.1	535.7	321.4
October	6.1	3.3	61	19	1.7	395.9	183.6	97.5	140.6	55.2	17.8	501.1	300.7
November	6.1	3.3	46.6	19	1.9	275.2	183.6	105.5	72.3	55.2	19.2	518.4	311
November	6.1	3.3	42.9	19	1.8	187.8	183.6	100.7	64.9	55.2	18.3	518.4	311
January	6.1	3.3	36.2	19	1.5	158.3	183.6	83.6	55.8	55.2	15.2	518.1	309.4
February	6	3.3	29.8	19	0.9	129	183.6	49	46.9	55.2	8.9	515	304.1
March	6	3.3	24.5	19	0.5	101.3	183.6	28.1	41.1	55.2	5.1	513.8	303.9

Table 4. Summary of Power Generation Results in Hydropower Plants within the Study Area under the Proposed Scenario.

Parameter	Unit	Dez	Bakhtiari	Gotvand	Godar-e-Lander	Shahid Abbaspour	Karun 2	Karun 3	Karun 4	Khersan 3
Normal Water Level	Masl	352	830	230	372	532.5	660	845	1028	1432
Minimum Operating Level	Masl	310	785	185	363	490	655	800	996	1400
Total Reservoir Capacity	MCM	2698.5	4845	4671	261.6	2438.6	197	2718.6	2279.7	1037.4
Active Storage Volume	MCM	1868.9	2122.6	3050.5	60.7	1614.4	27	1624.5	834.2	618.5
Reservoir Inflow	MCM	7614.7	4525.1	11506	10456.6	10233.1	9182.2	8943.3	4546.5	2865.7
Evaporation Losses	MCM	69.6	108.9	106	11.5	77.1	6.3	80.3	47.2	44.6
Powerplant Intake	MCM	4033.6	4400.4	11349.8	10421.4	9768.2	9084.7	8837.2	4455.5	2777.9
Spillway Discharge	MCM	2988.2	6.8	0.1	0.1	363.5	69.1	5	28.5	41.6
Installed Capacity	MW	520	1500	2000	2000	2000	642	2000	1000	400
Peak Energy	GWH	481.6	2243.3	2565.8	2696.2	2685.8	999.6	2769.9	1341	608.6

Off-Peak Energy	GWH	1058.8	929.2	564.4	734.7	889.6	1021.8	851.3	577.1	502.4
Total Energy	GWH	1540.4	3172.5	3130.1	3430.9	3575.4	2021.4	3621.2	1918.1	1110.9

This study was conducted using the HEC-HMS software. This software simulates floods on an event-by-event basis. The working method is as follows: First, several dominant floods in the watershed are selected for calibration (for example, in this study, 21 floods were selected for calibration in the sub-watersheds of the Dez River). Each flood is defined separately for the software, and then the components of the watershed model, including the area of the sub-watersheds, the geographical coordinates of hydrometric and rain gauge stations, and water diversion, are determined.

Afterward, methods for calculating rainfall losses—such as infiltration and evaporation—as well as methods for calculating the unit hydrograph and the start and end times of the flood are specified for the software. The software's core function is to minimize the objective function, which is the error (i.e., the difference between observed and calculated discharge).

After calibrating the watershed and calculating the relevant parameters, 24-hour rainfall data was used to predict floods in real time. The Muskingum hydrological method was employed for flood routing in different sections of the Dez River. The results of the calibration and flood routing of the Dez River watershed using HEC-HMS software are presented in detail in [Tables 5](#). Additionally, the configuration of the Dez River watershed is illustrated in [Fig. 3](#).

Dorood (48.27 hr), Dorood 3 (49.25 hr), and Sepid Dasht Sezar (27.03 hr) have very high values, indicating slower hydrological response (likely due to larger areas or flatter terrain). Tang Panj 3 (2.5 hr) and Tang Panj (2.0 hr) have much lower times, suggesting rapid runoff

(possibly steeper slopes or smaller drainage areas). Most sub-basins have a very short lag time (0.1 hr = 6 minutes), except Tang Panj 3 (2.5 hr) and Tang Panj (2.0 hr), which suggests differences in basin shape or flow resistance.

Tang Panj 3 (4.4 mm/hr) and Tang Panj (2.19 mm/hr) have higher infiltration rates, possibly due to more permeable soils. Dorood (1.1 mm/hr) and Dorood 3 (0.91 mm/hr) have lower infiltration, suggesting less permeable surfaces (e.g., clay soils or urbanization). Most sub-basins have a high initial loss (10 mm), meaning significant rainfall is needed before runoff starts. Tang Panj 3 (4.4 mm) and Tang Panj (2.0 mm) have much lower initial losses, implying quicker runoff generation. Large areas (3449 km² & 2655 km²), slow response (high Sc), low infiltration (0.91–1.1 mm/hr). Likely have gentle slopes or dense vegetation delaying runoff. Moderate areas (682–1062 km²), intermediate Sc values, and moderate infiltration (1.06–1.42 mm/hr). Very different behavior: fast response (low Sc & Tc), high infiltration (2.19–4.4 mm/hr). Likely steep, rocky, or highly permeable catchments.

[Table 6](#) provides Muskingum routing parameters (K and x) for different reaches in the studied sub-basins. These parameters are crucial for modeling flood wave movement through river channels.

K (hr): Represents the travel time of the flood wave through the reach. All reaches have K = 0.1 hr (6 minutes), suggesting very short travel times. This could imply:

- Short channel lengths.
- Steep slopes (rapid flow velocities).
- Highly efficient conveyance (e.g., concrete-lined or narrow channels).

Table 5. Final Computed Parameters for Infiltration and Unit Hydrograph of studied Sub-Basins.

Sub-Basin	Infiltration		Unit Hydrograph		Area km ²
	Initial Loss mm	Constant rate mm/hr	TC hr	Sc hr	
Dorood	10.0	1.1	0.10	48.27	3449
Dorood 3	10.0	0.91	0.10	49.25	2655
Sedpid Dasht Zaz	10.0	1.06	0.10	11.90	682
Sepid Dasht Sezar	9.7	1.42	0.10	27.03	1062
Tang Panj 3	4.4	4.40	2.50	2.50	6406
Tang Panj	2.0	2.19	2.00	2.00	1555

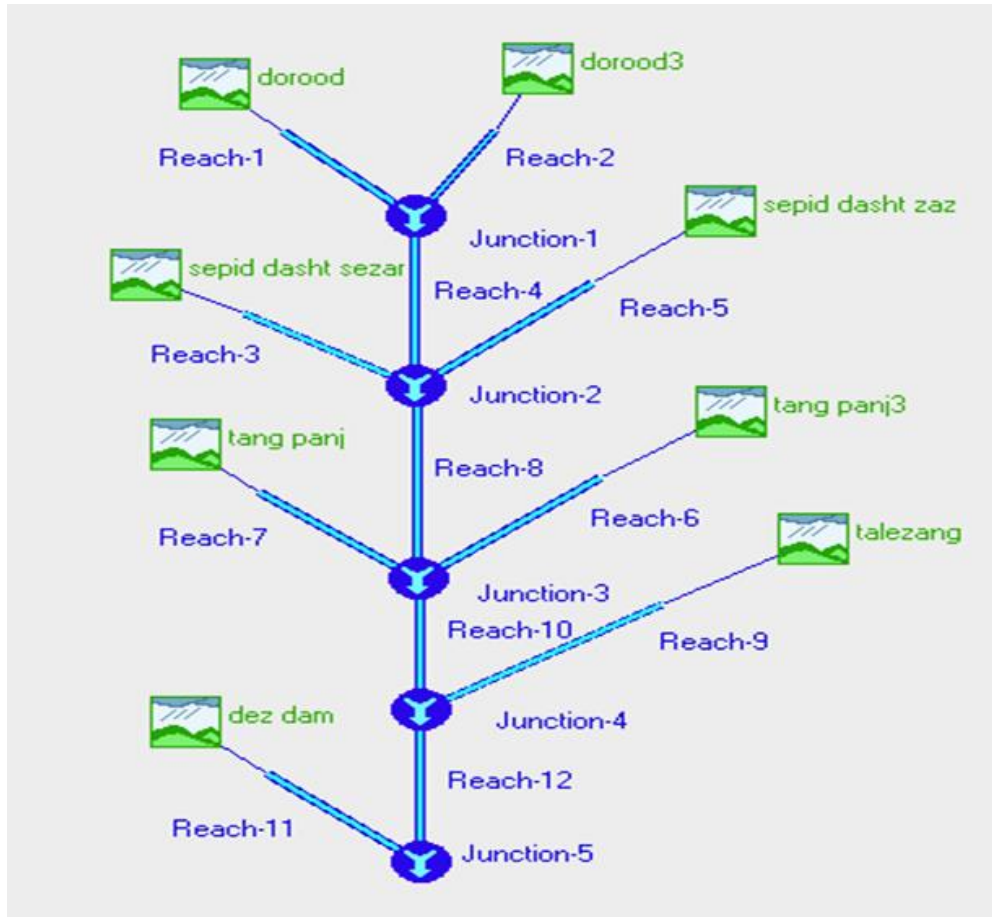


Fig. 3. Watershed Delineation of the Dez River Basin.

Table 6. Final Computed Parameters for Flood Routing in Studied Sub-Basins.

Reach Name	Muskingum Parameter	
	K (hr)	x
Reach 1	0.10	0.10
Reach 2	0.10	0.10
Reach 3	0.10	0.0011
Reach 4	0.10	0.10
Reach 5	0.10	0.0010
Reach 6	0.10	0.0010
Reach 7	0.10	0.0010
Reach 8	0.10	0.10

x (dimensionless): Reflects the weighting between inflow and outflow storage (0 = pure reservoir, 0.5 = pure translation). $x = 0.10$: Indicates moderate attenuation (flood peak reduction due to storage effects). $x \approx 0.001$: Near-zero, meaning minimal storage effects (almost pure translation, like a pipe flow). The Fig. 3 shows the Dorood, Sepid Dasht, Tang Panj, and Dez Dam as key sub-basins. Reaches 1, 3, 7 correspond to main channels (e.g., Dorood, Sepid Dasht Sezar, Tang Panj). Reaches with $x \approx 0.001$ align with steep tributaries (Tang Panj). Reaches with $x = 0.10$ may be wider, junction-influenced (e.g., near Dez Dam).

Currently, advanced countries have implemented systems in their river watersheds by installing appropriate devices and sensors to monitor events in real time, enabling them to prevent disastrous incidents such as floods and destructive avalanches as much as possible. The sensors installed in the watersheds are capable of recording real-time data, including: Rainfall intensity, Temperature, Snowpack volume at high elevations, Snow density, Water level at various river sections.

Today, various software programs are available to simulate the rainfall-runoff process and flood routing in different river sections. The use of such software can streamline integrated

watershed management, helping to mitigate potential damages during critical situations.

A comparison of the results obtained from the software used for a selected flood event (October 23, 1992) in the studied sub-

watersheds is presented in Table 7. As can be seen, the error percentage in the calculations is less than 10%, indicating a high level of accuracy.

Table 7. Calculation of percentage discrepancy in peak flood discharges at hydrometric stations.

Sun Basin	Observed Peak Discharge (cms)	Simulated Peak Discharge (cms)	Difference (cms)	Deviation Percentage
Dorood	152.00	144.00	8.00	5.56
Dorood 3	106.00	101.00	5.00	4.95
Sepid Dasht Zaz	135.00	136.00	-1.00	-0.74
Sepid Dasht Sezar	264.00	262.00	2.00	0.76
Tang Panj 3	1372.00	1371.00	1.00	0.07
Tang Panj	1191.00	1189.00	2.00	0.17
Dez Dam	3438.00	3132.00	306.00	9.77

This table compares simulated vs. observed peak flood discharges at hydrometric stations across different sub-basins, along with the percentage deviation between them. The results help assess the accuracy of the hydrological model used in the study. Most sub-basins (5/7) have errors <5%, indicating high reliability in flood peak predictions. Dez Dam stands out with ~10% deviation, suggesting: Upstream routing errors compounding. <10% deviation is generally good for flood forecasting (Moriassi et al., 2007). <5% is excellent for well-calibrated models. The results indicate slight overestimations in the rainfall-runoff conversion for Dorood & Dorood 3 (5% overestimation), suggesting potential overprediction in runoff generation along with marginally high infiltration losses in the model. Similarly, Dez Dam (9.77% overestimation) showed an elevated prediction, which could be attributed to either unaccounted reservoir releases or unmeasured inflows from minor tributaries.

Simulation of Dez Dam Reservoir Using HEC-RESSIM: Reservoir release priorities are a critical operational criterion that must be defined for most water systems. Reservoirs are primarily operated to meet their own storage requirements before addressing downstream demands. Using HEC-RESSIM software, we modeled the Dez Dam's operations to satisfy various downstream needs including municipal water supply (particularly for Dezful city through the Sobili Weir), industrial use, irrigation (via the Harmehl diversion weir serving both right and left bank canal networks), navigation requirements, aquatic habitat preservation, recreational uses, and water quality maintenance. The key

downstream consumers include: (1) drinking water withdrawals for Dezful from the Sabili Weir, (2) agricultural demands supplied through the Harmehl weir's canal systems and the Qir weir's Pump Stations 1 and 2, and (3) irrigation diversions along the Shavour River (Fig. 4).

Table 8 presents monthly water allocation (in million cubic meters, MCM) across multiple diversion points downstream of the Dez Dam, including canals, river branches (RB/LB), and pumping stations. The data reveals seasonal water distribution patterns critical for irrigation planning, hydropower, and ecosystem management.

Highest diversions occur in June (320.31 MCM) and July (323.63 MCM), coinciding with peak agricultural irrigation and low rainfall. Dez RB1 and Dez LB are the largest contributors (e.g., 101.4 MCM and 114.5 MCM in July). Lowest diversions in December (96.04 MCM) and January (86.75 MCM), reflecting reduced irrigation needs and higher natural flow availability.

Dez LB (Left Bank Canal), largest share in all months (e.g., 127.6 MCM in June). Likely serves major agricultural zones. Dez RB1 (Right Branch 1) has second-largest contributor, especially in summer (e.g., 105.7 MCM in August). May support hydropower or additional irrigation. Shavour Irrigation is significant in spring/summer (e.g., 28.9 MCM in April), but drops sharply by October (10.5 MCM). Pumping Stations (Dez Pump 1 & 2) are active in growing season (March–September), peaking in May (22.2 MCM and 16.5 MCM). Minimal use in winter, suggesting reliance on gravity-fed channels during high-flow months. The data highlights heavy irrigation reliance on Dez LB/RB1 in summer,

with potential trade-offs for hydropower and ecosystems. Correcting the March outlier and integrating climate resilience strategies (e.g.,

storage augmentation) will enhance water security.

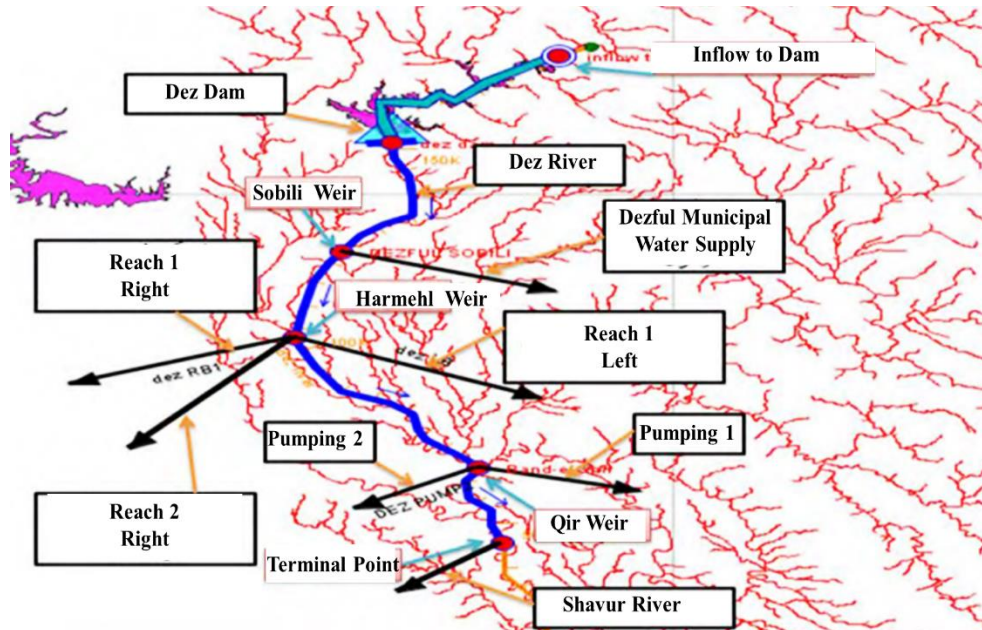


Fig. 4. Water resources and demand configuration of dez river and dez dam reservoir.

Table 8. Monthly water distribution downstream of Dez diversion weir to Qir weir.

Month	Diversion point	Dezful Sobily	Dez RB 2	Dez RB 1	Dez LB	Dez Pump 1	Dez Pump 2	Shavour Irrigation	Total
January		29.81	8.34	15.30	22.60	3.80	2.10	4.80	86.75
February		33.70	9.83	13.30	32.20	5.30	3.10	6.10	103.53
March		29.36	17.30	2960	52.30	16.80	8.90	19.90	174.16
April		29.46	24.64	45.60	81.00	23.70	13.60	28.90	248.90
May		22.13	37.84	64.20	105.40	22.20	16.50	26.00	294.27
June		20.86	47.55	76.10	127.60	13.90	17.00	17.30	320.31
July		17.07	51.16	101.40	114.50	11.10	16.60	11.80	323.63
August		14.56	49.54	105.70	103.00	9.40	14.80	11.90	308.90
September		15.80	43.56	88.70	97.00	6.80	11.00	12.60	275.46
October		14.83	29.13	56.60	69.90	4.30	7.10	10.50	192.36
November		24.54	15.81	19.00	53.40	5.80	5.10	10.30	133.95
December		22.58	9.96	14.70	32.00	5.90	3.30	7.60	96.04

Table 9 defines the rule curve for Dez Dam's conservation zone (active storage pool) under four scenarios of dam height increases. The rule curve specifies the target reservoir elevation (in meters above sea level, masl) for each month to balance water supply, flood control, and operational needs. The simulation of Dez Dam reservoir requires two main categories of data: physical characteristics and operational parameters. The physical data includes elevation-volume-area relationships, reservoir morphology, lake evaporation rates, seepage losses, and controlled outflow capacities, while the operational data encompasses flood control strategies, conservation storage rules, and dead storage volume. For this study, all necessary data were

compiled from existing technical reports, with the current normal water level set at 352 meters above sea level (masl) and three proposed raised dam scenarios at 359, 360, and 362 masl. In each scenario, the flood control zone was established at 2 meters above the normal water level, with monthly conservation storage operations and corresponding maximum/minimum flow rates specified in the accompanying tables. Additionally, the dead storage level was consistently maintained at 222.7 masl across all scenarios. The reservoir is operated at its full normal elevation (ranging from 352 to 362 masl, depending on the height increase scenario) to maximize water availability for irrigation (summer demand) and hydropower generation.

During winter and spring, water levels are gradually lowered to 334–350 masl to:

- Create flood storage capacity for incoming high-flow events.
- Prioritize downstream environmental flows to maintain ecological balance.

This operational strategy ensures optimal resource utilization while balancing flood control and ecosystem needs. The rule curve shows how Dez Dam's operational flexibility improves with height increases, but trade-offs exist. +8m (360 masl) offers a balanced solution for drought resilience and flood control. Table 10 defines the operational discharge limits (minimum and maximum) for Dez Dam under four height-increase

scenarios. These values are critical for flood control, hydropower generation, and downstream ecological requirements. The results demonstrate that elevated reservoir levels (360m/362m) substantially enhance flood control capacity by increasing available storage volume. However, these higher operational elevations necessitate corresponding upgrades to dam infrastructure to ensure structural integrity and safe operation. Concurrently, the imposed minimum environmental flows exhibit a marked increase under these elevated water levels, yielding dual benefits for downstream ecosystem sustainability and dry-season water supply reliability.

Table 9. Dez Dam rule curve for normal elevation under different height increase options (conservation zone).

Month	Normal Level 352	Normal Level 357	Normal Level 360	Normal Level 362
April	342.5	348.5	351.6	353.6
May	352	357	360	362
June	352	357	360	362
July	352	357	360	362
August	352	357	360	362
September	352	357	360	362
October	352	357	360	362
November	349.4	354.5	357.5	359.5
December	338.4	344.3	348.1	350.1
April	334.4	340.3	344.2	346.2
February	334.4	340.3	344.2	346.2
March	334.4	340.3	344.2	346.2

Table 10. Dez Dam rule curve for minimum and maximum discharge in various height increase options.

Month	Normal Level 352	Normal Level 357	Normal Level 360	Normal Level 362
Maximum discharge (cms)	472	496.8	1000.8	1000.8
Minimum discharge (cms)	59	62.1	83.3	83.3

Based on a comprehensive evaluation of these trade-offs, the 360m operational level is proposed as the optimal compromise. This elevation achieves a balanced performance by maintaining robust flood mitigation capabilities and ecological benefits while minimizing the need for extensive infrastructural modifications. The marginal additional gains offered by the 362m scenario do not sufficiently justify the associated incremental costs and engineering challenges.

Simulation Results of the Studied Scenarios:

This section presents the outcomes of simulating the different scenarios under investigation. The simulation was conducted for four distinct scenarios:

1. Current dam conditions at elevation 354 meters
2. Increased dam height scenarios: +5m, +8m, and +10m

The main downstream water users receiving releases from Dez Dam include:

- Municipal water supply for Dezful city (diverted from Sibili weir)
- Right Bank Canal Networks 1 & 2
- Left Bank Canal Network of Harmaleh diversion weir
- Pumping Stations 1 & 2 of Band-e Ghir diversion weir
- Shawar River

Water demands for both drinking and agricultural uses were calculated based on downstream requirements. All simulations were performed using actual reservoir inflow data as the primary input.

Scenario 1: Baseline Conditions (Dam Height: 354m, Normal Water Level: 352m). The first scenario simulated the Dez Reservoir under existing conditions, maintaining a normal water level of 352 meters. Fig. 5 presents the water

storage volume versus water surface elevation relationship for this baseline scenario.

Scenario 2: Simulation Results for Dez Dam with +5m Height Increase (Crest Elevation: 359m, Normal Water Level: 357m). Fig. 6 displays the simulated relationship between water storage volume and reservoir surface elevation under the modified dam structure. Key findings include.

Scenario 3: Simulation of Dez Dam with 8m Height Increase (Crest Elevation: 362m Normal Water Level: 360m). The simulation results demonstrate the operational

characteristics of the modified dam structure as Fig. 7.

Scenario 4: Simulation of Dez Dam with 10m Height Increase (Crest Elevation: 364m | Normal Pool Level: 362m). Fig. 8 presents the water storage volume versus water surface elevation for scenario 4. The simulation results demonstrate that increasing the dam height in each scenario leads to greater water storage capacity, with Scenario 4 (+10m height increase to 364m) achieving the maximum reservoir volume in the Dez Dam system.

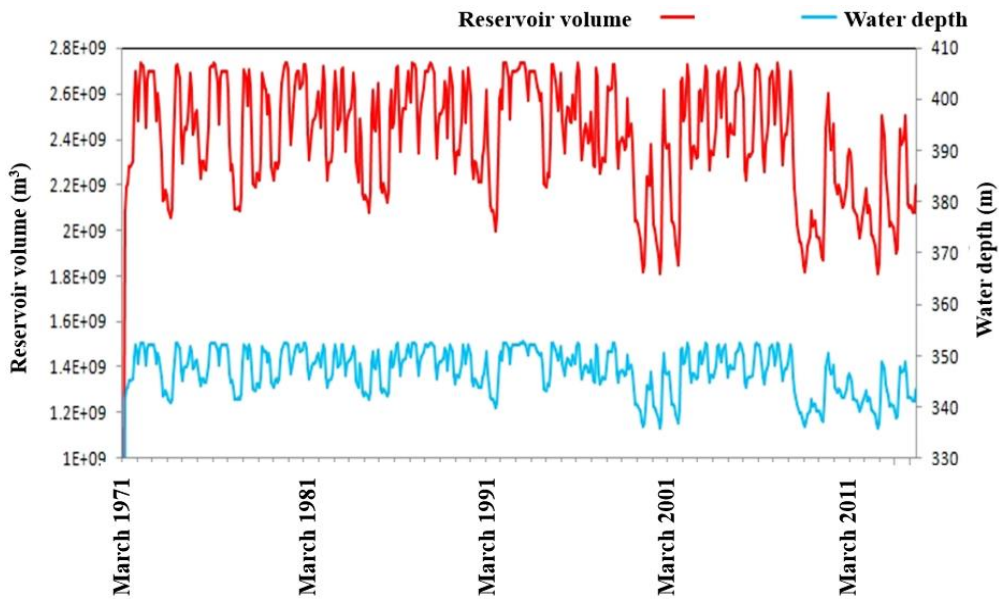


Fig. 5. Monthly mean water volume and surface elevation of Dez dam under current conditions (Scenario 1).

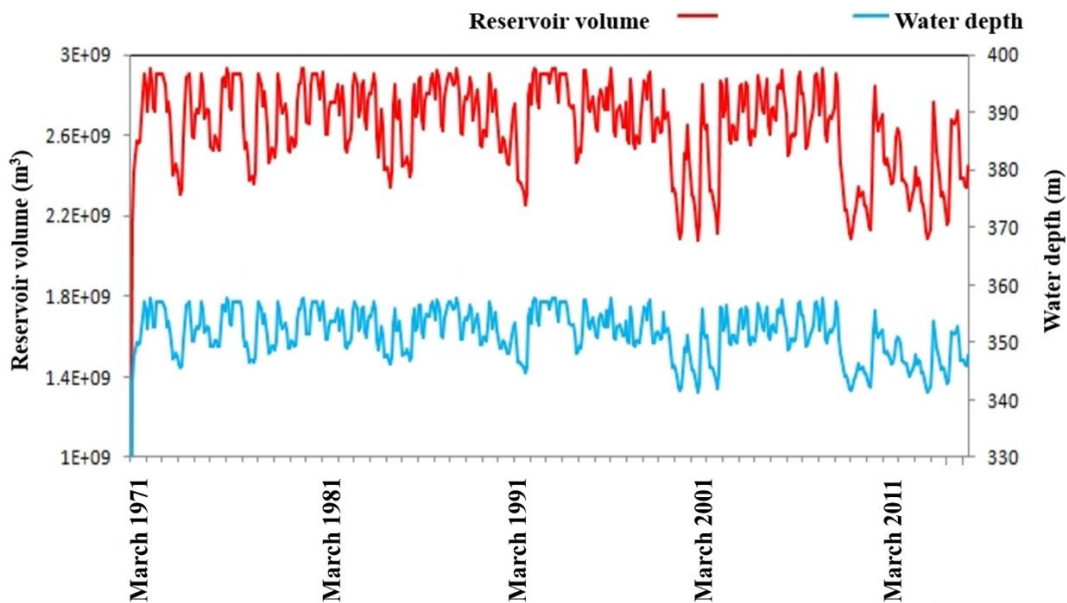


Fig. 6. Monthly mean water volume and surface elevation of Dez dam with 5m Height Increase (Scenario 2).

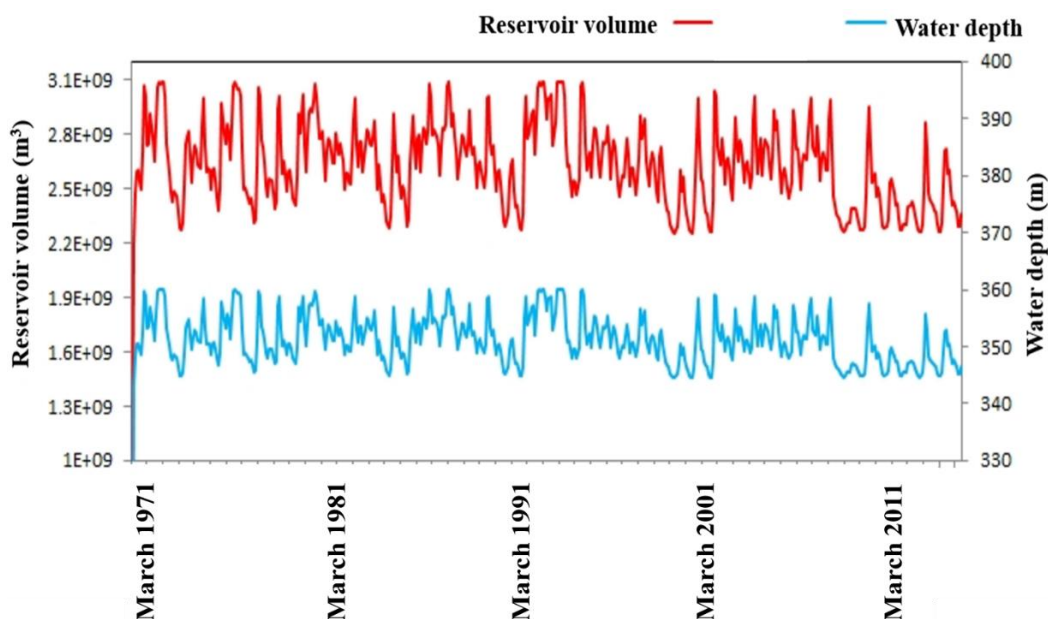


Fig. 7. Monthly mean water volume and surface elevation of Dez dam with 8m Height Increase (Scenario 3).

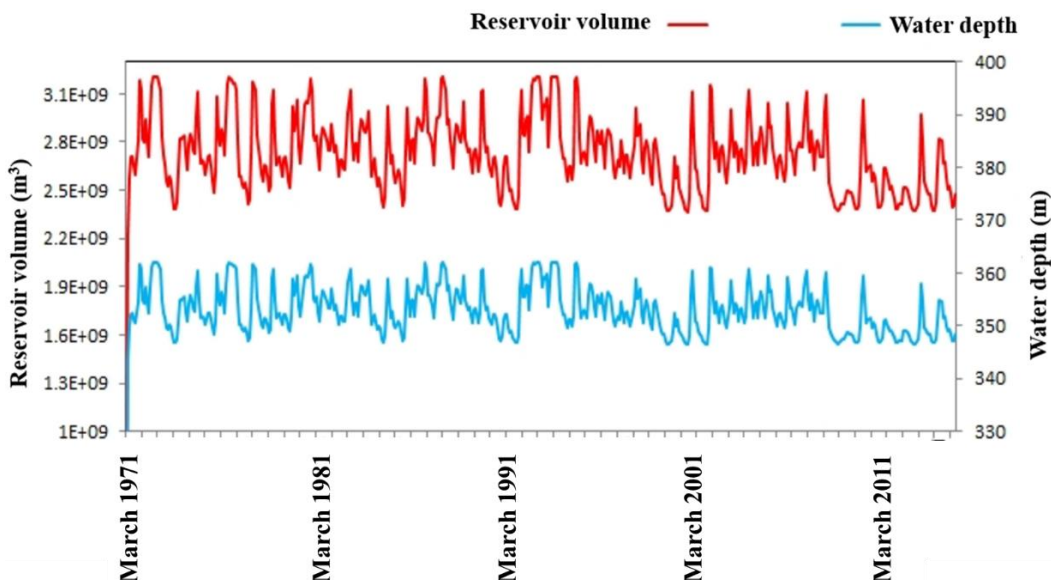


Fig. 8. Monthly mean water volume and surface elevation of Dez dam with 10m Height Increase (Scenario 4).

Scenario 1 (Current Conditions): Water level range: 335 to 351 m, and reservoir volume range: 1.89 to 2.9 billion cubic meters:

These results indicate significant seasonal fluctuations in Dez Dam's water storage, primarily due to rainfall variability and irrigation demands. Similar studies on other dams (e.g., Karkheh and Karun-3) show that 30-40% of reservoir volume is typically depleted during dry seasons under normal conditions (Ministry of Energy, 2021).

Scenario 2 (+5m Height Increase): Water level range: 340 to 358 meters, and reservoir volume range: 2.1 to 3 billion cubic meters. The 5-meter increase led to an 11-15% rise in

storage capacity compared to Scenario 1. This enhancement could improve water supply reliability during droughts. Studies on similar dams (e.g., Gotvand Dam) confirm that even minor height increases (5m) can significantly boost storage capacity (Water Research Institute, 2019).

Scenario 3 (+8m Height Increase): Water level range: 345 to 360 meters, and reservoir volume range: 2.3 to 3.1 billion cubic meters. This scenario demonstrated a 22-25% storage increase over the baseline. Such an expansion could substantially improve flood control and agricultural water supply. Past research on Dez Dam highlights that height increases beyond

7m require rigorous geotechnical and hydraulic assessments.

Scenario 4 (+10m Height Increase): Water level range: 348 to 361 meters and reservoir volume range: 2.4 to 3.2 billion cubic meters. This scenario offers the highest storage gain (27-30% over baseline). However, its technical challenges and implementation costs (e.g., structural reinforcement, spillway upgrades) demand careful evaluation. Global cases (e.g., Hoover Dam, USA) show that height increases exceeding 10m in large dams require heavy investment and extensive environmental reviews (USBR, 2021).

4. Conclusion

The global water crisis, characterized by limited freshwater availability and uneven distribution, necessitates optimized water resource management. To address this challenge, comprehensive regulations must be established for sustainable operation of rivers and reservoirs, which are critical components of water systems. Implementing such policies helps balance limited resources with growing demands while optimizing water use across agricultural, urban, and industrial sectors, ultimately supporting sustainable water management. For effective planning, particularly regarding dam reservoirs, managers must adopt optimal policies that integrate real-time monitoring, adaptive allocation strategies, and environmental flow requirements. The implementation of smart water grids and tiered pricing systems can further enhance efficiency, ensuring water security for future generations while maintaining ecosystem health. Such integrated management is essential for building climate resilience in water-stressed regions. The results demonstrate that the conceptual hydrological model HEC-HMS, which accounts for rainfall-runoff relationships, can effectively simulate predicted runoff data for reservoir operation modeling. In contrast, the hydrological model HEC-ResSim provides reliable results for reservoir modeling and is well-suited for simulating the Dez Dam reservoir, allowing for the examination of various scenarios. A key feature of this model is its ability to accommodate any arbitrary combination of reservoirs, power plant locations, water withdrawal points, and water inflow points, while considering the interactions between

parallel and sequential systems. Additionally, the model can implement different operational policies based on user-defined requirements. Furthermore, modeling with HEC-ResSim enables the simulation and analysis of various impacts on water resources, contributing to improved water management and climate change risk assessment. Overall, the simulation shows that increasing the dam height in each scenario leads to greater water storage and higher water levels in the Dez Dam reservoir, with Scenario 4 proving to be the most effective for reservoir and water level simulation. However, environmental risks must also be considered, including potential impacts on downstream ecosystems, sedimentation patterns, and long-term sustainability. Comprehensive assessments should be conducted to balance the benefits of increased storage capacity with ecological and structural challenges. According to another scenario, scenario 3 (+8m) is proposed as the optimal choice because it balances storage gains with cost-effectiveness and provides sufficient volume (2.3–3.1 BCM) to meet water demands and flood control needs. Poses lower technical and environmental risks compared to the +10m option. Scenario 4 (+10m) is only justified if adequate funding and detailed safety studies are available.

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