Flood Control Operation of a Multi-Reservoir System Using System Dynamics-Based imulation-Optimization Model

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Abstract

This paper presents a multi-objective optimisation model for multi-purpose reservoir operation model. Two conflicting objectives are to minimize downstream damage by reducing flood peaks at selected downstream control points and to maximize hydropower generation. The obtained Pareto optimal solution is a compromise between optimal alternatives of downstream and hydropower damages. The proposed model is applied to the reservoirs system of Karkheh river basin. The proposed model includes VENSIM simulation model based on system dynamics approach coupled with multi-objective particle swarm optimization (MOPSO) algorithm. The MOPSO-VENSIM model is employed to optimize the operation of cascaded reservoirs during flood through allocating an optimal initial flood control capacity to each reservoir in the river basin.

Keywords: Simulation, Optimization, Flood, System Dynamics, PSO.

INTRODUCTION

Flood control is typically one of the most significant purposes due to its role in reducing flood damage particularly in vulnerable areas. One more optimization model for reservoir flood-control operation is dynamic programming. Evolutionary algorithms such as (GA) (Malekmohammadi et al. 2011) Ant Colony Optimization (Afshar et al. 2009), Simulated Annealing (Ahmed and Mays 2013) and PSO are examples of meta-heuristic optimization techniques that have been extensively used for operation of reservoir flood control systems. PSO has been also used in many applications (Bayat et al. 2011).

The main purpose of this study is to examine the applicability of MOPSO-VENSIM model to a case study of Karkheh river basin in order to achieve optimal operating policy for flood control.

MOPSO-VENSIM MODEL

VENSIM is simulation software developed by Ventana System, Inc, for improving the performance of real systems. PSO algorithm was selected here because of some advantages such as simple running, etc.

-Objective functions: 1. minimizing a function of peak discharges at some control points 2. minimizing the total loss due to reduction of hydropower generation

$$1.\ \min D^{DS} = \sum_{k=1}^{m} f_1^k\left(\max\left(Q^k(t)\right)\right) \qquad 2.\ \min D^{HP} = \sum_{i=1}^{n} f_2^i\left(S_i^{FC}\right)$$

t: the index of time step; *k*: the index of downstream damage center; *m*: the number of downstream damage centers; D^{DS}: the total damage of downstream damage centers; $Q^k(t)$: the outflow hydrograph of the reservoir; f_1^k: the flood damage; *i*: the index of reservoir; *n*: the number of reservoirs; D^{HP}: the total hydropower generation damage; S_i^{FC} : the amount of control volume; f_2^i: the hydropower generation damage

-Constraints: 1. the finite difference formula of Reservoir Continuity Equation, 2. Physical Limitation.

$$1.\ S_{t+1}^i - S_t^i = \left(I_{t+1}^i + I_t^i\right)\frac{\Delta t}{2} - \left(Q_{t+1}^i + Q_t^i\right)\frac{\Delta t}{2} \quad \forall\, i,t \;\; i \in \Lambda \;\; t \in [t_0, T]$$

$$2.\ S_{dead}^i \le S_t^i \le S_{max}^i \quad \forall\, i,t \;\; i \in \Lambda \;\; t \in [t_0, T] \quad , \quad R_i^{min} \le R_t^i \le R_{i,t}^{max} \quad \forall\, i,t$$

$$R_{i,t}^{max} = f_3^i\left(S_{i,t}\right) \quad , \quad \left|R_t^i - R_{t-1}^i\right| \le CR_{acp}^i \quad \forall\, i,t$$

-River Routing Equation: In this paper the Muskingum linear channel routing method is used for river routing.

DESCRIPTION OF CASE STUDY

Karkheh River is the third largest river in Iran. Six reservoirs were planned to be located on the basin. Karkheh River Basin and its multi-purpose reservoir system have active storage capacity of about 14 billion cubic-meters and 1,827 MW potential of hydropower generation.

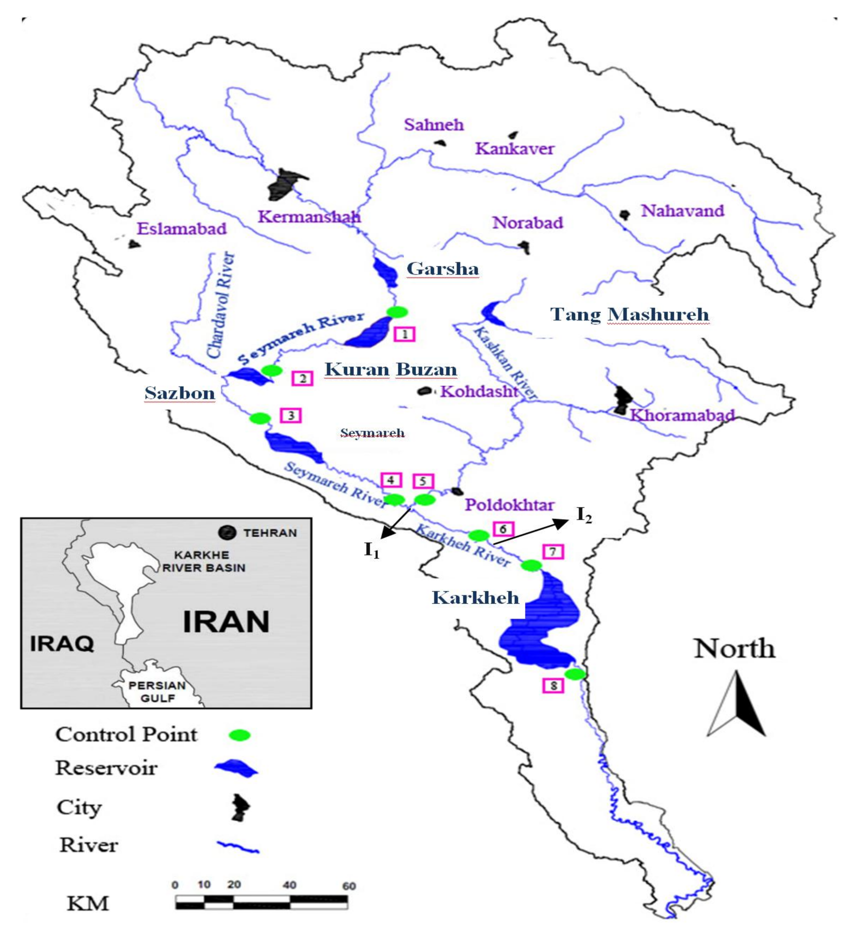

Figure 1. Map of Karkheh River basin, Iran.

DATA COLLECTION

1.50-year return period flood, 2.The flood hydrograph based on the analyses of possible storms and a rainfall-runoff simulation model using HEC-1,3.The potential hydropower generation in hydroelectric power plants.

$$P = \eta \times H \times R$$

η: hydroelectric power plant efficiency; H:effective water pressure head; R:water discharge flowing through the turbines of the hydroelectric power plant.

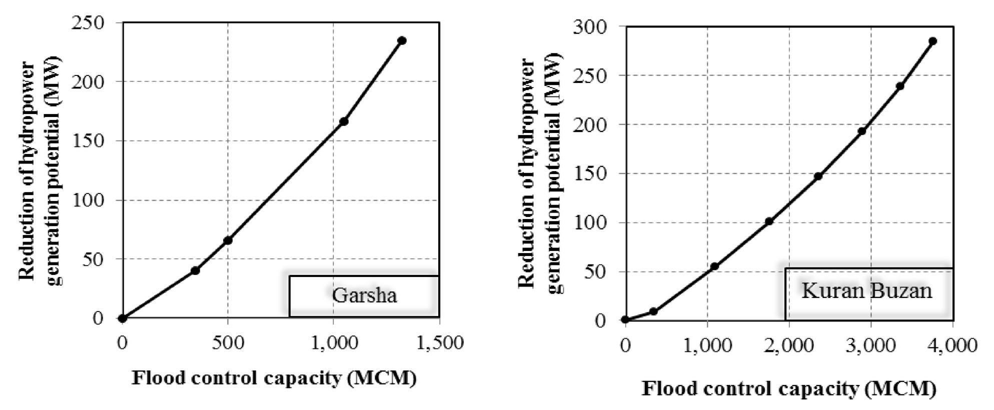

Figure 2. Curve between reduction in potential Hydropower generation and flood control capacity

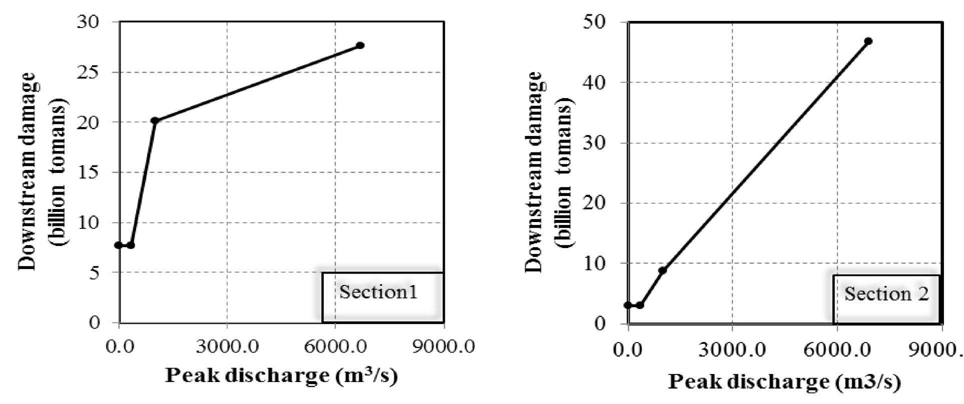

Figure 3. Relation between financial downstream loss and peak flow rate

APPLICATION OF THE METHODOLOGY

We consider a step-wise parametric operating rule with five discrete levels (volumes) for each of ones (steps). Therefore, the number of steps (parameters) represents the number of decision variables. In addition, initial flood control capacity of each reservoir is also considered as one more decision variable. The objective function of hydropower generation is considered as a constraint.

Therefore, the only objective is to minimize the total damage in vulnerable areas.

The assumed reservoir storage volume is divided into five parts with different decision variables for each part.

RESULTS

The proposed model is solved using a 4-hour flow routing time step for 240-hour duration. Maximum fluctuation of reservoir release is considered as a constraint so that the peak release does not exceed the maximum amount between two successive time steps. As mentioned earlier, five decision variables are considered in each reservoir in order to control the amount of reservoir release. One decision variable is also used for defining initial flood control capacity.

Table. 1. Number of decision variables

Scenario	Decision variable name	Number of decision variables
Non-developed	Reservoir volume	10
	Initial flood control capacity	2

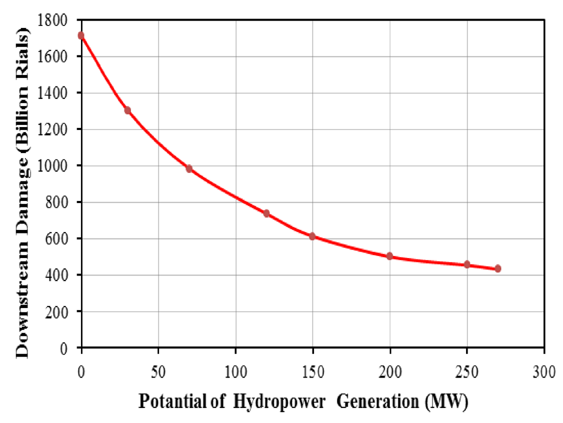

Figure 4. Pareto optimal operating curves

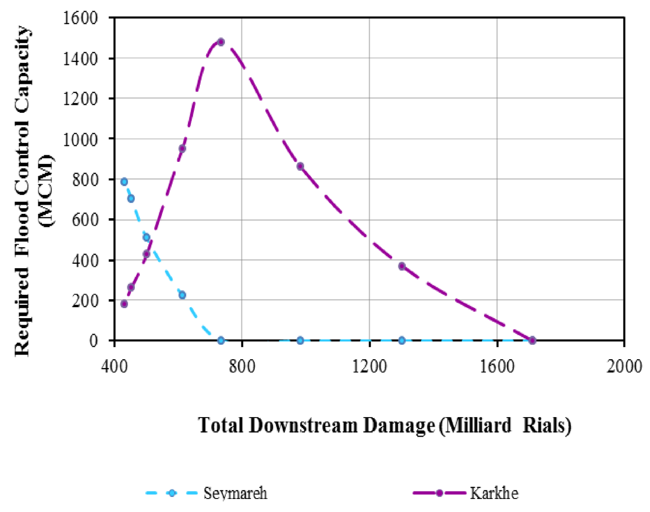

Figure 5. Trend of downstream damage increment in vulnerable areas with increase in total downstream damage.

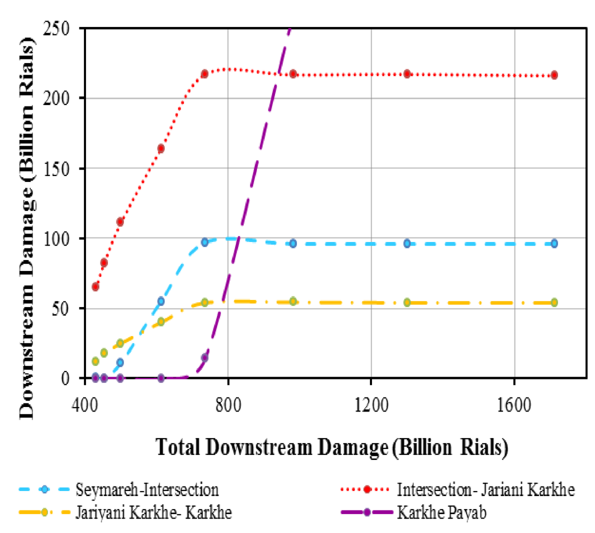

Figure 6. Change Trend of required flood control capacity of reservoirs with increase in total downstream damage.

These curves represent planning instructions for flood control capacity of Karkheh river-reservoir system in non-developed scenario.

CONCLUSION

This paper considering two conflicting objectives including minimizing downstream damage by reducing flood peaks at selected downstream control points and maximizing hydropower generation were analysed by using a multi-objective simulation-optimization model known as MOPSO-VENSIM model. Results indicate that in non-developed scenario, the minimum amount of downstream damage is equal to 435 billion Rials and there is no possibility of further reduction. The distribution of downstream damage between vulnerable areas and distribution of hydropower damage and corresponding initial flood control capacity between the reservoirs were presented. Furthermore, the distribution of initial flood control capacity between reservoirs represents planning instructions for flood control capacity in the reservoirs system of Karkheh river basin. As results show, the maximum amount of damage between vulnerable areas is allocated to vulnerable area of Karkheh downstream.

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