Chapter 33
Optimization of Spillway Operation for Flood Mitigation in Multi-reservoirs River System

Thanh Hao Nguyen, Philippe Gourbesville, Ngoc Duong Vo, and Nguyen Duc Phuoc Vo

Abstract The multi-reservoirs system in Vu Gia Thu Bon rivers catchment plays a significant role in production of annually alternative electrical and mitigation of flood damage. However, in the flood season, operational problems of the rivers and multi-reservoirs system are more likely to increases which result from developing conflicts objectives and the number of reservoir. In this research, a flood mitigation operation approach based on a simulation-optimization model is developed for minimizing vulnerability of flood in downstream of the system. For this purpose, an optimization algorithm is introduced, in which maximum water level at downstream control points is objective function and the spillway release discharges are the decision variables. A global optimization tool, Shuffled Complex Evolution (SCE) algorithm which implemented in the AUTOCAL software was coupled with the Mike 11 from DHI simulation model for optimizing stages level of spillway gates. Vu Gia Thu Bon rivers catchment including four major reservoirs of A Vuong, Song Tranh 2, Dak Mi 4 and Song Bung 4 is examined in historical flood events that happened in 2009. The results show that the reservoir system using the optimal operation is more effective in reducing maximum water level at the downstream control points comparing to the current regulations.

Keywords Optimization · Flood mitigation · Reservoir systems · SCE algorithm

---

T. H. Nguyen (✉) · P. Gourbesville
Université Cote d'Azur, Polytech La, Polytech Nice Sophia, 930 route des Colles,
06903 Sophia Antipolis, France
e-mail: thanh-hao.nguyen@univ-cotedazur.fr

P. Gourbesville
e-mail: Philippe.Gourbesville@unice.fr

T. H. Nguyen · N. D. Vo · N. D. P. Vo
University of Science and Technology, University of Danang,
54 Nguyen Luong Bang, Danang, Vietnam
e-mail: vnduong@dut.udn.vn

N. D. P. Vo
e-mail: vndphuoc@dut.udn.vn

© Springer Nature Singapore Pte Ltd. 2020

P. Gourbesville and G. Caignaert (eds.), *Advances in Hydroinformatics*, Springer Water,
https://doi.org/10.1007/978-981-15-5436-0_33

33.1 Introduction

The Vu Gia Thu Bon catchment is one of the largest river system in central Vietnam, covers major parts of Quang Nam province, Danang city and a small part of Kontum province. The whole river basin locates in 16°03′—14°55′ North latitude and 107°15′—108°24′ East longitude. The basin plays an important significant role in term of social and economic points of view for the central region of the country. This catchment is often hit by typhoons and inshore tropical depression which brings extreme precipitation. Due to typical characteristic of the rivers such as shorts and steeps with narrow valleys, steep riverbanks with many waterfalls, so as soon as a typhoon strikes, the upstream watershed receives voluminous rainfall in a short time, which quickly converges downstream when storm landing. Hence, it can easily lead to the flooding in the lowland area, causing considerable economic losses and casualties. The typhoon rainfall flows, however, is also the primary source for hydroelectrical generation uses during dry season. Reservoir have become the most important facilities for distributing water among various purposes [4].

In the flood season, reservoirs systems are operated in the following order of priority: safe protection of the dams, flood mitigation and hydropower generation. The analysis of multi-reservoir system operation typically involves optimization and simulation models which can provide the quantitative information to improve operational water management for this catchment. In recent years, the application of heuristic methods to various types of studies on water resources development and reservoir flood management has been increasingly grown up [1–3, 7]; [6].

In this present study, a simulation-optimization model which minimizes the flood peak at control point downstream of the Vu Gia Thu Bon multi-reservoir system is introduced. A global optimization tool, Shuffled Complex Evolution (SCE) algorithm which implemented in the AUTOCAL software was coupled with the Mike 11 from DHI simulation model for optimizing stages level of spillway gates.

33.2 Methodology

The simulation-optimization framework that is adopted for optimization of reservoir systems is illustrated in Fig. 33.1. The optimization criteria (the maximum water level at control point at downstream) are defined as objective functions in simulation which are numerical measured from the model. The model output, after that, are compare with user-specified targets (flood level). Based on the calculated objective functions the optimization algorithm selects new sets of control variables (release discharge of reservoirs system) to be evaluated. The process is repeated a number of times until no further improvement can be made [5].

In this research, in order to minimize the risk of flood damage using operation of spillway gates, a simulation model is coupled with an optimization solver. The Mike 11 hydraulic model is utilized for flood routing in reservoirs system and the

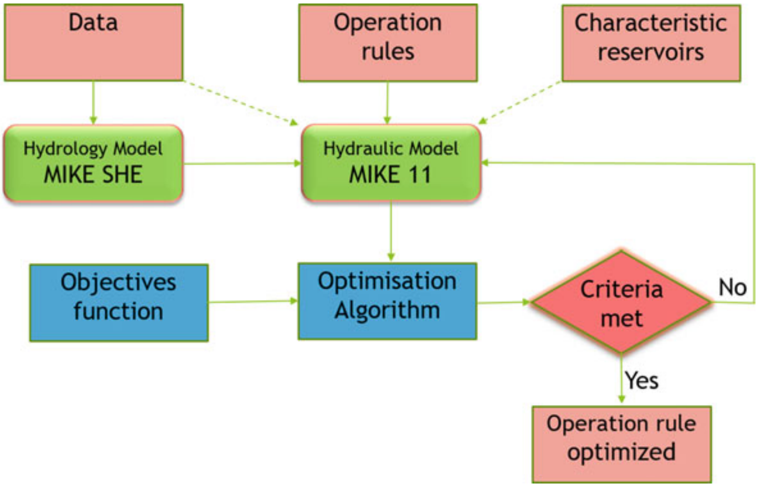

Fig. 33.1 Simulation-optimization framework

Shuffled Complex Evolution (SCE) algorithm which implemented in the AUTOCAL software for optimization of operating spillway gates.

33.2.1 Simulation Method

Mike 11 is suitable for simulation of the low in the river system including the reservoir operations. In this study, a simulation model which represent the releases from the four reservoirs, through the operational structures spillway gates, specified in Mike 11 as control structure (gate type is radial gate). The gate operation methods are determined from a control strategy. The control strategy describes how the gate opened level depends on the value of the control point such as the reservoir stage, the downstream water level and the time of the year. For a specific gate, it is possible to choose between an arbitrary number of control strategies by using a list of 'if' statements.

33.2.2 Optimization Model

The Shuffled Complex Evolution (SCE) method is a global optimisation algo- rithm that combines various search strategies, including (i) competitive evolution, (ii) controlled random search, (iii) the simplex method, and (iv) complex shuffling.

The SCE algorithm includes the following steps:

1. Initialisation. An initial sample of parameter sets θi are randomly generated from the feasible parameter space defined by the lower and upper limits of each parameter on the model parameters page. For each parameter set the objective function value $Fi = F(\theta i)$ is calculated. The initial sample has the size $s = pm$ where p is the number of complexes and m is the number of points in each complex.
2. Partitioning into complexes. The s points are ranked in order of increasing objective function value $(F(1) < F(2) < \dots < F(s))$. The s points are partitioned into p complexes, such that points corresponding to function values $\{F(1), F(p + 1), .., F((s\text{-}1)p + 1)\}$ form the 1st complex, points corresponding to function values $\{F(2), F(p + 2), .., F((s\text{-}1)p + 2)\}$ form the 2nd complex, etc.
3. Evolution. A sub-complex of size q is formed from the complex by randomly choosing q points from the p points in the complex. A triangular probability distribution is used for assigning the probability of a point to be included in the sub-complex (i.e. larger probability for points with smaller objective function value). The sub-complex is evolved (offspring generation) according to the simplex algorithm. Each complex is evolved β times.
4. Complex shuffling. The new sample of s points is shuffled, cf. step 2.
5. Steps 2-4 are repeated until one of stopping criterion achieve.

Three stopping criteria are defined:

- Maximum number of model evaluations.
- Convergence in objective function space. In this case the optimisation terminates if the objective function of the best parameter set has not changed more than a user-defined minimum value in a given number of shuffling loops.
- Convergence in parameter space. In this case the optimisation terminates if the range of parameter values of the entire population in the parameter space is less than a given value (not user-defined).

The search terminates when one of these criteria is met.

33.3 Case Study: Vu Gia Thu Bon Reservoirs System

The Vu Gia-Thu Bon system is located originates on the eastern side of the Truong Son mountain range. It has all characteristic of river in the area such as short, narrow valleys, steep riverbanks along with many waterfalls and rapids in upstream. In the middle reaches, the riverbed often widens and shallows. In the downstream reach, riverbanks become low, allowing overflow into fields and villages during the flood season. The Vu Gia-Thu Bon system has two main rivers - the Vu Gia and Thu Bon rivers (Fig. 33.2). The Vu Gia river has many tributaries, the most significant being the Dak Mi (or Cai river), Bung, A Vuong and Con rivers. The length of the Vu Gia river to its mouth in Da Nang is 204 km.

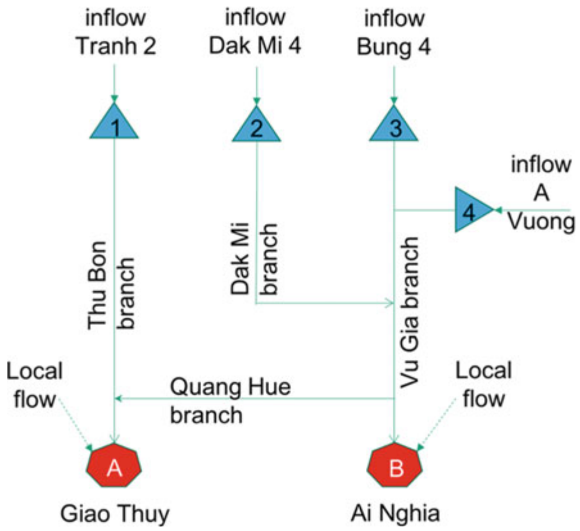

Fig. 33.2 Description of the Vu Gia Thu Bon multi-reservoirs river system

The Thu Bon river is 152 km long and originates at the borders of the three provinces of Quang Nam, Kon Tum and Quang Ngai at an elevation of more than 2,000 m. It runs in a north-south direction then changes its course to flow south-west—north-east and then west-east up to Giao Thuy before entering the sea through the Dai estuary. The total catchment area of the Vu Gia-Thu Bon river basin is 10,350 km^2.

Towards the downstream area, for some years, there is an exchange of flow between the two rivers. The Quang Hue river diverts part of flow from the Vu Gia into the Thu Bon. About 16 km from Quang Hue river, Vinh Dien river returns part of the flow from Thu Bon to Vu Gia. Apart from the flow exchanges, the river system is also supplied with additional water from other branches, i.e., the Tuy Loan

33.3.1 Multi-reservoir in Vu Gia Thu Bon Catchment

In the last few years, more than twenty hydropower plants have been constructed in the Vu Gia Thu Bon catchment. Steep slope of mountainous topography greatly limits the capacity of reservoir in the central region of Vietnam in general and the catchment in specific. Most projects are using dam for impoundment the river and using potential head of the river to build a system of hydropower reservoir cascade. Up to now, on the Vu Gia river and Thu Bon river, there are 4 large cascade hydropower reservoirs have been developed, with the major characteristics given in Table 33.1.

Table 33.1 The main characteristics of the four dams and their reservoirs

	A Vuong	Song Bung 4	Dak Mi 4	Song Tranh 2
Total storage capacity (10^6 m^3)	343.55	510.8	312.38	729.2
Active storage capacity (10^6 m^3)	266.48	233.99	158.26	521.1
Dead storage capacity (10^6 m^3)	77.07	276.81	154.12	208.1
Average annual inflow (m^3/s)	39.8	73.7	67.8	114
Installation capacity (MW)	210	156	148	190
Crest elevation of the dam (m)	383.4	229	262	180
Normal water level (m)	380	222.5	258	175
Dead water level (m)	340	205	240	140

All of large hydropower reservoirs in Vu Gia Thu Bon catchment are used guiding channel for transferring water from reservoir to hydropower plant. Almost all reservoirs in the area have no capacity for flood storage. All of the hydropower reservoirs on the Vu Gia Thu Bon catchment do not have flood control storage in design.

33.3.2 *Objective Function*

The major aim of this study is evaluation flooding mitigation capacity of the system which control by flood peak at critical downstream gauging points. Hence, the objective is to minimize the flood peak at control point (at Ai Nghia station and Giao Thuy station), which can be expressed by:

$$minimise\ F = \max\left(\sum_{j=1}^{2} H_j^2\right)_{t\in[t_o,T]}$$

where H_j is the flood peak that occurred at j station at the time step t of the flood season. T is the total number of time step, t_o is the operating initial time.

33.4 Application and Results

The flood-reducing capacity is the most significant variable of Vu Gia Thu Bon reservoirs system need to be considered in flood season. In this model, spillway gates operation of all reservoirs is optimized with pilot flood data happened from 26 September to 3 October 2009 comprising four reservoirs inflow hydrographs with base time of 216 h and 1-h time steps were used (Fig. 33.4). The decision variables of SCE algorithm were spillway gates level of four reservoirs.

The SCE parameters are found by a trial and error procedure represented as: number of complexes $p = 2$; maximum number of model evaluations is 2,000; number of iteration loops is 5; and minimum relative change in objective function is 0.01. Each routing model or fitness evaluation lapses about 3 min (using a computer—3.6 GHz CPU speed). Therefore, the total run time for the model with 2,000 was about 100 h. The Fig. 33.3 shows the objective function for the different model evaluations performed during the optimization.

The time variation of reservoirs storage and flood hydrographs at reservoirs results from different models are compared in Fig. 33.4. When the flood enters to the reservoirs, the release rate will increase gradually in order to prevent any sudden change in storage volume. Initially, the discharge amount and inflow rates were almost the same. Then inflow rate exceeded release rate, casing storage increase up to maximum value, and the reservoirs stay at its normal water level for a while before reservoir draw down.

Magnitude and duration of flooding in downstream critical control points obtain from simulation of two scenarios which are: the operations associated with the current rules and the operation running SCE algorithm are compare to highlight differences. Table 33.2 illustrates that the peak runoff and maximum water level at downstream derived from SCE algorithm are lesser than from current rules.

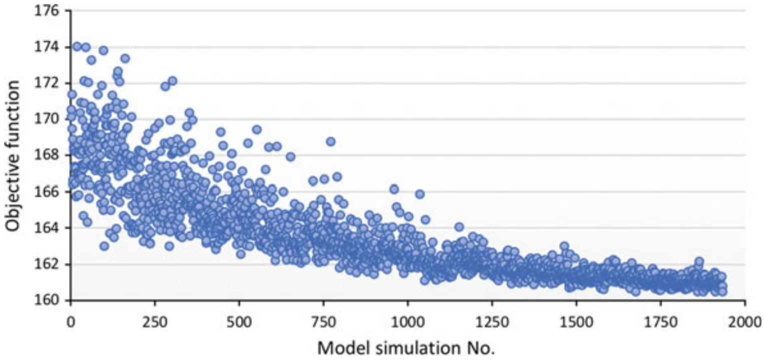

Fig. 33.3 Optimization iteration history

Table 33.2 Results for the two scenarios considered

Scenario	Downstream control-point			
	Peak runoff (m^3/s)		Water level (m)	
	Ai Nghia station	Giao Thuy station	Ai Nghia station	Giao Thuy station
Current rules	12,600	16,000	9.87	8.73
Optimal operation	11,460	14,500	9.54	8.44

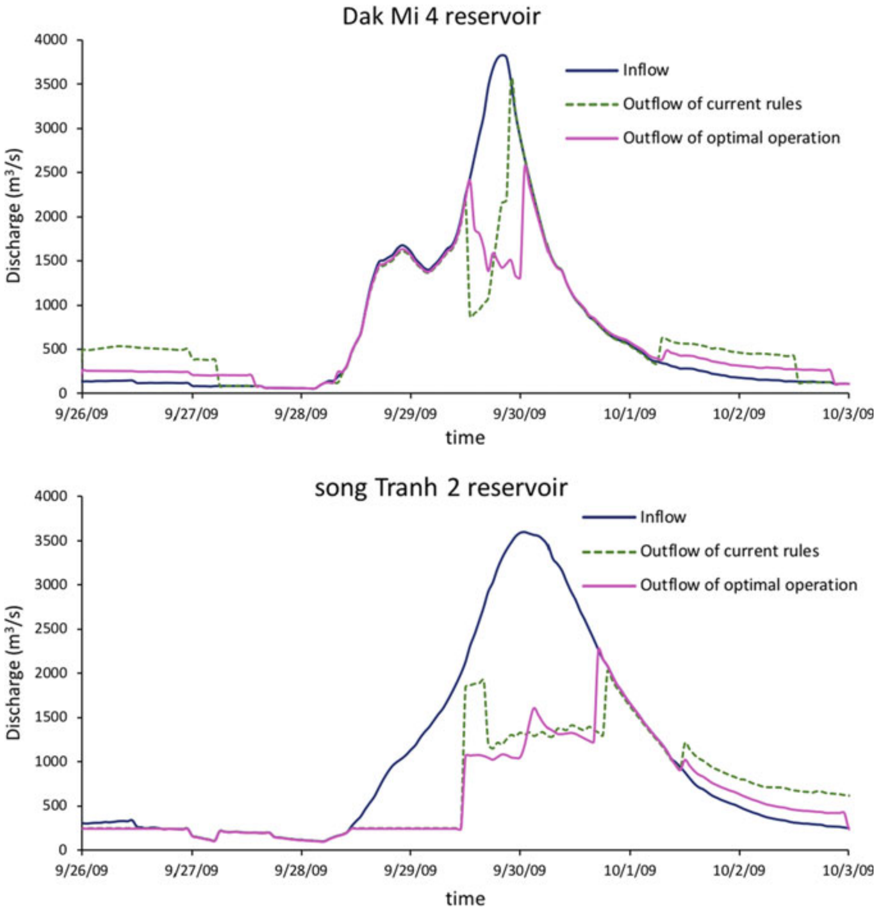

Fig. 33.4 Comparisons between the current rules with the optimal operation for four reservoirs

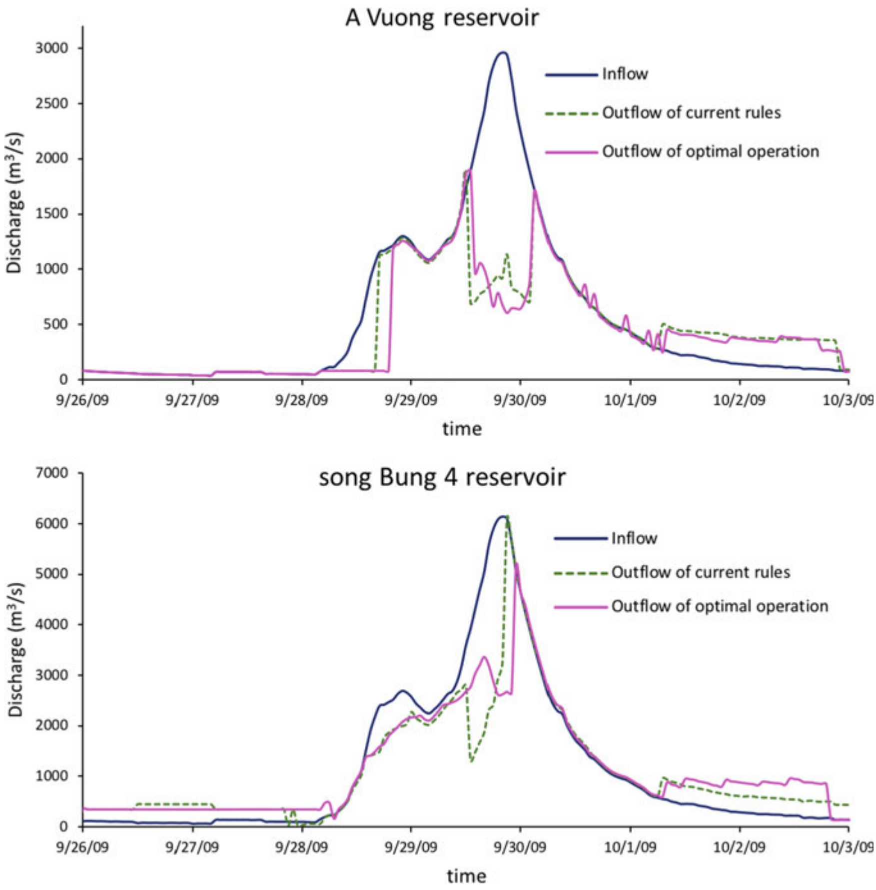

Fig. 33.4 (continued)

References

1. Chen Y-W et al (2014) The development of a real-time flooding operation model in the Tseng-Wen Reservoir. Hydrol Res 45(3):490
2. Cheng CC, Hsu NS, Wei CC (2008) Decision-tree analysis on optimal release of reservoir storage under typhoon warnings. Nat Haz 44(1):65–84
3. Dittmann R et al (2009) Optimum multi-objective reservoir operation with emphasis on flood control and ecology. Nat Haz Earth Syst Sci 9(6):1973–1980
4. Hsu NS, Wei CC (2007) A multipurpose reservoir real-time operation model for flood control during typhoon invasion. J Hydrol 336(3–4):282–293
5. Madsen H et al (2009) A real-time inflow forecasting and reservoir optimization system for optimizing hydropower production. Waterpower XVI:1–12
6. Prakash O, Srinivasan K, Sudheer KP (2015) Adaptive multi-objective simulation–optimization framework for dynamic flood control operation in a river–reservoir system. Hydrol Res 46:893–911
7. Yazdi J, Salehi Neyshabouri SAA (2012) A simulation-based optimization model for flood management on a watershed scale. Water Res Manage 26(15):4569–4586