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Short-term reservoir system operation for flood mitigation with 1D hydraulic model

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Abstract

Artificial reservoir operation is expected to affect significantly the flood disaster. It becomes more complicatedly towards the large systems where the operation of each reservoir has to meet fully with the systematic objective. Consequently, reservoir operation optimization is considered as a key factor to control the flood disaster at downstream area. Due to energy demand, more than twenty hydropower plants have been constructed over 10,350 km^2 of Vu Gia Thu Bon river catchments. The system has contributed importantly for economy development when provides annually a green electrical quantity up to 6 Terawatt-hour (TWh). Therefore, operation of system has still several limitations. It is judged to make the natural disaster increase in recent years. In order to reduce negative impacts of artificial reservoir system, four largest reservoirs are selected to simulate in this study. The simulation is carried out via Structure Control (SO) module of MIKE 11 model (DHI). The performance of operational scenario is demonstrated via the relation with the water level at two stations. The study is expected to provide an overview of the impact of artificial reservoir operation to flood disasters, as well as propose a new strategy to operate optimally the hydropower plants in Vu Gia Thu Bon catchments.

1 Introduction

In the last three decades, flooding has caused the most devastating and costly natural disasters in Vietnam. Base on statistic, during the period 1989-2009, the natural disaster annually killed around 510

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people and caused the damage of more than 5,175 billion VND. In the central of Vietnam, every year, the floods hit this area in 4-5 times, even 7-8 times in the Vu Gia Thu Bon catchment.

The Vu Gia - Thu Bon river catchment is ranked fourth in potential hydropower generation capacity in Vietnam after the Da, Dong Nai and Se San river systems. The total potential hydropower of the Vu Gia - Thu Bon river catchment is estimated to 1,300 MW with an annual potential energy at about 6 TWh [1]. In the last years, more than twenty hydropower plants have been constructed over 10,350 km^2 of Vu Gia Thu Bon river catchments. Therefore, operation of system has still several limitations. It is judged to make the natural disaster increase in recent years. The occurrence of flooding damage will easily elicit public outrage, which further increases the stress of decision makers while performing flood control operation [2].

Reservoirs play an important role in reducing the damage of flooding at downstream. Most reservoirs are operated for multiple objectives such as irrigation, drinking water supply, hydropower generation and flood control. Short term optimal operation of reservoir systems is a challenging task since the problem deals with many complicated variables such as inflows, storages, inter/intra-basin water transfers, flood protection, irrigation, industrial and/or municipal water supply demands and related uncertainties [3]. The reservoir systems of Vu Gia Thu Bon catchment are still managed based on fixed rule curves. The analysis of multi-reservoir system operation typically involves optimization and simulation models which can provide the quantitative information to improve operational water management [4]. Most literatures of reservoir flood control operation focused on studying the operating policies or releasing rules [2]. They used optimization technique such as linear programming, non-linear programming, dynamic programming, genetic algorithms to identify the optimal policies or rules of reservoir operation [5] [6][7][8][9].

Reservoir operation simulation can perform by using hydraulic models such as HEC-5, HEC-ResSim, Mike 11. Ngo et al. [10] used simulation techniques for operation rule curves for the Hoa Binh reservoir in the Mike 11 model. Yazdi et al. [11] used a simulation based optimization approach to optimize the design of multi-reservoirs for flood control in the watershed by coupling the Mike 11 hydrodynamic model and the NSGA-II multi-objective optimization model. Bayat et al. [12] applied the gate regulation curve operation policies available in HEC-5 for optimization-simulation for short-term reservoir operation under flooding conditions. Uysal et al [3] used HEC-ResSim model of USACE as a representative of a simulation-based approach to a flood management problem at Yuvacik Dam, Turkey.

In this paper, a simulation model has been elaborated with Mike 11 model (DHI, 2014). The main purpose is to examine the applicability of Structure Control (SO) module to the case study of the four reservoirs in Vu Gia Thu Bon catchment in order to operate for the flood control in the historical food events in 2009.

2 Case study: Vu Gia Thu Bon reservoirs system

The Vu Gia Thu Bon is the biggest catchment in the central region of Vietnam. This catchment has two main rivers, the Vu Gia river and the Thu Bon river (Figure 1). The topography over this region is complex with the relatively narrow mountainous area on the upstream and the flat coastal zone at the downstream. The mean annual rainfall of this catchment varies from 2,000 mm to 4,000 mm with 65% to 80% annual rainfall during in the rainy season, from September to December.

In the last 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 of this catchment in specific.

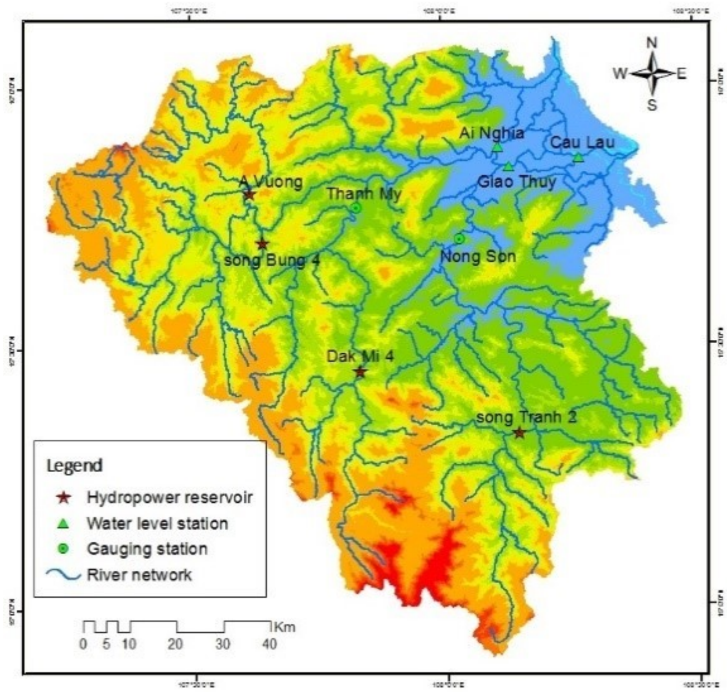

Figure 1: The Vu Gia Thu Bon catchment and four hydropower reservoirs.

In this catchment, there are four hydropower projects, were constructed with the medium storage capacity: A Vuong, song Tranh 2, Dak Mi 4, song Bung 4, which was completed in 2009, 2011, 2012 and 2014, respectively. The main purpose of their reservoir/hydropower plant project is hydropower generation facilities (Table 1).

Table 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

3 Model setup

3.1 Mike 11 model setup

- River network: this model is developed on 17 rivers and linking branches (figure 2). The four reservoirs have been placed in the reservoir branches of the network and the spillways have been included in the control structure of the model.

- Cross-section: the geometry of each river branch is specified via cross section from measurements and from the DEM. More than 400 cross-sections are used to define the four reservoirs.
- Boundary conditions: the upstream boundary and lateral boundary conditions are inherited from the Mike SHE model [13].
- Hydrodynamic parameters: This part mainly focuses on riverbed resistance. These parameters are represented via Strickler roughness coefficient M. The data used for model calibration are water level at Ai Nghia, Giao Thuy and Cau Lau station. For the upstream part of the Vu Gia Thu Bon, the roughness coefficient M is set to 30-50, whereas 60-80 is used for the downstream of the river.

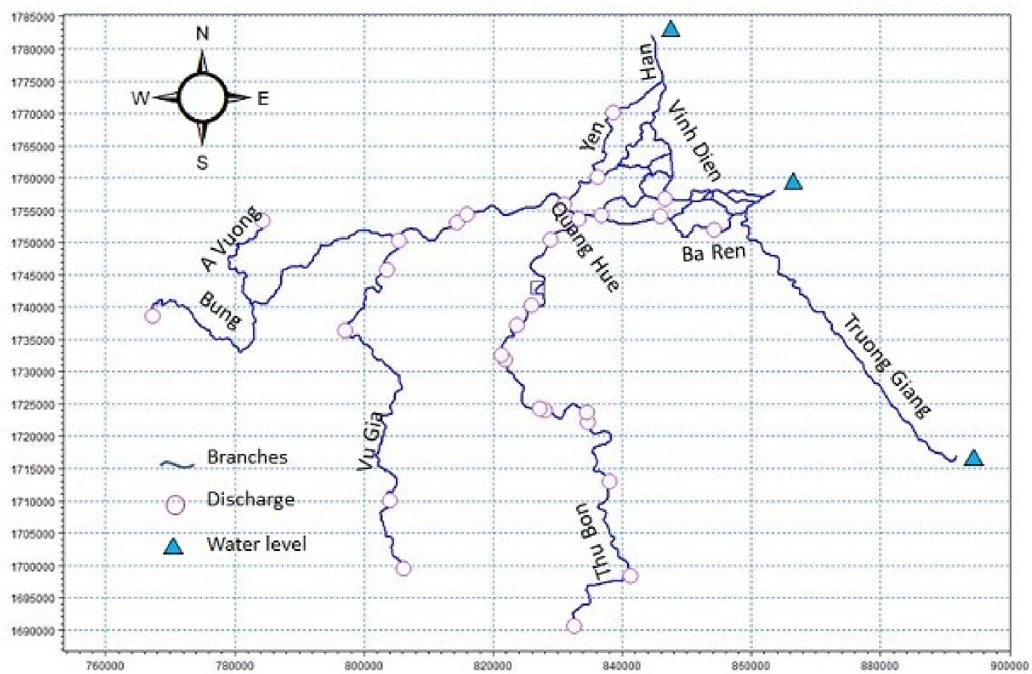

Figure 2: The Mike 11 model set up for Vu Gia Thu Bon river network.

3.2 Gates spillway operation

During the flood events, the operation of spillway gates can be seen the main problem in the reservoir management. In this study, a simulation model which simulate 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 way the gate operation is calculated is determined from a control strategy. The control strategy describes how the gate 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 [14].

In this setup, the target points are the gates level of the four radial gates in their reservoirs and more than three hundred of the logical statement is supplied to the model.

3.3 Initial and boundary conditions of four reservoirs

The Vu Gia Thu Bon is a big river system but observed data of this river system are still not sufficient to give a good simulation, there are only two discharge stations in this catchment. After setting up the calibration and validation of the Mike SHE model, the reservoir inflow of the system reservoir is extracted from this model.

This catchment is located at a tropical monsoon climate region where weather phenomena, such as rain and storm happen complicatedly, this region is annually attacked by 2-4 typhoons that bring huge rainfall and whirlwind during the rainy season (the period of September – December). Hence, the initial water level at reservoir are dead water level on September 1st annually.

4 Application scenarios

After setting up the calibration and validation of the Mike 11 hydrodynamic model, operating the reservoir system with three cases in the historical flood events in 2009:

- Case A: without the reservoir system.
- Case B: flooding-stricken individuals often accuse the operation of reservoir of causing inundations, even if the operation does not violate any regulations [2]. The reservoir system in Vu Gia Thu Bon catchment are planned as single purpose power generation facilities. Flood control storage and operation is not proposed. In this case, the reservoir system operation is implemented in SO module according to the normal regulation rules. It means that the spillway gates will operate if the water level in the reservoir is higher than the normal water level (table 1). The results expose the role of a hydropower reservoir system in flood control.
- Case C: in the reservoir system of flood control, the flood control capacity of the reservoir is the key in order to decrease probable flood damages. In this case, the flood control capacity of the reservoir system such as the A Vuong reservoir, the Dak Mi 4 reservoir, the song Tranh 2 reservoir and the song Bung 4 reservoir are defined to 35 million cubic meter (mcm), 31 mcm, 61 mcm, 75 mcm, respectively. There are the new operation strategies for these reservoirs system which consider the inflow reservoirs, the water level at reservoirs as well as the water level at downstream (at the Ai Nghia station and the Cau Lau station).

5 Results and discussion

In this study, the hydrographs of the historical flood events in 2009 were computed using calibration Mike SHE for the watershed and were considered as the inputs of the simulation of the reservoir operation model – Mike 11 model.

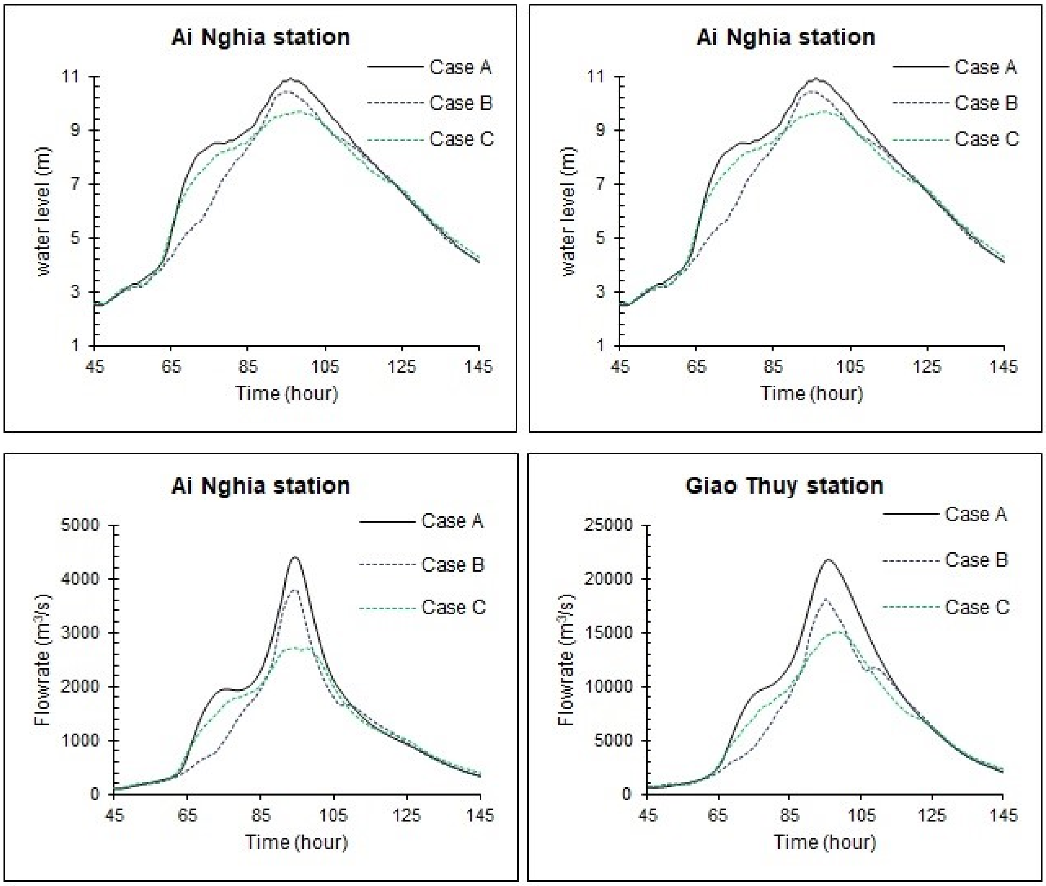

Figure 3: Water level and flow hydrograph at control point: Ai Nghia station and Giao Thuy station.

The most important issues of the flood control for the downstream part of Vu Gia Thu Bon catchment is the reduction in the peak flood level and the duration of high water level (the water level at control point is greater than the alarm level III).

As can be seen in figure 3, the flood storage capacity influences on the decrease of the peak flood level at downstream. At the Ai Nghia station, the maximum water level was reduced from 10.43 m to 9.68 m (without reservoir system, the maximum water level would have been 10.86 m). Similarly, the maximum water levels in the Giao Thuy station and the Cau Lau station decreased by 0.52 m and 0.39 m, respectively.

With the new strategies for the reservoir systems operation are more effective in reducing the maximum water level at downstream than the normal operating policy. Figure 5 gives the strategies for four reservoirs operation.

The hydrographs of the historical flood events in 2009 are represented in figure 5 (black line). The peak inflow of the reservoir system such as the A Vuong, the Dak Mi 4, the song Tranh 2 and the song Bung 4 are 3,253 m^3/s, 4,337 m^3/s, 4,500 m^3/s, 6,868 m^3/s, respectively. The simulated results in figure 5 shows that if the reservoirs are operated following to the proposed strategies, the peak release rate can be decreased from the normal regulation rules to the corresponding lower levels, specifically from 2,996 m^3/s to 1,763 m^3/s in the A Vuong reservoir, from 3,963 m^3/s to 3,264 m^3/s in the Dak Mi 4 reservoir, from 3,866 m^3/s to 2,385 m^3/s in the song Tranh 2 reservoir, from 6,394 m^3/s to 5,053 m^3/s in the song Bung 4 reservoir.

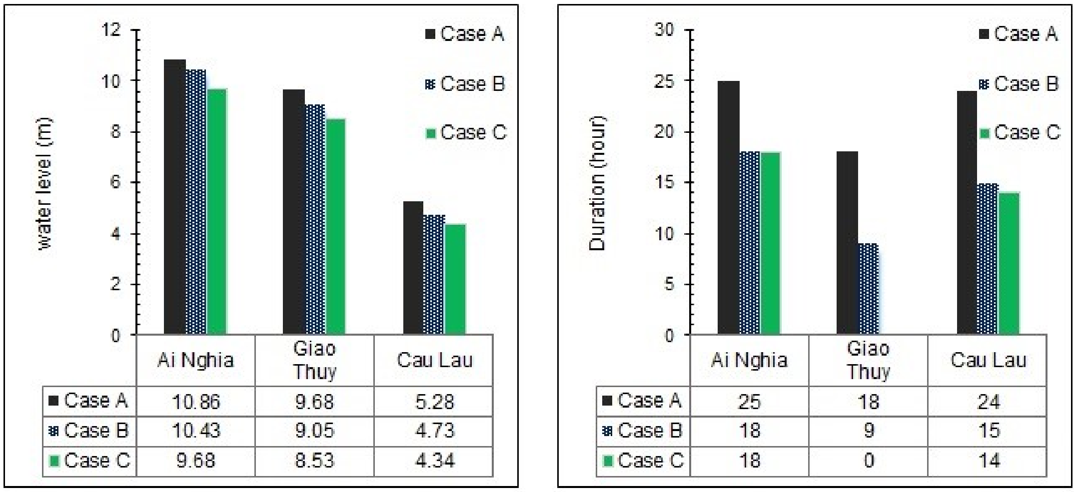

Figure 4: Comparison of the maximum water level and duration of water level above the alarm level III at control point downstream.

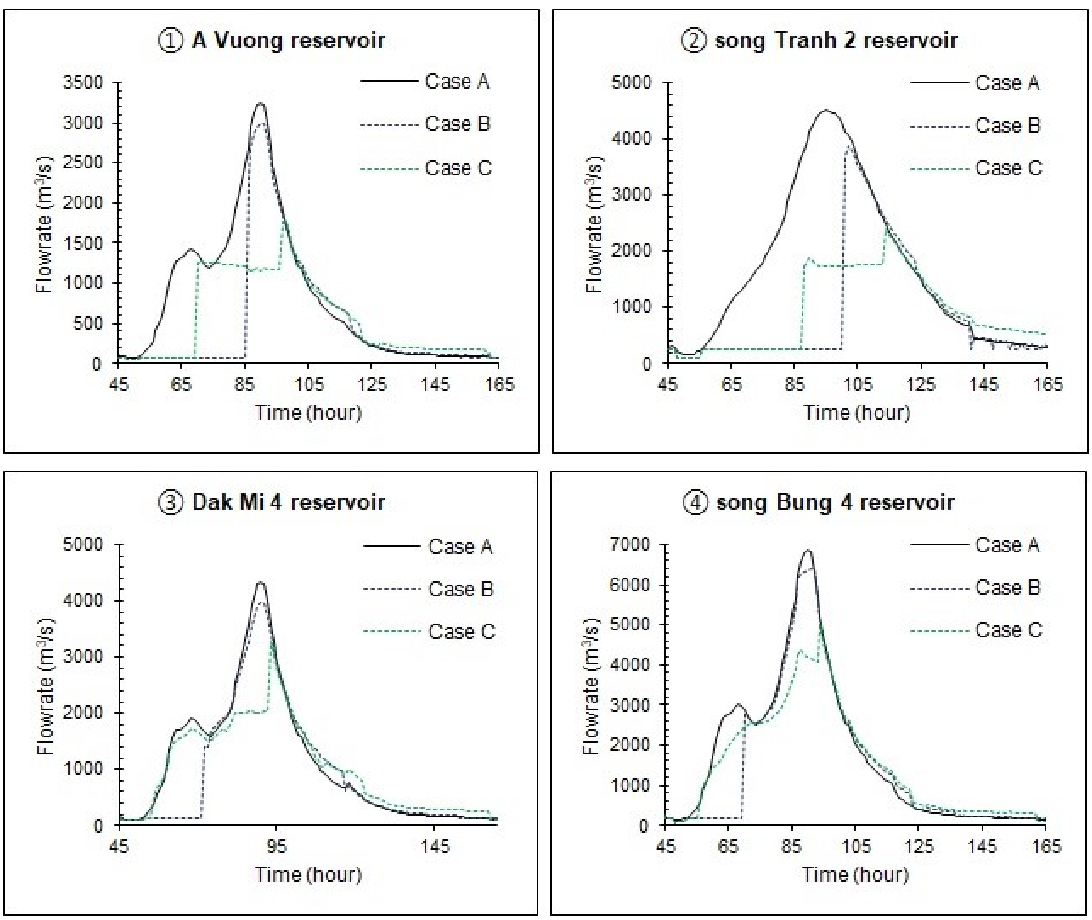

Figure 5: Inflow, outflow hydrograph for four reservoirs.

6 Conclusions

In the Vu Gia Thu Bon catchment, as the urban areas are sited on the coastal plain and the downstream of the hydropower reservoirs, the management of reservoir can influence on the increased risk of flooding during the rainy season. In the case of the large floods, the reservoirs will be not effective because of the insufficient stockage capacity or the poor operation of the flood opening gate. The reservoir system operation optimization is considered as a key factor to control the flood disaster at downstream area. A novel simulation for flood mitigation in a specific reservoir system with multiple reservoirs and control points is proposed. The results show that the reservoir system using the new strategies operation can reduce the maximum water level at downstream. These strategies can be useful in training the reservoir operators to develop a good knowledge of the reservoir system. In the next phase, the optimal allocation of flood control capacity will be carried out, in which the multi-objectives will be considered by using simulation-optimization framework.

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