ANALYSIS OF EFFECTIVE RESERVOIR OPERATION FOR MITIGATING FLOOD DAMAGES IN A VUONG DAM BASIN, VIETNAM

Nguyen Van Hoang[*]
MEE16728

Supervisor: Yoshihiro Shibuo[**]
Toshio Koike[***]

ABSTRACT

The present thesis seeks to investigate effective reservoir operation strategies for mitigating flood damages in the central Vietnam where flood vulnerability increased due to the rapid socioeconomic expansion. Potential benefit of dam water pre-release before flooding is analyzed by developing dam operation model, and implementing conversion of inundation into economic loss and released water into energy loss to hydrological simulation. The results show that flood damages can be reduced by the pre-release action and also the energy loss is comparably smaller than flood damages. Therefore if dam managers and administrative authorities among the basin could share the total cost of energy loss and flood damages, the basin as a whole could reduce the economic loss. Furthermore, pre-releasing water generally reduced the inundation and it delayed flood arrival in downstream, which will increase the safety of local residents and the risk management agency to plan emergency response.

Keywords: inundation analysis, dam pre-release, economic impact assessment, A Vuong dam basin

INTRODUCTION

Vu Gia and Thu Bon (VGTB) river basin is one of the major river basin in Vietnam and it is the largest and most important rivers in the central Vietnam. The socio economy in the region has been rapidly expanding in recent decades in accordance with rapid growth of GDP in the country. In order to sustain the expansion, major projects to construct dams for hydroelectric power production and water resources were propelled in VGTB. While such infrastructure has brought substantial profits to the region, the region is now facing serious issues in flood hazards because the economic expansion of the region increased the economic value, which increased vulnerability to flood hazard accordingly. The region is urgently in need of improved capability in flood risk management. As there do not exist flood control dams in the basin, use of available dams is a preferred solution. An important example is A Vuong dam basins which is located at the upstream of VGTB river basin (Fig.1). A Vuong dam is the largest reservoir in the region with the total reservoir capacity of about 343.6 million m^3 with power generation capacity of about 210 MW, which amounts to 0.64 % of hydropower energy produced in Vietnam.

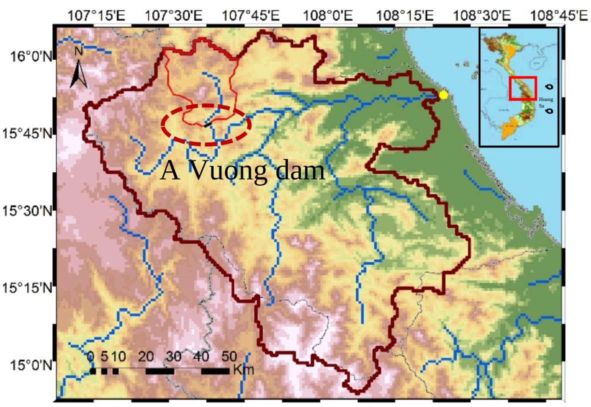


Figure 1: VGTB river basin

[*] Engineer, Sub Department of Natural Disaster Prevention and Control of Central and Highland, Vietnam
[**] Associate Professor, Int. Centre for Water Hazard and Risk Management, PWRI, Tsukuba, Japan
[***] Director, Int. Centre for Water Hazard and Risk Management, PWRI, Tsukuba, Japan

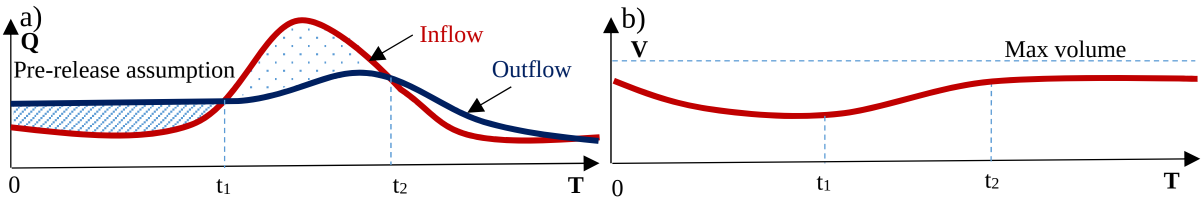


Figure 2: Schematic hydrograph showing strategy of reservoir pre-release (Valeriano et al. 2010)

While A Vuong dam is the important energy source in the region, flood casualty declined since 2011 when the dam started to lower the water level during the flood season. Therefore, there is a possibility that pre-release of dam water can reduce the damage cost in the downstream. The main idea of pre-release of dam water is to discharge a part of dam water and tentatively increase the storage capacity, and when the expected flood occurs, the loss of water shall be compensated, and ideally the water level after the flooding becomes equal to the level before the flooding (Fig 2). Furthermore, it may contribute to reduce flood peak at downstream. Considering this background, the objective of this study is to investigate the effectiveness of dam pre-release for reducing the flood damage in downstream and minimizing the energy loss of hydropower by the released water.

METHODOLOGY

General Overview

A new dam operation model is developed to implement the actual operation of A Vuong dam, and it is combined with Rainfall Runoff Inundation model, RRI (Sayama, 2015) to simulate inundation in the downstream. Simulated inundated areas are compared with the observed inundation, derived from MODIS satellite imagery and the flood marks survey, to calibrate RRI. Then by pre-releasing dam water from A Vuong dam, which is to be assigned as the boundary condition in RRI, resulting changes in inundation are evaluated. The magnitude of inundation is then evaluated in terms of damage cost, by applying water depth to the damage cost function. Also released water in the dam is expressed as energy loss. The sum of the damage cost and the energy loss is compared to the reported cost by flood damages after performing economic loss calibration. For this study, the 2013 flood event, at which the basin was most severely damaged, is targeted for simulation.

Inundation Simulation

RRI is used to simulate the inundated area. RRI simulates hydrological process from rainfall-runoff to flood propagation and inundation in the downstream. See more details in Sayama (2015).

Development of the Dam Operation Model

To model actual dam operations, following four components are included in the new dam model. Variable dam outflow as relative ratio to inflow can be calculated. Initial water level of a dam at the beginning of a flood event is introduced. Reservoir capacity and corresponding water level is calculated. Water level, water surface and reservoir capacity are included as state variables so that the highest level after flooding to be modelled. Pre-release option before flooding is added.

Inundated Area Analysis

To estimate the inundated areas in the 2013 flood event, the MODIS products and Terra surface reflectance 8 days Level 2 at the Land Process DAAC imagery were used. Also Flood Marks Survey (FMS), the survey product based on coordinates and water depths of inundation, is used for comparison and calibration of RRI inundation output at critical points.

Economic Impact Assessment

To assess flood damages, main losses of property are categorized into five sectors: housing losses; agriculture including paddy field, vegetables, and production land; plants for industry and forestry; infrastructure; telecommunications and electricity. Following equations are suggested to express each damage:

$$D_{total} = D_h + D_{ag} + D_f + D_i + D_t \quad \text{(Eq.4)}$$

$$D_h = a_h \times U_h \times N_h \quad \text{(Eq.5)}$$

$$D_{ag} = a_{ag} \times U_{ag} \times N_{ag} \quad \text{(Eq.6)}$$

$$D_f = a_f \times U_f \times N_f \quad \text{(Eq.7)}$$

$$D_i = a_i \times U_i \times N_i \quad \text{(Eq.8)}$$

$$D_t = a_t \times U_t \times N_t \quad \text{(Eq.9)}$$

where D_{total} is total damages cost (USD), D is damages cost (USD), U is value property (USD), N is number of damage points (-), a is calibration parameter (-), with subscripts standing for *total*: total of all damage, *h*: houses, *ag*: agriculture, *f*: forest, *i*: infrastructure, *t:* telecommunications and electricity.

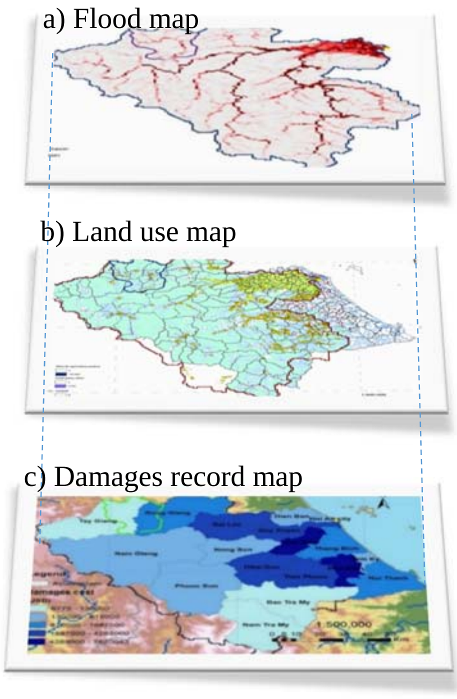


Figure 3: Estimated damage cost by map overlay

The number of damage points is identified by overlaying inundated area with land use map (Fig.3), and then the inundation depth is classified into the five levels of losses. The classification of relationship between inundation depth and classified flood damages is adopted from Japanese case defined by MLIT (Ohara, 2017) with modification to match the case defined in Vietnam. Since estimated damage cost in each district or city, can be different from the actual damage records, the parameter a is introduced as a ratio to calibrate the rates of simulated damage to the observed actual damage, which is applied to each damage level.

Energy Loss in the A Vuong Dam

Loss of water by pre-release of dam water needs to be converted into energy so that the loss of water can be economically compared to the damage cost by flooding. Ando (2017) estimated energy loss by

$$L = B \times E \times V \quad \text{(Eq. 10)}$$

where L is energy cost loss by release water (USD), B is electric bill (USD/Kwh), E is energy efficiency (Kwh/m^3), V is volume of water release (m^3).

Considered Scenarios

Following hypothetical pre-release of dam water is considered. The Vietnam National Center for Hydro Meteorological Forecasting (NCHMF) provided early warning information that heavy rainfall and flooding can occurr in the next 24 hours. By receiving the early warning information, dam managers of A Vuong dam decided to release water to downstream to lower the dam water level. The dam outflow is set to 300 m^3/s, which corresponds to the critical maximum flood discharge defined by the A Vuong dam operation, and the maximum outlow is assigned continuously for 24 hours. After 24 hours from receiving the warning message, the flood acctualy occurres. The results are compared to the simulation of actual cases in which no pre-release of dam water is performed.

DATA

Following data are used in this study. Digital elevation model (DEM), flow direction, and flow accumulation data in the Asia region with 15 arc second were downloaded from USGS website. Rainfall information and observed river water surface profile were collected from NCHMF. Dam operation information and unit of electric bill were obtained from Vietnam Electricity website. Land use data were obtained from Quang Nam Province Steering Committee for Natural Disaster Prevention and Control (SCNDPC) through personal communication which was combined with Global Map and Global Land Cover. Actual damage data and high water mark collection records in 2013 in the VGTB river basin were obtained from SCNDPC.

RESULTS AND DISCUSSION

Observed Inundation in the VGTB River Basin

Application of MODIS satellite imagery for deriving the inundated area in 2013 resulted that the entire area is recognized as water surface because whole basin was covered by cloud during the flooding. Furthermore, due to steep topography, flooding usually occurs quickly and has short duration, and inundation diminishes quickly. Therefore, inundated areas could not be verified from MODIS image in this region. As an alternative approach, FMS dataset was used to estimate extent of inundated area. Although it does not contain agricultural land and forest, flooded extent can be generally estimated from the scattering point of flood marks (Fig.4).

Performance of Dam Operation Model

Fig.5 compares simulated hydrographs of A Vuong dam. There is a noticeable gap between the simulated dam outflow using the dam option in RRI and measured discharge (Fig 5a), but it is significantly improved by the newly developed dam model and the simulated dam outflow shows similar trend to the measured dam outflow (Fig.5b). Fig.5c shows the simulated hydrograph but in this case with applying dam pre-release. By pre-releasing the peak outflow is reduced and the water level is kept high after the flooding.

Changes in Inundation

In following section, inundation of the actual dam operation and the hypothetical dam pre-release scenario are compared. The model parameters in RRI are calibrated by comparing the extent of inundation with that of FMS. Fig.6 and Fig.7 compares the simulated inundation and changes in inundation area with the timeline in two scenarios

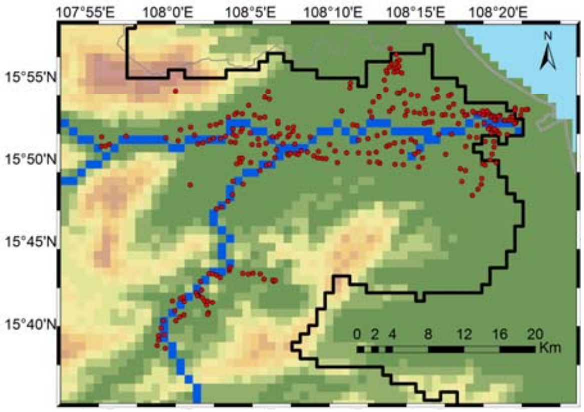
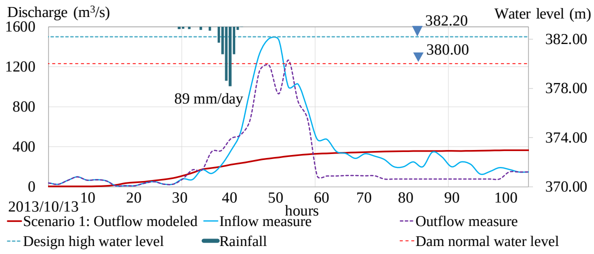
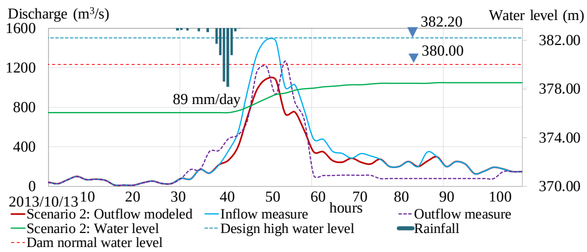


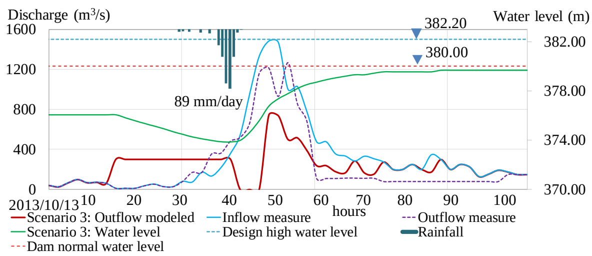
Figure 4: Estimated inundation areas derived from the FMS



a) Current dam option in RRI model.



b) The new dam model no pre-release option.



c) The new dam model with pre-release option

Figure 5: Hydrograph for 5 days simulation at the A Vuong dam

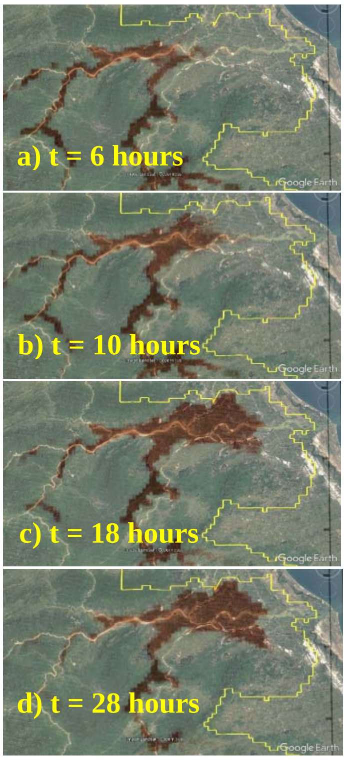


Figure 6: Actual scenario (no pre-release)

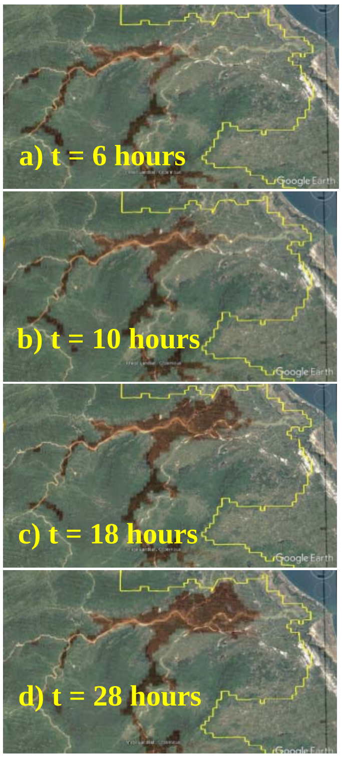


Figure 7: Dam pre-release scenario

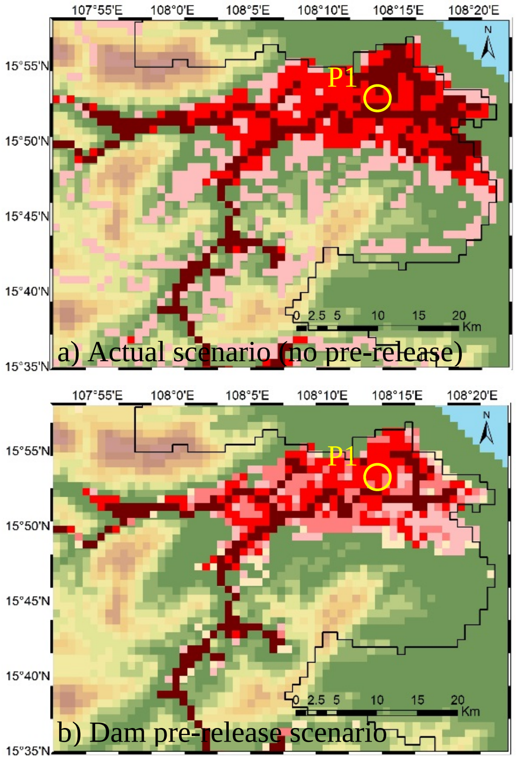


Figure 8: Maximum inundated depth

with actual dam operation (Fig. 6) and dam pre-release (Fig. 7). In comparison, less inundated area is observed in the pre-release scenario (Fig. 7). Also, the arrival of flooding in downstream was delayed in the pre-release scenario. Fig. 8 compares maximum extent of inundation between the pre-release scenario and the actual scenario. It is seen from Fig. 8 that inundated depth and extent are generally lower in the pre-release scenario than the actual scenario. Fig. 9 compares time evolution of the inundated water height at the critical point at Ai Nghia hydrological station (see P1 in Fig.8 for its location). The graph shows that the onset of flood was delayed about two hours in pre-release of dam water, and also that the peak of inundated water height was reduced. This can be explained that because the dam released stored water earlier, it could store subsequent flood discharge, which in turn reduced the flood peak. The reason of inundated water depth still increasing can be explained by the other VGTB river, which is located in the outside of A Vuong dam basin. Therefore, its discharge is not controlled.

Economic Assessment of Dam Pre-release

Using the calibrated RRI, damage cost was estimated by summarizing the point of damages in each region. Then flood information of inundated areas and water depth are translated in to the damage cost by using from Eq.4 to Eq.9. The potential energy, which was lost is estimated using Eq.10.

Table 1 summarizes the breakdown of damage cost in the actual condition and the pre-release condition. While the pre-release of dam water would result in about 526,222 USD of energy loss, in the same time it saved the flood damages of 933,393 USD (by 43.6%). When the total cost as a whole basin can be considered, almost half of the cost can be reduced.

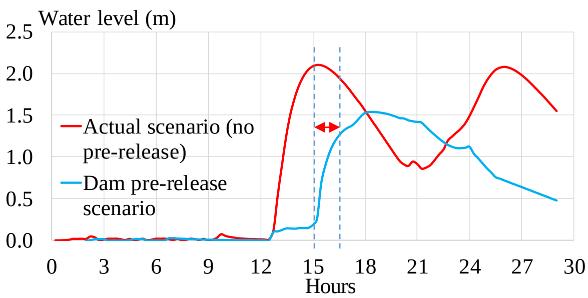


Fig.9: Comparison of simulated inundated depth

Table 1: Comparison of flood damage cost and energy loss between the actual- and pre-release scenarios

Category	Houses (USD)	Agriculture (USD)	Forestry (USD)	Infrastructure (USD)	Telecommunications (USD)	Total cost caused by flood (USD)	Energy cost loss (USD)
No pre-release	2,396,164	2,168,956	2,356,017	110,428	243,205	***7,274,771***	***0***
Pre-release	1,739,671	1,949,610	2,303,253	107,800	241,043	***6,341,378***	526,222
Difference	**656,493**	**219,346**	**52,764**	**2,628**	**2,162**	***933,393***	***526,222***

CONCLUSIONS AND RECOMMENDATION

Stored water in dams have tremendous value and releasing water is considered to be wasting the value. However, when the total cost caused by flooding is considered, it turns out that pre-releasing dam water could reduce the total cost of flood damage in the downstream and energy loss in A Vuong dam since the energy loss in the dam is comparatively smaller than the damage cost in the downstream. Therefore, the basin as a whole would pay less for compensation caused by flooding if the corresponding authorities can share the damage cost. Furthermore, pre-releasing operation delayed the onset of flood arrival in the downstream, which will help emergency response.

This study is considered to have identified a new insight that how the basin without flood control dam could improve resilience with utilizing available infrastructure. Such reference information can provide a harmonious solution to the integrated management of VGTB basin among the relevant parties in the river basin. Also, two research novelties are considered to be realized. One is the development of dam operation model, and the other is translation of hydrological information to regional economy. As far as the author is aware of, it is the first time in the central of Vietnam that the flood hazard information is quantitatively converted into economic consideration, which makes it possible to discuss how the flood hazard can be minimized in terms of economic loss. It would be a noteworthy reference information not only to VGTB basin, but also to other regions in the central of Vietnam.

This study focused on a single dam, but application of pre-release from multiple dams may have potential to further reduce the total cost of flood damage and energy loss, and therefore optimization of multiple dam releases is worthwhile to be investigated as a next step. Also flood forecasting is a major challenge in hydrology, as precise rainfall forecast might not be available, their uncertainty needs to be considered quantitatively as was described in optimizing dam pre-release (Saavedra et al. 2010) or real-time flood prediction (Shibuo et al. 2016). In the further study, care and consideration should also be given not only to economic aspect but also to potential effects on safety of local residents as well as other possible indirect losses.

ACKNOWLEDGEMENTS

I would like to express my deep and sincere gratitude to my supervisors Associate Professor Yoshihiro Shibuo for the continuous support, invaluable suggestions, instructions, indelible encouragement and excellent supervisions in the entire course. I am greatly thankful to Professor Toshio Koike for the patient guidance, valuable suggestion, encouraged and support during my research work.

REFERENCES

Ando, T. 2017. A proposal for evaluation methodology of flood damage reduction by using pre-release of power generation dam, bachelor's thesis, the University of Tokyo.

Ohara, M. 2017. Lecture Notes on Socioeconomic and Environmental Aspects of Sustainability-oriented Flood Management.

Sayama, T. 2015. RRI Manual: Rainfall-Runoff-Inundation (RRI) Model.

Shibuo, Y. et al. 2016. Implementation of Real-Time Flood Prediction and its Application to Dam Operations by Data Integration Analysis System, *Journal of Disaster Research*. 11 ed.

Valeriano, O. C. S. et al. 2010. Decision support for dam release during floods using a distributed biosphere hydrological model driven by quantitative precipitation forecasts.