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River information management and early flood release in response to climate change in Vietnam

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Abstract:

Increasing flood risks in a changing climate tend to put greater pressure on water-related infrastructure, existing operations, and management practices. This paper introduces preliminary research results on river information management and flood-risk reduction based on an early flood-release approach that has the goals of better reservoir operation, adapting to climate change, and ensuring dam safety in Vietnam. Early flood release is performed using inflow prediction information derived from a medium-range global numerical weather-prediction model. The results show that peak discharge and inundation areas are remarkably reduced, and are useful for improving the safety of dams and flood-risk management in downstream areas.

Keywords: **early flood release, flood detection, numerical weather perdition, river information.**

Classification number: **5.2**

Introduction

The trend of increasingly heavy rain in a changing climate will directly affect the management and development of river basins in the future; in particular, it will have a strong impact on the safety of water-related infrastructure such as embankment dams. Most existing dams were designed based on frequency analyses of historical rainfall patterns and extreme events, but this excluded consideration of climate change impacts [1]. Even so, the design criteria do not to take into account recent changes in frequency and severity, as described in the assessment reports of the Intergovernmental Panel on Climate Change [2]. For example, in the August 2002, flood water levels in Dresden, Germany, exceeded historical flood levels of the last few centuries [3].

Vietnam is heavily influenced by the tropical monsoon climate that comprises a distinct wet and a dry season. It is hence considered to be a water-abundant country. However, water distribution varies extremely between the wet and dry seasons. Approximately 80% of annual runoff occurs in the wet season. Results from recent studies show that changes in extreme rainfall events seem to be more crucial than changes in the average climate conditions [4]. Short-term precipitation intensities (e.g., the highest precipitation amount in a three-day period and the total precipitation when precipitation is greater than the 95th percentile of precipitation on very wet days) representing risks of flooding (in terms of frequency and scale) are expected to increase in most parts of the country in the near future (2015-2039), with the highest increases to occur in the northeast region and Ho Chi Minh city vicinities. Increasing flood risks tend to put more pressure on water-related infrastructure, existing operations, and management practices. This paper introduces preliminary research results on river information management and flood-risk reduction that are based on an early flood-release approach for ensuring better reservoir operation in adapting to climate change and ensuring

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dam safety in terms of a research cooperation agreement between the Vietnam Academy for Water Resources and the Foundation of River Basin Integrated Communications of Japan (FRICS).

Methodology and data

River information management

The objectives of river information management are to provide accurate, reliable, and quick collection, processing, and dissemination of the necessary information to assist with decision-making processes. For example, the amount of rainfall forecast by numerical weather-prediction (NWP) models monitored by weather satellites or radar, and observed at rain stations and as water levels in rivers. All of this information is particularly important to increase the efficiency of river-related infrastructure and to enhance river administration services through the dissemination of information to the public.

Basically, river information management includes three processes: (i) data collection, (ii) data processing, and (iii) data provision.

Data collection: there are a number of data types currently available for the river information management. These consist of point data (e.g., rainfall amounts, water levels, and discharge), area data (e.g., rainfall amounts estimated by weather satellites and radar), and image data (e.g., images recorded by closed-circuit television cameras).

Data processing: the data collected from different sources are processed and analysed to check for any missing measurements or irregular values and to remove any noise from the data.

Data provision: information is to be provided to the public via the internet and cellular phones. This includes information on water levels, rainfall amounts, flood forecasts and warnings, and dam-related parameters (notice of release of water from the reservoir, reservoir water storage, etc.).

Conceptual framework for flood-risk reduction

In light of the distinct water distribution in the wet and dry seasons, thousands of reservoirs have been built across Vietnam. They show the capabilities for flood control; however, not all floods have been entirely avoided because flood control storages are no longer able to accommodate the increasing inflow of flood runoff induced by intensified short-term precipitation. As a result, new reservoir operation rules for flood control have emerged as a vital tool in attempts to reduce flood risk.

The concept of early flood release applied to those reservoirs with controlled gates is illustrated in Fig. 1. Theoretically, the flood control storage would increase when the reservoir starts releasing water downstream before any incoming flood, while the efficiency of peak discharge cutoff depends on the forecast horizon, the longer lead time, and the greater efficiency of flood-risk reduction. Implementing flood-risk reduction based on the early-release operation approach to increase the volume of flood control storage is considered an appropriate solution to cope with climate change and to ensure dam safety. This approach is widely applied in such developed countries as Japan, the USA, and those in the Europe.

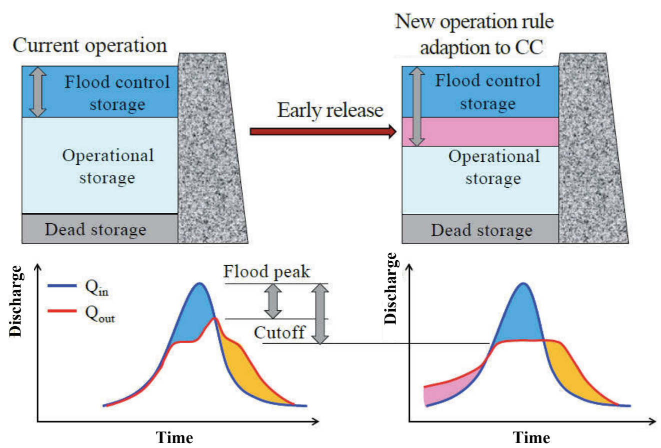

Fig. 1. Concept of reservoir operation for adapting to climate change (CC).

Incoming flow forecast

River flow forecast methods in general vary, depending on rainfall input. Conventional flood predictions based on real-time or near real-time observations of rainfall in the river basins and other hydrologic parameters provide a relatively short lead time because they are dependent on the runoff response of the river basins considered. The lead times for the forecasts are quite short for small and steeply sloped river basins. However, the forecasts show high accuracy.

NWP-based flood forecasts: benefiting from increased computational power, high-resolution NWP models are available to the public and offer a better forecast of rainfall and the forecast horizon. These advanced features allow the generating of short-term forecasts of inflow into the reservoirs. The NWP-based forecasts tend to promote higher efficiency of flood-risk reduction because of the forecast horizon of NWP models, which are either a few days or up to 10 days for the short and medium forecast ranges, respectively. However, there are inherent uncertainties in such forecasts: the longer the forecast horizon, the greater the uncertainty of the forecast.

In this paper, the medium-range rainfall prediction by a global NWP model operated at the Japan Meteorological Agency (JMA) is used to drive short-term flood forecasts. The NWP model has spatial resolution of 0.5 degrees and 60 vertical layers. In terms of forecast range, the model provides a quantitative estimation of the accumulated rainfall every 6 h. This is issued four times per day at 00:00, 06:00, 12:00, and 18:00 coordinated universal time (UTC) for the lead time of 84 h, and every 12 h (00:00 and 12:00 UTC) for lead time up to 132 h.

Rainfall-runoff inundation model: the Rainfall-runoff inundation (RRI) model, a two-dimensional (2D) model developed by the International Center for Water Hazard and Risk Management (ICHARM), Japan, is introduced in this paper. The detailed model structure is documented on the ICHARM website (http://www.icharm.pwri.go.jp/research/rri/rri_top.html). In short, the RRI model is capable of simulating rainfall-runoff and flood inundation simultaneously. The RRI model treats spatial hydrological processes and inundation analyses on a grid-cell basis. The 2D diffusive wave model is applied to simulate overland flow on the slope grid cells; while channel flow is routed using the 1D diffusive wave model. Flow exchange between the river channel and slope is calculated using overflowing formula, a function of water-level and levee-height conditions.

Case studies

The Huong and Vu Gia-Thu Bon river basins are large river systems in Central Vietnam. River tributaries begin in the mountains and run through narrow floodplains along the coastline and finally empty into the East Sea of Vietnam. Given the effects of the topography and climate pattern, the Huong and Vu Gia-Thu Bon river basins have more rainfall than other river basins in the region. Thus, these river basins have a higher risk of flooding, especially with large floods. Recent statistics show that large floods are becoming more extreme and more frequent. Most of the large floods of the last 50 years occurred during the 1995-2010 period. This statistic implies that, in a changing climate, there are significant increases in the frequency and severity of floods, which result in the exposure of water infrastructure to high flood levels, especially at the highly vulnerable earth dams in the region.

Results and discussion

In this paper, flood detection and forecast using NWP model outputs are examined and used to perform early flood release and inundation mapping. In order to reduce inherent uncertainties in the forecasts, it is suggested that a cascading process of the forecasts is implemented. First, flood detection is performed using the medium-range rainfall prediction of a global NWP model. Second, for as long as a flood is detected, detailed flood forecasts are realised using rainfall prediction by the NWP model and observations by weather radar and ground stations across the river basin. Third, optimal reservoir operation is applied and potential downstream inundation areas are analysed by the RRI model. More importantly, the flood forecasts are regularly renewed on a daily basis to improve their reliability for the data assimilation technique that improves the estimation of the model's initial state for the runs that follow.

Flood detection

As a pioneer among such centres, JMA offers the most advanced NWP model outputs and is continually working to improve its products. Figs. 2, 3 show the forecasts by the JMA NWP model for 24-h precipitation accumulation (issued at 7:00 AM) on September 28th and 29th, 2009, in the course of the influence of typhoon Ketsana on the Huong and Vu Gia-Thu Bon river basins. It is interesting to observe that the model is capable of capturing extreme rainfall, approximately 400-500 mm/day, near the centre of the cyclone. This indicates a very high risk of large-scale flooding in the region.

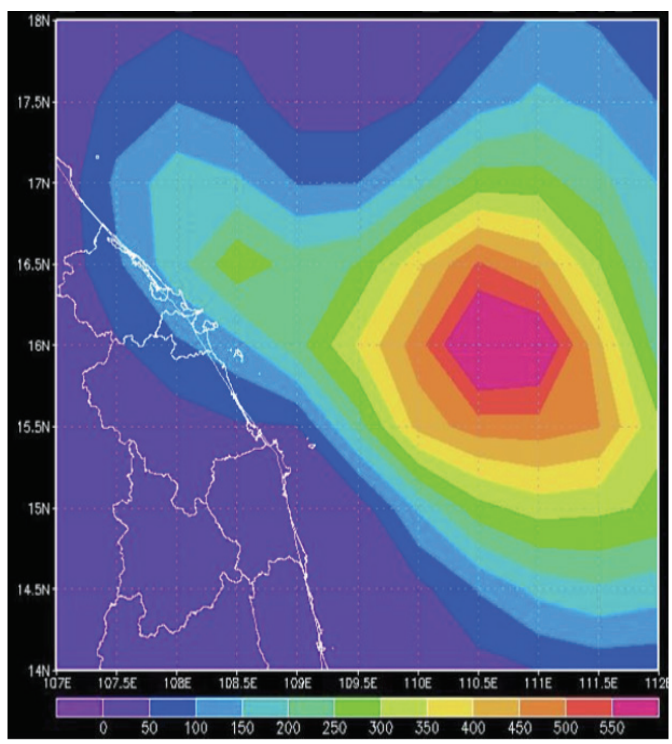

Fig. 2. 24-h precipitation accumulation (mm) forecast issued at 7:00 AM on September 28th, 2009.

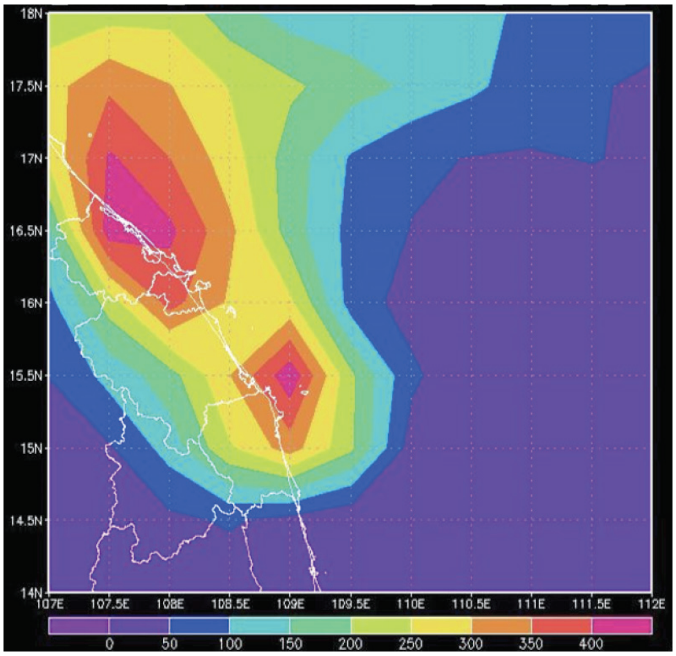

Fig. 3. 24-h precipitation accumulation (mm) forecast issued at 7:00 AM on September 29th, 2009.

Early flood release and inundation mapping

Once potential floods have been identified, appropriate reservoir operation rules can be considered [5]. Early flood release was first applied at A Vuong hydropower dam in the Vu Gia-Thu Bon river basin during the arrival of the typhoon Ketsana [6]. Based on the inflow prediction information, advance reservoir release was performed two days before the peak discharge occurred, as illustrated in Fig. 4. The results show that, compared to the actual situation as applied with the existing operation rule, peak discharge is considerably reduced when the new operation rule is applied. The peak discharge reduction rate is approximately 40%. The reduction rate is, however, likely to increase further as the forecast lead time is extended.

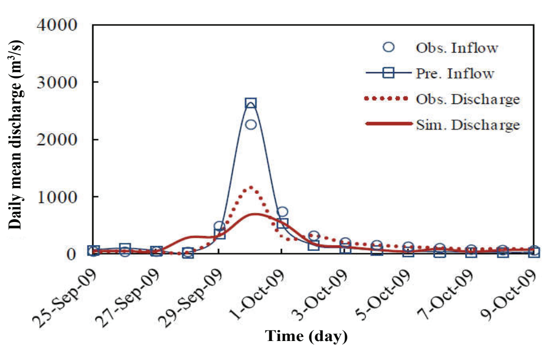

Fig. 4. Application of early flood release at A Vuong hydropower dam during typhoon Ketsana, September 28th - October 2nd, 2009 [7].

A similar procedure was then performed by FRICS at Huong Dien hydropower dam in the Huong river basin, and further analyses of downstream flood inundation were conducted using the RRI model [7]. Figs. 5 and 6 depict the water level and flow information at Huong Dien and Phu Oc stations, respectively. It can easily be seen that the peak discharge was cut significantly, especially when the optimized release was applied. The peak discharge reduction rate is up to 50%.

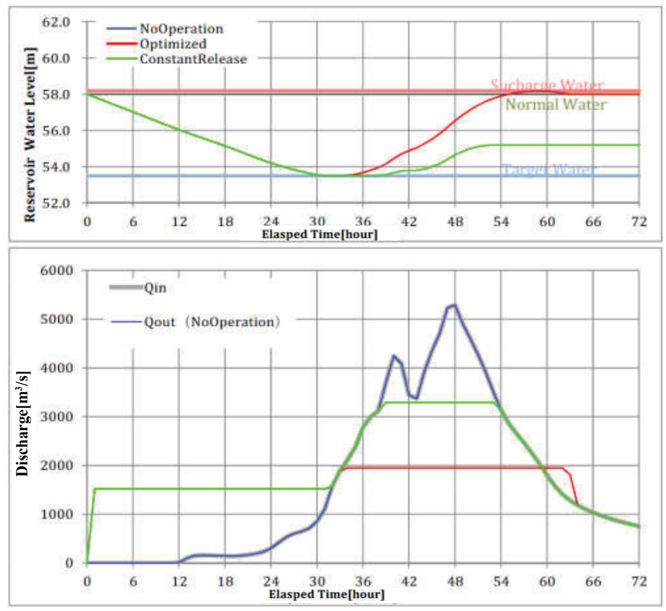

Fig. 5. Reservoir water level and discharge at Huong Dien hydropower dam with the implementation of advance release, two days before the peak discharge [7].

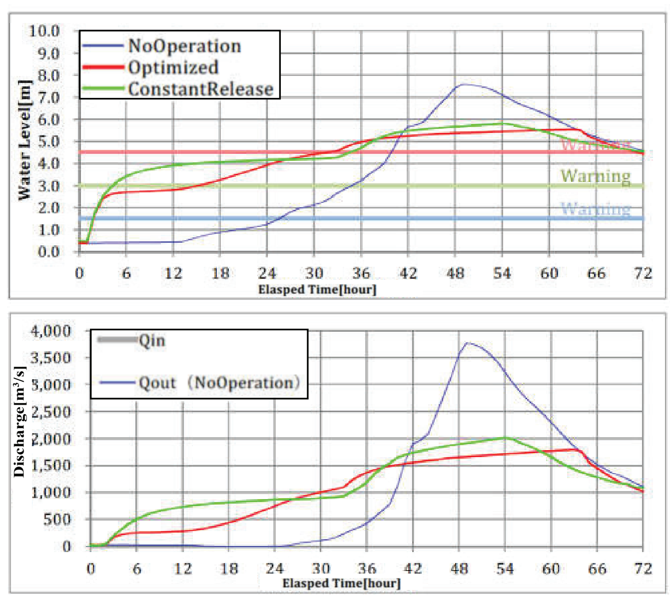

Fig. 6. Water level and discharge at Phu Oc station with (i) normal (no) operation, (ii) optimized release, and (iii) constant release [7].

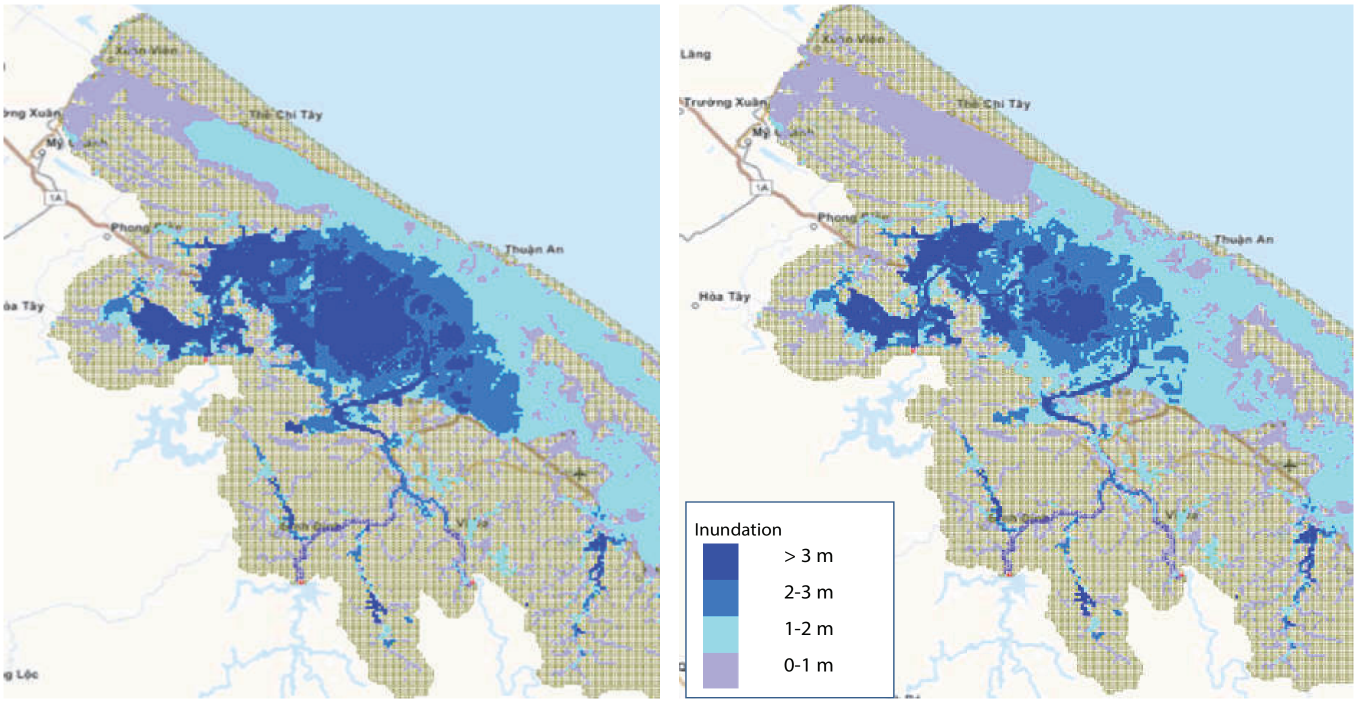

Fig. 7. Inundation risks in downstream areas without (upper) and with advance release (lower) during typhoon Ketsana, Sep. 28th - Oct. 2nd, 2009.

As a result, inundation risks for the downstream areas were analysed and are presented in Fig. 7. The figure depicts the remarkable reduction in the size of the inundation areas and in flooding severity when the advance release was performed using NWP-based inflow prediction. Such an inundation forecast is very useful for the real time operation of reservoirs in the river basins and for the implementation of flood risk-reduction measures in the downstream areas.

Conclusions and remarks

A new model of river information management and a flood risk-reduction approach in response to climate change has been introduced to promote informed decision-making about flood-risk reduction. The new model is crucially important for improving the safety of dams and flood risk management in downstream areas in that it allows the making of more informed decisions and the controlling of the timing of the storing and discharging of water from the dams.

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The authors declare that there is no conflict of interest regarding the publication of this article.

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