UTILIZATION OF FLOOD PREVENTION FUNCTION OF PADDIES AS AN ADAPTIVE COUNTER-MEASURE

L'UTILISATION DES RIZIÈRES COMME MOYEN DE PRÉVENTION DES INONDATIONS EN TANT QUE MESURE DE COERCITION ADAPTATIVE

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ABSTRACT

From a basin-wide water management viewpoint, agricultural lands in low-lying areas contribute to flood management by reducing the risk of flooding in downstream urban areas. Then, an adaptive water management measure of using flood storage function of paddies has been introduced. This function is illustrated in an example of the continuous heavy rainfall and floods of 2011 in the Chao Phraya River basin. Focusing on big floods, especially, the role of the flood storage in paddy regions was analyzed in the total flood processes. As a result, the maximum volume of the storage in the target region was estimated as 3,660 MCM (1.68m of averaged flood depth). Furthermore, the time from the start of the flooding to the peak flood volume in each block was calculated as about 1.5 months. On the other hand, the maximum flooded volume in the whole Thailand was estimated as 10,000 MCM. Although the timing to the peaks of the flooded volume are different in the target region and in Bangkok each other, the flood storage in the target area contributed to the storage itself of flooded water and the delay of its runoff greatly and to lessening the damage in Bangkok.

RÉSUMÉ

En vue de la gestion des bassins d'eau, les zones agricoles des basses terres aident à réguler les crues en réduisant le risque d'inondation des zones urbaines en aval. Cette mesure de gestion adaptative de l'eau qui utilise les rizières pour le stockage des crues a été introduite. Son usage a été illustré par exemple lors des fortes précipitations et crues de 2011 dans le bassin de la rivière Chao Phraya. En se concentrant particulièrement sur les grandes crues, le rôle de stockage des régions à rizières a été analysé dans le processus global des inondations. Il en a résulté que le volume maximum de la région visée était estimé à 3,660MCM (1,68M de profondeur moyenne de crue). De plus, le temps entre le début et le volume maximal de chaque block a été estimé à 1,5 mois. Par ailleurs, le volume maximal de l'inondation pour l'ensemble de la Thaïlande a été estimé a 10,000MCM. Bien que le timing des points culminants des crues soient différents entre la région ciblée et Bangkok, le stockage de la crue dans la région ciblée a contribué au stockage de l'inondation elle-même ainsi que grandement au retardement de son écoulement et à la réduction des dommages occasionnés à Bangkok.

Keywords: flood storage function ; low-lying paddies ; urban flood ; basin-wide flood management
(Mots-clés : Utilisation de stockage des crues ; rizières des basses terres ; inondation urbaine ; gestion globale des crues)

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1. Introduction

From a basin-wide water management viewpoint, agricultural lands in low-lying areas indirectly lead to the enhancement of comprehensive flood management by reducing the risk of flooding in downstream urban areas. A typical example is found in events for the Chao Phraya River Basin, which is the largest and most agriculturally productive basin in Thailand. In the basin, two huge multi-purpose dams are situated in the upper part of the basin. In the lower reaches of the basin is the Chao Phraya Diversion Dam, a major irrigation weir equipped with a series of flood control gates. These facilities are mutually managed and controlled to supply large areas with irrigation water and to control floodwaters in the lower basin. In 2011, the largest flood ever recorded in Thailand (70-year return period) inundated both irrigation and urban land in the Chao Phraya River Basin, especially low-lying areas including the megacity of Bangkok and neighboring Ayutthaya, resulting in damage on 1.37 million people of 4 million houses, 18,000 km^2 of agricultural lands, 32 urbanized areas and so on.

The objectives of this study are to introduce an adaptive water management measure by using flood storage function of paddies and to illustrate this function in examples of the big floods mentioned above in Thailand's Chao Phraya River Basin, in which the interaction between floods and agricultural water use is a main factor in watershed management. In addition, focusing on the event of the 2011 flood especially, the role of the flood storage in paddy regions was analyzed in the total flood processes.

2. Outline and Features of the Target Basin

2.1 Overview of the Chao Phraya River Basin

The size of the Chao Phraya River Basin is approximately 160,000 km^2, which is about one-third of the whole area of Thailand. **Figure 1** schematizes the basin including its important facilities. Within the Chao Phraya River Basin are eight sub-basins: the Ping, Wang, Yom, Nan, Pasak, Sakae Krang, Chao Phraya and Tha Chin. The main river originates in the mountains in the four northern sub-basins (the Ping, Wang, Yom and Nan). These four main tributaries converge at Nakhon Sawan, and below this point is the Chao Phraya delta plain with a maximum elevation of 20 m.

The basin is usually divided into upper and lower areas by the confluence of the main tributaries at Nakhon Sawan (**Fig. 1**), for which the Bhumibol and Sirikit dams situate in the upper area. The upper basin is almost completely covered by forests in mountainous areas. Rain-fed and irrigated paddy fields extend over the intermontane basin. In the lower reaches of the upper basin, the area from those two huge dams to the confluence at Nakhon Sawan, there are floodplains along the four tributaries. The lower basin is defined as delta plain areas to act as water diffusion and receiving areas. The most important irrigation facility is the Chao Phraya Diversion Dam, a weir equipped with a series of large floodgates at Chainat (slightly upstream from Station C.13 in **Fig. 1**). Royal Irrigation Department (RID) regulates water intake for the irrigation areas and to control floods in the lower basin. In the area from Ayutthaya to the seacoast, about 13% of the area is urbanized. The city of Bangkok is located along the main river and extends to the eastern and western sides of the plain.

2.2 Schematics of river and drainage and land use

Figure 2 shows the schematics of the river and drainage channel systems in the basin. Between the Chao Phraya Diversion Dam and Ayutthaya, the Lop Buri River branches off from the Chao Phraya River by gate control and joins the Pasak River at around Ayutthaya. The Lop Buri River is the main drainage canal for the eastern irrigated areas inside the Chainat-Pasak Canal and the Pasak River. Then, the Pasak River joins the Chao Phraya River on the left bank at the city of Ayutthaya.

Land use data are mainly classified into five categories: Forest, Agricultural, Water Body, Urban Area, and Others. Agricultural lands are divided into irrigation and non-irrigation areas. The areas of rain-fed paddies and upland crops are approximately 28% and 54% of the total agricultural area, respectively. Rain-fed areas are mostly located in the middle basin area. The total area of irrigated paddies is about 16×10^3 km^2, approximately 18% of the agricultural area.

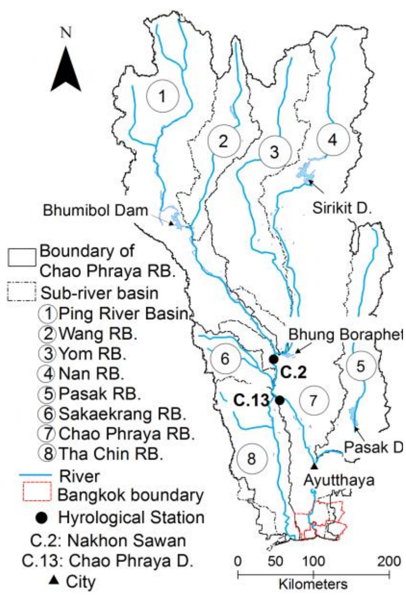

***Fig. 1** Outline of the Chao Phraya River*

2.3 Agricultural water use and water management

In the lower basin area, the Greater Chao Phraya Irrigation Project is supplied with water from the Bhumibol and Sirikit dams. RID classifies dams as large (storage capacity: 100 million m^3 or more), medium (1 million m^3 or more), and small (less than 1 million m^3) based on the storage capacity of their reservoirs. In the Chao Phraya River Basin, there are 10 large-scale reservoirs that have multiple purposes, including irrigation, domestic water supply, or hydroelectric power generation, and 62 medium-scale reservoirs that are used mainly for irrigation.

The Chao Phraya Diversion Dam (**Fig. 2**) mentioned above has a series of 16 flood control gates, which have a release capacity of 3,300 m^3/s. This dam controls the water level to divert water to the Greater Chao Phraya Irrigation Project on the eastern and western sides through five intake facilities. It is operated in tandem with intake facilities to regulate the water level and discharge at the main stream and to divert water into the irrigation canals in the dry season, as well as to control floods in the rainy season.

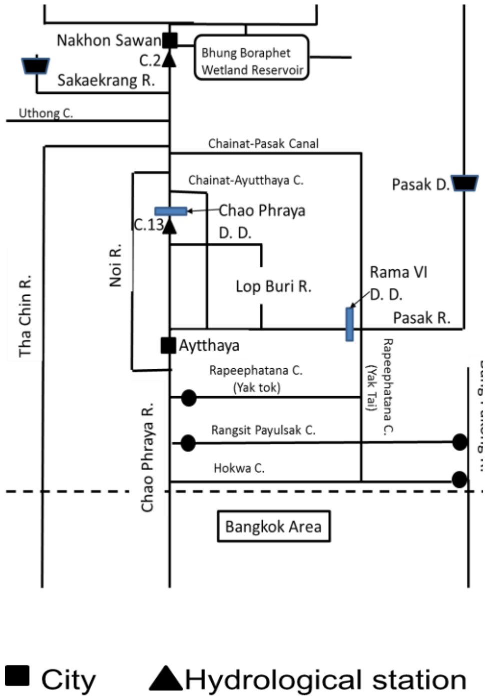

Fig. 2 Diagram of river and drainage systems in

2.4 Recent Floods in the Basin and the 2011 Flood

The Chao Phraya River Basin, particularly the delta plain area, experienced floods in 1983, 1995, 1996, 2002 and 2006. Record floods occurred in 1995 and 2006, with return periods of 30 and 20 years, respectively. The 1995 flood affected an area of 15,000 km^2 and the 2006 flood affected 19,000 km^2 [*Vongvisessomjai*, 2007].

A team from the National Institute for Rural Engineering (NIRE), NARO, surveyed the 2011 flood three times. The team's mission was to collect information on the 2011 flood in the Chao Phraya River Basin, such as flood management and flood mechanism, and to collect hydrological and meteorological data and data on irrigation facilities. From June to October, 2011, the Chao Phraya River Basin, particularly the upper and middle reaches, experienced heavy rainfall from five large tropical storms. The annual precipitation in 2011 is estimated 1.4 times higher than the average annual precipitation for 2004–2011. Flooding started around July in the upper reaches of the basin. These floods also reflect the large inflow into the Bhumibol and Sirikit dams, as mentioned earlier. In addition, floods occurred around the confluence of the Yom and Nan rivers in the middle part of the basin. These floods reached the upstream part of Nakhon Sawan, which is the confluence point of the four main tributaries. The RID reported the breach of 28 dikes (17 on the eastern bank and 11 on the western bank) (See **Fig. 5**). **Figure 3** depicts a time slice of areas inundated by floods (August–November) in the basin according to the data observed by satellite and normalized by GISTDA. Floodwaters initially inundated low-lying irrigation areas bounded by elevated main roads and railways, and then overflowed to flood surrounding areas. These floods reached Ayutthaya in October and hit the urban areas around Bangkok in November.

Flooding in the lower reaches was considered to be directly affected by the operations of both dams, the Bumibol and the Sirikit, so floodwaters were still lingering in the lower areas by November. In analogous contents for those dams the Pasak Dam released water from September through November to maintain its stability, while floods continuously affected the lower areas especially in Ayutthaya.

2.5 Damage caused by the 2011 flood

The flood severely affected agricultural production and manufacturing industries, as well as the Thai economy and human life. *World Bank* [2012] estimated the cost of damage due to the 2011 flood at about 1,425 billion baht (US$ 45.7 billion). The plain areas of the basin suffered from flooding for about five months, from July to November.

The total area of affected farmland was approximately 17,500 km^2, mostly located in the delta plain areas of the lower basin and in flat areas in the Yom and Nan sub-basins in the middle basin area [*Haraguchi and Lall*, 2013]. The estimated agricultural damage and loss was approximately 1,008.9 million US$ [*World Bank*, 2012]. Paddy fields suffered the highest loss, estimated at 70% of the total agricultural loss. Seven industrial parks were severely affected by flooding. These are located in the lower areas from Ayutthaya to the northern part of Bangkok on the eastern side of the Chao Phraya River. Inundation depth was reported as about 2–4 m. The highest number of those affected were Japanese manufacturers, at about 450 in total. World Bank reported that the overall damage due to floods in the industrial arena sector was approximately 7.4 billion US$. The Thai government reported that about 1.5 million houses and other structures were impacted throughout the duration of floods with nearly four million total structures estimated to have sustained affects [*Aon Benefield*, 2012]. The

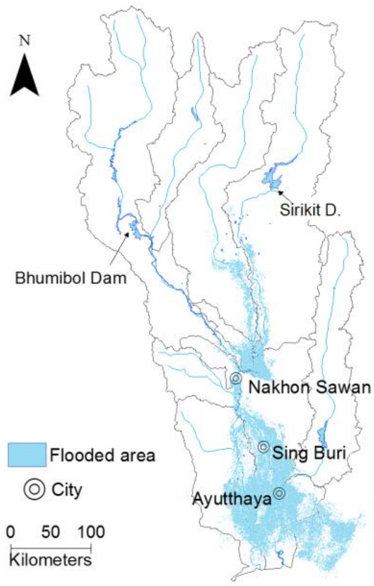

Fig. 3 *Flooded areas (Nov. 15, 2011)*

World Bank reported an economic loss of about 2.7 billion US$ for this sector of urban areas and infrastructures.

3. Evaluation of Flood Storage Function by Paddies

3.1 Features of the 2011 flood and further analysis

Due to the continuous heavy rainfall mentioned above, low-lying areas in the upper and middle reaches of the Chao Phraya River Basin suffered from inundation. Heavy rainfall continued through to mid-October, so floods extended to paddy areas and to industrial and residential areas in the northern and central area of Bangkok. Total precipitation was 1.2 to 1.8 times (1/50-year return period) that of a normal year, as mentioned earlier. Given the nature of the large floods, which were intensively covered by the mass media as disastrous events, and which caused urban inundation damage according to the heavy rainfall at the time, the role of flood storage in paddy regions was analyzed in the total flood processes.

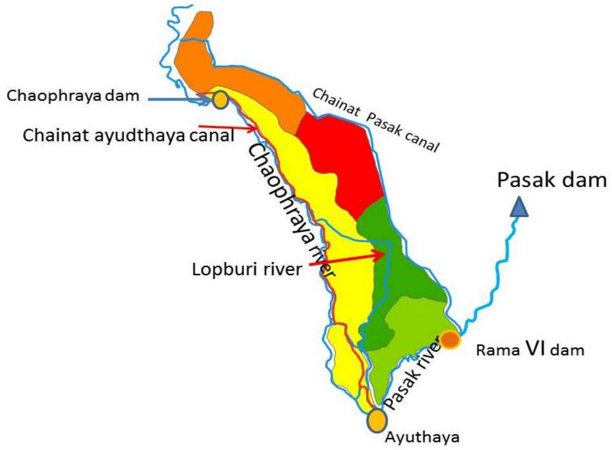

Fig. 4 *Division of the target area surrounded by irrigation and drainage canals/rivers*

3.2 Targeted paddy-dominant areas

The target area is an irrigated paddy region surrounded by the main stream of the Chao Phraya River, the Chainat-Pasak Canal and the Pasak River (**Fig. 4**). In the course of flooding, overflows and/or dike breaks/breaches occurred in the upper and lower reaches from the Chao Phraya Diversion Dam. Discharge at the point of the Chao Phraya Diversion Dam exceeded 3,700 m^3/s on September 21, 2011 Dike breaks started in the order of 1, 2, 3, ….., 12, etc., as shown in **Fig. 5**, from September 14 to October 7, 2011. As a result, a large amount of floodwaters moved into the paddies on the left side of the Chao Phraya River. In addition, floodwaters arrived at Bangkok and caused severe damage, affecting 71 provinces, 4 million people in 1.37 million houses, 18,000 km^2 of agricultural land, 32 urbanized areas (Ayutthaya to Bangkok) and so on.

3.3 Flooding in paddy areas and the effect of flood storage by paddies on the whole delta

3.3.1 Estimation method for evaluating the process and amount of paddy inundation

Floodwaters due to the dike breaks were stored in the paddy areas surrounded by main road networks and river dikes (serving as roads under certain conditions) (see **Fig. 5**). In the process of floodwater movement, floodwaters were stored in the paddy areas until the storage capacity was reached, and then the excess floodwaters moved over the crest of downstream roads. This cascade runoff process was repeated. The data required for the analysis included the starting time of the dike break at each point, the width of breached dikes, the elevation of breached dikes, details of elevations in flooded paddies, elevations of main roads and/or river dikes, and rainfall data for the area. Furthermore, for the drainage from the last sub-area (lower left in **Fig. 5**), most of the water returned to the Pasak River, which faces the edge of the downstream line, and the remaining water is assumed to have flowed over the left and right dikes of the Pasak River.

3.3.2 Relationship between flooding processes in paddy regions and floods near Bangkok

Figure 6 shows the hydrographs (temporal transition, daily) of the estimated flood volume in each block (sub-area in **Fig. 5**). The figure compares the total volume of the estimated floodwater with the flood volume calculated from satellite data obtained by GISTDA (Geo Informatics Space Technology Development Agency) in Thailand. The comparison matches quite well, which verifies that the estimation is reliable. As a result, the maximum storage volume in the target region was

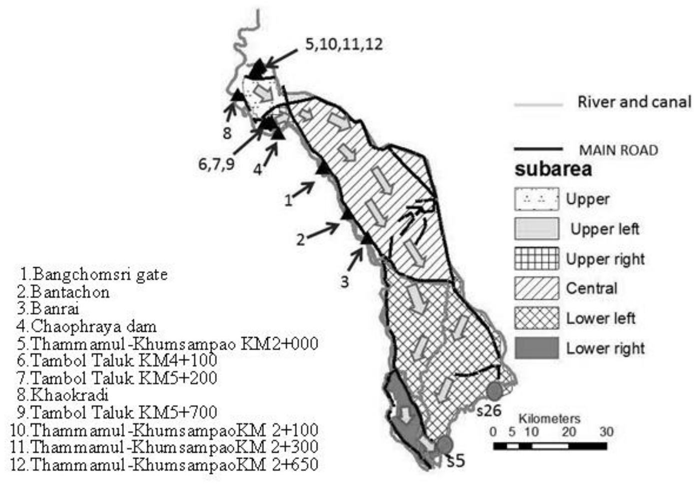

Fig. 5 *Division of flooded paddies surrounded by the Chao Phraya River and the Chainat-Pasak Canal*

estimated as 3,660 MCM (averaged flood depth of 1.68 m). Furthermore, the time from the start to the peak volume in each block was calculated as Upper: 8 days (Sep. 21, 2011), Upper Right: 3 days (Sep. 18), Central: 20 days (Sep. 14), Lower Left: 10 days (Oct. 3), Lower Right: 5 days (Oct. 12). The values in parentheses represent the starting time of the floods. On the other hand, the release from the Pasak Dam turned out to be quite large in spite of the storage conditions for maintaining the safety of the dam, so it is considered that the release affected the floods in the downstream area.

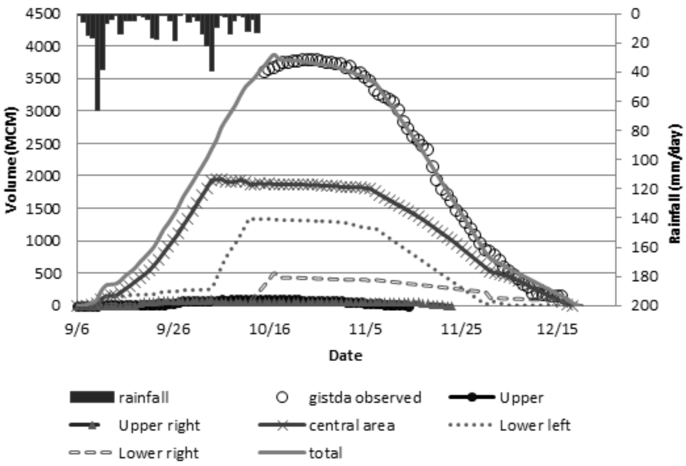

Fig. 6 *Estimation of flood volume in the target paddy areas during the flood in 2011*

3.3.3 Discussion

According to the hearing from Thai RID officials during the survey visit by NIRE staff, the maximum flood volume in the whole country was estimated as 10,000 MCM. Although the timing differs for each peak flood volume, the flood storage in the target area contributed greatly to the overall storage of floodwaters and the delay of runoff, reducing the damage in Bangkok. The quantitative evaluation of this function can be grappled with by utilizing an index proposed by *Masumoto et al.* [2006].

4. Conclusion

Climate change is predicted to result in an increased frequency of extreme weather events such as floods and droughts. To prevent or at least mitigate potential damage, countermeasures and/or adaptation to such extreme events must be proposed and evaluated. In actuality, the Chao Phraya River Basin was affected by extreme flooding in 2011. The analysis on the cause and effect of the 2011 flood in the basin reveals that the storage function of paddies, particularly in the eastern irrigation area, surrounded by the Chao Phraya River, Chainat-Pasak Irrigation Canal and Pasak River showed that water storage in this area significantly reduced the flood volume at Ayutthaya and Bangkok. However, the floods in this area were caused by dike breaches along the Chao Phraya River. For the development of adaptation and countermeasures by considering the importance of flood storage by paddies, the intake facilities used to divert water to this area should be increased, otherwise floodwaters cannot be effectively diverted and controlled. Although the development of a Seamless-DIF model (**D**istributed water circulation, **I**nundation and **F**lood model) is the next objective of the study [*Masumoto et al.*, 2009; *Taniguchi et al.*, 2009; *Yoshida et al.*, 2012; *Vongphet et al.*, 2015], the model also facilitates the development of adaptation and countermeasures to extreme events such as the 2011 flood as an adaptive flood management.

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