ORIGINAL ARTICLE

Effects on the upstream flood inundation caused from the operation of Chao Phraya Dam

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Abstract

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During the flooding events, the operation of Chao Phraya Dam to control downstream water discharge is one of the causes of the inundation occuring over the upstream area. The purposes of this research are to study the effects of the operation of Chao Phraya Dam upon the upstream flood inundation and to find out the new measures of the flood mitigation in the upstream areas of Chao Phraya Dam by using a hydrodynamic model. The results show that Manning's n in the Chao Phraya River and its tributaries is 0.030-0.035 in the main channels and 0.050-0.070 in the flood plain areas. The backwater due to the operation of the Chao Praya dam affects as far as 110 kilometers upstream. New methods of water diversion can mitigate the flood inundation without the effect on the floating rice fields. The construction of reservoirs in the Upper Sakaekang River Basin and the Upper Yom River Basin will mitigate the flood not only in their own basins but also in the Lower Chao Phraya River Basin. The coordinated operation of the Chao Phraya Dam, the regulators and the upper basin reservoirs will efficiently mitigate the flood inundation.

Key words : backwater effect, diversion dam, flood inundation, gate operation, hydrodynamic model

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บทคัดย่อ

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ผลกระทบต่อสภาพน้ำท่วมในบริเวณเหนือน้ำเนื่องจากการดำเนินงานเขื่อนเจ้าพระยา

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ในช่วงเกิดน้ำหลากการดำเนินงานเขื่อนเจ้าพระยาเพื่อควบคุมการปล่อยน้ำลงสู่ท้ายน้ำเป็นสาเหตุหนึ่งที่ทำให้เกิดน้ำท่วมขึ้นในพื้นที่ทางด้านเหนือน้ำ วัตถุประสงค์ของการวิจัยนี้เพื่อศึกษาผลกระทบของเขื่อนเจ้าพระยาต่อการเกิดน้ำท่วมทางด้านเหนือน้ำ และเพื่อหามาตรการใหม่ในการบรรเทาน้ำท่วมโดยอาศัยแบบจำลองพลศาสตร์การไหลเป็นเครื่องมือในการศึกษานี้ ผลการศึกษาพบว่า ค่าสัมประสิทธิ์ความขรุขระของแมนนิ่งในลำน้ำเจ้าพระยาและลำน้ำสาขามีค่าระหว่าง 0.030-0.035 และในพื้นที่น้ำท่วมริมตลิ่งมีค่าระหว่าง 0.050-0.070 ผลกระทบเนื่องจากเขื่อนเจ้าพระยาก่อให้เกิดสภาพน้ำเอ่อขึ้นไปทางด้านเหนือน้ำเป็นระยะทางสูงสุด 110 กิโลเมตร มาตรการผันน้ำแบบใหม่สามารถบรรเทาน้ำท่วมโดยไม่ก่อให้เกิดผลกระทบต่อพื้นที่ปลูกข้าวฟางลอย การก่อสร้างอ่างเก็บน้ำในพื้นที่ทางตอนบนของลุ่มน้ำสะแกกรังและลุ่มน้ำยมจะสามารถบรรเทาน้ำท่วมในลุ่มน้ำเจ้าพระยาตอนล่างได้ด้วย การดำเนินงานที่สอดคล้องกันของเขื่อนเจ้าพระยา อาคาร ปตร. และอ่างเก็บน้ำทางตอนบนจะช่วยบรรเทาน้ำท่วมในลุ่มน้ำเจ้าพระยาได้อย่างมีประสิทธิภาพ

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In the past, one measure of flood mitigation in the Lower Chao Phraya River Basin was the operation of Chao Phraya Dam to control the release of water downstream. This caused a higher level of backwater and the regulators diverted water to the irrigation canals. This operation caused inundation in the Greater Chao Phraya irrigation project that covered some areas of Chai-nat, Uthai-thani, and Nakhonsawan. By comparison, the great flood in the Year 1995 was equivalent to 25-year return period flood (CTI Engineering International Co., Ltd. *et al.*, 1999).

The objectives of this research are to study the effects of the operation of Chao Phraya Dam upon hydraulic characteristics of flood in various case studies based on hydrological data in 1995. The study clearly illustrates the hydraulic conditions and can be used to improve the efficiency of the operation of Chao Phraya Dam to manage floods in the Chao Phraya River Basin.

In this study, a mathematical model is used to simulate the networks of Chao Phraya River and its tributaries and calculate the upstream unsteady flow and backwater from Chao Phraya Dam.

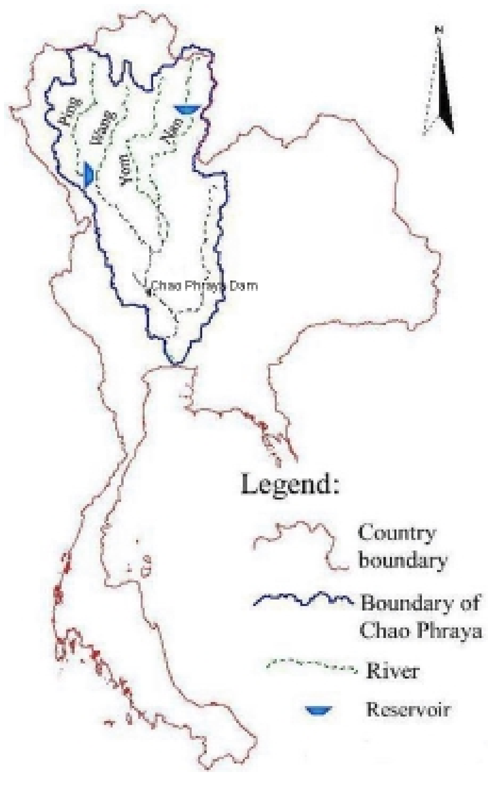

Figure 1. General map of Chao Phraya River Basin

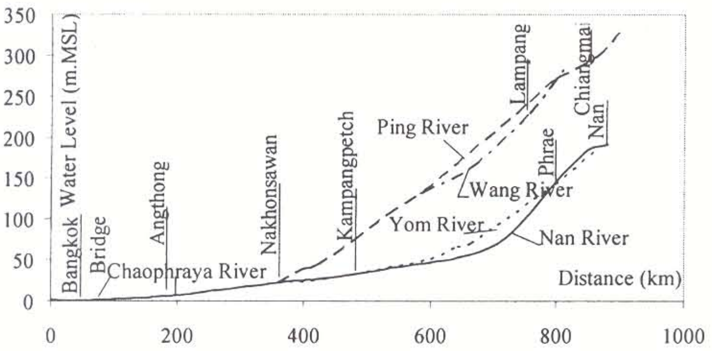

Figure 2. Profiles of the Chao Phraya River and the Tributaries.

Study Area

Features of the Area

The study area covers the Upper Chao Phraya River Basin from Chao Phraya Dam to its tributaries, i.e. the Ping River, the Nan River, the Yom River and the Sakaekang River (Figure 1). The Chao Phraya River Basin between Chao Phraya Dam and Nakhonsawan is a plain with elevations ranging from 17-25 m M.S.L. (Mean Sea Level) and 1:14,500 bottom slope of the river. The Lower Ping River Basin is a plain, with the elevations ranging from 25-100 m M.S.L. and 1:2,300 bottom slope of the river. The Lower Nan River Basin is a plain, with the elevations ranging from 25-50 m M.S.L. and 1 : 13,600 bottom slope of the river. The Lower Yom River Basin is a plain, with the elevations ranging from 20-50 m M.S.L. and 1 : 8,500 bottom slope of the river. The Sakaekang River Basin is a plain, with elevations ranging from 18-20 m MSL and 1 : 13,500 bottom slope of the river (Figure 2).

Scope of the Study Area

The study area covers the Chao Phraya River Basin from Chao Phraya Dam to its tributaries that are affected by the backwater due to the operation of Chao Phraya Dam including: the Ping River (the upstream boundary at the Hydrologic Station P.17, 42.5 km away from the dam), the Nan River (the upstream boundary at the Hydrologic Station N.10A, 106.5 km away), the Yom River (the upstream boundary at the Hydrologic Station Y.5, 74.5 km away) and the Sakaekang River (the upstream boundary at the Hydrologic Station CT.2, 13.4 km. away). The downstream boundary is at the Hydrologic Station C.13, 1 km.from the dam. The distance from Chao Phraya Dam to the confluence of the Ping River and the Nan River is 102 km (Figure 3).

The Chao Phraya Dam Project

The Chao Phraya Dam project diverses water to the Greater Chao Phraya irrigation project covering 1,220,000 hectares of irrigated area (77%

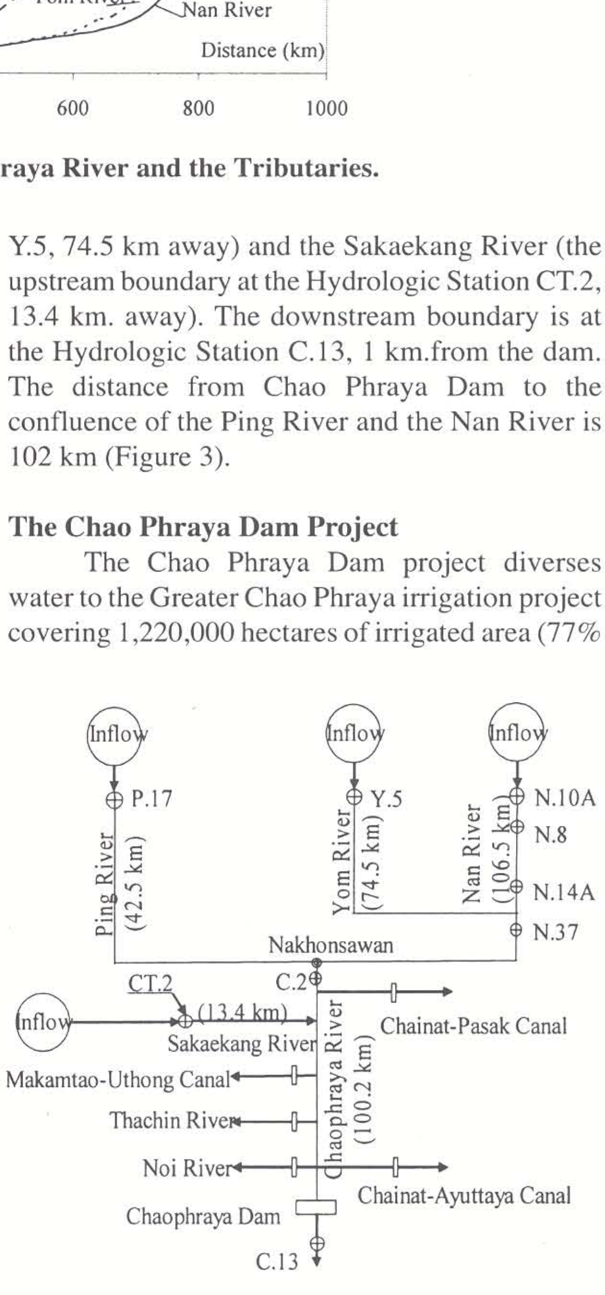

Figure 3. The schematic of the river network in the mathematical model

of the total irrigated areas of the Chao Phraya River Basin). It is the biggest irrigation project in Thailand.

The Chao Phraya Dam project comprises diversion dam and irrigation canals system, as follows:

The diversion dam

The head work of Chao Phraya Dam is a diversion dam (Figure 4). There are 16 gates (each 12.5 m long x 7.5 m high). Maximum discharge is 6,500 cms (equivalent to the 100-year return period flood). The normal water level at the upstream side of the dam is 16.5 m M.S.L. According to the flood management plan, the released discharge controlled by Chao Phraya Dam must be less than 3,000 cms to relieve flood inundation in the lower Chao Phraya River Basin (Asian Institute of Technology 1996).

Irrigation canal system

The irrigation canal system consists of 5 main channels as follows:

- The Noi River : maximum discharge capacity 260 cms, 127 km long.
- The Thachin River : maximum discharge capacity 320 cms, 325 km long.
- The Makamtao-Uthong Canal : maximum discharge capacity 35 cms, 104 km long.
- The Chainat-Pasak Canal : maximum discharge capacity 210 cms, 134 km long.

Figure 4. Chao Phraya Dam
(Color figure can be viewed in the electronic version)

- The Chainat-Ayuttaya Canal : maximum discharge capacity 75 cms, 127 km long.

The Flood Inundation in 1995

The flood inundation in the Chao Phraya River Basin in 1995 was equivalent to the 25-year-return period flood. The flood was caused by the South-East monsoon during the end of July to the beginning of September. The flood caused inundation in many parts of the Chao Phraya River Basin. The inundation area and the loss was about 15,000 km^2 and 72,720 million Thai Baht, respectively (CTI Engineering International Co.,Ltd. 1999).

In the study area, the flood inundation occurred along the Chao Phraya River to the Nan River and the Yom River in Pichit province and to the Sakaekang River in Uthaithani province. The maximum flood discharge was 4,557 cms at Chao Phraya Dam. It exceeded the planned allowable flood discharge, 3,000 cms and caused flood inundation in the Lower Chao Phraya River Basin.

Study Approach

The study approach has 5 items as follows (Figure 5) :

1. Data Collection : hydrological data, geographic maps, river cross-sections and information about the Chao Phraya flood management,
2. Developing the hydrodynamic model of the river network with the software HECRAS,
3. Calibration and verification for finding out the suitable parameters of the river-network model,
4. Application of the river-network model in many cases to study the flood hydraulics and the new measures of the flood mitigation,
5. Analysis and conclusion of the simulation results.

Mathematical Model

Theoretical basis for one-dimensional flow calculations applied in HEC-RAS program is the Saint Venant's equations consisted of the continuity

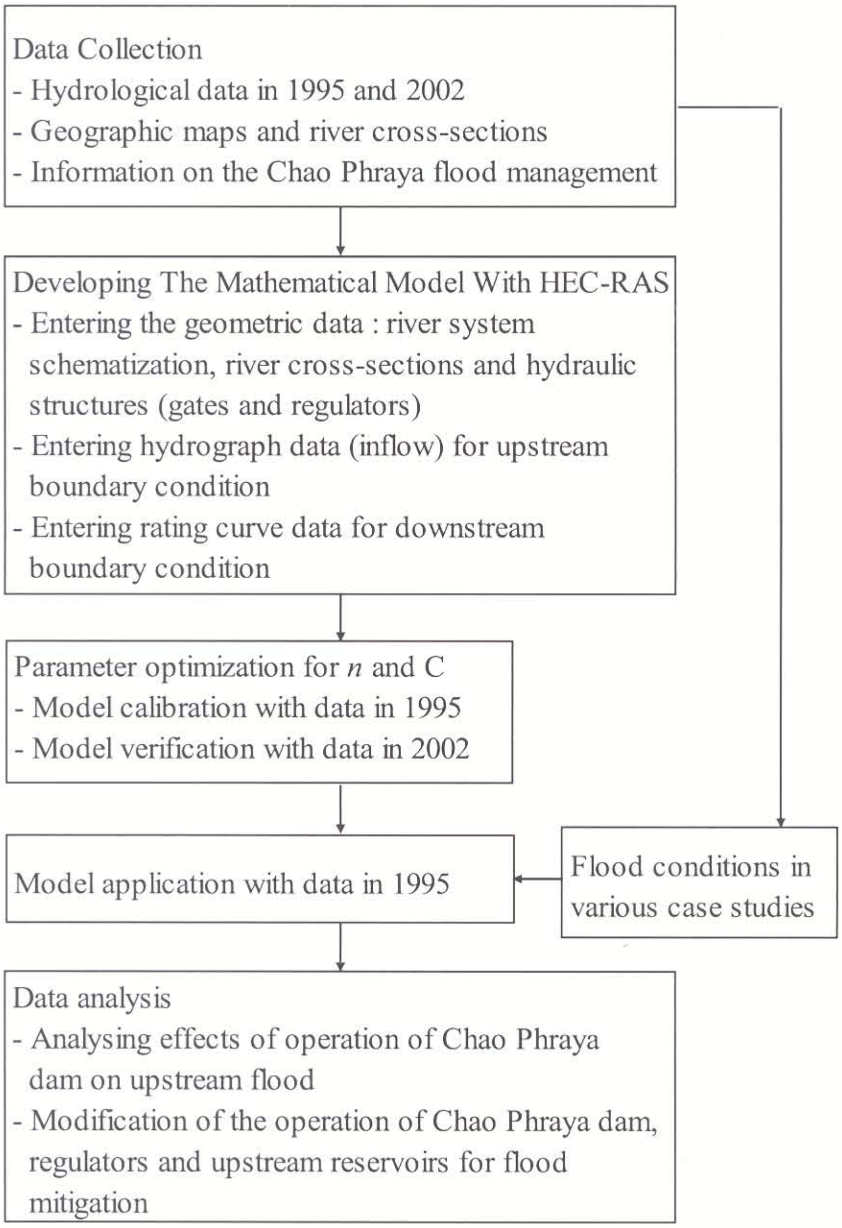

Figure 5. The schematic of the study approach

equation and momentum equation (see equation (1) and (2), respectively and Figure 6). The equations are in the form of partial differential equations solved by the four-point implicit finite differential scheme (Liggett *et al.*, 1975).

The continuity equation is

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} - q_1 = 0 \qquad (1)$$

The momentum equation is

$$\frac{\partial Q}{\partial t} + \frac{\partial QV}{\partial x} + gA\left(\frac{\partial z}{\partial x} + S_f\right) = 0 \qquad (2)$$

where

A = the cross-sectional area of the section
h = depth of flow at the section
z = elevation of surface above a datum at the section

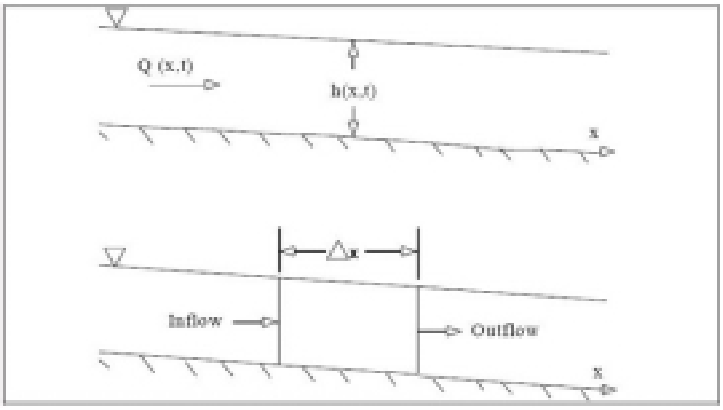

Figure 6. Elementary control volume for derivation of the continuity and momentum equations.

V = mean velocity at the section
Q = discharge at the section
q_l = discharge per unit length at the section
S_f = friction slope
x = position of the section measured from the upstream end
t = time
g = acceleration due to gravity

The mathematical model for the Chao Phraya River and the tributaries was created using HEC-RAS program (Brunner, 2002). There were 4 stations at the upstream boundaries, namely Station P.17 in the Ping River, Station N.10A in the Nan River, Station Y.5 in the Yom River and Station CT.2 in the Sakaekang River, and a downstream boundary at Station C.13 (Figure 3). The cross sections of the Chao Phraya River from Chao Phraya Dam to the confluence of the Ping River and the Nan River were surveyed in 2003 by Royal Irrigation Department. The cross-sections of the Ping River, the Nan River and the Yom River were surveyed in 1995 and the cross-sections of Sakaekang River were surveyed in 2000 by Marine Department. The intervals of the river cross-sections ranged between 100-5,000 meters.

Hydrological data during 1 July to 30 November, 1995 are used for model calibration, and 1 July to 30 November, 2002 for model verification. The results of the calibration and verification are found as follows: Manning's n in rivers and flood plains equals to 0.035 and 0.070, respectively, for the Chao Phraya River, the Nan River, the Yom River and the Sakaekang River and equals to 0.033 and 0.050 for the Ping River. The results of the calibration and verification are shown in Table 1, Figure 7 and Figure 8.

Study Results

The study results are as follows (see Table 2):

Table 1. The results of root mean square of error of water level in the calibration and verification of the model

Station	Test	RMSE (m)
C.13	calibration verification	0.76 0.66
Upstrem of Chaophaya Dam	calibration verification	0.46 0.50
C.2	calibration verification	0.45 0.70
N.14A	calibration verification	1.04 0.90
N.8	calibration	0.72
N.37	verification	0.90

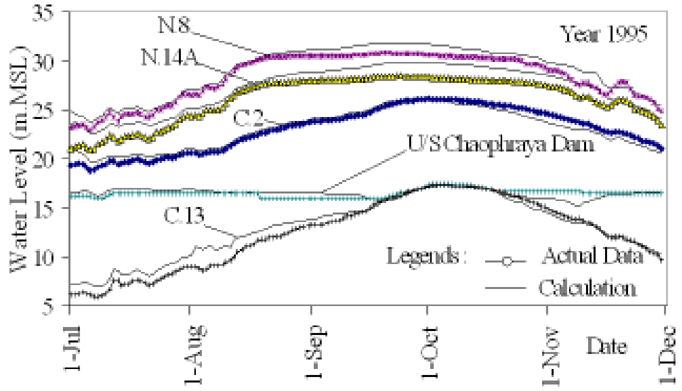

Figure 7. Comparison between actual and calculation water level in 1995 (for the model calibration).

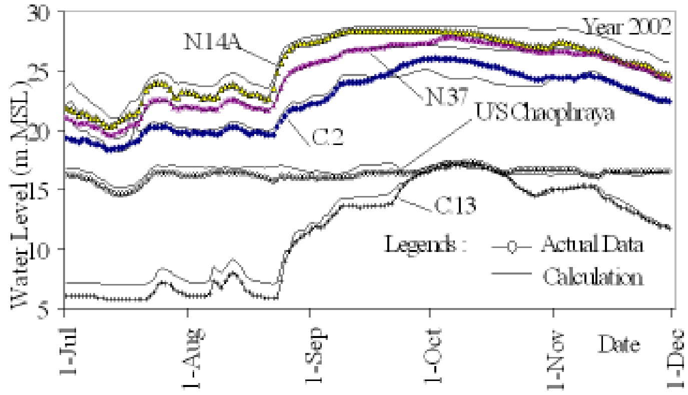

Figure 8. Comparison between actual and calculated water level in 2002 (for the model verification).

1. By the flood frequency analysis, the return period values of the peak discharge data in 1995 for the upstream rivers at the Hydrologic Station P.17, Y.5 and N.10A and for the Chao Phraya River at Station C.2 and C.13. are 2, 10, 23, 32 and 32 years, respectively (see hydrograph in Figure 9).

2. There are 4 cases, i.e. 1, 3, 5 meters gate opening and full opening of 8 meters to study the backwater caused by the operation of Chao Phraya Dam. The assumption is that there is no water diversion into the irrigation canals. The results reveal that the height of gate opening affects the backwater significantly. The maximum difference of water level between 1-meter gate opening and 8-meter gate opening is 2.86 meters and the backwater influences the flow as far as 110 kilometers upstream from Chao Phraya Dam along the Chao Phraya River to the Ping River and the Nan River (Figure 10). In addition, gate control affects the volume of flood inundation. Figure 11 shows the volume of the flood inundation over riverbank at the highest water level. The gate opening of 1 meter affects the volume of flood inundation more than all other cases with the higher gate opening. The effect of gate opening on the backwater and the volume of flood inundation decreases with the distance from Chao Phraya Dam.

3. The other measure of the flood mitigation can be done by releasing water into 5 irrigation

Table 2. All study cases in this research

Study Purpose	Case
1. To study the backwater at the upstream of Chao Phraya Dam	Case 1.1: 1 m gate opening Case 1.2: 3 m gate opening Case 1.3: 5 m gate opening Case 1.4: Full gate opening
2. To study the flood mitigation by the irrigation canals	Case 2.1: Twice capacity Case 2.2: Twice/half capacity Case 2.3: Twice/full capacity and 7.5/8 m gate opening
3. To study the backwater in the Sakaekang River	Case 3.1: No upstream flow in the Sakaekang River Case 3.2: With the upstream flow in the Sakaekang River
4.1 To study the capacity of the reservoir in the Sakaekang River on the flood mitigation	Case 4.1.1: With water discharge = 0 cms Case 4.1.2: The peak discharge < 600 cms Case 4.1.3: The peak discharge < 1,000 cms
4.2 To study the capacity of the reservoir in the Yom River on the flood mitigation	Case 4.2.1: The peak discharge = 200 cms Case 4.2.2: The peak discharge < 600 cms Case 4.2.3: The peak discharge < 1,000 cms
5. To study the modification of the reservoir operation	Case 5.1: The peak discharge < 1,500 cms Case 5.2: With delaying the peak discharge 14 days

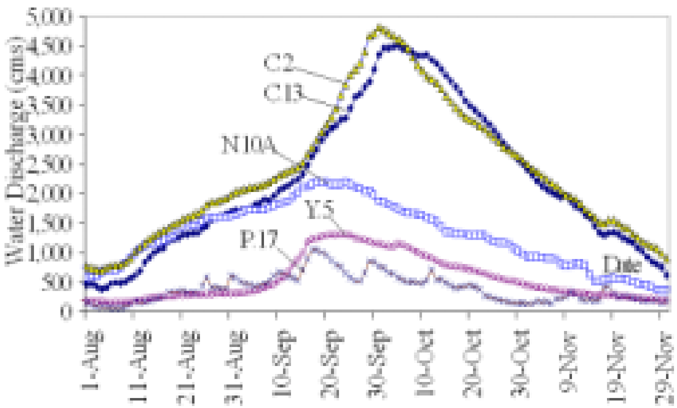

Figure 9. Flood hydrograph (data in 1995) from the river tributaries at P.17, Y.5, N.10A and the Chao Phraya River at C.2 and C.13.

canals (Figure 3), the Noi River (discharge capacity of 260 cms), the Thachin River (discharge capacity of 320 cms), the Makamthao-Uthong Canal (discharge capacity of 35 cms), the Chainat-Pasak Canal (discharge capacity of 210 cms) and the Chainat-Ayuttaya Canal (discharge capacity of 75 cms). To study how to develop the irrigation canals to increase the efficiency of the gate operation for the flood mitigation here, 3 cases of water diversion into the irrigation canals in the flood period are considered. Case 2.1: diverting water by twice the full capacity into the Chainat-Pasak Canal (420 cms) and the Thachin River (640 cms). Case 2.2: alternately diverting water into the Chainat-Pasak Canal at twice the capacity (420 cms) for 7 days and at half the capacity (105) for the next 7 days,

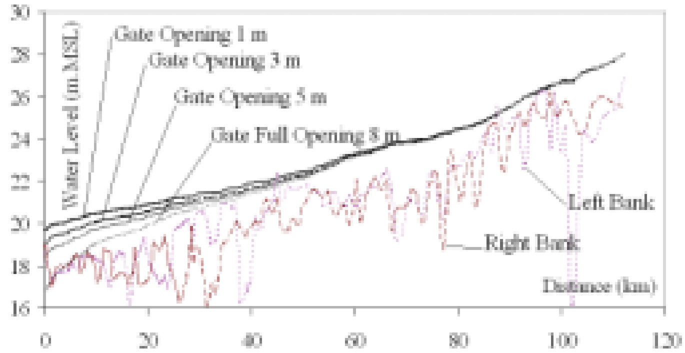

Figure 10. Highest water level along the Chao Phraya River in various cases of gate opening (use hydrological data in 1995 and assume no water diversion into the irrigation canals).

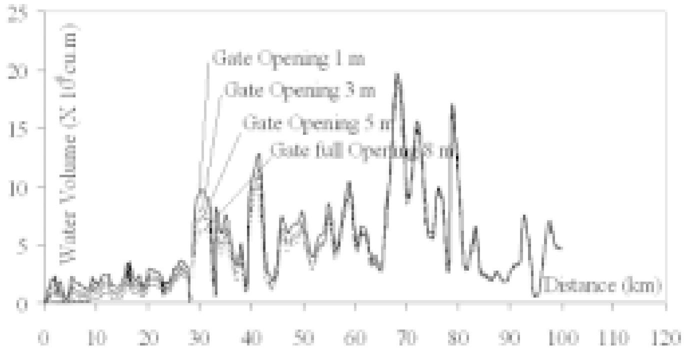

Figure 11. The volume of the flood inundation over riverbank along the Chao Phraya River at the highest water level in various cases of gate opening.

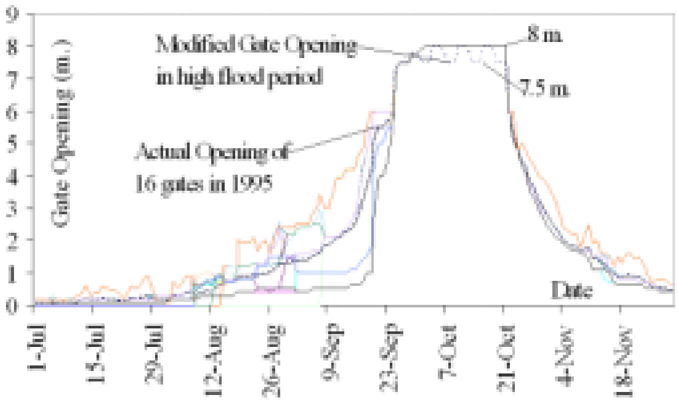

Figure 12. Comparison between the actual gate opening in 1995 and the modified gate opening in Case 2.3.

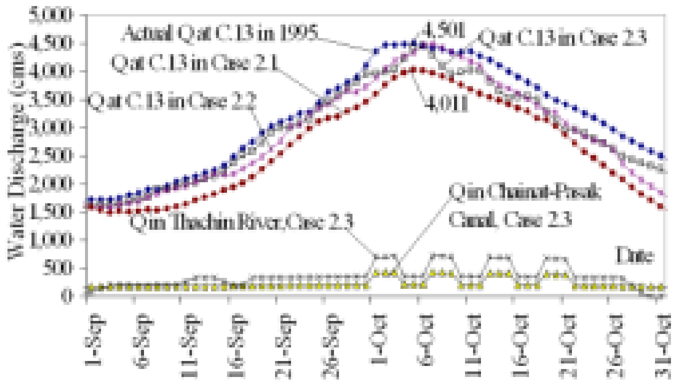

Figure 13. Comparison of water discharge at C.13 in Case 2.1, 2.2 and 2.3. And modified water diversion in the Thachin River and the Chainat-Pasak Canal in Case 2.3

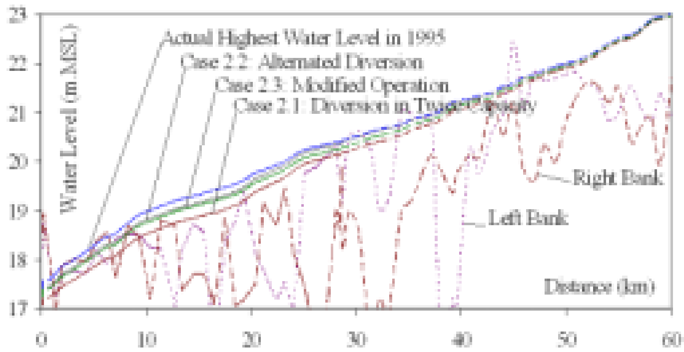

Figure 14. Comparison of the highest water level along the Chao Phraya River in Case 2.1, 2.2 and 2.3.

and simultaneously diverting water into the Thachin River at half the capacity (160 cms) for 7 days and at the full capacity (640 cms) for the next 7 days. Case 2.3: modifying the gate operation of Chao Phraya Dam in high flood period by opening the gates alternately from 8 m to 7.5 m for 3 days and increasing the opening from 7.5 m to 8 m for the next 3 days (Figure 12). When gate opening reaches 7.5 m, the water is diverted at twice the capacity into the Chainat-Pasak Canal and the Thachin River. And when gate opening is 8 m, the water is diverted at full capacity into the Chainat-Pasak Canal and the Thachin River (Figure 13).

The results indicate that the discharge at C.13, down stream of Chao Phraya Dam, is decreased for all case studies (Figure 13). Especially in Case 2.1, the peak discharge is decreased by 500 cms compared to the actual discharge in 1995 because of the diversion at twice the capacity during the entire high flood period. In addition, the highest water level along the Chao Phraya River also decreases for all cases (Figure 14). The highest water level of Case 2.1 is lower than those of Case 2.2 and 2.3.

4. To study the backwater in the tributaries caused by the operation of Chao Phraya Dam, the Sakaekang River is selected for study. The study shows that the operation of Chao Phraya Dam affects the backwater in the Sakaekang River because the confluence point of the Sakaekang River and the Chao Phraya River is only 28 kilo-

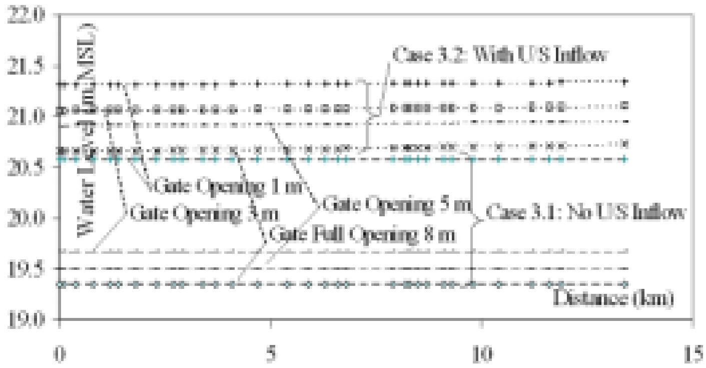

Figure 15. Comparison between the highest water level along the Sakaekang River in Case 3.1: No upstream inflow and Case 3.2: with upstream inflow

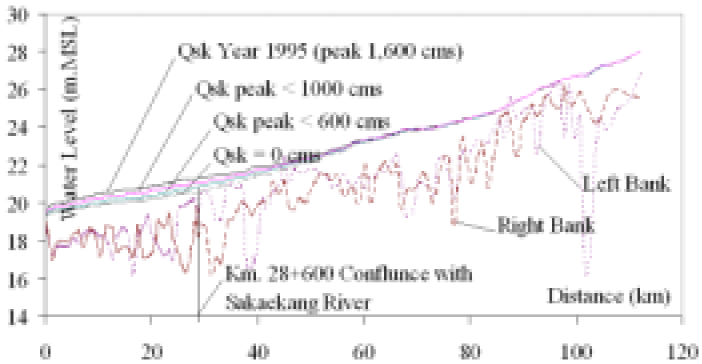

Figure 16. The highest water level along the Chao Phraya River in cases of controlling the peak discharge at CT.2: 0, 600, 1,000 cms and actual disharge in 1995.

meters away from Chao Phraya Dam, within the range affected by the backwater from Chao Phraya Dam.

There are 2 case studies. Case 3.1: with an assumption of no upstream flow in the Sakaekang River, and Case 3.2: with the upstream flow in the Sakaekang River. In both cases, it was assumed that the gate opening of Chao Phraya Dam is 1, 3, 5, and 8 meters (full opening) without water diversion into the irrigation canals. The result in Case 1 (no upstream flow) is that the difference in water level along the Sakaekang River between the 1-meter gate opening case and the 8-meter gate opening case is 1.23 meters (Figure 15), while the difference in water level is 0.61-0.65 meters for Case 3.2 (with upstream flow). By comparison between Case 3.2 (with upstream flow) and Case 3.1 (no upstream flow) with the 8-meter gate opening, the difference in water level is 1.33-1.38 meters. By comparing the 1-meter and the 8-meter gate opening of Case 3.1 (no upstream flow), the difference in water level is 1.23 meters due to the effect of backwater from Chao Phraya Dam. Likewise, by comparing the 1-meter gate opening of Case 3.2 (with upstream flow) and the 8-meter gate opening of Case 3.1 (no upstream flow), the difference in water levels is 1.96-1.99 meters (Figure 15). This is caused by the upstream flow in the Sakaekang River and the effect of the backwater from Chao Phraya Dam.

The results reveal that the flood in the lower region of the Sakaekang River is caused both by the upstream flow in the Sakaekang River and the backwater from Chao Phraya Dam.

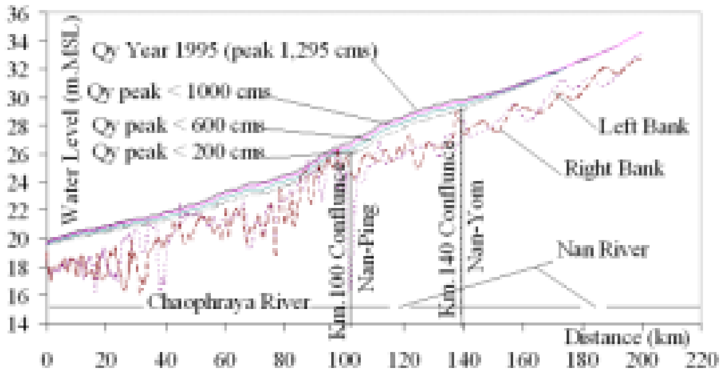

Figure 17. The highest water level along the Chao Phraya River in cases of controlling the peak discharge at Y.5: 200, 600, 1,000 cms and actual disharge in 1995.

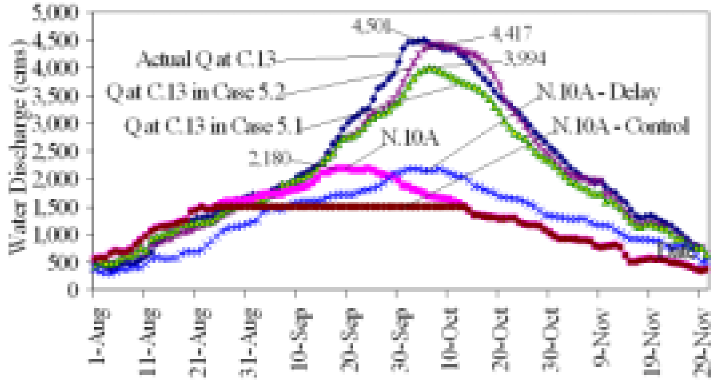

Figure 18. Comparison between water discharge at C.13 in Case 5.1: the peak discharge (<1,500 cms) and Case 5.2: delaying the peak discharge 14 days at N.10A.

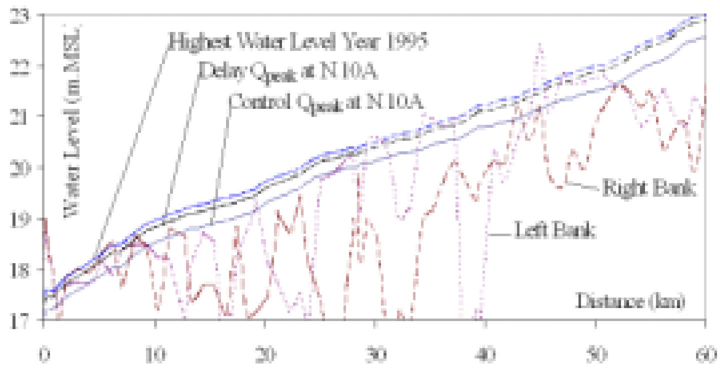

Figure 19. The highest water level along the Chao Phraya River in Case 5.1: the peak discharge (<1,500 cms) at N.10A and Case 5.2: delaying the peak discharge 14 days.

5. The reservoirs planned to be constructed in the future at the Upper Sakaekang River basin and the Upper Yom River basin are studied for their capabilities of flood mitigation in the Chao Phraya River basin. There are 3 cases for the reservoir in the Upper Sakaekang River Basin, Case 4.1.1: controlling all the upstream discharges (the discharge is zero at CT.2), Case 4.1.2: the peak discharge being less than 600 cms at CT.2, and Case 4.1.3: the peak discharge being less than 1,000 cms. For the reservoir in the Upper Yom River Basin, there are 3 case studies. Case 4.2.1: the peak discharge being less than 200 cms, Case 4.2.2: the peak discharge being less than 600 cms at CT.2, and Case 4.2.3: the peak discharge being less than 1,000 cms.

The results reveal that both reservoirs can lower the water level along the Chao Phraya River both upstream and downstream of the confluence of the rivers (Figure 16 and 17).

6. To study the modification of the reservoir operation for the reservoir in the upper Nan River Basin, there are 2 cases, Case 5.1: the peak discharge being less than 1,500 cms at N.10A, and Case 5.2: with delay of the peak discharge for 14 days at N.10A by controlling water discharge from the reservoir and keeping some water in retarding areas at the upstream of N.10A (Figure 18).

The results show that the peak discharge at C.13 is decreased compared to the actual data in 1995 about 507 cms for Case 5.1 and 84 cms for Case 5.2 (Figure 18). In addition, the highest water level along the Chao Phraya River is also decreased in both cases (Figure 19).

Summary and Recommendation

The summary and recommendation are as follows:

1. By calibration and verification, it is found that, for the Chao Phraya River, the Nan River, the Yom River and the Sakaekang River, Manning's n is 0.035 in the rivers and 0.070 in flood plains, and 0.033 and 0.050 for the Ping River.

2. The peak discharge of Chao Phraya River at C.2 and C.13 in 1995 is equivalent to the 32-year return period flood.

3. The operation of Chao Phraya Dam affects the backwater along the Chao Phraya River to its tributaries, the Ping River and the Nan River, as far as 110 kilometers upstream.

4. During the high flood period, water diversion into the irrigation canals should be increased to relieve the flood in the upstream area of the dam. In order to increase the efficiency of water diversion, enlargement of the irrigation canals is necessary. However, the effect of the enlarged irrigation canal on the irrigation pratice during normal conditions should be studied because lower water level might occur during normal conditions with adverse effects on farmers.

In addition, water diversion in high flood period should be done only in the floating rice fields. The new concept of diverting water alternately by increasing discharge for 3-7 days and decreasing for 3-7 days (as in Case 2.2 and 2.3 in the item 3 of the heading "Study Results") should be applied for the floating rice fields because the floating rice can survive in the high flood condition for 7 days or more.

5. The results show that the backwater in the Sakaekang River is caused by the upstream flow in the Sakaekang River and the backwater from Chao Phraya Dam. In order to mitigate the flood inundation in the Sakaekang River, a reservoir at the upstream of the Sakaekang River should be built to control its discharge. In addition, the operation of Chao Phraya Dam should match the discharge released from the upstream reservoir. The reservoir should be constructed at the upstream of the Yom River.

6. Upstream inflow from the Ping River and the Nan River should be controlled by the Phumipol dam and the Sirikit dam, respectively, to set the time-to-peak of the discharges at the different time when the peak discharge reaches to Chao Phraya Dam.

7. At present, the mitigation plan of flood inundation in the Upper Chao Phraya River Basin comprises 3 measures : (1) to control the upstream flow by reservoirs, (2) to control the operation of

Chao Phraya Dam, and (3) to divert water to the irrigation areas and low land areas. To effect the mitigation plan of flood inundation all measures should be done in harmony.

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