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Design of Chao Phraya River Flood Control System for Bangkok Based on Frequency Analysis of Flood Overtopping River Dikes

By

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บทคัดย่อ

ในปี พ.ศ.2529 คณะทำงานไทย-ออสเตรีย และสถาบันเทคโนโลยีแห่งเอเชียได้ออกแบบระบบป้องกันน้ำท่วมกรุงเทพฯ ที่เกิดจากน้ำเหนือไหลบ่าในแม่น้ำเจ้าพระยาซึ่งมีคาบเวลา 100 ปี ที่อำเภอบางไทร และน้ำทะเลหนุนสูงคาบเวลา 20 ปี ที่ป้อมพระจุล ระบบป้องกันน้ำท่วมนี้ประกอบด้วย เขื่อนผันน้ำแม่น้ำเจ้าพระยาที่อำเภอปากเกร็ด คลองผันน้ำยาว 52 กม. มีฐานกว้าง 135 ม. เริ่มจากเขื่อนผันน้ำมาทางฝั่งตะวันตกสู่ทะเล ประตูกั้นปากแม่น้ำพร้อมสถานีสูบน้ำขนาด 1,600 ม^3/ว และประตูกั้นปากคลองผันน้ำที่ทะเล

ในการศึกษานี้ได้ทำการวิเคราะห์ความถี่ของการเกิดสภาวะน้ำท่วมเพื่อหาคาบเวลาของการล้นข้ามทำนบฝั่งของแม่น้ำเจ้าพระยาที่กรุงเทพฯ ซึ่งขึ้นกับขนาดของระบบป้องกันน้ำท่วม การวิเคราะห์ได้ทำเป็น 2 ขั้นตอนโดยขั้นที่หนึ่ง ทำการหาความสัมพันธ์ของระดับน้ำสูงสุดของแม่น้ำเจ้าพระยาที่กรุงเทพฯ ที่อำเภอบางไทร และที่ป้อมพระจุล ขั้นที่สองคือการวิเคราะห์หาความถี่ของการล้นข้ามทำนบฝั่งแม่น้ำที่กรุงเทพฯ โดยอาศัยข้อมูลจากขั้นที่หนึ่งซึ่งพบว่าระบบป้องกันน้ำท่วมซึ่งออกแบบไว้ครั้งแรกมีขนาดใหญ่มากเกินไปเนื่องจากไม่ได้พิจารณาข้อมูลสถิติความเป็นไปได้ครบถ้วนและไม่ได้ใช้ประโยชน์ของความจุของลำแม่น้ำจากเขื่อนผันน้ำถึงประตูกั้นปากแม่น้ำ การศึกษาครั้งนี้ พบว่าสามารถลดขนาดคลองผันน้ำลงมาจากฐานกว้าง 135 ม. เหลือเพียง 40 ม. และไม่ต้องมีสถานีสูบน้ำที่ประตูกั้นปากแม่น้ำ ซึ่งระบบใหม่นี้สามารถป้องกันน้ำล้นข้ามทำนบฝั่งแม่น้ำที่กรุงเทพฯ ในคาบเวลามากกว่า 1,000 ปี

ABSTRACT

In 1986, the Thai-Austrian Consortium and the Asian Institute of Technology recommended an effective flood control system for Bangkok for a 100 year flood inflow at Bangsai and 20 year high tide at Fort Chula. It is consisted of a diversion dam at Pak Kret, a 52 km long and 135 m wide basewidth diversion channel from the diversion dam to the sea, a sea barrier with a 1,600 m^3/s pumping station at the river mouth and a sea salinity gate at the end of the diversion channel. In this study, a coincidence flood frequency analysis is applied to determine the return period of river flood overtopping the river dikes for various capacities of the flood control system. The procedure is made of two steps. The first step is the flood flow simulation to develop the flooding relationships of river flood levels at Bangkok and at two flood boundary stations at Bangsai and Fort Chula for various capacities of the flood control system. The second step is the coincident flood frequency analysis using the simulation results in step 1 to analyze the exceedance probability distributions of river flood overtopping the river dikes at Bangkok. By utilizing the river storage between the diversion dam and the sea barrier and selecting the flood control system having a 40 m basewidth diversion channel without pumping station at sea barrier, the flood control system can protect flood overtopping the river dikes at Bangkok for a return period of more than 1,000 years.

INTRODUCTION

Large floodings in Bangkok and its suburban areas are mostly incurred by the Chao Phraya river overtopping the existing river dikes. The river flood water level is excessively high during the simultaneous occurrence of flood inflow from the north and high tide at the river mouth. As it is impossible to properly solve such floodings by a single flood control structure, it becomes necessary to apply a flood control system to tackle such floodings.

In 1986, Asian Instiute of Technology and Thai-Austrian Consortium carried out a flood control study of Bangkok and recommended a very effective flood control system for a 100 year flood inflow magnitude at Bangsai and 20 year high tide at Fort Chula [1]. It is consisted of a diversion dam at Pak Kret (Km 70), a 52 km long and 135 m wide basewidth diversion channel, a sea barrier with a 1,600 m^3/s pumping station near the river mouth (Km 2), a salinity gate at the end of diversion channel near the sea barrier and surrounding flood embankments on the east and west of Bangkok (see Fig.1). This flood control system can control the river water level within the protected area of 1,400 sq.km. below mean sea level.

However, the original design of the flood control system [1] did not consider various probabilities of coincidence of flood inflow and high tide. Particularly, it does not utilize the available river storage between the Pak Kret diversion dam and the sea barrier. Such a design could be too conservative and uneconomical. If the relationship between various capacities of flood control system and return period of flood overtopping the existing river dikes can be known, a better selection of capacity of flood control system can be done on probabilistic basis.

This paper presents an application of a coincident flood frequency analysis to determine the exceedance probability distribution or the return period of flood overtopping the existing river dikes for various capacities of the flood control system.

THEORETICAL CONSIDERATION

The procedure is made of two steps. The first step is the flood flow simulation to develop the flooding relationships among river flood levels at Bangkok and at two flood boundary stations at Bangsai and Fort Chula for various capacities of flood control system. The second step is the coincident flood frequency analysis using the simulation results in step 1 to analyze the exceedance probability distributions of river flood level at Bangkok Ultimately, the developed exceedance probability distributions are used to determine the return period of the river overtopping the river dikes for each capacity of the flood control system.

Flood Flow Simulation Analysis

A one-dimensional flow model using a finite difference implicit scheme together with a node and branch schematization [2] is applied. The governing equations and finite difference implicit scheme are described as below.

Governing Equations

Continuity equation for a node :

$$F\frac{dH}{dt} = \sum_{i=1}^{m} Q_{in,i} - \sum_{j=1}^{n} Q_{out,j} + Q_l \qquad (1)$$

Momentum equation for a branch :

$$\frac{\partial Q}{dt} + \frac{2Q}{A}\frac{\partial Q}{dx} - \frac{Q^2}{A^2}\frac{\partial A}{\partial x} + gA\frac{\partial A}{\partial x} + \frac{gn^2 Q|Q|}{A^2 R^{4/3}} = 0 \qquad (2)$$

where A = flow cross-sectional area of a branch, F = water surface area of a node, g = gravitational acceleration, H = water level of the node, n = Manning's roughness coefficient, Q = discharge of the branch, $Q_{in,\iota}$ = i^{th} inflow to node, $Q_{out,j}$ = j^{th} outflow from the node, Q_l = lateral inflow to the node, R = hydraulic radius of the branch, t = time, x = distance

Finite Difference Implicit Scheme

The changes of water level and discharge in each itme step are based on the derivatives of water levels and discharges at time t and t+ Δ t as.

$$\frac{\Delta H}{\Delta t} = (1-\theta)\left.\frac{dH}{dt}\right|_{t} + \theta\left.\frac{dH}{dt}\right|_{t+\Delta t} \qquad (3)$$

$$\frac{\Delta Q}{\Delta t} = (1-\theta)\left.\frac{dQ}{dt}\right|_{t} + \theta\left.\frac{dQ}{dt}\right|_{t+\Delta t} \qquad (4)$$

where ΔH = change in water level of node, ΔQ = change in discharge of branch, Δt = time step, θ = time weighting coefficient

Substituting Eq. 1 into Eq.3, the continuity finite difference equation for a node is obtained. Substituting Eq.2 into Eq.4, the momentum finite difference equation for a branch is obtained. The continuity and momentum finite difference equation of all nodes and branches are solved simultaneously with Gaussian Elimination Method to determine ΔH for every node and ΔQ for every branch.

Coincident Flood Frequency Analysis

Coincident flood frequency analysis is applicable for determining a frequency distribution of a dependent variable such as the river flood level at Bangkok which is a function of two or more causative factors with known statistics of occurrence such as the river flood level at Bangsai and the tidal level at the Chao-Phraya river mouth [3]. The procedure uses two theorems which are described as below.

Coincident Probability Theorem: Consider A be a function of B and C which are mutually independent. It is assumed that A is more influenced by C than B. From their relationship, for given B_j, if A_i is exceeded, C_k will also be exceeded. Therefore,

$$P(A>A_i|B_j) = P(C>C_k) \qquad (5)$$

In practice, the conditional exceedance probability distribution can be developed by substituting the exceedance probability distribution of the dominant causative factor, C, in the relationship.

Total Probability Theorem : The conditional exceedance probability distribution expresses a set of exceedance probability distributions of A conditional on B in which there is a number of possible events to occur. $B_1, B_2, .., B_M$ represents a set of mutually exclusive and collectively exhaustive events for B. By the total probability theorem, the exceedance probability of A_i is determined as

$$P(A>A_i) = \sum_{j=1}^{j=m} P(A>A_i|B_j)*D(B_j) \qquad (6)$$

where

$P(A>A_i)$ = probability that event A_i is exceeded for a total time span m.

$P(A>A_i|B_j)$ = conditional probability that event A_i is exceeded given event B_j occurred.

$D(B_j)$ = increment of time span that B_j represents.

$P(C>C_k)$ = probability that event C_k is exceeded.

Knowing the relationship between A, B and C, the exceedance probability distribution of dominant causative factor C and the duration distribution of non-dominant causative factor B, the exceedance probability distribution of A can be developed (see Fig.2).

DATA USED

Data of Flood Flow Simulation

The Chao Phraya river from Bangsai to the river mouth at Fort Chula is schematized into 40 nodes and 40 branches with distance interval about 4 km (see Fig.1). The time step of 1,200 sec and the time weighting coefficient (θ) of 0.55 are used in the computation. The Manning's roughness coefficients of the Chao Phraya river and the diversion channel obtained from calibration are about 0.028 and 0.018 respectively [1]. The capacity of the flood control system depends on the diversion channel basewidth from 20 to 80 m and the sea barrier pumping capacity from 0 to 2,000 m^3/s. For the operating rules of the flood control system [4], it is intended to utilize the maximum diversion discharge of the diversion channel which is limited to the channel embankment crest level, i.e., at Pak Kret diversion dam at 2.70 m. MSL plus 0.30 m freeboard. The operating rule of the sea barrier, same as that of the salinity gate, is to fully open the gate when the river level is higher than the tidal level or to fully close the gate when the flood discharge reverses its flow direction into the river. The pumping station is operated to pump flood water from the river to the sea when the sea barrier is closed.

The model boundary conditions for this design study are observed hourly river water level hydrographs at Bangsai and Fort Chula from 1 October to 31 December for the period 1971-1993. Stochastic time series generating models are also used to generate hourly water level hydrographs at Bangsai and Fort Chula for higher flood peaks. The annual peak water levels considered range from 0.5 m.MSL (1 year return period) to 5.0 m.MSL (1,000 year return period) at Bangsai and from 0.5 m.MSL (1 year return period) to 2.2 m. MSL (10,000 year return period) at Fort Chula. The lateral inflow to the river is neglected in the computation since the river water level is greatly influenced by the river flood inflow and the high tide relatively much more than the lateral inflow due to local rainfall [1], [5]. The initial condition of water levels and discharges along the river from Bangsai to the Pak Kret diversion dam and along the diversion channel is specified based on a steady flow condition. For the river reach from the Pak Kret diversion dam to the sea barrier, the diversion dam and the sea barrier are considered to be closed initially. Hence, no flow condition with a horizontal water surface at mean sea level is specified.

Data of Coincident Flood Frequency Computation

Data on three functions are used : 1) the flooding relationships, 2) the frequency distribution of the dominant flood boundary condition and 3) the duration distribution of the non-dominant flood boundary condition. It is found that the frequency distribution of maximum river flood levels at Bangkok is more influenced by maximum inflow at Bangsai than high tide at Fort Chula [6]. Then the dominant boundary condition is the exceedance probability distribution of river flood levels at Bangsai while the non-dominant boundary condition is the average duration distribution of daily maximum tide levels at Fort Chula.

RESULTS AND DISCUSSIONS

Relationships of River Flood Levels at Bangkok for Various Capacities of Flood Control System

The flood peak level relationships of the computed peak levels at Bangkok and those of observed and generated boundary conditions at Bangsai and Fort Chula as described earlier for various capacities of the flood control system and without flood control system are shown in Fig. 3 [6]. It is found that a diversion dam and a diversion channel can significantly divert the exceessive flood inflow to the sea while a sea barrier can effectively reduce the backwater effect of high tide on the river water level. This flow regulation effectively lowers the river water level at Bangkok despite coincidence of large flood inflow from Bangsai and high tide at Fort Chula. When the diversion channel base width is larger, the river water level at Bangkok is more lowered. However, a pumping station can only slightly reduce the river flood level at Bangkok.

Frequency Distributions of River Flood Levels at Bangkok For Various Capacities of Flood Control System

The exceedance probability distributions of river flood levels at Bangkok for various capacities of the flood control system including that without flood control rystem are shown in Fig. 4 [6]. It is found that the return period of flood overtopping the river dikes at Bangkok is significantly increased by the proposed flood control system. When there is no flood control system, the return period of flood overtopping the river dikes at Bangkok is about 2.5 years. The flood control system with a 20 m basewidth diversion channel and a pumping capacity of 0 to 2,000 m^3/s at sea barrier can increase the return period of flood overtopping the river dikes at Bangkok up to 80 years without pumping station and to 460 years with a 2,000 m^3/s pumping station. The flood control system with a 40 m basewidth diversion channel without pumping station can increase the return period of flood overtopping the river dikes at Bangkok to more than 1,000 years. It indicates that the flow regulation using both the river storage between the diversion dam and the sea barrier and the proposed flood control system to discharge flood water by gravity to the sea can protect flood overtopping the river dikes at Bangkok for a maximum flood boundary condition of 1,000 years at Bangsai and 10,000 years at Fort Chula.

CONCLUSIONS

Coincidence frequency analysis is applicable for determining a return period of failure or an exceedance probability of a dependent variable such as the river flood level at Bangkok which is a function of two or more causative factors namely the river flood level at Bangsai and the tidal level at the Chao Phraya river mouth. The approach is useful for determining the relationship between various capacities of the structures and the return period of failure. In this study, the coincidence flood frequency analysis applied to determine the return period of the Chao Phraya river flood overtopping the river dikes at Bangkok for various capacities of the proposed flood control system. The proposed flood control system is consisted of a diversion dam across the Chao Phraya river at Pak Kret, a 52 km flood diversion channel from the diversion dam to the sea, a salinity gate at the outlet of the diversion channel and a sea barrier with a pumping station at the Chao Phraya river mouth. The capacity of the flood control system depends on a diversion channel basewidth varied from 20 to 80 m and a pumping capacity at the sea barrier from 0 to 2,000 m^3/s. The river flood level at Bangkok is considered as a function of river flood level at Bangsai and high tide at Fort Chula.

As the result of the flooding relationships, the proposed flood control system is found to be very effective in lowering river water level below the river dikes at Bangkok against coincidence of flood flow from Bangsai and high tide at Fort Chula. The diversion scheme can divert a significant portion of incoming flood through a diversion channel and releasing an unharmful flow through a diversion dam to the city. The sea barrier can significantly reduce the backwater effect of high tide on the river water level and consequently provide more river storage to accommodate the flood discharge released through the diversion dam. This flow regulation significantly lowers the water level at Bangkok against coincidence of flood flow from Bangsai and high tide at Fort Chula. The pumping station can only slightly lower the river flood level at Bangkok.

From the result of the exceedance probability distributions, the proposed flood control system can significantly increase the return period of river flood overtopping the river dikes at Bangkok. It is found that the flood control system with a 20 m basewidth diversion channel without pumping station can protect flood overtopping the river dikes with a return period at least 80 years while the 40 m basewidth diversion channel can protect flood overtopping the river dikes with a return period more than 1,000 years.

In conclusion, the proposed flood control system is very effective in protecting the river flood overtopping the existing river dikes at Bangkok against coincidence of flood flow from

Bangsai of a maximum return period of 1,000 years and high tide at Fort Chula of a maximum return period of 10,000 years.

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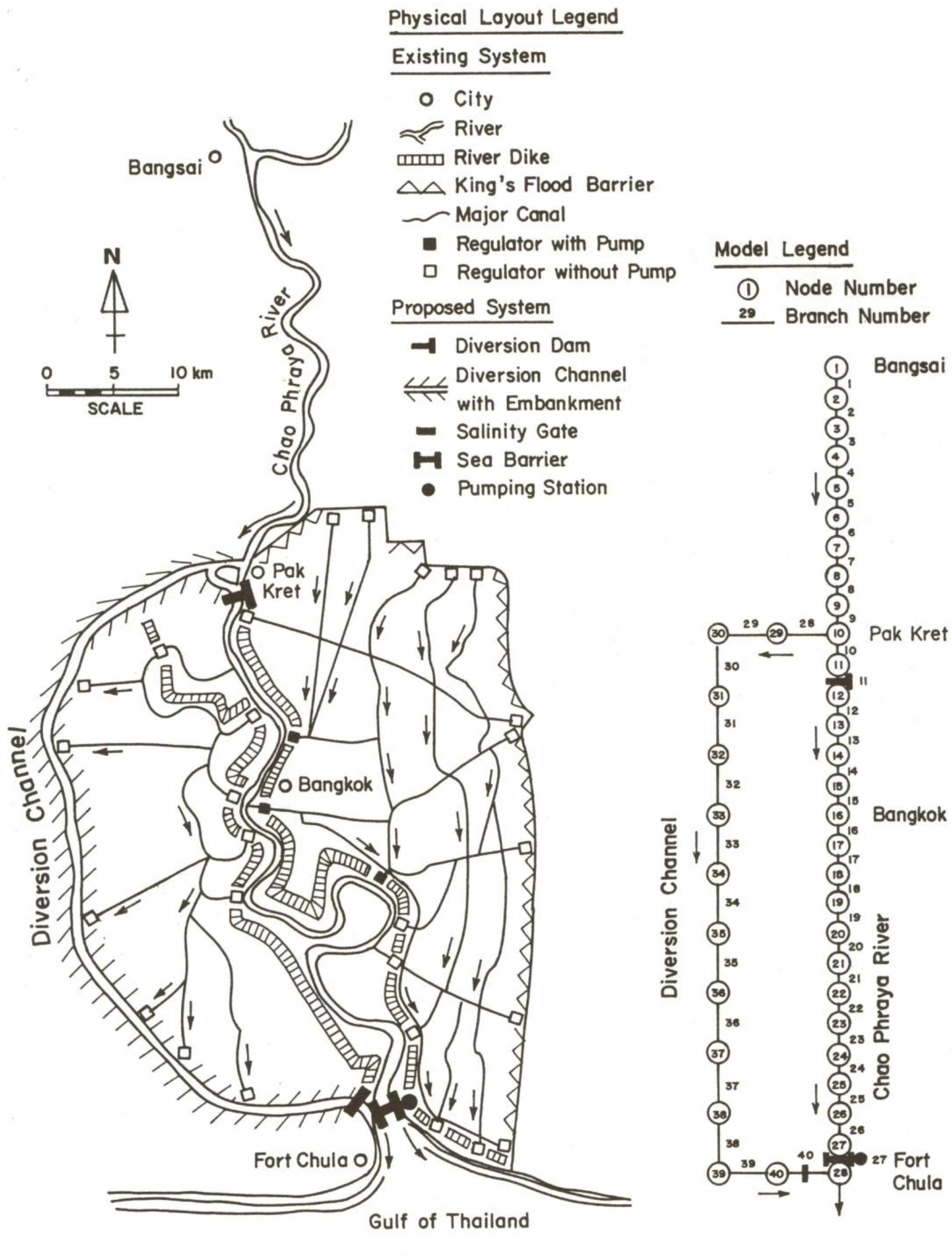

Figure 1 Lower Chao Phraya River, Existing and Proposed Flood Control System for Bangkok and Mathematical Model Configuration

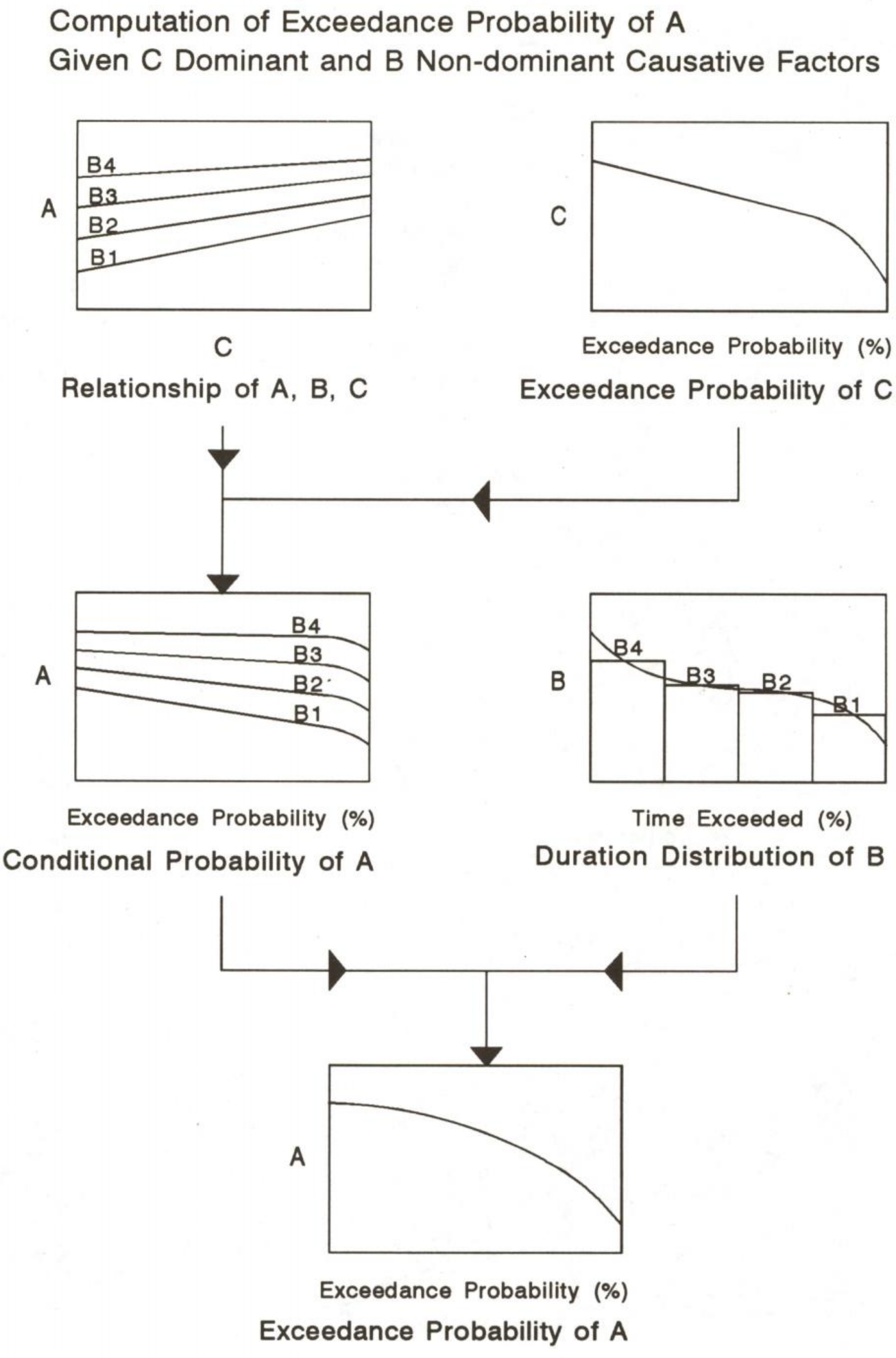

Figure 2 Schematic Diagram of Coincident Frequency Analysis

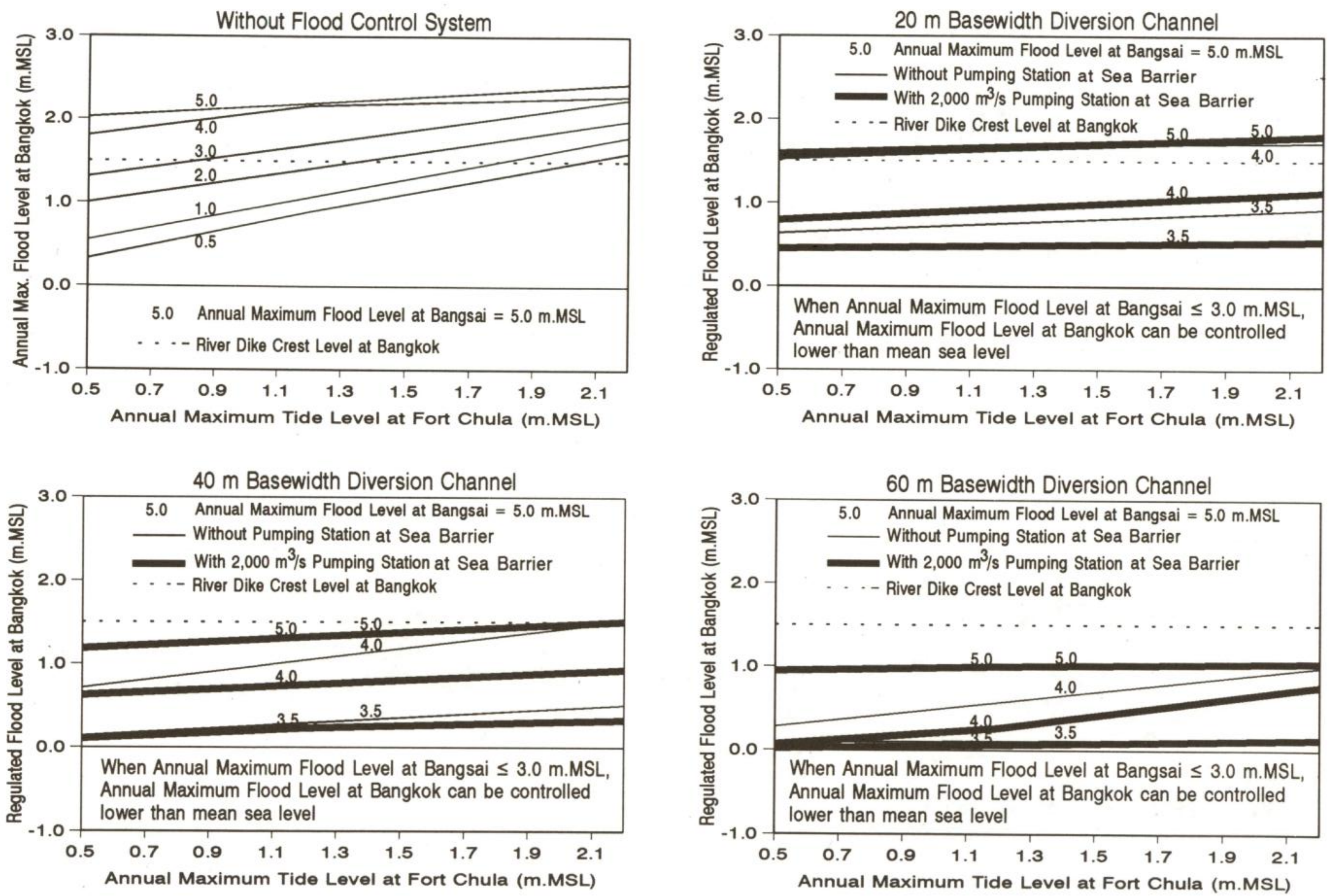

Figure 3 Relationships of Annual Maximum Flood Levels at Bangkok, Bangsai and Fort Chula for Various Capacities of Flood Control System

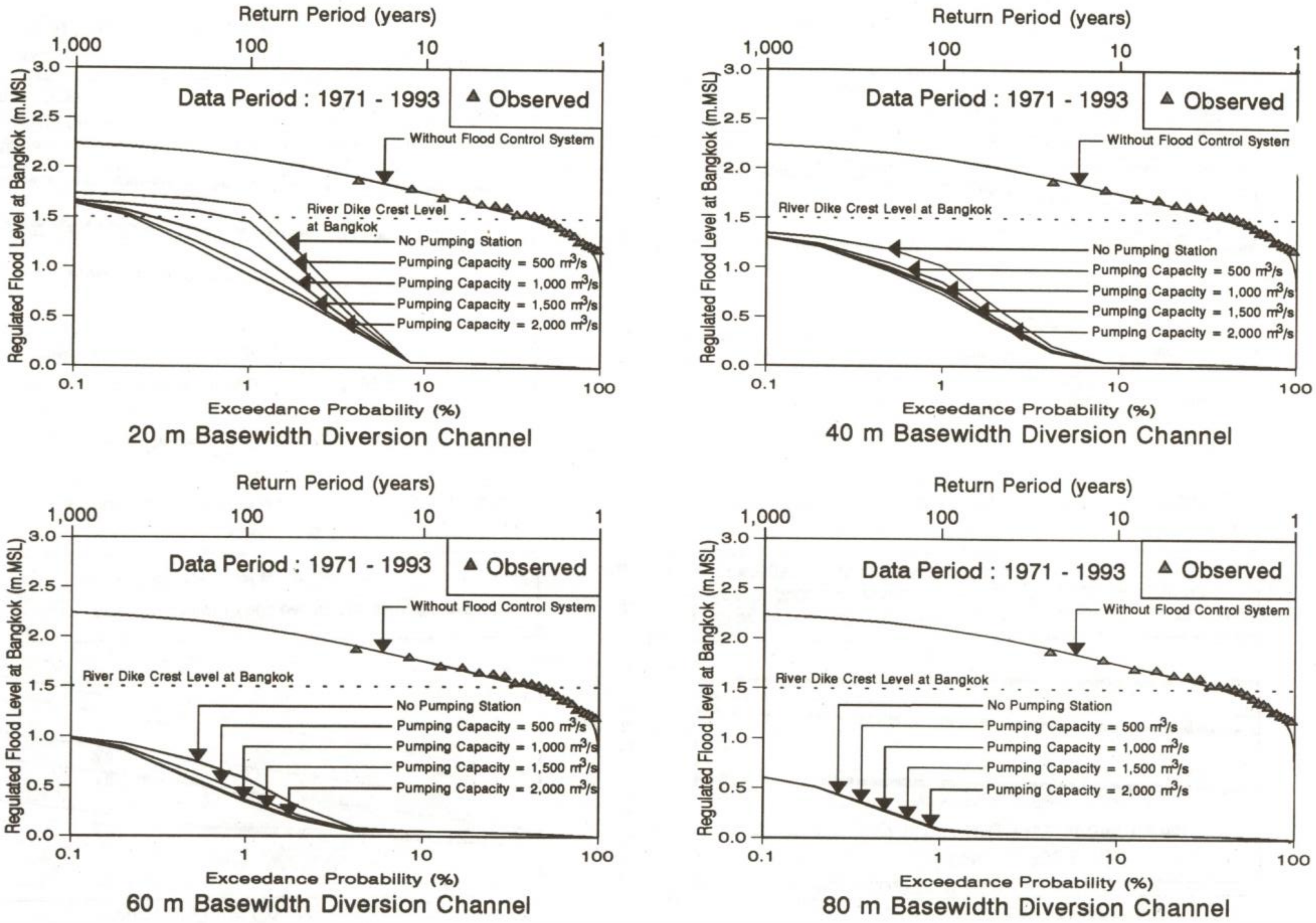

Figure 4 Frequency Distributions of Annual Maximum River Water Levels at Bangkok, for Various Capacities of Flood Control System