CHAPTER 3. BASIC ANALYSIS

3.1 Analysis of Flood Characteristics

3.1.1 Flood Inundation Survey

(1) Remote Sensing Survey

Using the remote sensing technique, flood inundation area maps for the 1995 and 1996 floods and a 1995 land use map are prepared in this Study.

To cover the flood prone area which is the target area for flood mitigation, six (6) LANDSAT TM photographs are required, as shown in Fig. 3.1.1. Such six photographs should have been taken on the same date, but due to the small coverage area of each photograph and the influence of clouds it was impossible to collect clear photographs on the same date. The collected sets consisted of photographs of different dates, in particular, the set for the 1995 flood analysis is composed of photographs taken in September to December. The processed false color images for the 1995 and 1996 floods are given in Fig. 3.1.2.

NOAA photographs are also useful because one shot can cover the whole flood prone area. Their resolution is low but the changing flood inundation area can be traced by collecting photographs of different dates. In this Study, NOAA photographs of six (6) different dates from the beginning to the end of the 1995 flood (September to December) were collected and processed to produce false color images, as shown in Fig. 3.1.3.

(2) Interview Survey

In this Study, an interview survey on flood inundation and damage was conducted to collect information on past major floods, i.e., 1983, 1995 and 1996. This survey covered some 30,000 km^2 of the Chao Phraya Delta and middle and downstream areas of the Nan and Yom rivers. The interview survey had two sources to collect information, the local government offices and the individuals in flood affected areas.

The survey results are adopted to the evaluation of flood damage potential, calculation of expected average annual flood damage, and establishment of flood simulation.

3.1.2 Preliminary Study on Flooding

Based on the information collected, consideration on the flooding in the Chao Phraya River Basin was made, as summarized below.

(1) Probable Maximum Inundation Area

Based on the flood inundation maps, satellite images and precise topographic maps with a contour interval of 1 m or less, the probable maximum inundation area was identified for the Nan and Yom flood plains and the Chao Phraya

Delta, as shown in Fig. 3.1.2. The total area is about 35,000 km^2, and the main land use is paddy but the area includes the Bangkok Metropolitan Area and other major urban areas such as Ayuthaya, Nakhon Sawan, Lop Buri and Phitsanulok and Sukhothai. The flood inundation analysis in the next section concentrates on this 35,000 km^2 area.

(2) River Flood and Inland Flood

The main cause of flooding is the low capacity of river channels. In the 1995 flood, dike breaching and overtopping occurred at almost every reach of the Chao Phraya River, its tributaries and distributaries. The river flood in the Nan and Yom plain is usually generated in late August, and reaches its peak in September or early October. The river flood wave enters the Chao Phraya Delta in early October, and arrives at Bangkok from late October to early November. Flood inundation lasts until January of the following year in some depressed areas.

The long flood period is because of spillage and retarding in the flood plains. Fig. 3.1.4 shows the propagation and attenuation of the flood waves of the recent five floods along the Chao Phraya River. At the lower stations the water hydrographs are attenuated and gentle. In 1995, drain flow from the flood plains surrounded by dikes seemed to be so significant that it heightened the peak water levels at the stations lower than C.7A, Ang Thong, in late October when the tide was also the highest.

In addition to the river flood, inland flood caused by intensive local rainfall is also serious. Inland flood areas are usually small and localized but the flood situation could become terrible if a river flood is added to the inland flood. The 1983 flood was the worst case when both the river flood and inland flood took place simultaneously as discussed in Subsection 2.5.1.

(3) Bottleneck Reaches

The flow capacity analysis in Subsection 3.3.3 reveals two significant bottleneck reaches. One is the reach of the Yom River near Sukhothai, and the other is the Chao Phraya River between the Khlong Bang Bal and Ayuthaya.

The river channel of the Yom River gets narrower from Sichanalai, an entrance to the Yom flood plain to the downstream. The narrowest section with a flow capacity of about 50 m^3/s is found 70 km below Sukhothai. From Fig. 3.1.5 which shows flood discharge hydrographs in 1983, 1995 and 1996, it is understood that the discharge hydrograph of the Yom River is made flatter due to the spillage from the channel as the river flows down. The ceiling of 300 m^3/s, the bankful capacity, can be seen at Sukhothai Station, Y.4. After the bottleneck reach, the channel becomes wider and deeper. The river discharge increases to over 1,000 m^3/s, collecting the spilled floodwater.

As for the Chao Phraya River, the narrowest reach is from Khlong Bang Bal to Ayuthaya with the minimum width of 100 m. Many breaches of the left dike were reported during the 1995 flood. Moreover, this narrow channel raises the water level, resulting in high water level on the upstream reaches which often causes overtopping and dike breaching.

(4) Influence of Tide

The lowest reach is threatened with a combination of high tide and flood runoff discharge flowing from the upstream. When flood discharge meets high tide, water level is raised by the backwater effect of the high tide, and may spill over banks. A flood of the Chao Phraya River usually starts in the end of September and lasts for about two months. Unluckily, the higher sea level season of the Gulf of Thailand often coincides with this long term flood.

Fig. 3.1.6 shows water level waves at the lowest reach of the Chao Phraya River during the 1983, 1995 and 1996 floods. The more upstream, the less is the tidal influence. At C.22, Pak Kret Station, which is located 72 km upstream of the river mouth, the tidal range is as small as about 20 cm at the highest level.

(5) Influence of Embankment in Flood Plain

Some embankments including roads, railways and irrigation canal dikes seem to affect the flooding condition. Fig. 3.1.7 shows examples.

Fig. 3.1.7(1/2) is a false color image of the 1995 flood. National Highway Route 32 is preventing river flood water to go down the vast flood plain in the east, resulting in deep and long inundation in the riverside area surrounded by the river and the road embankment. It has been observed that turbid floodwater was leaking and spreading from small openings of culverts crossing the road. The Chainat-Pasak Canal embankment was blocking side flow from the eastern hilly area. In Fig. 3.1.7(2/2) which is one of the 1996 flood, the railway embankment and the dike of the Klong Raphipat Yaek Tak form definite boundaries of flood inundation.

3.2 Establishment of Flood Simulation Model

To clarify the flood inundation mechanism in the Chao Phraya River Basin through modeling and to examine the effectiveness of conceivable measures, a flood simulation model consisting of runoff and inundation analyses is established by using the package software Mike11.

The flood simulation model covers the entire Chao Phraya River Basin of 163,000 km^2, but the inundation analysis concentrated on the 35,000 km^2 probable maximum inundation area determined in Subsection 3.1.2.

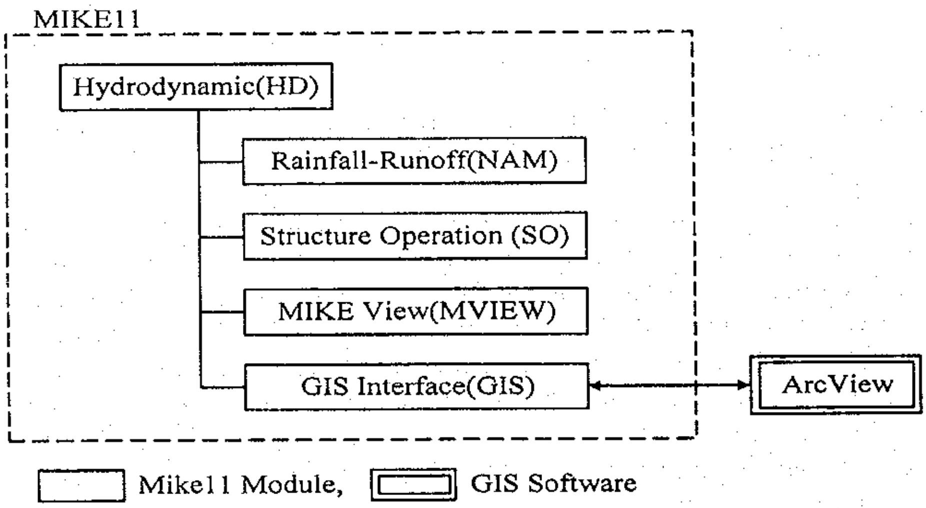
3.2.1 Outline of Modeling by MIKE11

In the MIKE11 model, runoff generated in the sub-basins was calculated by the NAM module and given to flood routing of the Hydrodynamic module as the upstream model boundary. The NAM module simulated the rainfall-runoff process in rural river basins as a lumped model. It operated by continuously accounting for the moisture content in the four different and mutually interrelated storage tanks.

The Hydrodynamic (HD) module, the core of MIKE11, was originally a one-dimensional dynamic flow model but can be applied to looped networks and quasi two-dimensional flow simulation on flood plains. A flood plain is expressed as a flood plain channel or a flood plain cell. Water exchange between the river channel and the flood plain can be solved by the orifice equation, or the weir equation according to the link condition.

Besides the HD and NAM modules, the Structure Operation (SO), MIKE View (MVIEW) and GIS Interface (GIS) modules were used for this simulation. The SO module was for gate structures, the MVIEW for presentation of simulated hydrographs, and the GIS, for interface to a GIS software, ArcView. Simulation results by the HD module were exported to the MIKE11 GIS for generating a map and animation of flood inundation. In return MIKE11 GIS gave HD module cross sections and elevation-area tables of flood plains.

Constitution of Mike11 Modules Necessary for Flood Simulation



3.2.2 Preparation of DEM

A DEM (Digital Elevation Model) is essential for the flood inundation simulation. In this Study, a DEM for the probable flood inundation area of 35,000 km^2 was prepared by digitizing contours and spot elevations of various topographic maps given in Fig. 3.2.1.

Accuracy of the simulation depends on that of the DEM. As shown in Fig. 3.2.1, however, the accuracy of the prepared DEM is different from area to area because a series of precise maps covering the whole flood inundation area was not available and several series of maps of different accuracies were used. Even RTSD maps which have less topography information, namely 20 m contour interval and thinly distributed spot elevation points, were unwillingly used for fringe areas of the inundation area which account for one-fourth of the total area. Accurate simulation results are hardly expected for these areas.

The above topographic maps were digitized to ARC/INFO data format with UTM coordinate system, and combined into one digital map. Fig. 3.2.2 shows three-dimensional views of the probable maximum inundation area based on the digital map.

Then, the digital contour line data were converted to X, Y, Z values, which were used for generating the DEM by MIKE11 GIS. Finally, the inundation area was divided into 750m x 750m grid cells with an elevation value, which are the basic topography information for the flood simulation. Moreover, dikes were also digitized into ARC/INFO data format, and assigned with elevation values.

3.2.3 Model Structure

A schematic diagram of the simulation model is given in Fig. 3.2.3 and described as follows:

(1) River Channel

Ten (10) river channels are included in the model. They are the Chao Phraya, Tha Chin, Noi, Pasak, Lop Buri, Khlong Bang Kaeo, Khlong Bang Luang, Yom, Nan and Ping Rivers. Intervals of cross sections range from 3 km for Chao Phraya River to 10 km for the Nan and Yom rivers.

(2) Flood Plain Division

In the simulation model, the inundation area is divided into several flood plain channels, flood plain cells and others, as shown in Fig. 3.2.4. The flood plain channels are treated as river channels with higher resistance, but the flood plain cells are treated as ponds, each of which has only one water level in the area. The other areas, namely the west bank of the Yom River, the east bank of the upper Nan River, the west and east banks of the upper Chao Phraya River and the west bank of the upper and lower Tha Chin River where no definite embankments splitting the flood plains and the rivers exist, are treated as extended river channels. Cross section data and area-elevation curves of the flood plain channels and cells were obtained from the DEM prepared in the previous Subsection.

(3) Inflow from Sub-basin

A river channel is given runoff by the NAM model as inflow from the sub-basin. On the other hand, a flood plain receives effective rainfall according to the flooded area, plus the proportion of NAM runoff from the remaining dry catchment.

(4) Structures

The gate operation of the Chao Phraya Dam is simulated through calibration. Actual intake discharges are distributed from the head regulators, Phonlathep on the Tha Chin River, Borommathad on the Noi River and Manorom on the Chainat-Pasak Channel. Drainage pumps located along the sea and the Bang Pakon River are also included in the model.

(5) Boundary Conditions

The boundary conditions are set as follows:

Boundary	Applied Data
Upstream end of Ping River	Bhumibol Dam Outflow
Upstream end of Yom River	Y.14 Discharge
Upstream end of Nan River	Sirikit Dam Outflow
Upstream end of Pasak River	S.9 Discharge
Downstream end of Chao Phraya River	Pom Phrachul Tide
Downstream end of Tha Chin River	Samut Sakhorn Tide

3.2.4 Model Calibration

(1) Target Flood

Three floods, 1983, 1995 and 1996 are selected as target floods for the model calibration. Information on the flooding condition and the rivers in the recent floods in 1995 and 1996 was collected intensively in this Study. The 1983 flood is selected as a representative of hybrid floods caused by both river and inland floods although the flood is so old that available data on the river and flood condition at that time are insufficient.

The simulation period is as long as six months to cover the flood period completely from the beginning to the end.

(2) Calibration Result

Quite a few trial runs were made until an acceptable accuracy was obtained, adjusting not only model parameters including the NAM model parameters and roughness coefficients of river and flood channels but also model structures including location and geometry of link channels between rivers and flood plain channels/cells. The water level and discharge hydrographs in the 1995 flood and the maximum inundation maps in the three floods are presented in Fig. 3.2.5 and 3.2.6, respectively.

As seen in the figures, the calibration results are generally good enough. In conclusion, the obtained simulation model is considered to be acceptable and applicable for further simulations in future cases.

3.3 Hydrological Study on Flooding Condition Based on Simulation Result

3.3.1 Water Balance

Water balance of the Chao Phraya River Basin in the flood season from July to December was calculated for the three years, 1983, 1995 and 1996 based on the flood simulation result. A schematic diagram of the estimated water balance is given in Fig. 3.3.1 based on the four division areas, Upper Central Plain, Nakhon Sawan, Higher and Lower Deltas in the Lower Central Plain, as shown in Fig. 3.3.1. The maximum flood inundation volumes are also shown in the figure.

The runoff volumes to the sea were 32 billion m³ in 1983, 39 billion m³ in 1995 and 30 billion m³ in 1996. If the stored volume in the two giant dam reservoirs is included, the total runoff volume increases to 39, 47 and 35 billion m³. The runoff ratio in the flood season is 26, 32 and 29% since the corresponding six months rainfall is 919, 903 and 750 mm, respectively.

3.3.2 Inundation Volume

The 1995 flood was the biggest in terms of inundation area and volume, followed by the 1983 flood. The spatial distribution of flood inundation is different by year. Huge inundation took place in all the areas in 1995. The 1983 inundation concentrated in the Lower Central Plain due to the heavy local rainfall.

Simulated Maximum Inundation Area and Volume

Year	Upper Central Plain	Nakhon Sawan Area	Lower Central Plain		Total
			Higher Delta	Lower Delta	
1983	2.0	0.3	4.5	5.8	12.6
	2.8	0.8	5.9	3.8	13.3
1995	5.0	0.6	4.6	4.7	14.9
	5.1	1.3	7.0	2.5	15.9
1996	2.8	0.4	3.6	2.8	9.6
	3.5	1.0	4.9	1.3	10.7

Upper : Inundation Area (thousand km²)
Lower : Inundation Volume (billion m³)

3.3.3 Flow Capacity of Rivers

Flow capacities of the rivers and major khlongs in the Chao Phraya River Basin are estimated in Sector VII, River Improvement Plan, as shown in Fig. 3.3.2 and summarized as follows:

The flow capacity of Yom River is quite small along almost all the stretches from Sukhothai to Nan River. The flow capacity at Sam Ngam, Y.17, is about 900 m³/s, which is less than the 2-year discharge. There is a bottleneck at the downstream of Sukhothai, which has a flow capacity of only 50 m³/s.

The flow capacity of Nan River is also small. The flow capacity is between 1,000 m³/s and 1,500 m³/s, while the 2-year discharge is 1,100 to 1,300 m³/s according to the simulation result. The lower stretches near Nakhon Sawan is influenced by backwater from the Chao Phraya River. Water levels in these stretches are possibly raised high over the dike levels by the backwater even when the river discharge is small.

The flow capacity decreases toward the downstream, from 4,000 m³/s at Chao Phraya Dam (corresponding to the 3-year discharge) to 3,000 m³/s in Bangkok (much less than the 2-year discharge). This implies that spillage from the river channel gradually occurs in the upstream when a large scale flood occurs; hence, spillage do not concentrate in the downstream. This situation contributes to alleviation of flood damage to Bangkok, while the spilled water is widely retained in the agricultural area in a manner of inundation.

3.3.4 Characteristics of Inundation

Huge inundation took place in all the areas in 1995. As also seen in Fig. 2.5.1, however, it is presumed that most of the floodwater was generated in the Nan and Yom river basins. Firstly, the floodwater originated in the upper basin then flowed down along the Nan and Yom rivers, repeating collection of tributaries' runoff water and spillage by overtopping and dike breaching. The total water volume which swelled to 31 billion m^3 at Nakhon Sawan then entered the delta areas and spilled over the river banks to the adjoining flood plains. The contribution of local rainfall to the inundation in the Lower Central Plain, namely the Higher and Lower deltas, was not significant.

The 1996 flood inundation is considered to be similar to the one in 1995 but considerably smaller. The inundation in the delta areas was mostly caused by the flood water generated in the upper basin, and local rainfall was less.

The flood situation in 1983 was totally different from 1995 and 1996. As discussed in Subsection 2.5.2 and 3.1.2, heavy local rainfall worsened the flood inundation in the Lower Central Plain. The simulation result shows that the total inundation volume in the delta areas in 1983 was the largest among the three floods in spite of the smallest discharge volume at the entrance gate into the delta areas, the Chao Phraya Dam.

3.4 Flood Damage Analysis

Flood damage analyses were conducted to identify the present flood damage conditions, the influence of future developments and the effectiveness of proposed measures.

3.4.1 Flood Damage Data in the Past Flood

(1) Available Records

The official flood damage records in Thailand started in 1978 (Public Welfare Department, Ministry of Labor and Social Welfare). Since 1988 the Civil Defense Department (DOLA) has been responsible for this task. Both of these records are infrastructure damages; however, the data before 1988 are incomparable with those after 1988. Fig. 3.4.1 is a series of annual damage records from 1988 on infrastructure damage, e.g., repair cost of roads and river structures in the whole country.

Several departments in MOAC keep statistical data in their local offices in the provinces. Fig. 3.4.2 presents the agricultural, fishery and livestock damage amounts of the 1995 flood (together with infrastructure damage recorded by MOI mentioned above) in each province in the Chao Phraya River Basin. Table 3.4.1 and 3.4.2 show the agricultural flood damage between 1984 and 1993. As identified from the tables, the Chao Phraya River basin has been suffering from flood damage almost every year.

No statistical data were available for flood damage on buildings and goods of residential houses, industrial and commercial enterprises.

(2) Historical Record and Scale of Damage

As shown in Fig. 3.4.1, the cost of infrastructure damage amounted to 12 billion Baht for the whole country in 1995 and is the worst on record. Besides those of the 1995 flood, large amounts of damage have been recorded almost every year.

(3) Composition of Damage

Fig. 3.4.2 compares the damage amount of agriculture, fishery, livestock, and infrastructure in provinces in the study area in 1995. The total damage amount is 6,356 million Baht. The share of agricultural damage is 48% of the total damage excluding those of household, commerce, industry and other establishments. Briefly, the significance of agricultural damage is observed. Further, integrating fishery and livestock damages, the total agricultural related damage cost is 3,976 million Baht, which is 1.7 times as high as the infrastructure damage of 2,381 million Baht.

3.4.2 Flood Damage Mechanism

(1) Damaged Area

A province (Changwat) is divided into several districts (Amphoe), while some districts have municipalities (Tesaban) and sanitary cities (Sukabiban). A municipality and a sanitary city are considered as an urban area and a hub city, respectively.

Flood damages concentrate on the municipality in case of a district having a municipality. Otherwise, flood damages concentrate on the agricultural sector in case of a district without a municipality.

Most of the private sectors such as houses, commercial shops, and small factories are located in the municipalities. Most houses, commercial shops and small factories are of low floor type, and in such floor types, a large amount of assets exist.

On the other hand, a small number of buildings in the private sector are in districts without a municipality. Thus, a small amount of assets is in the district except assets in the agricultural sector. In addition, most of the houses are of high floor type in rural areas, so that these houses are, functionally, relatively durable against floods.

(2) Wisdom of Flood Countermeasures

When floods strike, people try to protect their assets or mitigate flood damage by taking countermeasures. Since inundation comes up slowly, people can determine when the flood comes and have enough time to take countermeasures. Inundation level comes up several centimeters per day, and it took 20 to 30 days from the beginning of the inundation to reach the highest level in the case of Ayuthaya in 1995. The flood information is sometimes broadcast on radio or TV.

People make efforts to move their assets such as furniture and television to the second floor or an upper place like a shelf or desk in most cases. Some people try to construct a new floor on a higher level to move their household effects, and they live and sleep on this floor. Shop owners construct protection walls made of cement.

Large factories are located around municipalities or sanitary cities in general. Most of these factories have their own dikes for protection against floods. They usually have large amounts of assets such as facilities, machinery, materials and products, and with these flood protection works, the assets are relatively protected against floods. However, once these are submerged, the damage amount becomes very large.

People have developed the wisdom of providing flood countermeasures through their experiences. However, they cannot prevent or mitigate big floods and, actually, much damage has been inflicted.

(3) Situation in Flood

During floods people go shopping by small boats, or peddlers come to their houses. Due to the flooding situation, however, people suffer because it is very difficult to go somewhere or to buy daily necessities in the inundated areas. As for drinking water, people in urban areas buy bottled water, while people in rural areas drink rainwater because they normally stock rainwater from their roofs in big pots. As for food, people tend to eat dry noodles.

(4) Composition of Damage

It is easy to recognize direct damage on houses or its assets. Direct damage is not so much because people remove their assets to higher locations as mentioned before.

On the other hand, it is difficult to recognize indirect damage. Business suspension is considered as an indirect damage. People cannot work during floods, and floods sometimes take a long duration of more than three months.

In addition, the cost of countermeasures can be considered as an indirect flood damage. To estimate the total amount of damage, indirect damage cannot be ignored because the amount is unexpectedly large.

There is an interesting report by PWD. It shows diseases due to flood, consisting of 19% of conjunctivitis, 11% of diarrhea, 45% of athlete's foot, and 7% of food poisoning in 1995. It also shows curative costs for waterborne diseases amounting to 1,449 baht per household. In addition, it mentions problems such as traffic, commerce, sanitation, settlement, food, drinking water, diseases and others. These kinds of damage are also indirect damages. Indirect damage becomes more serious if these damages are taken into account.

Another interesting report on Ayuthaya by PWD mentions tourism damage. Ayuthaya is one of the most famous places for tourists in Thailand, therefore, income from tourism is a large amount. Since during floods no tourist come to Ayuthaya, the damage on tourism is estimated to be large.

It is difficult to recognize and estimate all indirect damage amounts as well as intangible damage.

3.4.3 Flood Damage Estimation

(1) Components of Flood Damage

Fig. 3.4.3 shows the components of flood damage. Flood damage is divided into two (2) categories, tangible damage and intangible damage. The latter, which includes negative psychological impact such as fear, depression and health, etc., was excluded from the damage analysis because it is next to impossible to estimate such psychological conditions.

Tangible damage further has two (2) categories: direct damage and indirect damage. Direct damage is measurable and often referred to as the damage. Indirect damage is not physical but subsequent negative effect on economic activities. Sales loss, for instance, is a typical indirect damage due to business suspension in a shop forced to close by inundation. Direct damage also includes loss of tourism and expenses for diseases and so on.

Direct damage consists of damage to households, commerce, industry, agriculture, fishery, livestock and public utilities.

(2) Basic Formula for Damage Amount Estimation

The 35,000 km^2 flood inundation area is divided into some 1,600, 5 km x 5 km square cells as shown in Fig. 3.4.4. The cell is a unit area for the flood estimation. Flood damage information is categorized into household, agriculture, commerce, industry and other sectors. Flood damage at a certain inundation depth is calculated by the equation below:

Total Damage Amount = Σ *(Damaged Quantity* × *Unit Value* × *Damage Rate) + Indirect Damage Amount*

As for the flood damage data, the basic data are concerned with each category mentioned above. In addition to these data, the damage rate and unit value are needed when the damage amount is estimated.

(3) Distribution of Assets Value in the Study Area

Fig. 3.4.5 shows the distribution of assets value in the study area, taking into consideration the assets value and farm gate prices given in Table 3.4.3 and 3.4.4. Assets value is mainly concentrated in the lower delta including Bangkok. Agricultural value shares just 0.67% in the total assets value. Thus, most asset values are in the private sector covering houses, commerce and industry.

(4) Damage Rate

The damage rate on houses was derived mainly from the survey by RID in 1997 and referring to the results of flood damage survey as given in Table 3.4.5. This is applied to the other three sectors (commerce, industry and other establishments) as well, since no significant difference is observed in the damage rate of these sectors.

Damage rates on agricultural crops were set, considering RID, Indonesian study and Japanese practice, as presented in Table 3.4.4.

(5) Direct Damage

Direct damage was calculated as follows:

(a) Household, Commerce, Industry and Public Utility

Flood damage for household, commerce, industry and public utility is calculated at a given depth, as follows:

Flood Damage of Sector = Value of building × Damage Rate (a) + Value of assets × Damage Rate (b) (1)

Flood Damage of this section = Σ (Damage of Residence, Commerce, Industry and other establishments) (2)

(b) Agriculture, Livestock, Fishery

Agricultural damage is calculated as follows:

One type of damage = area × yield × farm gate price × damage rate (3)

Agricultural damage = Σ (damage of rice, field crops, vegetable and fruit) (4)

Livestock damage = (4) × 0.7/100 (5)

Fishery damage = (4) × 10/100 (6)

(c) Public Utility

Public utility damage in rural area = (4) × 70/100 (7)

Public utility damage in urban area = (1) × 52/100 (8)

(6) Indirect Damage

Although statistics on income and sales are available, it is impossible to draw the relation between income or sales loss and inundation depth. With the developing condition of Thailand, however, the estimation of such indirect damage cannot be neglected. In the Japanese practice, which was successfully applied to similar studies in the neighboring countries, indirect damage is assumed to be 6% of direct damage and this is applied to the Study.

Further, expressway or trunk road damage is not considered in the estimation of indirect damage. The Department of Highways commented that these roads were well prepared for flooding in terms of budget and material, and freight economy could not be much negatively influenced.

(7) Flood Damage Estimation in the Past Floods

Damage amount is estimated for representative floods in 1983, 1995 and1996. The estimated damage amount in the objective study area is 71, 72 and 32 billion baht, respectively, as shown Table 3.4.6. This estimation is under the situation of asset values in 1998.

Flood damage amount in each sector is high in the order of industry, commerce, and households. If the damage amounts of these three sectors are added, they will become a little more than 90% of the whole damage amount. Other damage amounts including agriculture are 10% or less of the whole damage amount.

If the damage amounts for industry, commerce, and households are distributed among the four areas (Upper Central Plain, Nakhon Sawan Area, Higher Delta, Lower Delta), the damage in each sector would concentrate on the Lower Delta. With regard to the other sector containing agriculture, the damage amount will concentrate on the Higher Delta, because the agricultural area is large and the inundation is deep in this area.

The Ministry of Interior estimated the damage amount including the private sector in the year 1995 in its report on flood damage for 1995. If the damage in the private sector is taken into account, the damage amount would come to about 50 billion baht. This official damage amount including the whole sector estimated by the Ministry of Interior is nearly the same as the estimation result in this Study. Therefore, the simulation model is considered to be appropriate.

CHAPTER 4. STRATEGY FOR THE FORMULATION OF MASTER PLAN

4.1 Basic Concept for the Formulation of Master Plan

The primary purpose of the Master Plan is to mitigate flood damage in flood prone areas of the Chao Phraya River Basin. The Master Plan has to consider technical and environmental soundness, social acceptability and ease of operation, and economic efficiency is one of the important indices for the selection of the optimum measure among the conceivable options.

Hence, in consideration of the characteristics of flood damage caused by previous floods as discussed in Section 2.5 of Chapter 2, the Master Plan is formulated in the following concepts:

- According to the past flood occurrence, flood conditions in the Chao Phraya River Basin is featured with the existence of extensive inundation areas, which play an important role to retain flood discharge flowing into the Chao Phraya River, resulting in the mitigation of flood damage in the downstream. In this connection, the flood mitigation plan is formulated putting emphasis on preservation of the natural retarding effect. The concept is a global one for flood mitigation through the provision of nonstructural measures and also corresponds to the monkey cheek concept that is being practiced in Thailand.

- On the other hand, the Chao Phraya River basin, especially the Chao Phraya Delta, tends to be developed continuously in the future, even in such natural retarding area, which results in the decrease of retarding effect causing the increase of flood discharge to the downstream. To minimize the influence due to decrease of retarding effect, suitable measures for comprehensive flood mitigation including structural and nonstructural measures are introduced. The river basin is broadly divided into four (4); namely, Upper Central Plain, Nakhon Sawan Area, Higher Delta in Lower Central Plain and Lower Delta in Lower Central Plain in consideration of the flood damage characteristics in each area.

- Flood mitigation measures are also classified according to the extent of flood, i.e., basin-wide flood or local inland water. In this study, the Master Plan is formulated by putting emphasis on flood mitigation measures for basin-wide flood. As for local inland water, the conceivable measures for drainage system improvement is examined for agricultural areas as well as the prioritization for implementation of improvement works.

- The flood prone areas in the basin are mainly composed of urban and agricultural areas. Among them, the urban areas will take priority for flood protection because their social and economic impacts are considerably much higher than the agricultural areas. Urban areas like Bangkok, Ayuthaya, Nakhon Sawan and others are to be protected by effective measures against bigger scale floods.

- The agricultural areas play an important role as retarding area during big scale floods, and this role should be preserved. On the other hand, for small-scale floods, the present flood damage condition should be improved, providing suitable measures within the allowable extent that will not cause adverse influence to the other areas.

- Flood damage conditions are influenced by nonstructural measures such as control of land use and groundwater extraction, and such influence would finally affect the effectiveness of structural measures. In this connection, the selection of an optimum measure is made through a comparative study on alternatives, considering the most effective combination of structural and nonstructural measures.

- In general, higher priority of flood damage mitigation is given to the downstream reaches to minimize the adverse influence of flood mitigation measures adopted in the upstream. Thus, the project scale in the downstream is set higher than the upstream.

- Although the primary purpose of the Master Plan is flood mitigation, it is also important to consider the shortage of municipal water supply in the dry season. The multipurpose use of the proposed flood mitigation measures is thus examined, especially for irrigation and municipal water supply.

4.2 Basic Conditions for the Formulation of Master Plan

Based on the above concept, the following conditions are applied for the formulation of the Master Plan.

4.2.1 Target Project Completion Year

The year 2018, which is 20 years after the completion of this study, is applied as the target year, considering the target years for related development projects as shown in Table 4.2.1.

4.2.2 Project Scale

(1) Project Scale for the Protection of Major Urban Areas

In the previous studies and plans, the proposed protection works for major urban areas such as Bangkok Metropolitan Area and the provincial capitals adopted the project scale of 100-year return period. Among these works, the flood barrier along the Bangkok core area is under construction, while the flood protection works for the other urban areas such as provincial capitals and several municipalities are under detailed design, master planning or feasibility studies.

Therefore, to be consistent with these previous plans, it is desirable to apply the same project scale for the protection of major urban areas along the Chao Phraya River. The project scale of 100-year return period is thus applied for the protection of urban areas.

(2) Project Scale for the Protection of Agricultural Land

For the protection of agricultural land, the project scale is not clear in the previous studies. However, according to the interview survey with the agencies concerned, RID has been promoting protection works with the project scale of 25-year return period. Most of the agricultural lands are thus currently protected by a project scale of between 5 and 25-year return period.

In this study, the appropriate project scale for the Master Plan is decided, considering the economical and social aspects as well as the current flood control plan.

4.2.3 Expected Future River Basin Condition

River basin conditions are rapidly changing and some of the changes may seriously affect the flooding condition. The following factors that relate to the target project completion year of the Master Plan are considered to be contributory to the future flooding condition (refer to Fig.4.2.1).

(1) Ring Levee with Drainage System Improvement for the Protection of Urban Areas

The construction of a ring levee with drainage system improvement for urban areas is considered as one of the factors that could seriously affect the flooding condition in the future. The project will result in the increase of flood discharge to the Chao Phraya River.

In this connection, it is expected that the following urban areas which are suffering directly from the damage caused by floods of the Chao Phraya River are to be protected by the construction of a ring levee with drainage system improvement:

- Bangkok Metropolitan Area
- Fourteen (14) provincial capitals (Sukhothai, Phitsanulok, Phichit, Nakhon Sawan, Chainat, Sing Buri, Ang Thong, Ayuthaya, Pathum Thani, Nonthaburi, Samut Prakan, Supanburi, Samutsakon and Saraburi)
- Eighteen (18) municipalities (Sawankalok, Ban Mun Nak, Taphan Hin, Chumsaeng, Krok Phra, Phayuha Khiri, Watsing, In Buri, Phrom Buri, Pamok, Bang Luang, Bang Pho Thai, Katumban, Aomnoy, Phapntabat, Nongkhea, Keangkoy and Songpeenong)

Fig. 4.2.1 shows the location of these areas. The drainage capacity from the urban areas to the river is shown in Table 4.2.2 and in Figs. 4.2.2 and 4.2.3. For the areas with no drainage system improvement plan, the capacity of the drainage facility is presumed on the basis of figures from the feasibility study and detailed design (refer to Fig. 4.2.4).

(2) Land Subsidence

Land subsidence in the BMA and neighboring areas is one of the factors which will seriously affect the flooding condition, mainly in the following manner (refer to Fig. 4.2.5):

- Decrease of flow capacity of the Chao Phraya River around the Bangkok metropolitan area, because the dike height may also decrease in accordance with the subsidence.

- Decrease of capacity of drainage channel and pump due to lowering of height of drainage channel and pumping station compared to the water level at the outlet.

Several studies have been conducted as to land subsidence. Among them, the following are specified:

- Study on Management of Groundwater and Land Subsidence; JICA, 1995.

- Master Plan for Basic Infrastructure Systems and Preliminary Design for the Flood Protection and Drainage System in Eastern Suburban Bangkok; BMA, 1996.

The former study presented nine (9) scenarios to predict future land subsidence based on the tendency of groundwater abstraction by pump. The latter study presumed the future land subsidence of 2 cm/year for the formulation of a drainage improvement project with 2006 as the target year. The land subsidence of 2 cm/year corresponds to the average land subsidence among the said nine scenarios in the former study. (refer to Fig. 2.8.3)

Based on the latter study, BMA is implementing the project to raise the height of dikes as flood barrier. BMA assumes that this height of dike is maintained for adoption by projects proposed in the future, because piles are driven 20 m deep under the river dike to minimize the influence of land subsidence.

(3) Road Development Plan

The road development plans will also affect the flooding condition because the constructed roads may function as barrier in the flood prone area. At present, the major road development plans are the Outer Ring Road and the Truck Route. Their outlines are shown in Fig. 2.11.4.

These road development plans are proposed to have an embankment of 90 cm in height above the recorded maximum inundation water level and this will change the behavior of inundation water. It is thus necessary to consider such condition for the formulation of the Master plan, so that the future flooding condition is examined in this study, assuming that these road development projects are completed.

(4) Loop-Cut at Bangkok Port

In principle, the optimum river improvement plan is to be proposed in this study. However, there are some ongoing plans for river improvement to protect urban and agricultural areas. Among them, the loop-cut at Bangkok Port is specified as follows:

To shorten the drainage path and to increase the flow capacity by making a steeper gradient, the loop-cut project at Bangkok Port is ongoing and it is expected to be completed in a few years (refer to Fig. 2.6.3). By cutting off the loop, the flow capacity of the Chao Phraya River channel through Bangkok will increase from 130 to 440 m^3/s depending on the tide water level during a flood peak of 3,000 m^3/s.

In this study, therefore, the Master Plan is formulated, assuming that the loop-cut is completed.

(5) Future Change of Land Use

As discussed in Section 2.7.3, land use projection is made with the target year of 2018. The future land use is shown in Fig. 2.7.9.

(6) Drainage System Improvement Plan in Agricultural Land

As discussed in Section 2.6.3, there is one ongoing drainage system improvement plan called "Monkey Cheek Improvement" (refer to Fig. 2.6.8). Since the improvement plan could be implemented within a few years, this present study is conducted, assuming that the drainage project is completed before the target year 2018.

(7) Dam Projects

In the context of water resources development, there are several dam projects. Among them, the following dam projects have been planned and/or being implemented independently from this Study. In this Study, the Master Plan is formulated, assuming that the dam construction projects are completed before the target year 2018 (refer to Chapter 5).

- Pasak Dam (under construction)
- Keaen Sua Teng Dam (under planning)
- Kuae Noi Dam (under planning)

(8) Other Related Projects

As for the other related projects, there are several ongoing projects at present. Among them, the following projects are assumed completed before the target year 2018. (refer to Fig. 4.2.1 and the General Map)

- Damming Chao Phraya Project (under planning)
- Kok-Ing-Nam Project (under planning)

4.2.4 Future Flooding Condition

In combination with the future development and flood mitigation works, the flooding condition will change. Such a change of flooding condition is evaluated using a simulation model. As the simulation result, the following points are specified (refer to Table 4.2.3 and Fig. 4.2.6):

(1) Upper Central Plain (Upstream of Nakhon Sawan)

In the upper river basin, the major land uses are composed of agricultural area and several urban areas, and flood damage is reported in these areas due to poor river channel capacity. As the future condition, a drastic change in land use is not expected, although protection works for urban areas such as Sukhothai and Phitsanulok will be promoted.

According to the simulation results, it is revealed that the flooding condition will not change from the present situation ,and protection works for urban areas will not bring about severe adverse influence so much.

(2) Nakhon Sawan Area (between Nakhon Sawan and Chainat)

In the Nakhon Sawan area, the situation is similar to that in the upper central plain. The flooding condition will not change from the present condition and protection works for urban areas will not bring about severe adverse influence so much.

(3) Higher Delta in Lower Central Plain (between Chainat and Ayuthaya)

In the higher delta in lower central plain, change of agricultural land use in a manner of diversification as well as change of cropping pattern in paddy fields has been progressing. Urban areas are also expanding and protection works for urban areas such as Chainat and Ayuthaya will be promoted. Since the diversification is mainly made from paddy to cash crops, which are more vulnerable to flood damage, flood damage tends to increase. However, as far as the simulation result is concerned, any change of flood discharge is not observed and severe adverse influence to the downstream is not expected.

(4) Lower Delta in Lower Central Plain (Downstream of Ayuthaya)

In the area, change of land use is severe. Urbanization has been rapidly progressing and protection works for urban area such as Pathum Thani and Nonthaburi will be provided.

As the result, the adverse influence mainly caused by protection works for Pathum Thani and Nonthaburi is quite large to downstream Bangkok. Because of this, the safety level of Bangkok is expected to lower from 100-year return period to 10-year return period (refer to Figs. 4.2.7 and 4.2.8).

4.3 Major Issues Considered for the Formulation of Master Plan

Under the above conditions, the issues to be considered for formulation of the Master Plan are emphasized as follows:

(1) Upper Central Plain and Nakhon Sawan Area

In these areas, the following points are considered:

- For urban areas, they will be protected with 100-year return period and the protection works will not bring severe adverse influence to the downstream.

- For agricultural areas, flood damage will still occur in the future. So it is considered to provide protection works for the agricultural areas to mitigate flood damage. However, such protection works will result in the reduction of natural retarding effect and bring about an adverse influence to the downstream.

Consequently, the issues for flood mitigation in these areas are emphasized with the following points:

- To seek measures to mitigate flood damage in agriculture areas, but not to cause adverse influence to the downstream, or

- To seek the allowable extent to mitigate flood damage, providing countermeasures to absorb such adverse influence.

(2) Higher Delta in Lower Central Plain

In addition to the condition in the upper central plain and Nakhon Sawan Area, the following points are considered:

- In the area, the change of land use is progressing, so that flood damage tends to increase.

- Since the agricultural area plays an important role as natural retarding basin, it is necessary to consider preservation of the effect.

- Since paddy fields are widely inundated and suffering from flood damage, it is necessary to consider mitigation of flood damage in paddy fields.

Eventually, the issues for flood mitigation in these areas are emphasized with the following points:

- To control and guide the change of land use, so that flood damage will not increase and the effect of the natural retarding basin will be maintained.

- To seek measures to mitigate flood damage to agricultural areas.

- To seek measures to mitigate flood damage in paddy fields, maintaining the natural retarding effect.

(2) Lower Delta in Lower Central Plain

In the area, the following points are considered:

- In the area, change of land use especially urbanization is severe, so that flood damage tends to increase and natural retarding effect will decrease.
- Since the protection works for Pathum Thani and Nonthaburi would bring about severe adverse influence to Bangkok, it is necessary to consider measures to cope with the adverse influence.
- Since paddy fields are widely inundated and suffering from flood damage, it is necessary to consider mitigation of flood damage in the paddy fields.

Eventually, the issues for flood mitigation in these areas are emphasized with the following points:

- To control and guide the change of land use, so that flood damage will not increase and the area with natural retarding effect will also be maintained.
- To seek measures to cope with the adverse influence.
- To seek measures to mitigate flood damage in paddy fields, preserving the natural retarding effect.

4.4 Strategy for Formulation of Master Plan

4.4.1 Procedure for Formulation of Master Plan

The Master Plan is composed of several conceivable measures, which are classified into structural and nonstructural measures, as shown in Fig. 4.4.1.

In principle, alternative cases to select the optimum measure(s) are set by a combination of these conceivable measures. However, the number of alternative cases by the combination of applicable measures is so large that it may not be practicable to examine all of them. To facilitate the selection of optimum measure(s) in this study, the following steps are taken:

(1) First Step: Preliminary Selection of Applicable Measures

The applicability and necessity of measures among the conceivable ones are preliminary examined considering their features. Through the preliminary examination, the measures to be included in the Master Plan are identified. Also, the measures that need a further study to evaluate effectiveness in a quantitative manner are identified.

(2) Second Step: Evaluation of Measures based on the Simulation Model

The effectiveness is evaluated based on the simulation model for measures identified with the necessity of further study in the first step. The necessity of further study for optimization of measures in combination with other measures is also identified, considering effectiveness of the measures.

(3) Third Step: Selection of Measures in combination with Other Measures

The optimization of measures in combination with other measures is made for those identified with the necessity of further study. For the optimization, the cost and effectiveness of each combination are roughly calculated to identify the economic advantage.

Through the economic comparison among the measures mentioned above, the optimum combination is selected. The Master Plan is composed of the optimum combination together with the measures identified to be applicable in the first step.

4.4.2 Selection of Optimum Case, Preliminary Design and Cost Estimate

(1) Formulation of the Master Plan

The Master Plan is formulated to consist of the optimum combination of measures including measures whose applicability have been identified.

(2) Preliminary Design of Proposed Structural Measures

For the preliminary design of structural measures proposed to mitigate the flood damage, the specific items such as location and dimensions are determined.

(3) Cost Estimate

Project cost is estimated on a preliminary level by calculating construction cost, operation/maintenance cost and land acquisition cost for each structure, applying the exchange rate as of December 1998; namely, $1.00 = ¥115.7 = 36.5 Bahts.

(4) Implementation Plan

Among the measures selected, the priority for implementation is examined considering cost-effectiveness, easy implementation, social and environmental impacts, and others. A phased implementation plan is prepared for the structural measures based on their priority, organizing the most preferable work schedule for all the structures proposed in the study area

4.4.3 Evaluation of the Master Plan

The proposed Master Plan is evaluated in terms of technical soundness, economic viability, social acceptability and environmental sustainability. Among them, technical soundness and social acceptability are evaluated through the confirmation of previous practices on the application of structural measures. The economic viability and environmental sustainability are examined in the following manner.

(1) Economic Viability

The economic viability of the Master Plan is examined in terms of internal rate of return (IRR), benefit-cost ratio (B/C) and net present value (NPV), comparing the economic project cost and annual average benefit which may accrue in accordance with the expected cost-benefit flow in the project life. The benefit and cost are obtained based on the following procedure.

(a) Annual Benefit

Major flood control benefit is defined as the reduction of potential flood damage attributed to the provision of structural measures. The reduction is obtained as the difference between the estimated flood damage under the with- and the without-the-project situations.

The annual average benefit or potential flood damage is calculated by square units (5km x 5km), applying the inundation depth obtained from the flood inundation analysis. Such benefit or flood damage is estimated at the development stage in the target completion year 2018.

(b) Economic Cost

For the economic evaluation, the aforementioned project cost is converted to economic cost, which is a nominal figure reflecting the true economic value of goods and services involved. For the purpose, transfer items such as taxes and duties imposed on construction materials and equipment, including government subsidy and contractor's profit, are excluded from the elements of financial cost.

(2) Environmental Sustainability

The optimum measure among all conceivable measures is selected. During the master plan study stage, IEE (Initial Environmental Examination) is conducted to assess the selected alternatives from the environmental point of view.

(a) Parameters included in the IEE

In April 1979, the National Environmental Board issued a manual, Guidelines for Preparation of Environmental Impact Evaluations, which also mentions IEE. According to the Guidelines, parameters for the IEE should be the same as in a full-scale environmental study (EIA). However, the Guidelines provide parameters only for the following project types that require EIA:

"Agro industries, Coastal zone development, Dams and reservoirs, Dredging and filling, Highways, Housing projects, Human settlements, Industrial estates, Industries, Institutions, Mining, Nuclear power, Offshore mining, Oil pipelines, Ports and harbors, Rapid transit projects, Thermal power, and Land drainage."

The alternative measures proposed by this Study may not be included in these project types and, therefore, may not be obligated by law to undergo the official EIA process. However, the environmental impact of measures adopted in this Study may not be negligibly small; therefore, it is necessary to abide by the Guidelines.

Since the Guidelines do not stipulate any suitable set of parameters for proposed flood control measures, a customized set of parameters, as shown in Table 4.4.1, is used for the IEE of each alternative measure.

(b) Extent of the Study for IEE

The Guidelines state that the objective of IEE is "to reach a decision on whether such evaluations (detailed evaluation of each environmental parameter) are needed." However, it is also stipulated that "if the conclusion of the study is that an EIS (detailed evaluation) is not needed, IEE will serve as EIS." Therefore, it is important that IEE is arranged in a manner to satisfy this purpose.

(c) Evaluation in the IEE Stage

In principle, the IEE will cover similar contents as the EIA except that the evaluation is done based on readily obtained information. It has four major components as follows:

- Description of proposed measures.
- Discussion of probable environmental effects caused by proposed measures according to the parameters shown in the above table together with the references used for the evaluation.
- Tabulation of impacts found in initial evaluations as the summary.
- Conclusions including comments on the necessity of further study.

CHAPTER 5. STUDY ON APPLICABLE MEASURES

In accordance with the strategy discussed in Section 4.4, the applicability of conceivable structural and nonstructural measures were preliminary examined, as the first step, assuming that these measures are solely applied. Then, the effectiveness of some of the measures was evaluated in a quantitative manner, as the second step, based on the simulation model. Herein, the discussion is made on these steps and the applicability of measures is preliminarily identified.

5.1 Preliminary Selection of Structural Measures

The following are the applicable structural measures (refer to Vol. 3, Supporting Report, Sector VI, Flood Mitigation Plan):

- River Improvement
- Flood Diversion Channel
- Tidal Barrage with Pump
- Retarding Basin

5.1.1 River Improvement

The applicability of river improvement is broadly examined, dividing the objective stretch, i.e., from the river mouth of the Chao Phraya River to the Yom and Nan rivers; from the river mouth to Nakhon Sawan, and from Nakhon Sawan to the Yom and Nan rivers.

Considering the present river flow capacity of these stretches and the influence to the downstream when the upstream stretch is improved, the applicability of river improvement is described as follows:

(1). River Improvement of Upstream from Chainat

The river improvement will result in the increase of flood discharge in the downstream as an adverse influence. As discussed later, the river improvement in the downstream has some restrictions at the Bangkok metropolitan area, so that it is necessary to minimize such an adverse influence to the downstream. In this connection, the river improvement in the upstream is applicable only within the above situation.

(2) River Improvement of Downstream from Chainat to the River Mouth

The river improvement in this stretch is applicable under the restriction that it will not cause severe adverse influence to the down stream.

(3) Further Study Cases for Optimization

Although river improvement has some restrictions, it is still one of the essential measures to mitigate flood damage. In this connection, further study is necessary for optimization of the scale of river improvement in combination with other measures. Several cases of flood discharge of between 2-year and 25-year return periods are thus further examined to optimize the scale of river improvement in both upstream and downstream.

5.1.2 Flood Diversion Channel

(1) Selection of Suitable Route

The flood diversion channel is considered as a measure to mitigate flood damage in the downstream from Nakhon Sawan to the river mouth. There are ten (10) conceivable routes and the suitable route is selected through the rough comparison study related to cost and benefit such as number of house relocation, construction cost, and number of expected beneficiaries (refer to Fig. 5.1.1).

Summary of Cost of Diversion Channel Routes

Case	Diversion Route	Cost (in million Baht)		
		Q=500m³/s	Q=1,000m³/s	Q=1,000m³/s
1	Tha Chin River Diversion (Mouth to 319 km)	87,165	52,689	22,325
2	Chainat-Pasak-Rahpipat-Sea Diversion (Mouth to 260 km)	87,505	60,016	33,115
3	Chainat-Pasak-Rahpipat-Ban Pakong Diversion (Mouth to 362 km)	130,546	87,326	46,996
4	Pasak-Rahpipat-Sea Diversion (Mouth to 127 km)	42,728	30,051	18,126
5	Pasak-Rahpipat-Ban Pakong Diversion (Mouth to 229 km)	86,573	58,684	33,725
6	Ayuthaya-West Bank-Sea Diversion (Mouth to 105 km)	74,353	52,339	30,336
7	Ayuthaya-West Bank–Tha Chin Diversion (Mouth to 160 km)	81,417	53,441	34,646
8	Ayuthaya-East Bank-Sea Diversion (Mouth to 96 km)	59,060	35,000	23,476
9	Chao Phraya II Diversion (Mouth to 57 km)	77,460	53,961	30,639
10	Greenbelt Diversion (Mouth to 78 km)	95,247	66,954	38,559

Number of House Relocation

Case	Diversion Route	No. of House Relocation		
		Q=500m³/s	Q=1,000m³/s	Q=1,500m³/s
1	Tha Chin River Diversion (Mouth to 319 km)	6,500	4,000	1,500
2	Chainat-Pasak-Rahpipat-Sea Diversion (Mouth to 260 km)	2,400	2,200	1,700
3	Chainat-Pasak-Rahpipat-Ban Pakong Diversion (Mouth to 362 km)	3,000	2,800	2,000
4	Pasak-Rahpipat-Sea Diversion (Mouth to 127 km)	1,400	1,200	1,000
5	Pasak-Rahpipat-Ban Pakong Diversion (Mouth to 229 km)	2,000	1,900	1,300
6	Ayutaya-West Bank-Sea Diversion (Mouth to 105 km)	3,200	2,900	2,200
7	Ayuthaya-West Bank–Tha Chin Diversion (Mouth to 160 km)	3,600	2,500	1,500
8	Ayuthaya-East Bank-Sea Diversion (Mouth to 96 km)	1,600	1,500	1,400
9	Chao Phraya II Diversion (Mouth to 57 km)	11,000	8,000	5,700
10	Greenbelt Diversion (Mouth to 78 km)	2,500	2,300	2,300

From the comparison results above, it seems that one of the optimum routes of the diversion channel is Case 4, Pasak-Paphipat-Sea Route. The applicability of the Chainat-Pasak-Raphipat-Sea Route and the Ayuthaya-East Bank-Sea Route is also worthy of examination. (Refer to Fig. 5.1.2.)

(2) Necessity of Further Study for Optimization

As mentioned above, the flood diversion channel is one of the applicable structural measures. For the optimization of route and scale of the three routes of diversion channel, Pasak-Raphipat-Sea, Chai Nat-Pasak-Raphipat-Sea and Ayuthaya-East Bank-Sea, it is necessary to conduct a further study on their combination with other measures after confirmation of the effectiveness by simulation.

5.1.3 Tidal Barrage with Pump

The construction of a tidal barrage is proposed and the effectiveness was examined in the previous study named "Chao Phraya Flood Management Review" in 1996. As the result of hydraulic simulation, the negative reverse flow, which emerges in the range of 1,000 m³/s at maximum when the tide rises up, is cut off. The discharge capacity of the Chao Phraya River is thus increased from 3,000 m³/s to 3,250 m³/s by operation of the barrage, considering the water level reference point at Pakret.

In this connection, the effectiveness of a tidal barrage is further examined in combination with the drainage pump that can lower the water level through the constant drainage of flood discharge. As a result, it is concluded that this alternative measure should not be implemented immediately from the economic and technical points of view, and thus, this measure is not taken into consideration for further study on alternatives. However, it should also be noted that there is a possibility for this measure to be considered in combination with other measures in the future.

5.1.4 Retarding Basin

As discussed in the strategy for the Master Plan, the basic concept of flood mitigation is preservation of the present natural retarding effect of most of the agricultural areas in flood time. To preserve the present natural retarding effect, it is essential to apply nonstructural measures, especially, control and guidance of land use.

On the other hand, providing a retarding basin, in general, means introducing some structures such as embankment, water intake facilities and drainage facilities to let a certain area or areas have a retarding function. To apply such an area as a retarding basin, it is necessary to procure such an area or provide compensation for utilization of the area.

In this connection, the study on the retarding basin is emphasized with the following points:

- The possibility of enhancing the present natural retarding function through the introduction of additional facilities.
- The possibility of applying areas such as swampy areas and ponds as retarding basins.

(1) Possibility to enhance the present natural retarding function

As the target area to examine the possibility, paddy fields widely spread in the flood prone area. However, due to the topographic disadvantage, paddy fields would not be effective as retarding basin by enhancing the retarding function. Also, a huge compensation cost as well as construction cost for necessary facilities is required, which is confirmed through the cost comparison for the hydrological effectiveness (refer to Vol. 3, Supporting Report, Flood Mitigation Plan). Thus, it is not recommendable to enhance the present natural retarding function, but to provide flood mitigation measures in paddy fields (refer to Subsection 5.3.3).

(2) Possibility to apply areas such as swampy areas as retarding basin

(a) Sites Conceivable as Retarding Basin

In the Chao Phraya River Basin, the following areas are conceived as sites for retarding basin, judging from the topographic and runoff conditions:

- Existing Lake and Large Swamp
- Ponds Along the Old River Course

(b) Evaluation of Applicability of Retarding Basin

As the result of rough evaluation of the effect, the possible retarding basins are as given in the following table:

Evaluation for Possible Retarding Basins

Item	Sub-item	Possible Area for Retarding Basin (km^2)
Existing Lake and Large Swamp	Bung Boraphet Lake	219.8
Pond along Old River Course	-	Not Applicable

In this connection, the applicability of Bung Boraphet is considered as follows:

- Bung Boraphet Lake is currently used as a large-scale fish farm under the administration of the Fishery Department. A social problem will ensue for people engaged in the fish farm when the lake is used as a retarding basin.
- The area surrounding the lake is a precious habitat for wildlife as designated in the United Nations Convention for Wetlands (Ramsar Convention). Therefore, to take any artificial action for utilization of the lake as a retarding basin will also cause a significant environmental problem.

Thus, it is not advisable to apply the lake as an artificial retarding basin, because the lake is envisioned to function as a natural retarding basin.

(3) Necessity of further study for optimization

Through the above discussion, a further study on the retarding basin was not undertaken in the Master Plan. However, a study was done for the preservation of natural retarding effect by nonstructural measures as well as for flood mitigation measures in the natural retarding basin by structural measures.

5.2 Preliminary Selection of Nonstructural Measures

Nonstructural measures are essential to mitigate flood damage, or flood risk. The applicability of the following six (6) nonstructural measures is thus herein discussed (refer to Appendix-A in this report):

(1) Modification of Reservoir Operation Rule

(2) Strengthening of Control and Guidance

- Land Use Control and Guidance on Development
- Groundwater Extraction Control

(3) Flood Disaster Response

- Flood Forecasting and Warning System
- Flood Fighting Activity
- Disaster Recovery

(4) Financial Response

- Subsidy and Taxation
- Flood Insurance

(5) Watershed Management

(6) Institution and Organization

5.2.1 Modification of Reservoir Operation Rule

The potential use of both existing and planned dams for flood control is herein examined. Among 45 dams the operation rules of five (5) dams were reviewed. These dams are the Bhumibol, Sirikit, Kwae Noi, Kaeng Sua Ten and Pasak, with locations as shown in Fig. 5.2.1.

Modification of operation rule is examined in the following procedure:

(1) Setting up Operation Period for Flood Mitigation

The period of reservoir operation is decided as below, expecting the effectiveness for flood mitigation at the reference points:

- Sirikit Dam: July 1st to November 30th
- Kwae Noi Dam: August 1st to October 15th
- Kaeng Sua Ten Dam: August 1st to September 15th
- Pasak Dam: September 1st to October 15th

(2) Setup of Reservoir Capacity for Flood Mitigation

Three (3) cases of reservoir capacity are proposed as follows:

- Case-1: In this case an ideal capacity for flood mitigation without any loss to irrigation and power generation is proposed.
- Case-2: This case accepts a loss to irrigation and power generation to some extent. The reservoir capacity is set as the medium case between Case-1 and Case-3.
- Case-3: This case is a case for the maximum development. The active storage volume is fully used for flood mitigation.

The proposed reservoir capacities for flood mitigation are summarized as follows:

Reservoir Capacity for Flood Mitigation (million m^3)

Dam	Case-1	Case-2	Case-3
Bhumibol	2,960	4,000	5,500
Sirikit	2,810	4,600	6,500
Kwae Noi	597	665	733
Kaeng Sua Ten	575	850	1,125
Pasak	473	605	772
Total	7,415	10,720	14,630

(3) Setup of Rule Curve for Reservoir Operation

After determining the operation period and flood mitigation capacities, operation curves are drawn, as shown in Figs. 5.2.2 and 5.2.3.

(4) Costs for Modification of Reservoir Operation Rule

The modification of reservoir operation rule will affect the original functions of the reservoir, through the reduction of water supply for irrigation and hydropower generation. Therefore, it is necessary to compensate for such loss, and the compensation cost is regarded as the cost for modification of reservoir operation rule.

The total annual compensation costs are summarized in the following table.

Average Annual Compensation Cost (in million Baht)

Item / Case	Total			Bhumibol			Sirikit			Kwae Noi			Pasak			Kaeng Sua Ten		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Average annual compensating cost	-	10	234	-	-	41	-	-	148	-	5	12	-	1	6	-	4	27

(5) Other Related Study

An additional evaluation study for cases where the Kwae Noi and Kaeng Sua Ten dams or the Kok-Ing-Nan water diversion project are excluded from the future condition is carried out in order to know how much these projects would contribute to flood mitigation. The results of examination are summarized as follows:

(a) Without Kwae Noi and Kaeng Sua Ten Dam

The flood mitigation effects of both dams mainly appear in the Upper Central Plain. At this area, the Kaeng Sua Ten and Kwae Noi dams could decrease inundation volume by 777 and 110 million m^3, respectively, in the 1995 flood. However, their contribution to the flood mitigation in the Chao Phraya delta is so small that they can reduce flood inundation by only 2 million m^3.

(b) Without Kok-Ing-Nan Water Diversion Project

The Kok-Ing-Nan Project is expected to convey about 2 billion m^3 of water into the Sirikit Dam Reservoir from the Mekhong River Basin in the rainy season. Without the project, the total inflow volume to the reservoir could be much smaller. This smaller inflow volume allows the reservoir capacity for flood mitigation to decrease. According to the trial calculation, the Case 3 capacity of 6,500 million m^3 could be decreased to 4,500 million m^3.

(6) Necessity of Further Study for Optimization

Modification of the reservoir operation rule is one of the essential nonstructural measures to expect the effectiveness of flood mitigation in a quantitative manner. Therefore, it is necessary to confirm the effectiveness of each case by flood simulation.

5.2.2 Strengthening of Control and Guidance

For the Chao Phraya River Basin, the following considerations are taken in terms of management strengthening: control of land use and guidance on land development, and control of groundwater extraction.

(1) Land Use Control and Guidance on Land Development

In the Chao Phraya River Basin, land development is being promoted in accordance with the economic growth. Such land development is sometimes conducted in a disorderly manner such as the urbanization of flood prone area and the conversion of paddy from low yield variety to high yield variety in low-lying land resulting in the increase of flood damage potential.

Land development in a flood prone area will result in the decrease of natural retarding function during floods. Thus, it is necessary to control land use and provide guidance on land development to minimize the increase of flood damage potential and the decrease of flood retarding function.

(2) Control of Excessive Groundwater Extraction

In Bangkok and vicinity in the Chao Phraya River Basin, land subsidence due to excessive groundwater extraction is one of the major issues related to flood control. The land subsidence is directly connected to the decrease of dike height resulting in the decline of safety level against floods of the Chao Phraya River.

In the previous study results, it is mentioned that the rate of land subsidence along the Chao Phraya River in Bangkok and vicinity will gradually come to a constant level of 2 cm/year. Assuming that the rate of 2 cm/year will continue up to the target year 2018, the flood barrier being constructed by the BMA with a crest elevation of EL. 3.00 m above MSL, for example, has the possibility to settle down to the level of EL. 2.60 m, and this implies a corresponding reduction in the river discharge capacity. Thus, the control of excessive groundwater extraction is strongly recommended so as not to lower the safety level of dikes against floods of the Chao Phraya River.

(3) Necessity of Further Study

Control of land use and guidance on land development and control of groundwater extraction are also essential measures to mitigate flood damage. However, the effectiveness of these measures is sometimes uncertain, because the realization of these measures will rely on public participation and efforts by agencies concerned. Considering such conditions, the necessity of further study is to be examined after the confirmation of effectiveness by a simulation model.

5.2.3 Flood Disaster Response

(1) Flood Forecasting and Warning System

(a) Flood Forecasting System in the Chao Phraya River Basin

The flood forecasting system is one of the solutions to mitigate the flooding problem. The system would also contribute to further flood mitigation even after the comprehensive flood mitigation plan is provided. In case of the Chao Phraya River Basin, it is considered to preserve the natural retarding effect in the lower delta where flood damage in paddy fields is expected. To minimize the damage in paddy fields, it is necessary to distribute the inundation water. For that purpose, strengthening of the flood forecasting system, including monitoring, is essential.

In the currently practiced flood forecasting system, enough forecasting time is assured because of the longer traveling time of flood from upstream to downstream. However, as for the accuracy of forecasting results, there may be some room for improvement.

To enhance the accuracy of forecasting results and to disseminate flood prediction results more often, this Study recommends improvement of the system in the following aspects: (1) hydrological observation network; (2) data transmission system; (3) data management system; (4) data dissemination system; and (5) improvement of flood forecasting model.

(b) Flood Warning System

At present, flood warning is issued on different levels by several agencies. This Study recommends that the warning system be provided in a more systematic way through the preparation of guidelines for warning, including such items as objective, role, responsibility and restriction of the warning system, and agency responsible for the issuance of warning.

(2) Flood Fighting

In the Chao Phraya River Basin, flood fighting is undertaken by several agencies to protect their respective management areas of responsibility. Through these activities, it is in general evaluated that the present system of flood fighting is relatively well developed, organized and funded by the concerned agencies such as RID, BMA and the Local Government.

The following recommendations are made towards further improvement of flood fighting activities as a result of the comparison with the practices in foreign countries:

- To give primary responsibility for flood fighting to local administrative organizations such as mubans and tambons; and
- To involve local people more in flood fighting operations.

(3) Flood Disaster Recovery

Flood disaster is sometimes very severe even after direct flood damage has almost settled down, so that recovery works in a proper way is essential in the case of the Chao Phraya River Basin. This Study recommends that the following actions should be taken to implement prompt recovery works: (1) assurance of enough funds for recovery works; and, (2) promotion of advertisement and education on the necessity of prompt action for recovery.

(4) Necessity of Further Study

The above three nonstructural measures are essential to mitigate flood damage and they are applicable to the Master Plan. However, their effectiveness cannot be evaluated in a quantitative manner, so that their features are discussed only on the master plan study level. No further study has been undertaken in this Study for these three measures.

5.2.4 Financial Response

(1) Subsidy

For stabilizing the life of people engaged in agriculture, the introduction of a support system for damages due to abnormal weather condition is considered. In the current support system for damages, farmers can be benefited in the form of compensation and reduction of interest on loans within a certain range. However, the level of compensation seems to be less than enough to cover damages, especially flood damage. Since the agricultural areas are expected to retard floodwaters and, therefore, the flood damage in the area will still occur in the future, it is essential to provide some kind of support to people living in the area.

Thus, this Study recommends the strengthening of the current support system with measures consisting of compensation for flood damage and reduction of interest on loans.

(2) Flood Insurance

It seems to be inappropriate to support people frequently suffering from flood damage through subsidies because of financial constraint. To cope with the inadequate support system, the strengthening of the current flood insurance is considered.

Under the circumstances, in the 8th Agriculture Development Plan from 1997 to 2001 approved at the Cabinet Meeting in November 1996, it was proposed that the Government should take actions on strengthening agricultural insurance. This Study proposes strengthening and improving the existing agricultural insurance system in the context of flood insurance.

(3) Necessity of Further Study

As well as the three measures in flood disaster response, these two nonstructural measures are also essential to mitigate flood damage and they are applicable to the Master Plan. However, their effectiveness cannot be evaluated in a quantitative manner, so that the features of these measures are discussed only in the master plan study level. No further study is made for these two measures in this Study.

5.2.5 Watershed Management

The forest area was reduced from 166,000 km^2 in 1942 to 106,000 km^2 in 1983, and to 92,000 km^2 in 1995. Such deforestation influences flood occurrence through the reduction of water conservation effect, resulting in the increase of peak flood discharge as well as decrease of low water discharge. Although the influences on flood due to the reduction of forest area are hardly evaluated in a quantitative manner, watershed management, as generally understood, is essential so as not to increase the flood peak discharge and maintain the current low water discharge.

Fortunately, deforestation in the recent 10 years shows a decrease of about 4% (26% of the territory is covered with forest in 1993), due to the strict government control after the Cabinet Resolution of December 3, 1985 which aims to keep 40% as forest area through reforestation.

In this connection, this Study recommends that agencies concerned in watershed management exert further efforts through restrictions on logging in forest areas and reforestation in order not to increase flood peak discharge, but to increase the recharging capacity of the watershed for flood mitigation and water resource conservation, respectively.

Needless to say, the measure is applicable to the Master Plan. However, further study on watershed management is not made in this Study, because of the difficulty of evaluating effectiveness in a quantitative manner.

5.2.6 Institution and Organization

In Thailand, most of the necessary institutional arrangements have been established together with the setting up of the necessary organization. In principle, there is no conflict in the designation of the agencies responsible for operating and managing flood mitigation measures, as long as these measures can be managed solely in accordance with their purpose. However, to enhance the flood mitigation function of these measures, coordination of their operation and management among the agencies concerned is necessary.

In Thailand, there is neither a single agency nor a coordination agency administering river and/or flood basin-widely, and thus such coordination is in general not undertaken. A coordinating committee among the agencies concerned has thus become necessary so that the Government set up the National Water Resource Committee in 1989. Further recognizing the current problems on water related situations such as shortage of water during dry season and flooding during rainy season, preparation is ongoing on the Water Resources Act, which stipulates the establishment of a River Basin Committee as the organization to handle the problems.

It sometimes take a long time to set up a new organization together with the necessary law to designate the role of the organization. However, resolution of most of the present deficiencies on the realization of a comprehensive flood control is expected through the Water Resources Act.

Thus, this Study recommends that the Water Resources Act should be pursued and promulgated as early as possible.

Considering the above situation, it is not necessary to undertake a further study on institution and organization in this Master Plan study.

5.3 Evaluation of Effectiveness of Measures based on the Simulation Model

In the preceding sections, the applicability of both structural and nonstructural measures was preliminary examined. The effectiveness of measures is herein evaluated in a quantitative manner based on the simulation model.

5.3.1 Evaluation of Influence of Future Development

As mentioned in Subsection 4.2.3, Expected Future Basin Condition, the Chao Phraya River Basin will have several development projects which will influence the flood water behavior. As the first step to evaluate the effectiveness of flood mitigation measures, the the following influences of future development are evaluated by the flood simulation:

- Influence of urban development through the provision of ring levee together with drainage pumps.
- Influence of change of agricultural cultivation in combination with urban development.
- Influence of dam construction in combination with urban development and change of agricultural cultivation.
- Influence of loop-cut in combination with urban development, change of agricultural cultivation and dam construction.

The 1995 flood was applied to the simulation, and the results are summarized in Table 4.2.3.

(1) Influence of Urban Development with Ring Levee and Pump

The urban area is expected to develop in accordance with the development plan of DTCP, and the protection works for the future urban areas will be provided by PWD in a manner of ring levee together with drainage pumps.

The influence of future development will be very severe, because it will result in the increase of water level at Samsen in Bangkok from 2.32 m MSL at present to 2.80 m MSL after the urban development in the 1995 flood situation. Thus, it is desirable to minimize the increase of water level through the preservation of retarding function when the flood prone area is developed or urbanized.

(2) Influence of Urban Development and Change of Agricultural Cultivation

In parallel with urban development, the change of agricultural cultivation has also been promoted mainly from paddy to fruit tree in the flood prone area of about 2,000 km^2. Although the area where the change is predicted is hardly identified, it is assumed that the change is expected in areas adjacent to the current fruit tree cultivation areas.

The influence of change of agricultural cultivation is not large compared with that of urbanization. The change of agricultural cultivation will lead to the increase of water level of only 1 cm at Samsen in the 1995 flood situation, while the urbanization will raise the water level by 48 cm.

(3) Influence by Large Scale Development of Agricultural Area in Combination with Urban Development

In the above Case (2), it is assumed that the change of agricultural cultivation from paddy to fruit tree will be gradually promoted in the area adjacent to the existing fruit tree area. A extreme case of agricultural development was also examined by the simulation model assuming that 2,700 km^2 of the deep flood inundation in 1995 near Ayuthaya where floating rice and deep water rice is mainly cultivated is converted to fruit tree areas through land reclamation, as shown in Fig. 5.3.1.

The influence of such extreme development is relatively large and will result in the additional increase of water level of 81 cm at Samsen from the water level under the urban development condition.

(4) Influence of Land Subsidence in Combination with Urban Development and Change of Agricultural Cultivation

In Bangkok metropolitan and adjacent areas, land subsidence is still going on. Through the simulation model, the influence of land subsidence to the inundation condition was calculated.

The water level in Bangkok will lower slightly as the influence of land subsidence while total inundation volume will increase in a wide range, resulting in the increase of flood damage. This is because the inundation water spilling over the river channel will hardly return to the river channel due to increase of difference between water level in river channel and the ground level.

(5) Influence of Construction of Dam in Combination with Urban Development, Change of Agricultural Cultivation and Land Subsidence

As discussed before, there are three (3) dams planned for construction within the target year. Although the primary purpose of these dams is irrigation, they will, in general, bring about favorable influence to flood mitigation. Furthermore, the effect of modification of reservoir operation of the Sirikit Dam is included, which can be attained by the newly installed discharge facilities. The influence is evaluated in combination with the other factors such as urban development and change of agricultural cultivation.

The construction of planned dams has an effect on the decrease of water discharge of about 490 m^3/s at Nakhon Sawan, finally decreasing the water level at Samsen by 4 cm, although the influence at Ayuthaya is as small as 10 m^3/s. This is because the influence is attenuated by the spillage from the river channel between Nakhon Sawan and Ayuthaya. For Bangkok, the construction of Pasak Dam has a relatively large influence on flood mitigation, which is identified from the decrease of flood discharge of about 150 m^3/s at Bang Sai.

(6) Influence of Loop Cut in Combination with Construction of Dam, Urban Development, Change of Agricultural Cultivation and Land Subsidence

As discussed before, BMA has a river channel improvement project in a manner of loop cut at Bangkok Port. The primary purpose of the project is to decrease the water level at Bangkok by increasing the flow capacity of the Chao Phraya River channel. Therefore, the project has a limited influence; i.e., only to the downstream of the Chao Phraya River. The influence is evaluated in combination with the other factors: construction of three dams, urban development and change of agricultural cultivation.

(7) Evaluation of the Influence of Future Development

(a) Evaluation based on the 1995 Flood

As gleaned from the discussion above, future development including all factors will finally result in the decrease of flood discharge by about 500 m^3/s at Nakhon Sawan and the water level rise of 25 to 30 cm in Bangkok based on the conditions of the 1995 flood. However, this will not bring about the increase of inundation at flood prone areas including the Bangkok metropolitan area. The decrease of inundation volume is estimated at about 1,600 million m^3, corresponding to a decrease of inundation area of 2,000 km^2 in total.

(b) Evaluation based on 45 Previous Floods

By applying the future development condition to the simulation model, flood simulation for the past 45 years from 1952 to 1996 was made to evaluate the flood condition, which were further used for the frequency analysis of flood discharge and water level at several reference points.

Based on the calculation results, the probable discharges and water levels at the reference points were obtained through frequency analysis. According to the results, the 100-year water level at Samsen in Bangkok increases from 2.40 m to 2.80 m above the mean sea level, as shown in Fig. 4.2.8.

5.3.2 Evaluation of Effectiveness of Nonstructural Measures

(1) Effectiveness of Land Use Control and Guidance

The water level in the Chao Phraya River is increased by urban development and change of cultivation in agricultural area by 49 cm at Samsen in Bangkok in the 1995 flood situation (refer to Table 4.2.3). In this connection, it may be theoretically possible to maintain the present water level by preservation of present land use through land use control and guidance, and, at least, to minimize the increase of water level. Thus, the measures are effective for flood mitigation and should be included in the Master Plan. Sometimes the construction of public facilities, especially embankment of roads and canal dikes in flood prone areas, which does not only result in narrowing down the natural retarding area but also increase damage to the area impounded with flood water, will bring about unfavorable influences to flood damage mitigation. Such influences should be minimized in the context of land use control and guidance.

(2) Effectiveness of Strengthening of Control of Groundwater Extraction

Judging from the influence of land subsidence, flood damage can be mitigated by strengthening the control on groundwater extraction, so that this measure is applied to the Master Plan.

(3) Effectiveness of Modification of Reservoir Operation Rule

As one of the major nonstructural measures whose effectiveness can be evaluated in a quantitative manner, the modification of reservoir operation rule for the Sirikit, Kwae Noi, Kaeng Sua Ten and Pasak dams is considered in three cases, as discussed in Subsection 5.2.1.

(a) Hydrological Effectiveness

Through the simulation model, the effectiveness of modification of reservoir operation rule was evaluated and the simulation results are summarized in Table 5.3.1. Judging from the results, the effectiveness in Case 3, with the flood mitigation capacity of 14,630 million m^3 in total, is the reduction of peak discharge by 290 m^3/s at Nakhon Sawan and the reduction of 1,000 million m^3 of inundation volume in the whole inundation area under the 1995 flood situation. The effectiveness for Bangkok is expected mainly from Pasak Dam, which will reduce the water level from 2.45 m to 2.41 m under the same flooding situation.

(b) Cost Effectiveness

The cost effectiveness in a manner of ratio between flood damage decrease and cost is also given in Table 5.3.1 and Fig. 5.3.2.

(c) Applicability of Modification of Reservoir Operation Rule

The cost effectiveness decreases as the flood control volume increase. However, it seems that the applicable extent of modification of the reservoir operation rule is 14,600 m^3, although it is necessary to identify the suitable scale through a further study in combination with the other measures.

5.3.3 Evaluation of Effectiveness of Structural Measures

(1) River Improvement Works

As discussed in Subsection 5.1.1, river improvement in the upstream may have an adverse influence to the downstream. Considering such an adverse influence, the effectiveness of river Improvement was evaluated in the following procedure:

(a) Simulation Results

The simulation results are summarized in Table 5.3.1. As shown in the figure, the river improvement in the upstream causes an increase of discharge and water level in the downstream. In the case of river improvement from Phatum Thani to the upstream with a project scale of 2-year return period, the flood discharge is 3,400 m^3/s at Nakon Sawan, which almost corresponds to a 6-year return period probable discharge before river improvement in the upstream.

(b) Cost Effectiveness

The cost effectiveness in a manner of ratio between flood damage decrease and cost is also given in Table 5.3.1 and Fig. 5.3.2.

(c) Applicability of River Improvement

In general, based on the ratio between cost and effectiveness, the applicable size of river improvement may be obtained. Practically, however, river improvement shows a negative effectiveness to Bangkok, and thus, river improvement is not applicable due to the adverse influence on the downstream when the measure is solely applied. Consequently, it is necessary to examine the applicability of river improvement in combination with the other measures such as retarding basin and flood diversion channel, to minimize the adverse influence. In this context, the applicable size of river improvement shall be examined further in combination with the other measures.

(d) Typical Case of River Improvement for Reference

To identify the adverse influence of river improvement to the downstream, the following three typical cases of river improvement were examined:

(i) The Case where All Flood Discharges are Confined in the River Channel

The simulation results are shown in Table 5.3.2. As noted from the table, in the 1995 flood situation, the flood discharge of 4,850 m^3/s at Nakhon Sawan swells to 6,420 m^3/s at Bang Sai, resulting in the water level rise at Samsen by 125 cm.

(ii) Case where the Dike of the Whole Channel Stretch is Heightened

In the case of heightening of dike to 20 cm, the flood discharge at Nakhon Sawan is 4,110 m^3/s, which corresponds to a 50-year return period under the future basin condition, and the water level at Samsen rises by 38 cm.

(iii) Case of Heightening of Dike to Protect Bangkok Metropolitan Area

For the protection of Bangkok metropolitan area from a 100-year return period flood, it is necessary to raise the dike height to 40 cm on the average, unless other measures to lower the water level are undertaken. For the heightening of dike to 40 cm, the cost of 310 million baht is required, which is not too much compared to the cost of other measures such as the diversion channel (refer to Table 5.3.3).

(2) Diversion Channel

In Subsection 5.1.1, three (3) alternative routes of diversion channel are proposed: Pasak-Raphipat-Sea, Chainat-Pasak-Raphipat-Sea and Ayuthaya-East Bank-Sea. For these alternative routes, the effectiveness of the diversion channel is evaluated in the following procedure:

(a) Study Cases of Diversion Channel and Simulation Results

Cases of design diversion channel discharge; namely, 500 m^3/s, 1,000 m^3/s and 1,500 m^3/s, were examined for the diversion channel. The simulation results are summarized in Table 5.3.1.

(b) Cost Effectiveness

The cost of diversion under each case is summarized in Table 5.3.1. The cost effectiveness in a manner of ratio between flood damage decrease and cost is also given in Table 5.3.1 and Fig. 5.3.2.

As shown in the figure, the diversion channel of Ayuthaya-East Bank-Sea is the most effective to reduce the water level as well the inundation volume at Bangkok, and the case with 500 m^3/s on the route shows a higher effectiveness.

(c) Applicability of Diversion Channel

In principle, the diversion channel is effective only for the mitigation of flood damage to the downstream area where it is provided. In this connection, the Ayuthaya Diversion Channel is effective for the mitigation of flood damage to Bangkok metropolitan and adjacent areas. Furthermore, the diversion channel is effective as a measure to absorb the adverse influence due to flood mitigation work in the upstream; namely, increase of flood discharge resulting from the protection of agricultural areas in the upstream from Ayuthaya. Thus, through combination with the other measures, it is possible to mitigate flood damage in the other areas.

In the case of Chainat-Pasak-Raphipat-Sea diversion, it is effective for the mitigation of flood damage in the area between Chainat and the river mouth.

(3) Preservation of Retarding Area

As discussed earlier, it is essential to preserve the present retarding area and not to increase the flood damage due to land development in the future. In principle, the present retarding area shall be preserved through land use control and guidance.

On the other hand, the retarding area suffers from damage when a severe flood occurs. In this connection, a study on this matter was undertaken, to mitigate the flood damage in the retarding area.

(a) Rough Evaluation of Retarding Effect of Paddy Field

As identified from the simulation result of the 1995 flood in Table 4.2.3, the present paddy field contributes to mitigation of the peak discharge in the Chao Phraya River (e.g., from 4,600 m^3/s at Nakhon Sawan to 4,150 m^3/s at Bang Sai in the 1995 flood situation).

The area of the paddy field that plays a natural retarding function roughly amounts to 20,000 km^2 in the flood inundation area. Assuming that the maximum water depth stored in the paddy field without inflicting any damage is about 30 cm on an average, the total water volume stored in the inundation area is about 6 billion m^3. With this volume the river discharge could be decreased considerably.

However, the paddy field actually suffers from flood damage when the inundation volume amounts to such level. In the case of the 1995 flood, the total inundation volume amounts to about 16 billion m^3, which roughly corresponds to the total active reservoir capacity of Bhumibol and Sirikit.

(b) Conceivable Mitigation Measures of Flood Damage

As the measures to mitigate flood damage in paddy fields, the following are conceived:

- Distribution of inundation water in paddy field from the area with serious inundation to that with less serious inundation through the distribution system improvement.
- Prompt drainage of inundation water to reduce the inundation volume and water level, and to shorten the duration through drainage system improvement.
- Change of cropping pattern to avoid suffering from flood damage.

(c) Examination of possibility to minimize flood damage through distribution of inundation water

The paddy field of 5,600 km^2 in the Higher Delta of the Lower Central Plain is considered as a probable area for flood water distribution. An ideal relationship between the retarding capacity (inundation water volume) and the flood damage which minimizes the flood damage is made, as presented in Fig. 5.3.3, considering the damage rates of rice varieties in Table 3.4.4. The priority order for the distribution of inundation water is also shown in Fig. 5.3.4.

Actually, flood damage at a certain inundation volume is more than that on the relation, since the inundation causes flood damage at random. Consequently, the relationship shows the least flood damage for the inundation volume in paddy field. According to the figure, the 5,600 km^2 of paddy field can harmlessly accommodate about 2.1 billion m^3.

Table 5.3.4 compares the actual flood damage amounts and the least damage amounts on the ideal relationship for the past 45 years of flood. As noted from the table, it is expected to mitigate the flood damage within a certain range; especially, it is very effective for small-scale floods. On the other hand, the effectiveness for big scale floods like the 1995 flood is very limited, because there are not enough areas to distribute the large amount of inundation water.

The rate of damage mitigation is 30% on an average, although it is necessary for the purpose to provide a guideline for distribution of inundation water and to improve flow control facilities.

The system improvement for floodwater distribution is to be realized through the improvement of irrigation channel and flow control structures.

(d) Prompt Drainage of Inundation Water

In the Chao Phraya Delta, inundation water remains for a long time until the water level in the Chao Phraya River lowers, resulting in a huge flood damage. In this connection, it is considered to reduce the flood damage through the improvement of the drainage system. However, the drainage to the Chao Phraya River in the flood season is substantially difficult, because the water level almost reaches up to the bank height. This study proposes the drainage system improvement to promptly drain the inland water to the sea, by widening and deepening the existing drainage channels or providing new channels if necessary in the east and west bank areas. It is also proposed to install gates at the outlets of the drainage channels to the sea to prevent reverse flow at flood time.

The effectiveness of the drainage system improvement was roughly examined, applying the simulation model to the 1983, 1995 and 1996 floods. The drainage improvement consisting of widening and deepening of present channels and providing new channels if necessary was represented by an additionally assumed drainage channel for the simulation. Several cases of two different channel lengths and three different channel capacities between 75 m^3/s and 300 m^3/s were set up, as shown in Fig. 5.3.5.

Since the simulation model was developed to identify the basin-wide flood condition, there may be some constraints in the accuracy of simulation results. However, according to the results, it can be said that the improvement of drainage system is relatively effective to mitigate inundation volume and duration, so that flood damage could be mitigated. The longer channel can reduce inundation in the upper deep inundation areas such as Nakhon Luang, Phak Hai and Chao Ched Bang Yeehon, while the shorter channel is effective only in the lower areas.

In terms of cost effectiveness expressed by the ratio between the decrease of flood damage and cost, the shorter and smaller channel is advantageous, as shown in Fig. 5.3.6 and Table 5.3.5. Case B-1, which is the minimum development case, with the shorter stretches from the sea to Rangsit Tai for the east bank and from the sea to Phrayabanlue, and the smallest capacity of 75 m^3/s, was applied as an optimum case. The flood damage was mitigated by 26% for the east bank and 30% for the west bank by the drainage system improvement.

(e) Change of Cropping Pattern

To minimize the flood damage in paddy field, it is considered to change the cropping pattern, i.e., change of cultivation schedule and variety.

At present, the flood damage is widely observed at cultivation areas of floating rice, deepwater rice and high yield variety. Judging from the current practice of cultivation, it may difficult to change the cropping pattern from the following reasons:

- The current cultivation schedule of high yield variety is arranged to minimize the flood damage by avoiding the flood season, and the schedule for floating rice and deep water rice is arranged to use enough water in the flood season.
- The varieties currently practiced seems to be the most suitable ones to maximize the production amount; namely, in the habitual inundation areas, flood tolerant varieties are cultivated, while in the other areas, high yield variety is practiced.
- Consequently, it may be difficult to rearrange the cultivation schedule and to change the variety, unless the production amount is sacrificed to avoid the flood damage.

5.4 Applicability of Measures to Each Divided Basin

5.4.1 Upper Central Plain and Nakhon Sawan Area

Considering the major issues in these areas as discussed in Section 4.3, the following measures are practically applicable (refer to Table 5.4.1):

(1) Nonstructural Measures

Among the nonstructure measures, the following are emphasized as the applicable ones:

- Preservation of retarding area by land use control and guidance
- Modification of reservoir operation rule

Needless to say, other nonstructural measures such as flood fighting and subsidy are also applicable in wider sense.

(2) Structural Measures

Substantially, the applicable structural measures in these areas seem to be river improvement only. Since the river improvement, however, brings about an adverse influence, it is necessary to confirm the allowable extent to mitigate flood damage by assuming countermeasures to absorb such an adverse influence in the downstream. The allowable extent is confirmed by further examination.

5.4.2 Higher Delta in Lower Central Plain

Likewise, the following measures are applicable in the area, mainly to mitigate flood damage in agricultural areas:

(1) Nonstructural Measures

Among the nonstructure measures, the following are emphasized as the applicable ones:

- Preservation of retarding area by land use control and guidance

- Change of reservoir operation rule
- Other nonstructural measures such as flood forcasting, flood fighting and subsidy

(2) Structural Measures

The applicable structural measures in the area are as follows:

- River improvement within the allowable extent not to cause adverse influence to the downstream
- Diversion channel within the acceptable scale from the economical, social and environmental viewpoints.
- Mitigation measure of flood damage in paddy fields through the improvement of distribution and drainage systems

For the selection and optimization of these measures, it is necessary to further examine them by applying the simulation model in several cases of combination.

5.4.3 Lower Delta in Lower Central Plain

The following measures are applicable in the area, mainly, to maintain the natural retarding effect and to absorb the adverse influence due to protection works for Pathum Thani and Nonthaburi and also to mitigate flood damage in the agricultural area:

(1) Nonstructural Measures

Among the nonstructure measures, the following are emphasized as the applicable ones:

- Preservation of natural retarding area by land use control and guidance
- Change of reservoir operation rule
- Other nonstructural measures such as flood forcasting, flood fighting and subsidy

(2) Structural Measures

The applicable structural measures in the area are as follows:

- Diversion channel within the acceptable scale from the economical, social and environmental viewpoints.
- Mitigation measure of flood damage in paddy fields through the improvement of distribution and drainage systems

In this area, one of the major issues of flooding is the decrease of safety level at Bangkok from a 100-year to a 10-year return period due to protection works for Pathum Thani and Nonthaburi. To cope with this situation, the following options were also examined aside from the above measures to select the suitable solution:

(1) To maintain the present condition for Pathum Thani and Nontha Buri. (not to implement protection works);

(2) To enhance the safety level only up to the level in which an adverse influence to Bangkok is not expected so much;

(3) To lower the safety level of 100-year return period at Bangkok to a certain level, but to slightly enhance the safety level for Pathum Thani and Nontha Buri;

(4) To narrow down the protection area for Phathum Thani and Nontah Buri in order to minimize the adverse influence;

(5) To heighten the flood barrier to cope with the increase of water level at Bangkok; and

(6) To construct a diversion channel to divert the excess discharge.