JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

ROYAL IRRIGATION DEPARTMENT
KINGDOM OF THAILAND

THE STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN

FINAL REPORT

Vol. 3 : SUPPORTING REPORT(1/2)
(SECTOR I TO VI)

AUGUST 1999

CTI ENGINEERING INTERNATIONAL CO., LTD.
INA CORPORATION

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HYDROLOGY AND FLOOD SIMULATION

SECTOR I: HYDROLOGY AND FLOOD SIMULATION

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1. GENERAL CONDITION

1.1 Climate

The climate of the Chao Phraya River Basin belongs to the tropical monsoon. The annual rainfall is between 1,000 and 1,400 mm and it registers higher in the northeastern region of the basin. According to the rainfall pattern, about 85% of the annual rainfall is registered in the period between April and October (refer to Fig. 1.1.1). Tropical cyclones occur between September and October and may strike the Chao Phraya River Basin. In this case, rainfall continues for a long period of time in a relatively wide area due to climatic disturbances. The peak river discharge is registered in October, the end of the rainy season, and serious flood damage may arise with high tide in this period. Detailed data on the above are compiled in Chapter 2.

The temperature ranges from 27-32°C during the rainy season, while it drops to 20-27°C during the dry season. As for the spatial distribution, the temperature is rather uniform, except in the mountainous region around Chiang Mai where temperature is lower than the other areas by about 5°C (refer to Fig. 1.1.2).

The pan evaporation in the basin is normally at its highest in April and lowest in August to September with an annual total value of about 1,200 mm in the northern mountainous area and 2,000 mm in the inland area around Nakhon Sawan.

1.2 Hydrology

1.2.1 River Flow

The river flow rate shows a seasonal variation with a distinctive imbalance of precipitation between the rainy and dry seasons. The river flow rate starts to increase in April, and reaches its peak in September or October when an intensive precipitation is caused by the tropical cyclonic disturbances.

A stream gauging station at Nakhon Sawan (Sta. C2) is regarded as the The river flow rate shows seasonal variation with the distinctive balance of key station to measure the flood discharge from Ping, Yom and Nan. According to the record at the station, the maximum discharge was observed at 4,800 m^3/s in 1995. The maximum discharges were estimated at about 0.04 $m^3/s/km^2$ in terms of discharge per unit drainage area. Such a rather small discharge per unit drainage area is due to large drainage area with the large retarding effects in the catchment area.

1.2.2 Tide

The tide in the Gulf of Thailand is the mixed tide with a maximum tidal range of about 3.5 m. During the dry season, the seawater reaches Pamok, 160 km upstream from the river mouth. On the other hand, the tidal wave is damped by the river flood flow during the rainy season. For instance at the peak of the 1995 flood tidal effect was barely observed even at Pakkret, 70 km upstream from the river mouth at the peak of the 1995 flood. The tidal wave along the lowest reaches of the Chao Phraya River is shown in Fig. 1.2.1.

Seasonal variation of the sea level is found in the Thai Gulf. The sea level is high from October to January and low from June to August, as shown in Fig. 1.2.2. Such sea level variation is caused by the combination of astronomical and meteorological effects. Unfortunately, the peak river flow mostly coincides with the swelling of the sea in October. The river water level is raised higher by the backwater from the swelled sea. This makes the flooding problems in Bangkok more severe.

1.3. Past Flood Events

As far as people in Thailand could remember, the biggest flood was the 1942 flood. In the flood, the highest water level marked at the Memorial Bridge in Bangkok was 2.27 m MSL, and the entire area of Bangkok City suffered catastrophic damage.

In the last two decades where data and information are more available, years 1978, 1980, 1983, 1995 and 1996 are rated as flood years, among which the 1983 and 1995 floods were most serious. Spatial distribution of 5 months rainfall from July to December and flood inundation areas in these years are given in Figs. 1.3.1 and 1.3.2. In addition, flood discharge hydrographs at major stations are also presented in Fig. 1.3.3.

Past Major Flood

Year	Maximum Discharge at Nakhon Sawan (C.2) (m^3/s)	Maximum Discharge at Chainat (C.13) (m^3/s)	Maximum Water Level at Ayutthaya (S.5) (m^3/s)	Maximum Water Level at Memorial Bridge (C.4) * (m MSL)
1942	n.a.	n.a.	5.15	2.27
1978	3,540	3,770	4.60	1.99
1980	4,350	3,800	4.70	1.92
1983	2,290	3,290	4.54	2.04
1995	4,820	4,550	5.00	2.20
1996	3,100	3,250	4.38	2.12

* : After adjustment (refer to Subsection 2.3.2).

In the last two decades where data and information are more available, years 1978, 1980, 1983, 1995 and 1996 are rated as flood years, among which the 1983 and 1995 floods were most serious. Spatial distribution of 5 months rainfall from July to December and flood inundation areas in these years are given in Figs. 1.3.1 and 1.3.2. In addition, flood discharge hydrographs at major stations are also presented in Fig. 1.3.3. The following are descriptions of the respective flood events listed in the above table.

(1) 1942 Flood

Although the official record was not good in quality and the inundation map was not available, the river flood in 1942 may have caused one of the largest inundations in the Chao Phraya River Basin. The peak water level at Nakhon Sawan (C.2) was estimated to be 1.5 m higher than that recorded in 1995. The water level at Memorial Bridge reached 2.27 m MSL, which was the highest on record in the observation period. Flood control measures in the basin were almost non-existing, and natural habitation on its flood plain was much smaller than at present.

(2) 1978 Flood

Heavy rainfall took place in the Nam, Yom, Ping and Pasak river basins, resulting in swelling of the Chao Phraya River in October 1978. At Nakhon Sawan (C.2) and Chainat (C.13), maximum flood discharges of 3,500 m^3/s and 3,800 m^3/s were recorded, respectively. Floodwaters overtopped the riverbanks at many locations and spread into klongs between Chainat and Ayutthaya, resulting in extensive flood inundation in the adjacent flood plains, as shown in Fig. 1.3.2(1/5). At Ang Thong, the river discharge decreased to 2,900 m^3/s.

Local rainfall also caused inundation along the Chainat-Pasak Canal and Lop Buri River. The damage to Bangkok was reported as a normal one.

(3) 1980 Flood

Inundation took place at several places by local rainfall, spilling and distribution from rivers. Flood discharges of 4,400 and 3,800 m^3/s were observed at Nakhon Sawan and Chainat, respectively. Serious inundation occurred on both sides of the Chao Phraya River between Chainat and Ayutthaya as shown in Fig. 1.3.2(2/5), inflicting tremendous damage to the agricultural areas. In addition, urban areas along the Chao Phraya River including Nakhon Sawan, Chainat, Sing Buri, Ang Thong and Ayutthaya were also exposed to the flood water.

(4) 1983 Flood

The flood in 1983 was well known by its considerable damage, primarily in Bangkok, that lead to the present flood protection facilities. Exceptionally large rainfalls were recorded in the upper reaches of the Chao Phraya River from September to November. The discharge at Chainat reached 3,400 m^3/s in October and November, adding the flood discharge from the Sakae Krang tributary to the 2,300 m^3/s at Nakhon Sawan.

In the lower basin, heavy rainfall in August (434 mm compared to 170 mm on the average) caused local flooding. After that, the total rainfall from September to November was recorded at 405 mm (215 mm on the average), which resulted in the peak water level of 2.04 m at Memorial Bridge in November and extensive inundation in and around Bangkok, as shown in Fig. 1.3.2(3/5).

(5) 1995 Flood

The flood in 1995 caused inundation to an extensive area of nearly 15,000 km^2 from the Nan and Yom upper to lower reaches, as shown in Fig. 1.3.2(4/5). The difference with the other cases of flooding was that Bangkok was practically free from floodwaters, and hence did not suffer much damage in contrast with the heavy damage outside of the city. The infrastructure damage inflicted by the flood was estimated at about 6.4 billion Baht on the assumption that the damage equals the repairing cost for damaged roads, bridges, riparian structures and other infrastructures recorded at the 21 provincial offices in the study area. No statistical data on the damage to houses, crops, industrial activities, etc., was available.

The cause of heavy rainfall was a sequence of tropical storms from the end of July to early September. The August's rainfall in the Nan and Pasak catchment areas was recorded at 450 mm and 345 mm, respectively. The discharge at Nakhon Sawan reached 4,800 m^3/s. A substantial volume of water was released into the floating rice area and some sections of the left bank between Chainat and Ayutthaya were breached, attenuating the flood discharge of 4,500 m^3/s at Chainat into the 2,700 m^3/s at Ang Thong.

The Sirikit Dam's huge reservoir, the water level in which was near the upper rule curve at the end of July due to large quantity of inflow in 1994, was filled with inflow from the upstream catchment in August and September. Then the spillway came into operation in September for the second time following 1972, resulting in local flooding in downstream reaches.

In spite of the spillage, the Sirikit Dam was able to store 3 billion m^3. The Bhumibol Dam Reservoir, the water level in which was below the lower rule curve at the end of July, was free from spillage and stored 4.5 billion m^3 from August to October. Had it not been for these reservoirs' capacities, the peak discharge at Nakhon Sawan could have reached 6,000 m^3/s according to the Flood Review by the World Bank (1996).

(6) 1996 Flood

A big flood occurred in 1996 consecutively with extensive flood inundation by local rainfall, as well as spilling and distribution from the rivers, as shown in Fig. 1.3.2(5/5). The flood magnitude was rather smaller than that of the 1995 flood, but discharge of over 3,000 m^3/s was observed at Nakhon Sawan and Chainat. The two huge dam reservoirs, Bhumipol and Sirikit stored 3.4 and 2.7 billion m^3 of flood water, respectively, without any spillage. Heavy local rainfall in the west of Tha Chin River filled the Krasieo Dam Reservoir and spilled water caused inundation along the river in Supan Buri Province.

The damage to infrastructures was estimated at about 1.5 billion Baht on the same assumption as the 1995 flood.

2. BASIC ANALYSIS

2.1 Rainfall Analysis

2.1.1 Data Availability

Rainfall in the study area is observed mainly by two agencies, RID and MD. In addition to those of RID and MD, some rainfall stations are operated by other agencies such as DEDP and EGAT. In this Study, all the daily rainfall records in the provinces related to the Chao Phraya River Basin which are stored in the digital database of IEC were collected on floppy and magnetic optical disks.

The total number of rainfall stations in the Chao Phraya River Basin is 605, and among them 307 are RID stations and 272, MD stations. Digital daily rainfall data in and after 1952 are available. The older daily data before 1952 which were observed by MD are unreliable and missing according to the officials of MD. An inventory of the rainfall stations is given in Table 2.1.1.

Fig. 2.1.1 shows the location of rainfall stations. The distribution density of the stations is 80 km^2/station in the Chao Phraya Delta downstream of Chao Phraya Dam and 540 km^2/station in the other areas. This higher density in the Chao Phraya Delta where irrigation systems are well developed is because more precise rainfall data is required for water management of the irrigation areas.

2.1.2 Selection of Rainfall Stations

(1) Subbasin Division

In this Study the Chao Phraya Basin is divided into 18 subbasins as shown in Fig. 2.1.2, of which catchment areas are summarized in Table 2.1.2. The subbasins are the minimum units for the runoff calculation using NAM model as described in Section 3.3.

(2) Rainfall Stations Used for Basin Mean Rainfall

Elevation is considered as one of the main factors which influence rainfall. Generally the higher is the elevation, the more rainfall occurs. Therefore, in calculating the basin mean rainfall in each subbasin which is the most important input to the runoff simulation model, the spatial distribution of rainfall stations in mountainous subbasins is carefully examined to estimate the basin mean rainfall as accurately as possible.

33 stations with shorter observation periods and located in excessively crowded areas in the mountainous subbasins, as well as Station Nos. 1, 2 and 7 were disregarded. Consequently, 572 stations from the total 605 stations were selected for the mean basin rainfall calculation. The distribution of the selected rainfall stations is presented in Fig. 2.1.3.

2.1.3 Basin Mean Rainfall

The arithmetic average method was applied to calculate basin mean rainfall of the subbasins for a period of 45 years from 1952 to 1996. The monthly rainfall by subbasin is summarized in Table 2.1.3. Fig. 2.1.4 shows the monthly rainfall for the three years, 1983, 1995 and 1996 which were selected as the targets flood years for the flood simulation model simulation as discussed in Section 3.3. In addition, Fig. 2.1.5 compares the six month rainfall in the flood season (July to December) of the 45 years.

2.1.4 Statistical Analysis

A statistical analysis was carried out to estimate probable rainfall of principal river basins by applying the Gumbel distribution as shown in Fig. 2.1.6. Probable six month rainfall in the flood season (July to December) is given in Table 2.1.4.

2.2 Discharge

2.2.1 Data Availability

RID is the principal agency responsible for water level and discharge measurement in rivers of the Chao Phraya River Basin, and MD, PAT, EGAT and DEDP also operate some water level stations. There are 325 water level and discharge stations which are being operated or used to be operated by RID in the Chao Phraya River Basin.

Among the stations, 46 were used in this Study for the flood simulation and planning of flood mitigation, taking into account their location and observation periods. The records of the 46 stations were extracted from the IEC digital database and the yearly hydrological data books, as shown in Table 2.2.1, and the location map is given in Fig. 2.2.1.

2.2.2 Influence to Discharge and Water Level

River discharge is likely to be much influenced by various developments in the catchment area. Flow regulation by dam reservoirs, flow diversion for irrigation, land use change, river training works such as diking and channel excavation, and land subsidence are considered as major factors of the influence. Among them, the completion of two huge dam reservoirs, Bhumipol and Sirikit has been the most influential in recent years. Observed discharge data of different years were resulted from different basin conditions of the years in line with the progress of the developments. Therefore, special attention must be paid to use raw observed data.

2.2.3 Discharge Hydrograph

In order to know the characteristics of river discharge into the Lower Central Plain which should be given high priority in terms of flood mitigation, synthetic discharge hydrographs of Chainat (C.13) on Chao Phraya River and Rama IV Barrage on Pasak River were drawn for 32 years from 1965 to 1996 as shown in Fig. 2.2.2.

In 1978 and 1995, the synthetic peak discharge went over 5,000 m^3/s. The 1995 flood is the biggest in both peak discharge and volume. The peak discharge of the 1983 flood which caused the severest damage to Bangkok, is comparatively small, exceeding 4,000 m^3/s narrowly.

2.2.4 Runoff Ratio

Runoff ratio which is expressed by "runoff/rainfall" was estimated at principal key stations and the existing two huge dams, Sirikit and Bhumibol, to identify the basic relationship between rainfall and runoff discharge. The results are summarized in Table 2.2.2.

The annual runoff ratio is in a range of 0.13 to 0.45. A higher ratio was found for the Sirikit Dam basin which is comparatively richer in rainfall and lesser developed for irrigation. In the flood season from July to December the runoff ratio was comparatively higher because water loss by evaporation, surface storage, infiltration, etc., is smaller in the wet basin condition.

2.3 Tide

2.3.1 Data Availability

Tide is one of the important factors influencing flooding in the Chao Phraya River Basin. Besides the water level stations of RID, there are 8 tidal gage stations being operated by PAT and the Hydrographic Department of the Royal Thai Navy on the lower stretch of the Chao Phraya River. At the Tha Chin river mouth, the Habour Department is operating a tide station named Samut Sakhon. The location of stations is as shown in Fig. 2.3.1, and data availability is summarized in Table 2.3.1.

2.3.2 Adjustment of Tide Data

Special attention should be paid in using observed tidal data because most of the tidal gages seem to have subsided to some extent in the progress of land subsidence. Table 2.3.2 presents observed annual maximum water levels, and Fig. 2.3.2 shows their long-term trend. It appears that water levels at some of the stations like Pom Phrachul, Pak Nam and Phra Pradaeng have been rising since about 1965 when the land subsidence became significant. Thus some modification is necessary to use the data.

(1) Past Gage Adjustment

The three gages of RID, C.4 (Memorial Bridge), C.12 (Samsen) and C.22 (Pak Kret), and the gage of the Hydrographic Department of the Royal Thai Navy have been lifted a few times to adjust their elevation as follows:

Past Gage Lifting

Date	C.4 (Mem. Br.)	C.12 (Samsen)	C.22 (Pak Kret)	Hydro. Dept.
17 Oct. '80	-	0.11	-	-
Feb. '81	0.198	0.19	0.15	-
Sep. '86	0.080	0.110	-0.028	-
Apr. '92	-	-	-	0.21
Total	0.278 m	0.410 m	0.122 m	0.21 m

(2) First Order Leveling Survey

To know the present elevation of 9 gages on the lower Chao Phraya River, a first order leveling survey was conducted under this Study in June 1997. This survey used bench marks whose elevations were surveyed in "The Study on

Management of Groundwater and Land Subsidence in the Bangkok Metropolitan Area and Its Vicinity, JICA, 1996". The results of the leveling survey are summarized in Table 4.1.9 together with the elevation which is being used currently by their managing organizations.

As shown in the table, a big difference of from 30 to 60 cm is seen between this survey result and those of PAT, while the difference with the RID stations is smaller because of the past gage adjustments.

(2) Adjustment of Observed Water Level

Assuming that land subsidence began in 1965 and had continued at a constant rate for 32 years since then, the past change of the gage elevation was estimated as shown in Fig. 2.3.3. The gage adjustments by RID were also considered in the estimation.

Based on this estimation, adjustment values which should be added to observed data of every year are proposed in Table 2.3.4. Table 2.3.5 gives annual maximum water levels which were obtained by adding the adjustment values to the raw observed data of Table 2.3.3. Fig. 2.3.2 shows the long-term trend of the adjusted annual maximum water levels too. After the adjustment no definite long-term trend is observed, although yearly variation is seen.

(3) Statistical Analysis

Pom Phrachul Station, which is located at the Chao Phraya River Mouth, was used as the downstream boundary of the flood simulation discussed in Section 3.3. In order to know the characteristics of the tidal fluctuation at this station, monthly maximum tide level, monthly mean tide level and monthly minimum tide level for 45 years from 1952 to 1996 were estimated as summarized in Tables 2.3.6, 2.3.7 and 2.3.8, respectively. Moreover, a statistical analysis was carried out to estimate probable maximum tide level in the flood season from October to November by using the adjusted data of Pom Phrachul. The results are given in Fig. 2.3.4 and summarized as follows:

Period	Probable Maximum Tidal Level (m MSL)				
	5-year	10-year	25-year	50-year	100-year
Flood Season (Oct. to Nov.)	1.77	1.84	1.92	1.98	2.04
Year Round (Jan. to Dec.)	1.84	1.91	2.00	2.07	2.13

Data Period : 1940 to 1996

2.4 Flooding Condition

2.4.1 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 have been prepared in this Study.

To cover the flood prone area which is the target area for flood mitigation, six (6) LANDSAT TM photographs were required as shown in Fig. 2.4.1. 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 was composed of photographs taken in September to December. The processed false color images for the 1995 and 1996 floods are given in Fig. 2.4.2.

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. 2.4.3.

(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 following terms were emphasized for the flood inundation and damage survey on flood events in 1983, 1995 and 1996:

(a) Inundation depth
(b) Inundation duration
(c) Time of start of inundation
(d) Location of flooding
(e) Flood cause (by inland water and/or river water)
(f) Economic damage (on properties and income)
(g) Action taken against flood (flood fighting, evacuation and others)
(h) Request and expectation from community (or individuals)

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

The flood inundation maps prepared through a comprehensive examination of these satellite images and the results of the interview survey to RID project offices, local government offices and local people are presented in Figs. 3.3.10(1/3) and (2/3) together with flood maps simulated by the model.

2.4.2 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. 2.4.2. The total area was about 35,000 km^2, and the main land use was paddy but the area includes the Bangkok Metropolitan Area and other major urban areas such as Ayutthaya, 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. 2.4.4 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 seems to have been 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 Section 1.3.

(3) Bottleneck Reaches

The flow capacity analysis in Subsection 3.4.3 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 Ayutthaya.

The river channel of the Yom River is getting narrower from Sichanalai which is 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. 2.4.5 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. A ceiling of 300 m^3/s which is 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 over 1,000 m^3/s, collecting the spilled flood water.

As for the Chao Phraya River, the narrowest reach is from the Khlong Bang Bal to Ayutthaya 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 about two months. Unluckily, the higher sea level season of the Gulf of Thailand often coincides with this long term flood.

Fig. 2.4.6 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 Krat 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. 2.4.7 shows examples.

Fig. 2.4.7(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 is observed that turbid flood water 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. 2.4.7(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. ESTABLISHMENT OF FLOOD SIMULATION MODEL

3.1 Introduction

3.1.1 Objective of Flood Simulation

Objectives of the flood simulation are summarized as follows:

- To clarify the flood inundation mechanism in the Chao Phraya River Basin through modeling;
- To determine basic hydrological parameters for designing countermeasures, such as design discharge and design water level;
- To examine the effectiveness of probable countermeasures; and
- To demonstrate the effectiveness of proposed countermeasures to the public and decision makers.

3.1.2 Target Area for Modeling

The flood simulation model consisting of runoff and inundation analyses covers the entire Chao Phraya River Basin of 163,000 km^2, but the inundation analysis is concentrated on the 35,000 km^2 probable maximum inundation area determined in the previous Section.

3.2 Selection of Software

3.2.1 Requirement of Software

The requirements of the software for flood simulation are summarized as follows:

(1) Accurate Simulation

Accuracy is the principal requirement for the simulation software. The software must give satisfactory simulation results for the study area, incorporating many different factors such as control structures, interaction of river and tide flows, and complex river channel networks.

(2) Estimation of Inundation Depth in Flood Plain

Since the simulation software is required to output flood water level at every site of the flood plain for the damage estimation, the software must have a function of not only flood runoff analysis but also flood inundation analysis.

(3) Visual Presentation by GIS

With the recent progress of computer software and hardware, visual presentation of simulation results was earnestly requested by RID for the purpose of demonstrating the effectiveness of the proposed countermeasures to the public and decision makers. Thus, GIS has become a necessary tool for the planning of flood mitigation, and the flood simulation software should be linked to this new technology.

(4) User-friendly Environment

Transfer of technology to the Thai counterpart personnel is one of the main objectives of the Study. Therefore, the simulation software should be user-friendly for easy use.

3.2.2 Software Alternatives

Two software alternatives for the flood simulation are proposed to fulfill the four requirements mentioned above, based on an investigation on the previous studies. The two options are as tabulated below:

Alternative 1	Combination of Conventional Models (Tank Model, River Routing Model, Flood Plain Model, and One-dimensional Unsteady Flow Model) and GIS
Alternative 2	MIKE11 (HD, NAM, SO, GIS and MIKE View Modules) and GIS

In Alternative 1, the four conventional models are combined and linked to a GIS software. MIKE11 of Alternative 2 is a package software optionally equipped with modules having functions similar to the four conventional models. An interface module to a GIS software, ArcView, is also available, and a user-friendly environment has already been provided.

3.2.3 Selection of Optimum Software

The advantages and disadvantages of the two software alternatives are compared as follows:

Advantages and Disadvantages of Two Software Alternatives

Item	Alternative 1 (Combination of Conventional Models)	Alternative 2 (Package Software)
Model/Software	• Tank Model • River Flow Routing Model • Flood Plain Model • One-dimensional Unsteady Flow Model • GIS software (ArcInfo, ArcView)	• MIKE11 (HD, NAM, SO, GIS and MIKE VIEW Modules) • GIS software (ArcInfo, ArcView)
Advantage	• Modification of program is freely possible.	• Programming is unnecessary • Very popular in Thailand • Interface to GIS is available
Disadvantage	• Programming is necessary (Four models, linkage of four models, user-friendly environment, interface to GIS)	• Input data are very many • Modification of program is impossible

The functions of the two alternatives are not different from each other. In case of Alternative 1, however, the software program has to be developed for the Study because it is not presently available, and a considerable time and cost will be taken for its development. However, the developed program can be modified freely according to need.

MIKE11 of Alternative 2 is a ready-made software. Program development is unnecessary but modification of the software is impossible. Since MIKE11 is basically a hydraulic model, it needs many input data such as river cross section, topography, and structure dimensions.

As a conclusion, Alternative 2 is selected in this Study based on the preference of the Thai officials concerned, considering the following:

- Commercial availability and applicability in Thailand;
- Future use of the software by engineers of RID; and
- Easiness of technical transfer to engineers in RID and other agencies.

3.3 Modeling

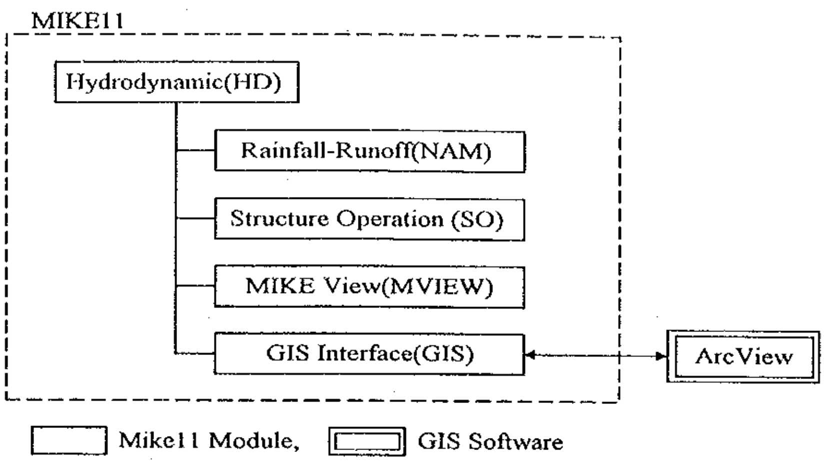
3.3.1 Outline of Modeling by MIKE11

In the MIKE11 model, runoff generated in the subbasins is calculated by the NAM module and given to flood routing of the Hydrodynamic module as the upstream model boundary. The NAM module simulates the rainfall-runoff process in rural river basins as a lumped model. It operates by continuously accounting for the moisture content in the four different and mutually interrelated storage tanks (Fig. 3.3.1).

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, as shown in Fig. 3.3.1. 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 are used for this simulation. The SO module is 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 are exported to the MIKE11 GIS for generating a map and animation of flood inundation. In return MIKE11 GIS gives HD module cross sections and elevation-area tables of flood plains.

Constitution of Mike11 Modules Necessary for Flood Simulation



3.3.2 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. 3.3.2.

Accuracy of the simulation depends on that of the DEM. As shown in Fig. 3.3.2, however, the accuracy of the prepared DEM is different from area to area because a series of precise maps covering whole the flood inundation area is not available and several series of maps of different accuracy 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. 3.3.3 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 devided into 750m x 750m grid cells with an elevation value, which are basic topography information for the flood simulation. Moreover, dikes were also digitized into ARC/INFO data format, and assigned with elevation values.

3.3.3 Model Structure

A schematic diagram of the simulation model is given in Fig. 3.3.4, and described as follows:

(1) River Channel

Ten (10) river channels were 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 the cross sections ranges from 3 km for Chao Phraya River to 10 km for 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. 3.3.5. The flood plain channels were treated as river channels with higher resistance, but the flood plain cells were treated as ponds, each of which has only one water level in the area. The other areas, 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, were 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 Subbasin

A river channel was given runoff by the NAM model as inflow from the subbasin. On the other hand, a flood plain received 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 was simulated through calibration. Actual intake discharges were 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 were also included in the model.

(5) Boundary Conditions

The boundary conditions were set as follows:

Boundary	Applied Data
Upstream end of Ping River	Bhumipol 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

3.3.4 Model Caribration

(1) Target Flood

Three floods in 1983, 1995 and 1996 were 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 was selected as a representative of hybrid floods caused by both river and inland floods although the flood was so old that available data on the river and flood condition at that time are insufficient.

The simulation period was taken 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 calibration results at the key stations are summarized in Table 3.3.1. The water level and discharge hydrographs and the maximum inundation maps are presented in Figs. 3.3.6, 3.3.7, 3.3.8 and 3.3.9, respectively. For the 1983 floods, the estimated hydrographs only downstream from Nakhon Sawan where flooding was significant are presented in Fig. 3.3.8.

As seen in the figures, the calibration results are generally good enough. For the 1995 and 1996 floods, in particular, the hydrographs and the inundation maps show good match with the observed ones. However, considerable gaps between the estimated and observed discharges and water levels are also found in the old flood in 1983. These gaps might be attributed to the racking of data on the river condition at that time. In conclusion, the obtained simulation model is considered to be acceptable and applicable for further simulations in future cases.

3.4 Hydrological Study on Flooding Condition Based on Simulation Result

3.4.1 Water Balance

Water balance of the Chao Phraya River Basin in the flood season from July to December is calculated for the three years, 1983, 1995 and 1996 based on the flood simulation result. A schematic diagrams of the estimated water balance is given in Fig. 3.4.2 based on the four division areas, Upper Central Plain, Nakhon Sawan, Higher and Lower Deltas in the Lower Central Plain as shown in Fig.3.4.1. The maximum flood inundation volumes are also shown in the figure.

The runoff volume to the sea is 32 billion m^3 in 1983, 39 billion m^3 in 1995 and 30 billion m^3 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 m^3. The runoff ratio in the flood season is 26, 32 and 29 % since the corresponding six month rainfall is 919, 903 and 750 mm respectively.

3.4.2 Inundation Volume

The 1995 is the biggest in terms of inundation area and volume, followed by the 1983 flood. The spatial distribution of the flood inundation is different by year. Huge inundation took place in all the areas in 1995. In 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 km^2)
Lower : Inundation Volume (billion m^3)

3.4.3 Flow Capacities of Rivers

Flow capacities of the rivers and major khlongs in the Chao Phraya River Basin have been estimated in Sector VII, "River Improvement Plan" as shown in Fig. 3.4.3, 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 m^3/s, hich 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 m^3/s and 1,500 m^3/s, while the 2-year discharge is 1,100 to 1,300 m^3/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 contribute to alleviation of flood damage to Bangkok, while the spilled water is widely retained in the agricultural area in a manner of inundation.

3.4.4 Characteristics of Inundation

Huge inundation took place in all the areas in 1995. As seen in Fig. 1.3.1 too, however, it is guessed most of flood water was generated in the Nan and Yom River Basin. Firstly the flood water originated in the upper basin 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 adjourning flood plains. The contribution of local rainfall to the inundation in the Lower Central Plain, namely 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 Section 1.3 and Subsection 2.4.2, 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.

4. FLOOD SIMULATION FOR MASTER PLAN STUDY

4.1 Flood Simulation for Future Development

4.1.1 Future Development

Various developments which may affect the flood condition in Chao Phraya River Basin, are anticipated in the near future until the target year of the master plan, 2018 as discussed in Sector VI, "Flood Mitigation Plan". They include urban development, change of agricultural cultivation, land subsidence, construction of new dams, construction of loop cut. To evaluate the influence of these developments, flood simulations were conducted for the following cases:

(a) Urban development by providing ring levee with drainage pump,

(b) Change of agricultural cultivation in combination with urban Development,

(c) Land subsidence in combination with urban development and change of agricultural cultivation,

(d) Construction of dam in combination with urban development, change of agricultural cultivation and land subsidence,

(e) Construction of loop cut in combination with urban development, change of agricultural cultivation, land subsidence and construction of dam, and

(f) Large scale development of agricultural area in combination with urban development

Among the above six cases, '(5) Construction of loop cut in combination with urban development, change of agricultural cultivation, land subsidence and construction of dam' is the future basin condition in the target year 2018 which has been set up as the condition for the Master Plan.

4.1.2 Simulation Condition and Model Modification

The simulation condition of each case is summarized in Table 4.1.1. Major modifications which were made for integrating the above developments into the simulation model are also described in the table.

4.1.3 Simulation Result

The 1995 flood was applied to the simulation. The results are summarized in Table 4.4.2, and hydrographs at Nakhon Sawan (C.2), Bangsai, Samsen (C.12) and Memorial Bridge (C.4) are presented in Fig. 4.1.5.

4.1.4 Additional Simulation for Ring Levee in Lower Chao Phraya River

According to the simulation result, the urban development, especially ring levees proposed along the about 90 km stretch on the lower Chao Phraya River from Samut

Prakan to Pathum Thani by BMA and PWD (Fig. 4.1.6) seem to raise the water level at Bangkok considerably.

To look into this adverse effect more closely, a case in which the ring levee stretch is shortened by 20 km to 70 km from Samut Prakan to Nontha Buri was set up and tested by the flood simulation. The result is shown in Fig. 4.1.7 and summarized in Table 4.1.3.

4.1.5 45 Year Run

As discussed in 2.2.2, river discharge and water level are likely to be much influenced by various developments in the catchment area. Every observed data contain to some extent such influence, which often hampers a statistical analysis to evaluate the magnitude of past floods precisely.

In this Subsection, past 45 year floods from 1952 to 1996 were reproduced under a common condition, namely the future basin condition in 2018 by applying the 45 year rainfalls to the simulation model as shown in Table 4.1.4. Then, a statistical analysis was also made to estimate probable discharges and water levels in the future condition. Figs. 4.1.8 and 4.1.9 present probable plots of discharges and water levels at principle stations, and the estimated probable discharges are summarized in Table 4.1.5.

Moreover, flood inundation maps for the representative three floods, 1983, 1995 and 1996 are presented in Fig. 4.1.10.

4.2 Simulation for Applicable Measures

4.2.1 Applicable Measures Solely Applied

The following measures are considered to be worth evaluating the effectiveness for flood mitigation through the flood simulation:

(a) Modification of Dam Operation Rule,

(b) River Training (Pathum Thani to Nan and Yom Rivers),

(c) River Training (Pathum Thani to Chainat)

(d) Pasak-Raphipat-Sea Diversion

(e) Chainat-Pasak-Raphipat-Sea Diversion

(f) Ayutthaya-East-Sea Diversion

(1) Simulation Condition and Model Modification

The simulation condition of each case is summarized in Table 4.2.1. Major modifications which were made for integrating the above measures into the simulation model are also included in the table.

Prior to the simulation for the river training, the design discharge distribution was determined as shown in Fig.4.2.1. The design discharges for the river improvement from Pathum Thani to Nan and Yom Rivers was based on the probable discharges under the full confinement condition in which river water is confined in the rivers, not allowing any spillage. Table 4.2.2 is the results of the 45 year run for the full confinement condition and the estimated probable discharges are presented in Table 4.2.3 and Fig. 4.2.2.

The design discharges for the river improvement from Pathum Thani to Chainat is based on the probable discharges at Chainat and RamaIV Barrage under the future basin condition as shown in Table 4.2.5. The discharges at the two upstream ends of the river improvement work were distributed to the distributaries, Lop Buri River, Khlong Bang Kaeo, Khlong Bang Luang and Klong Ban Ban, and then rejoined into the Chao Phraya River as shown in Fig. 4.2.1(2/2).

(2) Simulation Result

The three floods, 1983, 1995 and 1996 were applied for each case of the measures. The magnitude of the three representative floods are evaluated in Table 4.2.4, and the simulation results are presented in Table 4.2.5 and Fig. 4.2.3.

4.2.2 Prompt Drainage of Inundation Water

As discussed in Sector VI, "Flood Mitigation Plan", drainage channel improvement by widening and deepening of existing channels or providing new channels if necessary is proposed to drain inundation water in the Higher and Lower Deltas promptly. The simulation model was applied to evaluate the effectiveness of several cases of the channel improvement as shown in Fig. 4.2.4.

(1) Model Modification

For the model modification, a slit as big as the additional cross area of the channel improvement was added to the cross sections of the flood plains in the East and West Bank. (refer to Figs. 3.3.5 and 4.2.4). A control gate which prevents reverse flow from the sea is also given to the outlet of the flood plains to the sea.

(2) Simulation Result

The three floods, 1983, 1995 and 1996 were applied for each case of the measures. The simulation results are presented in Table 4.2.6 and Fig. 4.2.5.

4.2.3 Flood Simulation for Master Plan

Following alternatives are proposed as the Master Plan in the Study as discussed in Sector VI, "Flood Mitigation Plan". They are simplified as the combinations of the following measures:

Combination of Measures for Master Plan

Alternative	Combinations of measures						
	Flood Control Capacity of Modified Dam Operation	River Improvement with Retarding		Drainage Improvement	Protection of N.B. and P.T.	Heightening of BMA Flood Barrier	AES Diversion
		River Improvement	Retarding				
Alt. 1	15.6 bil. m3	10yr (P.T. to Chainat	5,600 km²	Case B2	Partial	No	No
Alt. 2-1	15.6 bil. m3	10yr (P.T. to Chainat)	5,600 km²	Case B2	PWD Plan	30 cm	No
Alt. 2-2	15.6 bil. m3	25yr (P.T. to Chainat)	5,600 km²	Case B2	PWD Plan	No	1,100 m3/s

AES : Ayutthaya-East-Sea
N.B. : Nonthaburi
P.T. : Pathum Thani

(1) Simulation Condition and Model Modification

The design discharge distribution for the river improvement with retarding was made as shown in Fig. 4.2.6 by modifying the one without retarding (Fig. 4.2.1) so that flood discharge could be attenuated by retarding. The simulation model for each case was also remade by combining model parts of the applied measures.

(2) Simulation Result

The three floods, 1983, 1995 and 1996 were applied for each case of the combinations. The simulation results are presented in Table 4.2.7 and Fig. 4.2.7. The simulated flood maps for the Alternative2-1 and Alternative2-2 are shown in Figs. 4.2.8 and 4.2.9 respectively.

4.2.4 Further Study on AES Diversion Channel

(1) Confirmation of Capacity

In order to confirm the proposed capacity of AES Diversion Channel of 1,100 m^3/s, a frequency analysis of water levels under the Alternative 2-1 was made. Table 4.2.8 presents the simulation results of the 45 year run from 1952 to 1996 under the Alternative 2-1. Fig. 4.2.10 gives plotting the estimated water levels on the Gumbel distribution paper, and the probable water levels at the major stations are summarized in Table 4.2.9.

As seen in Table 4.2.9, the 100-year water levels at Samsen (C.12) and Memorial Bridge (C.4) are 2.40 m MSL and 2.30 m MSL respectively, which correspond to the 100-year design water levels of the current BMA flood barrier. This means that the capacity of 1,100 m^3/s is appropriate for the protection of BMA with a return period of 100 years.

(2) Water Level Decrease by AES Diversion Channel

The proposed AES Diversion Channel will not only save BMA even in a 100-year flood, but also decrease water levels in BMA considerably even in smaller floods. This will result in an increase of gravity drain and an decrease of pump lift heights which may contribute to a cut of the pump operation cost. The following is the comparison of water levels at Memorial Bridge (C.4) among Alternatives 1, 2-1 and 2-2.

Duration of Water Level at Memorial Bridge in 1995 Flood

Alternative	Duration by Water Level (hrs)	
	1.5 to 2.0 m MSL	Over 2.0 m MSL
Alt. 1(Partial Protection of P.T. and N.B.)	964	31
Alt. 2-1(Heightening of BMA barrier)	918	154
Alt. 2-2(AES Diversion Channel)	328	22

4.2.5 Water Level at Major Urban Areas

As discussed in Sector X, "Urban Drainage Plan", several urban areas will be protected in a manner of ring dikes and drainage pumps by PWD. However, these 100-year design water levels were all obtained from frequency analyses of past observed water levels. Influence of past and future probable developments such as confinement of flood water by embankment and installation of regulators were not considered in the estimation.

This subsection compare the estimated 100-year water levels under the Master Plan with the PWD design water levels for consideration, as shown in Table 4.2.10.

4.3 Hydraulic Analysis for Pump Drain

As discussed in 4.1.1, major urban areas will be protected by ring dikes with drainage pumps by PWD and BMA. Particularly in the metropolitan area including Pathum Thani, Nontahburi, BMA and Samut Prakan, the total pump capacity will be increased by about 500 m^3/s from the existing capacity of 818 m^3/s to 1,343 m^3/s. This increase of the pump capacity will decrease inland inundation caused by local rainstorm very much. However, it will lead to a increase of the river discharge. If pump drain with the full capacity is made during high tide in a flood time, water levels may go higher over the flood barriers and dikes.

In this Section, a hydraulic analysis is made for the metropolitan area to know influence of the pump drain in a flood time in relation to the tidal fluctuation. This study result will be useful to consider an integrated pump operation method which takes into account the changing tide level.

4.3.1 Analysis Condition

The following conditions are set up and a schematic diagram of the applied simulation model is presented in Fig.4.3.1:

(1) River Model

A 120 km river stretch from the river mouth to Bang Sai with five lateral inflow points is considered. These inflow points represents pump stations in Pathum Thani, Nonthaburi, BMA, Southern BMA and Samut Prakan. Pumps in BMA are split to two groups, upper and lower ones from the Memorial Bridge.

(2) Boundary Condition

Observed tide level at Pom Phracul in 1995 is given as the downstream end At the upstream end, Bang Sai, a constant discharge of 3,000 m3/s is given.

(3) Pump Capacity

Two cases of the pump capacities are considered as follows:

Present and Future Pump Capacity (m^3/s)

Case	Pathum Thani	Nonthaburi	BMA	Samut Prakan	Total
Present	0	0	692	126	818
Future*	119	235	863	126	1,343

*: Pump capacity after completion of PWD and BMA plan.

(4) Pump Operation

Three cases of pump operation, namely no operation, full operation during high tide and full operation after high tide are considered. In 1995 the maximum tide took place at 9:00 on October 28. In case of the operation during high tide, pump drain with full pump capacities is made for six hours between 6:00 to 12 :00 when the tide is the highest. In the operation after high tide, the pump operation are assumed to start three hours later after the peak tide when the tide has subsided considerably and to continue six hours from 12:00 to 18:00 as shown in Fig.4.3.2.

4.3.2 Simulation Result

The simulation results are presented in Fig.4.3.2 and summarized as follows:

Maximum Water Level (m MSL) at Memorial Bridge (C.4)

Pump Operation	Pump Capacity (m^3/s)	
	Present (Q = 818)	Future (Q = 1,343)
No Pump Operation (Q = 0)	2.39	
During High Tide	2.47	2.54
After High Tide	2.39	2.39

If the pump operation coincides with the peak tide, the maximum water level at Memorial Bridge is raised by 8 cm from 2.39 m to 2.47 m MSL under the present pump capacity. The future increase of pump capacity further raises the water level by 7 cm from 2.47 m to 2.54 m MSL.

If the pumps are operated after the peak tide, influence of the pump operation to the water level is small. The maximum water level at Memorial Bridge is the same as the case of no pump operation.

5. FLOOD SIMULATION FOR FEASIBILITY STUDY

5.1 Updating of Simulation Model

The flood simulation model established in the Master Plan Study was updated in the Feasibility stage. Major modifications from the old model are as follows:

5.1.1 New Cross Section Data

A river cross section survey was newly done for the Chao Phraya and Pasak Rivers, Khlong Bang Kaeo, Khlong Bang Luang, and Khlong Bang Phra Mo as shown in Fig.1.4.1. Old cross section data used in the flood simulation model for the Master Plan were replaced by the new data.

5.1.2 Addition of Khlongs

To more precisely express water flow in the river and khlong network of the Chao Phraya River System, the Khlong Bang Bal, Khlong Bang Phra Mo, Khlong Bang Phra Khru and a short cut channel at Pak Krat were additionally incorporated into the simulation model.

5.1.3 Model Calibration

Following the modification, model calibration was made for the 1995 flood through quite a few trial runs adjusting mainly geometry of link channels between rivers and flood plain channels/cells. The calibrated model structure is given in a schematic diagram of Fig. 5.1.2. The water level and discharge hydrographs and the flood inundation map are presented in Figs. 5.1.3 and 5.1.4 respectively. As seen in the figures, the calibration results are generally good enough.

5.2 Flood Simulation for Future Development

5.2.1 Expected Future Development

Various developments in the Chao Phraya River Basin are expected until the target year 2005 for the Feasibility Study after the 1995 flood. Some of them were made already. Among them the following factors seem to be more important from a view of flood hydraulics:

(1) Rehabilitation and heightening of dikes after the 1995 and 1996,

(2) Increase of discharge capacity of Sirikit Dam in 1995,

(3) Start of operation of Pasak Dam (conventional rule) and Modification of Sirikit Dam Operation proposed by JICA KIN Study.

(4) Construction of Loop-cut, and

(5) Urban area protection by PWD and BMA.

During the recent floods, especially the 1995 flood, dikes were breached and damaged in a manner of erosion, slope failure and total collapse, etc. at many locations along the Chao Phraya River and its tributaries and distributaries as shown in Fig. 5.2.1. Those damaged dikes were rehabilitated after the floods, and moreover some lower portions where overflow was found during the floods were heightened by 0.5 to 1 m together with upgrading of the roads. The location of such heightening is presented in Fig. 5.2.2.

The Sirikit Dam experienced spillage in 1995. The released discharge including that from the spillway reached 1,963 m^3/s and cause an extensive inundation in the downstream. The additional installation of a generator immediately after the 1995 flood was a good news for not only power generation but also flood mitigation. It means an increase of the total discharge capacity through generators from 575 m^3/s to 700 m^3/s, and with this additional generator the reservoir water level could have been maintained within the upper rule curve even in the 1995 flood, and consequently the spillage could have been avoided.

The above two factors, the dike heightening and the increase of discharge capacity of Sirikit Reservoir are not future but past developments until the present after the 1995 flood. The other factors are all future developments until the target year 2005. The Pasak Dam are about o start its operation soon, and The JICA Kok-Ing-Nan (K.I.N.) Study proposes the modification of the Sirikit Dam operation before 2005. The loop-cut project and mosts of the urban area protection works by BMA and PWD are also scheduled to be completed by the target year, 2005. The comprehensive condition accumulating the five developments is the basic future basin condition in 2005 without the proposed two F/S projects, the modification of dam operation and the river improvement.

5.2.2 Simulation Result

Using the updated simulation model, the influence of the development was estimated for the 1995 flood as summarized in Table 5.2.1.

The dike rehabilitation/heightening strengthens the protection of the adjourning area but increases the discharge to the downstream instead. It finally results in a water level rise of 12 cm at Samsen (C.12). By avoiding the spillage from the Sirikit Dam with the additional generator, the water level at Samsen decreases by 4 cm. The Pasak Dam with the conventional rule and the Sirikit Dam with the JICA KIN Study rule are slightly effective, and decrease the water level by 2 cm. The Loop-cut is so effective that it can lower the water level at Samsen by as much as 9 cm.

The urban area protection seems to cause an adverse impact to the downstream while it enhances the safety level of the urban areas. As pointed out in the Master Plan Study, the big water level rise by 37 cm at Samsen is mainly due to the protection of Pathum Thani and Non Thaburi which are located just upstream of BMA.

5.2.3 Transition of Safety Level of BMA

BMA is now implementing the dike heightening with design water levels of 100-year return period which are based on a frequency analysis of past observed data. As seen in Table 5.2.1, however, the water levels in Bangkok is much influenced by the developments. The flood discharge control by the dam reservoirs and the Loop-cut can lower the water levels but the discharge confinement in the rivers by the dike heightening and the construction of the urban ring dikes result in water level rise in BMA. Finally the protection level goes down to the 10-year level.

5.3 Flood Simulation for Dam Reservoir Operation

Three dam reservoirs, Bhumibol, Sirikit and Pasak are selected as the objective dam reservoirs for the Feasibility Study on the modification of the operation rule. In order to know the effectiveness of the proposed modification for the three dams, a flood simulation analysis are made as follows:

5.3.1 Without-project Simulation

The effectiveness of the proposed modification is expressed as a difference of flooding condition between before and after the proposed modification. As discussed in Sector VIII, "Integrated Dam Operation Plan", the following rules are applied as the rules before the modification, namely the without-project condition:

Dam Reservoir	Rule before Modification
Bhumibol	Current Rule (Observed Outflow)
Sirikit	Rule proposed by JICA KIN Study
Pasak	Conventional Operation

Giving dam outflow discharges based on the above rules to the upstream boundaries of the simulation model under the 2005 condition, flood simulations are conducted for 33 years from 1964 to 1996. The year, 1964 is the year when the Bhumibol Dam started its operation. The simulation results are presented in Table 5.3.1, and the dam outflow hydrographs and discharge and water level hydrographs at the major stations are presented in Fig.5.3.1.

5.3.2 With-project Simulation

The with-project condition is that after the proposed modification. The boundary dam outflow data are replaced by those for the operation rules proposed in Sector VIII in the simulation model. Firstly flood simulations for each dam are made to know the effectiveness when its operation alone is modified, and then simulations are made also for the case when all the three dam operations are modified as proposed.

In the three dam case, flood simulations are conducted for all the 33 years, but only ten floods, in 1972, 1973, 1979, 1983, 1984, 1985, 1987, 1992, 1995 and 1996 are applied in the individual dam cases. The representative floods are selected among the 33 years in consideration of flood magnitude and spatial distribution of rainfall as shown in Table 5.3.3. The simulation results are presented in Table 5.3.1, and the dam outflow hydrographs and discharge and water level hydrographs at the major stations are presented in Fig.5.3.1.

5.4 Flood Simulation for River Improvement

The river improvement in the middle Chao Phraya River System from Chainat to Pathum Thani is selected to be subjected to the Feasibility Study. Flood simulations are conducted to determine hydraulic condition for the river improvement plan as discussed in Sector VII, "River Improvement Plan".

5.4.1 Condition for River Improvement

The modification of the dam operation is very effective for flood mitigation with less cost, according to Sector VIII. Moreover, it can be implemented soon if an agreement is reached among the agencies concerned. For the Feasibility Study on the river improvement, therefore, it is assumed that the dam operation modification has been completed before the implementation of the river improvement. This means that the without-project condition for the river improvement includes the proposed modification of the dam operation.

5.4.2 Discharge Distribution in Chao Phraya River System

Prior to the simulation for the river improvement, the discharge distribution in the Chao Phraya River System below the Chao Phraya Dam are determined for several return periods as shown in Fig.5.4.2. These discharges are based on probable discharges at all the stretches under the full confinement condition in which river water is confined in the rivers, not allowing any spillage. Simulation results of 45 year runs from 1952 to 1996 are tabulated in Table 5.4.1. Plotting of the simulated discharges on the Gumbel distribution paper is presented in Fig. 5.4.1 and summarized in Table 5.4.2.

The discharge at the Chao Phraya Dam is distributed to the distributaries, Lop Buri River, Khlong Bang Phra Khru, Khlong Bang Kaeo, Noi River, Khlong Bang Luang, Khlong Ban Bal and Khlong Bang Phra Mo, then rejoined into the Chao Phraya River, receiving a discharge from the Pasak River.

It is noted that the estimated flow capacities are not under the actual condition in which spillage over the dikes can take place, resulting in dike breaches. They are under the full confinement condition. Fig. 5.4.2 means, for example, that if all the rivers are improved to accommodate the 5-year return period discharge, the discharge of 3,200 m3/s at the Chao Phraya Dam will swell to 4,100 m3/s at Bang Sai after collecting a discharge from the Pasak River. Finally this swelled discharge flows down to the metropolitan area.

5.4.3 Hydraulic Study on Influence to BMA

Two project scales of 3 and 5 year return periods are proposed for the river improvement. In case of the 3-year improvement, the BMA's flood barrier can accommodate the flood discharge swelled by the overall improvement, in which all the stretches of flow capacity less than the 3-year discharges are upgraded to that level. As for the 5-year improvement, all eight problem areas (Fig. 5.4.3) are not allowed to be protected to the 5-year level. If all protected, BMA will be damaged by the flood water swelled by the river improvement. Some areas should be preserved as they are now, so that they will be able to continue to function their retarding effects not to increase flood damage in BMA.

To know the maximum extent of the 5-year river improvement, the water level rise in BMA by the river improvement are estimated by the flood simulation. The 1996 flood which nearly corresponds to the 5-year flood is used for the simulation.

The farther the improvement stretches are located, the less the influence becomes generally. This means that upper stretches should be given higher priorities for the river improvement to protect more areas. Considering this point, eight combinations of the protection areas are set up by adding every one area from the most upstream, the Area-1 to Area-8. The flood simulation is conducted for these eight combinations.

The Samsen (C.12) station of RID is selected as a check point of the influence of the river improvement because this station is located in the most upstream stretch in BMA and sensitive to an influence of a change in the upstream. If the water level at Samsen exceeds the design water level of 2.40 m MSL, the river improvement is regarded too much and harmful. The simulation results are summarized in Fig. 5.4.4.

As the protection area increases, the water level becomes higher gradually. Areas-1 to 4 is the maximum extent of the protection area which never affect BMA. If Area-5 is added to the protection area, the water level at Samsen exceeds the design water level of 2.40 m MSL.

5.4.4 Flood Simulation for Conceivable Cases

Five cases of the river improvement are conceived, namely one case for the 3-year improvement and four cases for the 5-year one as follows:

Conceivable Cases for River Improvement

Case No.	Protection Level	Protection Area of River Improvement	Area (km2)
5-1	5-yr	Area-1	410
5-2	5-yr	Area-1 to 2	1,260
5-3	5-yr	Area-1 to 3	1,330
5-4	5-yr	Area-1 to 4	1,510
3	3-yr	Area-1, 4,5,6,7 and 8	2,035

In order to the effectiveness of the above five cases, flood simulations are conducted. The 1957 and 1996 floods which nearly correspond to the 3-year and 5 year floods respectively in terms of the discharges at the Chao Phraya Dam are applied for the simulation. The simulation results are given in Table 5.4.3.