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. 4 : SUPPORTING REPORT (2/2)
(SECTOR VII TO XV)

AUGUST 1999

CTI ENGINEERING INTERNATIONAL CO., LTD.
INA CORPORATION

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I N A C O R P O R A T I O N

The cost estimates in this Study are based on price levels as indicated below and expressed in Thai Baht according to the following exchange rates:

US$1.00 = Thai Baht 36.5 = Japanese Yen 115.7

As of December 1998

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SECTOR VII

RIVER IMPROVEMENT PLAN

SECTOR VII
RIVER IMPROVEMENT PLAN

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1. EXISTING CONDITION

1.1 River System

The Chao Phraya River basin is as large as 162,800 km^2, one-third of the whole territory of Thailand (514,000km^2). The basin is often divided into three for hydrological features; the upper basin of northern highland, the middle basin of the flood plain with the surrounding watersheds, and the lower basin of the Chao Phraya Delta as shown in Fig.1.1.1.

The Chao Phraya River system consists of four principal tributaries: the Ping, Wang, Yom, and Nan rivers all originated in the northern highland. The Wang River joins with the Ping River and the Yom River joins with the Nan River in the middle basin. Then, the Ping and Nan rivers join to form the Chao Phraya River at Nakhon Sawan, which flows down to the lower basin through Chai Nat, Ayuttaya and Bangkok, then finally reaches the Gulf of Thailand. In the lower basin the Chao Phraya River joins with tributary of Pasak River, while the Tha Chin River diverges from the Chao Phraya main stream.

The catchment areas of the respective rivers are tabulated in Table 1.1.1.

1.2 River 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 River Morphology

1.3.1 River Channel Profile and Cross-section

In the upper plain upstream of Nakhon Sawan, the slope of the Yom and Nan rivers are less steep than that of the Ping and Wang rivers. From Nakhon Sawan to the river mouth the Chao Phraya River has gentler slope than other rivers. Main properties of these river channels are tabulated in Table 1.3.1.

1.3.2 Meandering

Meandering is generally observed in the Chao Phraya River from Nakhon Sawan to the river mouth. Particularly from Ayuttaya to the river mouth the Chao Phraya River heavily meanders with a maximum amplitude of about 9 km.

The principal rivers, Ping, Wang, Yom, Nan rivers also generally meander in the upper plain. In comparison with the heavily meandering Chao Phraya River, these tributaries meander in a smaller scale with an amplitude from 1 km to 2km.

1.3.3 Sediment

(1) Suspended Sediment Load

Sediment runoff is affected by constructing of the large-scale dam reservoirs such as the Bhumipol dam and the Sirikit dam. Fig.1.3.1 and Table 1.3.2 shows the change of yearly quantity of suspended sediment in the Chao Phraya River at Nakhon Sawan for the period from 1960 to 1996. The annual sediment runoff decreased by 82 % after the completion of the Bhumipol and Sirikit Dam Reservoirs.

(2) River bed Material

A riverbed survey was carried out along the river channels of the Chao Phraya River and its major tributaries. The particle size distribution of each sample is summarized as a gradation curve in Fig.1.3.2. The Figure shows: the 60 % grain daiameter of, Pin River at Phet vary from 0.7 to 1.3 mm in medium sand range, Nan River at Phitsanulok vary from 0.2 to 0.45 mm in fine sand range, Chao Phraya River at Nakhon Sawan vary from 0.85 to 1.2 mm in midium range.

(3) Sand Quarrying

Sand quarrying is being carried out in the Chao Phraya River, Ping River, Sakae Krang River as shown in Fig. 1.3.3. Particularly the quarrying volume along the Ping River is as much as 70 % of the whole quarrying volume in the Chao Phraya River basin. Along the Chao Phraya River, Ayutthaya Province is a major source, occupying 63% of the total production. The total of quarrying volume is 443,200 m^3 as tabulated in Table 1.3.3.

1.4 Water Quality

NEDECO carried out sampling water analysis at 15 sampling stations in the Chao Phraya, Nan and Ping rivers in 1995. The location of water sampling stations is presented as Fig.1.4.1

Table 1.4.1 presents the conclusion of water quality analysis. The comparisons between the studied water quality and the standard surface water quality show that the water quality at the stations, No.6-9(Sing Buri - Payunakeeri),10-15(Nakhon Sawan - Pichit) is good in cold (January), hot (March), and rainy (June) seasons. At station No. 1-5 (Bangkok - Ang Thong), however, the quality of dissolved oxygen is low.

It is noteworthy that during the hot season the quantity of cadmium observed at all stations is higher than the standard value. Besides, at the stations No. 10-15 during the hot season the quantity of heptachlor epoxide is higher than standard value, while during the rainy season it happens to the BHC (benzene hexachloride). This may be caused by the contamination from agricultural sources.

Water quality at No.6 to 15 stations is good enough for all kinds of plants, but salinity is so high at No.1 to 5 stations the plants growing in salty areas alone might be applicable.

1.5 Riparian Structures

1.5.1 Dikes/Levees

From the ancient times, the Chao Phraya River had made the low alluvial ridge area, named *Natural Levee*, adjoining the channel. Most of people had lived on the Natural Levee along the Chao Phraya River and has cultivated rice in general in the *hinterland* of which elevation is lower than it of the natural levee. The natural levee prevented people from small-medium flooding.

In nowadays, flood protection dikes are constructed mainly on the natural levees along the Chao Phraya River, the Tha Chin River and the lower portion of the Pasak River. In addition, in actual flood, banks of canals for irrigation or embankments of road on the natural levee along rivers have taken the place of flood protection dikes. Fig 1.5.1 shows the existing dike alignment in the Basin in plan view.

1.5.2 Diversion Weir and Regulator

There are five (5) major diversion weirs/barrages in the Basin, which are operated primarily for irrigation. Moreover, a lot of regulators have been installed on the rivers and canals. Table 1.5.1 indicates main features of the diversion weirs/barrages and major regulators. Their locations are given in Fig.1.5.2.

Among these regulators, Phonlatep Head Regulator and Manorom Head Regulator are more important for flood mitigation. Because flood water in the Chao Phraya River can be diverted to the Tha Chin River and Chainat-Pasak Canal respectively with the gate of Regulators opened.

On the other hand, RID has formulated a plan, named the Upper and Lower the Tha Chin River Project, to construct new two (2) barrages across the Tha Chin River. One of them will be installed at 100km upstream from the river mouth named Site 6, and the other at the lower reach from 20 km upstream of the mouth named Site 1A.

Harbor Department has also formulated a plan, named the Damming Chao Phraya Project to constructed new two (2) barrages along the Chao Phraya River.

1.6 Flow Capacity along River Channels

1.6.1 Method of Flow Capacity Computation

Flow capacities of the rivers and major khlongs in the Chao Phraya River Basin, which are the Chao Phraya, Noi, Lop Buri, Pasak, Tha Chin, Nan and Yom Rivers, are estimated based on the water level vs. discharge curves obtained from a hydraulic analysis.

1.6.2 Conditions of Flow Capacity Estimation

Basic conditions for the flow capacity estimation are as follows:

Basic Condition for Flow Capacity Estimation

Analysis	Item	Condition
Hydraulic Analysis	Simulation Model	• Full Confinement Model (See Sector I)
	Applied Flood Pattern	• 1995 Flood
	Cross Section Data	• See Table 1.6.1
Flow Capacity Estimation	Target Water Level for Capacity Estimation	• Dike Crest Level – 30 cm (free board), and/or • Design Water Level by BMA/PDW

1.6.3 Flow Capacity Estimation

Fig.1.6.1 shows plots between water levels and discharge curves obtained at river sections through the hydraulic simulation. Fig.1.6.1 (1/2) presents examples of upper river stretches which are free from the tidal influence, while Fig.1.6.1 (2/2) presents those of lower stretches under the tidal influence.

One-to-one relation between water levels and discharges is clearly observed in Fig. 1.6.1 (1/2), and a discharge corresponding to a target water level are easily determined. In Fig. 1.6.1(2/2), however, it is impossible to determine a corresponding discharge because the tidal fluctuation is prevailing over the river discharge in the lower stretches. For the lower stretches below Bang Sai, therefore, relation between daily maximum water levels at river section (Hd) and daily mean discharges at Bang Sai (Qb) are used for the determination of the flow capacity. Fig.1.6.2 shows a Hd-Qb graph at S-14 section of the Memorial Bridge as an example.

The calculated capacities are presented in Figs. 1.6.3 and summarized in Table 1.6.2. The detailed considerations of rivers on flow capacity are given in Sector VI and VII.

2. MASTER PLAN STUDY

2.1 Basic Condition

Basic conditions for the Master Plan Study are discussed in the Sector VI, "FLOOD MITIGATION PLAN" and summarized as follows:

Basic Condition for Master Plan Study

Item	Condition
Target year	• 2018 (20 years later after the completion of the Study)
Project scale	• 100-year return Period for major urban areas • 5 to 25-year return period for agricultural areas
Land use	• Projected future land use in 2018
Land subsidence	• 2 cm/year
Expected future development	• Urban area protection works by PWD and BMA • Loop-cut by RID • Drainage system improvement in agricultural areas by RID • Construction of new dams (Pasak, Kwae Noi and Kaeng Sua Teng) by RID • Kok-Ing-Nan Water Diversion Project by RID • Damming Chao Phraya Project by HD

2.2 Study on Applicability of River Improvement

River improvement aims to confine more flood water in the enlarged river cross section by providing dikes, widening or deepening of the river channel. The measure is regarded as a primary flood mitigation measure because it can directly protect flood prone areas and generally bring large effects with comparatively small costs, although dike heightening and widening are becoming difficult along densely populated areas.

In planning a river improvement work, a special attention shall be paid not to increase damage potential in the downstream. An improvement of the flow capacities may result in an increase of harmful discharge to the downstream. The flow capacities shall be well balanced from the upstream to the downstream to avoid a disaster in the downstream. In this section possibility of river improvement is examined, considering such adverse effects.

2.2.1 Consideration of Flow Capacity

RID has been making great efforts to enhance the protection level of agricultural areas in the Chao Phraya River Basin by building dikes along the rivers and khlongs as shown in Fig.1.5.1. According to RID, these embankments were designed to a standard of 1 in 25 years as shown in Fig. 2.2.1. However, the actual protection levels seems to be a lot less than the 25-year return period level. When the design water levels were estimated, 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 of the 25-year design water levels. They were determined based on a frequency analysis of past observed water level data.

In this section, the estimated flow capacities of the rivers in Fig 1.6.3 are reevaluated based on the probable discharge under the full confinement condition from the Nan and Yom Rivers to the river mouths obtained in the hydraulic Simulation as shown in Table 2.2.1 and Fig.2.2.2(1/2). These probable discharges are used as the design discharges for the river improvement as discussed in 2.2.3.

(1) River Condition of Upstream of Nakhon Sawan

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, 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 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.

(2) River Condition of Downstream from Nakhon Sawan to River Mouth

The Chao Phraya River System from Nakhon Sawan to the Lower Delta (from Nakhon Sawan to the river mouth) has a very complicated channel network. The Chao Phraya River has distributaries, the Tha Chin, Noi, Lop Buri Rivers and a tributary, the Pasak River. In addition, many khlongs connects these rivers.

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.

The flow capacity in Bangkok is as small as 3,600 m^3/s even after the completion of the on-going flood barrier dikes.

2.2.2 River Improvement Method

In general, river improvement to increase the flow capacity is undertaken in the following manner as shown in Fig.2.2.3:

- Heightening of Existing Dike or Construction of New Dike,
- Deepening of Riverbed by Dredging, and
- Widening of River Channel by Excavation of Channel Slope or Retreating of Dike Alignment.

In the Chao Phraya River Basin, which may require increase of channel flow capacity in relatively large scale, "Heightening of Existing Dike or Construction of New Dike" is selected among these measures from the following reasons (See Table 2.2.2):

In general, the most economical way to increase the flow capacity is by heightening existing dikes or providing new dikes, though it also lead to an increase of water levels. If the existing dikes are heightened, land acquisition and house evacuation will be minimum. Deepening of channel bed is not preferable from a viewpoint of channel bed stability because the Chao Phraya River System transports a huge amount of sediment from the upstream. It needs considerable cost to maintain the deepened river bed. Excavation of channel slope and retreating of dike alignment require a number of house relocations.

2.2.3 Hydraulic Analysis on River Improvement

In this Section, a hydraulic analysis is made to identify the effectiveness of river improvement works in the Chao Phraya Basin, using the flood simulation model developed in Sector I, "Hydrology and Flood Simulation".

(1) Analysis Cases and Discharge Distribution

Six combination cases of the target stretches and the scales for the river improvement are set up for the hydraulic analysis as follows:

Case No.	Target Stretch	Scale (Return Period)
1	Pathum Thani to Nan and Yom Rivers	2 years
2	(All the areas of Upper Central Plain, Nakhon	3 years
3	Sawan and Lower Central Plain)	5 years
4	Pathum Thani to Chainat (Chao Phraya Dam)	5 years
5	(Lower Central Plain)	10 years
6		25 years

Cases 1, 2,and 3 covers long stretches from Nan and Yom Rivers in the Upper Central Plain to Pathum Thani in the Lower Delta in the Lower Central Plain, although the improvement scales are smaller. Cases 4, 5 and 6 are for the middle stretches below the Chao Phraya Dam with larger scales.

Prior to the hydraulic analysis for the 6 cases, the design discharge distribution for the river improvement is determined as shown in Fig.2.2.2. The design discharges for the river improvement from Nan and Yom Rivers to Pathum Thani is based on the probable discharges under the full confinement condition in which river water is confined in the rivers, not allowing any spillage, while that for the river improvement from Chao Phraya Dam to Pathum Thani is based on the probable discharges at Chainat and RamaIV Barrage under the future basin condition in 2018. The discharges at the two upstream ends of the river improvement work are 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. 2.2.2(2/2).

(2) Simulation Results

The 1995 flood is applied to the modified flood simulation model for the six cases. The simulation results are shown in Table 2.2.3 and Fig. 2.2.4.

The river improvement works reduce flood inundation volumes where the improvement works are provided. However, they influence the downstream instead.

As shown even in Case 1 with the small scale of 2-year return period, it increases the water level at Samsen by 35 cm from 2.62 to 2.97 m MSL, resulting in 600 million m^3 of inundation in BMA, although it reduces the flood inundation volume by about 1 billion m3 in the Upper and Lower Central Plain except BMA. Cases 4, 5, and 6 which target only the Lower Central Plain also increase the water level in BMA. Even Case 4 with the 5-year return period increases the water level at Samsen by 19 cm from 2.62 to 2.81 m MSL.

(3) Cost Effectiveness

The cost effectiveness in a manner of a ratio between the flood damage decrease and the cost is also given in Table 2.2.3 and Fig. 2.2.5 to compare its effectiveness with those of other measures, modification of dam reservoir operation and diversion channels. As shown in Fig. 2.2.5, the cost effectiveness of all the river improvement cases is negative because they all result in huge damage amounts in BMA which surpass a lot the damage reduction made by the improvement works in the flood plains.

(4) Applicability of River Training

Based on the above results, the applicability of river improvement is considered as follows:

The river improvement is effective to mitigate flood damage to the area along the river course where it is provided. In this sense, this measure is applicable for the protection of any of the divided areas; namely, Upper Central plain, Nakhon Sawan area, Higher and Lower Deltas in Lower Central Plain.

However, the river improvement shows the negative (-) effectiveness, and thus, it is not applicable due to the adverse influence on the downstream when this measure is solely applied. Consequently, it is necessary to examine the applicability of river improvement in combination with other measures such as flood distribution system improvement and flood diversion channels, to minimize the adverse influence.

2.2.4 Combination with Other Measures

As measures to absorb adverse influence caused by river improvement, flood distribution system improvement and a diversion channel are examined as follows:

(1) Combination with Flood Distribution System Improvement

According to the Sector VI "Flood Mitigation Plan", some 8,000 km^2 paddy fields in the total area including the Upper and Lower Central Plains can accommodate about 3.1 billion m3 of inundation harmlessly if flood water is ideally and appropriately distributed through irrigation canals and control structures. The Lower Central Plains alone can accommodate as much as 2.1 billion m^3 in its 5,600 km^2 paddy field areas.

If a part of these damage free capacities of the flood plains is used to retard river flood water, the flood protection levels in such agricultural areas can be enhanced to some extent. If an average depth of 20 cm is assumed to be used for storage of local rainfall, the rest volumes of 1.5 billion m3 and 1.0 billion m3 could be used for retarding of river flood water in the total area and the Lower Central Plain respectively.

Fig. 2.2.6 shows the probable discharge distribution for the combination of the river improvement and the flood distribution system improvement. Comparing this figure with Fig. 2.2.2 where the river improvement is solely applied, the effectiveness of the retarding in the flood plain is understood.

In the case of the river improvement in the Lower Central Plain from Pathum Thani to the Chao Phraya Dam (Chainat), the 10-year total discharge of 4,700 m^3/s at Nakhon Sawan (3,600 m3/s) and Rama VI barrage (1,100 m^3/s) can be attenuated to 3,600 m^3/s below Bang Sai with such retarding effect. Since this 3,600 m3/s corresponds to the flow capacity of the on-going flood barrier in BMA, the 10-year river improvement with 1 billion m^3 retarding in the Lower Central Plain is applicable with no harm to BMA.

(2) Combination with Diversion Channel

If the river improvement is upgraded from the 10-year to 25-year level, a measure to absorb the adverse influence to be caused by the improvement must also be provided to absorb the adverse influence to be caused by the improvement. A flood diversion channel is applicable for this purpose. According to the hydraulic study, an additional capacity of 300 m3/s of Ayutthaya-East-Sea Diversion Channel can absorb such increased discharge as shown in Table 2.2.4.

2.3 Master Plan

2.3.1 Alternatives of Master Plan

The Master Plan is formulated consisting of structural and non-structural measures as shown in Fig.2.3.1. For flood mitigation in the urban areas of Pathum Thani, Nonthaburi and Bangkok, the three (3) alternatives are provided: Alternative 1, partial protection of Pathum Thani and Nonthaburi, Alternative 2-1, heightening of flood barrier at Bangkok ,and Alternative 2-2, construction of diversion channel.

The difference of the measures applied in these alternarives is only the way of flood mitigation in these urban areas and the other measures are commonly applied to these three alternatives.

2.3.2 Staged Implementation of River Improvement

River improvement is undertaken in two (2) stages. Stage 1 is prompt implementation with the 10-year return period in combination with the flood distribution system improvement as shown in Fig. 2.2.4. Implementation of Stage 2, the purpose of which is to enhance the safety level to the 25-year return period, depends on the selection of alternatives. In case of Alternative 1 and Alternative 2-1, river improvement is terminated with Stage 1. In case of Alternative 2-2, the river improvement is expanded in Stage 2 to the safety level of the 25-year return period. However, the implementation of Stage 2 is proposed only after the diversion channel is ready to absorb the adverse influence to be caused by upgrading of the river improvement.

3. FEASIBILITY STUDY

The possibility of river improvement for the middle reaches of the Chao Phraya River System from Pathum Thani to Chainat to mitigate flood damage in the agricultural areas was examined in the Master Plan Study. It was concluded that it may be possible to enhance the flood protection level from 2-5 year return period to 10-year return period for the agricultural areas by the river improvement in combination with the improvement of the flood water distribution system under the future basin condition in 2018 as discussed in Chapter 2.

In the Feasibility study stage, the possibility of river improvement is further examined to clarify possible improvement scales and stretches. The project area is the midstream of the Chao Phraya River System from Chao Phraya Dam to Pathum Thani, including its tributary, the Pasak River, and distributaries, Noi and Lop Buri Rivers and some major khlongs. Since the study on the flood water distribution system is not included in the Feasibility study, the possibility of the river improvement is examined based on the assumption that the flood water distribution system improvement is not undertaken.

3.1 Basic Condition for River Improvement

The basic conditions for the feasibility study on the river improvement are set up as follows:

3.1.1 Target Year

The target completion year for the river improvement is set in 2005, in accordance with the implementation schedule proposed in the Master Plan.

3.1.2 Project Scale

In the Master Plan, the agricultural areas in the Higher Delta is proposed to be protected with a return period of 10 years by a combination of the river improvement, the flood water distribution system under the future basin condition in 2018. In this 2018 condition, however, two planned dams, Kwae Noi and Kaeng Sua Teng of which completion is expected to be delayed after 2005 are included. In addition, the distribution system improvement is not included in this Feasibility Study as aforementioned above. Thus, the project scale enhanced by the river improvement alone might be lower than 10-year return period.

3.1.3 Expected Future Basin Condition

The following conditions are taken into account as the future basin condition in the target year 2005.

(1) Land Use

The land use in the target year should be considered for the river improvement study. The future land use in 2005 is projected by applying the same annual growth rates of land use in the Master Plan Study as discussed in Sector III, "Land Use".

(2) Related Works

To cope with the flood problems, the agencies concerned are undertaking flood mitigation and protection works, which are taken into account for the formulation of the Master Plan. Some of them are planned to be completed by the target year 2005, and are incorporated in the future condition in the following manner:

(a) Construction of Flood Barrier undertaken by BMA

BMA is now constructing flood barriers along the Chao Phraya River. This work is scheduled to be completed in 2001, and the flood barriers are incorporated in the future condition.

(b) Flood Protection Works for Major Urban Areas

PWD is planning to provide flood protection works to major urban areas in a manner of ring dikes with drainage pumps, of which tentative implementation schedules are as shown in Tables 3.1.1 and 3.1.2. All the protection works which are scheduled to be completed by 2005 in these tables are assumed to be existing in 2005. The location of the urban ring dikes are given in Fig. 3.1.1.

Strictly speaking, the urban protection work in Pathum Thani will not be completed, but a part of the work, the Bang Pho Tai – Bang Luang Polder Work will be still going on in the target year 2005 as presented in Fig. 3.1.2. However, all the protection work is incorporated in the 2005 condition because the protection work, which will affect BMA very much as highlighted in the Master Plan Study, will be completed just only 2 years after the target year.

(c) Loop Cut at Bangkok Port by RID

To mitigate flood damage in agricultural areas, RID is going to implement a loop cut near Bangkok Port, which is scheduled to be completed in 2002. Thus, the loop-cut is also incorporated in the future condition in 2005.

(d) Modification of Operation of Bhumibol, Sirikit and Pasak Dam Reservoirs

Modification of the reservoir operation of the three dams, Bhumibol, Sirikit and Pasak is very effective for flood mitigation and proposed to be implemented soon as discussed in Sector VIII, "Integrted Dam Operation Plan". The proposed optimum operation rules for the three dams are assumed to be applied by the target year 2005.

(v) Regulators and Barrage

Four regulators are now under construction on the Lop Buri River and Khlongs Bang Kaeo and Bang Phra Khru by RID as shown in Table 3.1.3 and Fig. 3.1.3, and are scheduled to be completed in 1999. In addition, RID is constructing some 30 regulators on khlongs joining the Chao Phraya River between Bang Sai and Pathum Thani as shown in Fig. 3.1.4. Harbor Department has a plan to construct two barrages on the Chao Phraya River in Sin Buri and Nakhon Sawan Province by 2004 for navigation as presented in Table 3.1.2 and Fig. 3.1.3. These control structures are also incorporated in the 2005 condition.

3.1.4 River Improvement Work

Heightening of existing dikes or building of new dikes are considered the most economical among measures to increase the flow capacities of the Chao Phraya River System as discussed in Subsection 2.2.2. Thus, this feasibility study is made under the condition that such dike heightening will be made as a basic work for the river improvement.

3.2 Existing Condition

In order to know the existing condition of the rivers and to identify problem areas, flow capacities of the rivers and the khlongs are examined as follows:

3.2.1 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 for the 2005 condition was determined for several return periods as shown in Fig.3.2.1.

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. 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. 3.2.1 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.

3.2.2 Flow Capacities

Flow capacities of the rivers and the khlongs are compared with the discharge distribution under the full confinement condition in Fig. 3.2.1 and are presented in a form of return period as shown in Fig. 3.2.2 and Table 3.2.1.

The upper stretches of the Chao Phraya River from the Khlong Bang Bal have comparatively large capacities greater than the 5-year discharge. The flow capacities of the lower stretches are very small. Several stretches below Ayutthaya can not accommodate even the 3-year discharge. Except for the Khlong Bang Luang and Khlong Bang Phra Khru, the Pasak, Lop Buri and Noi Rivers and the other khlongs have flow capacities as small as the 3 to 5-year discharges or less.

(1) Flow Capacity in BMA

The flow capacity at the design water level in BMA was estimated at some 3,600 m^3/s, which corresponds to the 3-year discharge in an extreme case that all the flood water is confined in the rivers from the Chao Phraya Dam to BMA.

(2) Flow Capacity in Pathum Thani and Nonthaburi

The flow capacities in Pathum Thani and Nonthaburi are estimated at 3,700 m^3/s and 3,200 m^3/s which correspond to the 3.5 and 2.2-year discharges under the full confinement condition respectively. These small capacities are estimated at the design water levels which have been applied in the on-going urban area protection plan by PWD.

(3) Discussion on Water Levels in Pathum Thani and Nonthaburi

According to the D/D Report of PWD, the design water levels are 100-year water levels obtained by a frequency analysis of the past observed water levels. However, the design water levels seem to be too low if it is compared with the 100-year water levels obtained in the Master Plan Study. PWD's design water level at Pak Kret (C.22) is as low as 2.50 m MSL (the design dike level is 3.0 m MSL), while the 100-year water level after the confinement has been estimated at 3.07 m MSL in the Master Plan Study.

Similar problems has been pointed out for BMA's flood barrier in the Master Plan Study and for the RID embankments in this Feasibility Study. The gap between the PWD plan and this Study is generated from the different evaluations on the influence of the proposed dikes along the river. The PWD plan seems to have underestimated or neglected the influence, as understood from the fact that the frequency of the past observed data only were considered. On the other hand, this Study has been taking the influence seriously into an account, and the water level rise after the confinement by the dikes has been closely examined.

The protection works are going to commence in 2001 according to the implementation schedule. On the other hand, the discussion on the Master Plan for the protection of the metropolitan areas including not only Pathum Thani and Nonthaburi but also BMA have not been settled yet. Three alternative plans have been proposed in the Master Plan Study. The water levels in these areas depend upon which alternative is applied, and the design water levels and dike levels should be determined considering the Master Plan.

The estimated flow capacities in Nonthaburi are smaller than that of BMA, but in this Feasibility Study the design water levels and dike levels in Nonthaburi are assumed to be raised high enough for the safety level of BMA, the 3-year level at least.

3.2.3 Problem Areas

Based on the flow capacities, problem areas of which safety levels are lower than the 5-year return period level are identified by the JICA Study Team. The areas are divided into eight areas by the river and major khlong dikes, and named Area-1 to 8 in order of the distance from the river improvement stretches to BMA as shown in Fig.3.2.3, and summarized in Table 3.2.2.

(a) Area-1

This area of 410 km^2 is surrounded by the Lop Buri and Pasak Rivers, Chainat-Pasak Canal and Khlong Bang Phra Khru. The main land use is rice, High Yield Variety (HYV) in the higher area close to the Chainat-Pasak, Deep Water Rice (DWR) in the lower area. Floating Rice (FR) are planted in the lowest depression area. The safety level of this area is as low as the 2 to 3-year return period.

(b) Area-2

This area of 850 km^2 is located in the south of the Pasak River, surrounded by the Pasak River, RID's left dike of the Chao Phraya River, Khlong Raphipat Yack Tak and Raphipat Canal. The main land use is rice, HYV in the higher area close to the Raphipat, and DWR in the lower area. FR is also seen in the depression area. The safety level of this area is comparatively higher because dikes and roads along the Chao Phraya and Pasak Rivers were heightened to some extent after the 1995 flood, although a part of the Pasak River dike is still as low as the 3 to 5-year level upstream of Khlong Bang Phra Khru.

(c) Area-3

This small area of 70 km^2 is surrounded by the Lop Buri and Pasak Rivers and Khlong Bang Phra Khru. The main land use is DR. The dike of the Lop Buri River is so low that the safety level is lowered to the 3 to 5-year level.

(d) Area-4

This area of 410 km^2 is surrounded by the Chao Phraya and Lop Buri Rivers and Khlong Bang Kaeo. The main land use is DWR. The safety level is less than the 2-year return period. This poor safety level is caused by the low right dike of the Lop Buri River. A low dike spot with the 3 to 5-year return period is also found along the Chao Phraya River.

(e) Area-5

This area of 45 km^2 is surrounded by the Chao Phraya and Noi Rivers, and Khlongs Bang Luang, Bang Bal and Bang Phra Mo. The main land use is DWR. The safety level is less than the 2-year return period. This poor safety level is caused by the dikes of the Noi River and Khlong Bang Bal.

(f) Area-6

This area of 180 km² is surrounded by the Chao Phraya and Noi Rivers, and Khlong Bang Bal. The main land use is DWR. The safety level is less than the 2-year return period. This poor safety level is caused by the low dikes of the Noi River and Khlong Bang Bal.

(g) Area-7

This area of 120 km² is located in the east bank of the Chao Phraya River downstream of Ayutthaya, and the RID dike forms the eastern boundary of the area. The main land use is DWR. The dike on the riverside is so low that flood water overflows it and causes extensive and deep inundation between the river and the eastern RID dike. The safety level of this area is estimated less than the 2-year return period.

(h) Area-8

This west bank area of 1,100 km² is located below the Khlong Phraya Ban Lu. The main land use is HYV rice. This area functions as a final buffer to absorb flood water before it enters the metropolitan area. The dike along the Chao Phraya River is poor and has no regulators at many small khlongs. on the many small khlongs have no regulator. The safety level is less than the 2-year return period.

3.3 Determination of Project Scale and Target Stretches

The improvement scale and the target stretches are studied in this Subsection as follows:

3.3.1 Strategy

The river confinement work reduces the spillage discharge at the improvement section but increase the discharge to the downstream at the same time. This is the dilemma of the river improvement, and might arise a conflict between the protected area by the river improvement and the downstream area which becomes to receive more water from the upstream. In addition, what makes the river improvement in the Chao Phraya River System more difficult and complicated is the small flow capacity at the downstream end of the Chao Phraya River, in BMA. As discussed in the previous subsection, the flow capacity in Bangkok is as small as 3,600 m³/s, constrains the extent of the river improvement.

If all the stretches from Pathum Thani to the Chao Phraya Dam are improved at a unique level, such river improvement can be applied with a scale of the 3-year return period at the maximum. If the 5-year return period is applied as the scale of the river improvement, the discharge of 4,100 m³/s comes down to BMA even in a 5-year flood, and it results in terrible flood damage in BMA where the flow capacity is only 3,600 m³/s as shown in Fig. 3.2.2. Thus all the stretches can not be improved, but the improvement should be limited to only some selected stretches in case of the 5-year improvement.

Based on the above understandings, the following principles are made:

(1) Project Scale of River Improvement

As described in Subsection 3.1.2, the project scale of the river improvement is set up lower than the 10-year return period, and two cases, the 3-year and 5-year return periods are proposed.

(2) Maintaining of Safety level of BMA

BMA is the capital of Thailand which is a core center of political, economic and social activities in the country. Once this area is hit by a flood, it may give fatal damage to not only BMA but also the whole country. For planning the river improvement, therefore, special consideration should be made not to lower but maintain the safety level of the metropolitan area.

(3) Overall Improvement and Partial Improvement

The 5-year improvement is a partial improvement, and the river improvement should be limited to some selected areas. The 3-year improvement is overall improvement, and all the river stretches with a flow capacity of less than the 3-year discharge are allowed to be improved without increasing of flood damage in BMA.

3.3.2 Conceivable Cases

In line with the above principles, five cases of the river improvement are conceived, namely one case for the 3-year improvement and four cases for the 5-year-one. Case-3 is the 3-year improvement, overall improvement.

As for the 5-year improvement, the four partial protection cases, Case 5-1 to 5-4 which will not increase flood damage in BMA are conceived through a hydraulic analysis as shown in Fig. 3.3.1. Case 5-4 is the maximum protection case. If more area are protected, it will results in an increase of flood damage to BMA. The details of this simulation is described in Sector I, "Hydrology and Flood Simulation".

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

3.3.3 Selection of Optimum Case

To select an optimum case among the five conceivable cases, an economic analysis is made and summarized in Table 3.3.1. Simulated inundation volumes and damage amounts in each problem area for the 1957 and 1996 floods which have return periods of 3 years and 5 years in terms of the discharge at the Chao Phraya Dam respectively are also presented in Table 3.3.2. In conclusion, Case 3, the 3-year river improvement is selected from the following reasons:

The other 5-year cases, Case 5-1 to 5-3 are economically viable, but result in an imbalance of impacts. The partial improvement cases improve the protected areas considerably but increase flood damage significantly in the unprotected areas instead, although the increased damage will be balanced by benefits created by the proposed modification of dam reservoir operation if the combination with the reservoir operation is considered. The unprotected areas will be left in the lowest safety levels. On the other hand, the 3-year improvement is also economically feasible, and can upgrade all the problem areas of the lowest safety levels to the 3-year level. This overall improvement will lead to well-balanced development of the delta area.

The preliminary design, cost estimate and implementation schedule of the 3-year river improvement are discussed in Sector XII, "Preliminary Design, Cost Estimate and Construction Plan". The economic evaluation and environmental aspects of the river improvement are discussed in Sector XIII, "Environmental Consideration" and Sector XIV, "Environmental Consideration" respectively.

Tables

Table 1.1.1 CATCHMENT AREAS OF RESPECTIVE RIVERS

River Basin	Catchment Area (Km2)
Ping River	36,018
Wang River	11,708
Yom River	24,720
Nan River	34,577
Pasak River	15,206
Residual Area	40,569
Total	162,798

Table 1.3.1 DIMENTION OF RIVER CHANNELS

River	Stretch	Length(km)	Channel Width[1](m)	Depth[2](m)	Longitudinal Gradient
Ping River	Nakhon Sawan-Chiang Mai	600	150-350	5-15	1:1600 to 1:2300 (10 to 335 MSL)
Wang River	Tak-Pha Yao	305	50-150	5-10	1:1300 to 1:2000 (130 to 300 MSL)
Yom River	Nakhon Sawan-Phrae	530	50-150	8-10	1:2100 to 1:8500 (10 to 180 MSL)
Nan River	Nakhon Sawan-Nan	610	100-300	10-15	1:3500 to 1:13600 (10 to 130 MSL)
Pasak River	Ayuttaya-Phetchabun	510	100-150	10-15	
Tha chin River	The Gulf-Chai Nat	200	50-100(600[3])	5-15	1:4200 (-10 to 10 MSL)
Chao phraya River	The Gulf-Nakhon Sawan	380	150-300(1000[3])	10-20	1:7000 to 1:25000 (-15 to 10 MSL)

1) Width of low water channel

2) From river bed to top of dike of low water channel

3) River mouth width

Table 1.3.2 QUANTITY OF SEDIMENT OF CHAO PHRAYA RIVER IN NAKHON SAWWAN, C_2 STATION (BASIN AREA 107,023Km^2)

(10^3ton)

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Whole year
1960	1	27	62	172	1,984	7,094	10,067	1,718	259	29	10	6	21,429
1961	5	44	460	610	2,565	13,246	35,353	9,890	317	89	221	7	62,807
1962	4	17	52	321	1,330	7,062	22,701	3,937	102	10	4	4	35,544
1963	3	2	34	225	3,934	6,010	10,428	5,482	800	31	30	25	27,005
1964	31	74	218	595	829	5,311	20,942	5,400	333	57	46	73	33,908
1965	76	104	224	383	1,012	2,931	2,191	977	136	44	45	67	8,189
1966	53	156	815	498	2,553	10,926	4,817	1,220	219	76	54	70	21,456
1967	67	76	166	231	526	2,502	9,063	1,125	247	84	47	52	14,184
1968	65	287	425	640	1,441	1,412	858	198	113	59	41	28	5,569
1969	34	33	177	555	1,579	6,020	7,526	1,452	218	92	96	80	17,861
1970	115	374	969	3,213	6,544	22,274	20,142	3,041	570	160	111	117	57,631
1971	130	208	406	656	2,482	6,165	6,715	2,113	354	129	106	121	19,584
1972	80	79	133	176	400	507	815	463	209	62	68	104	3,096
1973	110	107	203	261	709	1,800	3,026	723	162	76	89	126	7,391
1974	141	187	164	162	533	1,108	1,556	1,719	361	95	80	149	6,256
1975	210	206	302	455	896	5,490	9,615	2,226	483	154	184	271	20,491
1976	328	506	514	403	659	2,297	3,941	2,500	435	176	151	243	12,152
1977	319	428	298	283	412	1,814	1,197	526	178	68	80	127	5,731
1978	202	190	191	826	1,153	1,326	2,563	745	283	186	184	313	8,163
1979	339	348	489	371	436	495	507	356	258	102	69	88	3,861
1980	83	191	381	480	782	1,395	2,948	801	247	133	176	239	7,854
1981	283	355	476	476	1,099	967	595	734	383	167	205	312	6,052
1982	300	245	201	244	328	634	950	541	234	158	225	287	4,345
1983	317	283	198	190	341	673	1,285	1,322	419	132	208	317	5,683
1984	279	225	304	206	279	568	721	542	251	133	199	313	4,021
1985	291	237	199	267	370	634	1,086	1,170	577	123	200	298	5,453
1986	278	539	516	369	381	543	438	398	257	86	219	298	4,321
1987	152	75	53	20	304	5,975	12,547	916	180	2	12	109	20,345
1988	195	293	331	327	335	597	1,148	754	258	111	146	233	4,728
1989	280	262	478	166	264	401	634	482	234	75	99	260	3,635
1990	130	158	393	138	132	309	349	204	137	44	51	89	2,134
1991	62	33	27	18	148	377	265	128	70	23	30	39	1,219
1992	135	124	66	51	321	214	532	297	217	99	109	107	2,271
1993	127	129	173	92	155	426	285	138	92	24	34	46	1,720
Total	5,222	6,602	10,097	14,077	37,215	119,504	197,807	54,237	9,592	3,089	3,628	5,016	466,086
Average	154	194	297	414	1,095	3,515	5,818	1,595	282	91	107	150	13,711

Table 1.3.3 ANNUAL SAND QUARRYING VOLUME

River	Province	Amphoe	License Condition	
			Area(m2)	Volume(m3)*
Chao Phraya	Ayuttaya	Bang Sai	41,600	83,200
	Chai nat	Muang	16,000	32,000
		Manorom	8,000	16,000
Ping River	Nakhon Sawan	Muang	48,400	96,800
		Banphot Phisai	10,400	20,800
	Kampaeng Phet	Muang	65,800	131,600
		Khlong Klung	13,800	27,600
		Kanuvorarakuri	16,000	32,000
Sakae Krang	Nakhon Sawan	Latyao	1,600	3,200
Total			221,600	443,200

Note * : Quarrying volume is estimated by multiplying quarrying depth to quarrying area.

Table 1.4.1 WATER QUALITY IN CHAO PHRAYA RIVER, NAN RIVER AND PING RIVERS

January,1995

Water Quality Index	Station No. 1-5	Station No. 6-9	Station No. 10-15	Water Quality Standard Type 1	Type 2	Type 3	Type 4
Temperature,°C	27.5 - 32.5	28.0 - 38.5	27.0 - 29.0	n	n'	n'	n'
pH	7.25 - 7.97	7.65 - 7.81	7.69 - 8.13	n	5-9	5-9	5-9
Dissolved Oxygen, mg/l	1.1 - 7.8	6.4 - 7.9	7.3 - 8.0	n	>6.0	>4.0	>2.0
BOD, Mg/l	1 - 2	1 - 2	1 - 2	n	<1.5	<2.0	<4.0
Nitrate (NO_3 -N), Mg/l	0.03 - 0.59	0.08 - 0.13	0.01 - 0.17	n	<5.0	<5.0	<5.0
Coliform Bacteria, MPN/100ml							
- Total Coliform	>2,400	>2,400	1,100 - >2,400	n	<5,000	<20,000	
- Faecal Coliform	210 - >2,400	460 - >2,400	460 - >2,400	n	<1,000	<4,000	
Heavy Metals, mg/l							
- Copper (Cu)	0.040	0.01	0.010 - 0.060	n	maximum not over 0.1		
- Zinc (Zn)	0.697	0.735	0.558 - 0.727	n	maximum not over 1.0		
- Mercury (Hg)	0.002	ND	ND - 0.001	n			
- Cadmium (Cd)	0.001	0.001	0.001	n	maximum not over 0.002*, 0.05**		
- Cromium (Cr)	ND	ND	ND	n	maximum not over 0.05		
- Lead (Pb)	0.025	0.025	0.020 - 0.021	n	maximum not over 0.05		
Pesticides, mg/l							
- DDT	ND	ND	ND	n	maximum not over 1.0		
- BHC	ND	ND	ND	n	maximum not over 0.02		
- Dieldrin	0.01	0.02	ND - 0.04	n	maximum not over 0.1		
- Aldrin	ND	ND	ND	n	maximum not over 0.1		
- Heptachlor epoxide	ND	ND	ND	n	maximum not over 0.2		
- Endrin	ND	ND	ND	n	Not detected		

Remarks :
- 1/ = See TABLE 4.3-4
- n = Natural
- n' = Natural but variable not more than 3°C
- * = Hardness not more than 100 mg/l as $CaCO_3$
- ** = Hardness more than 100 mg/l as $CaCO_3$
- ND = Non-detectable

March,1995

Water Quality Index	Station No. 1-5	Station No. 6-9	Station No. 10-15	Water Quality Standard Type 1	Type 2	Type 3	Type 4
Temperature,°C	29.5 - 31.0	29.0 - 31.0	28.0 - 31.0	n	n'	n'	n'
pH	7.3 - 8.0	7.9 - 8.9	7.8 - 8.2	n	5-9	5-9	5-9
Dissolved Oxygen, mg/l	2.0 - 6.7	6.6 - 7.5	7.1 - 7.6	n	>6.0	>4.0	>2.0
BOD, Mg/l	1 - 2	2 - 3	1 - 2	n	<1.5	<2.0	<4.0
Nitrate (NO_3 -N), Mg/l	0.13 - 1.15	0.05 - 0.15	0.02 - 0.16	n	<5.0	<5.0	<5.0
Coliform Bacteria, MPN/100ml							
- Total Coliform	>2,400	460 - >2,400	> 2,400	n	<5,000	<20,000	
- Faecal Coliform	>2,400	460 - >2,400	240 - >2,400	n	<1,000	<4,000	
Heavy Metals, mg/l							
- Copper (Cu)	0.009	0.005	0.005 - 0.009	n	maximum not over 0.1		
- Zinc (Zn)	0.48	0.332	0.374 - 0.525	n	maximum not over 1.0		
- Mercury (Hg)	ND	0.001	ND	n			
- Cadmium (Cd)	0.007	0.01	0.006 - 0.009	n	maximum not over 0.002*, 0.05**		
- Cromium (Cr)	ND	0.001	ND - 0.001	n	maximum not over 0.05		
- Lead (Pb)	0.005	0.012	0.006 - 0.010	n	maximum not over 0.05		
Pesticides, mg/l							
- DDT	ND	ND	ND	n	maximum not over 1.0		
- BHC	ND	ND	0.06 - 0.07	n	maximum not over 0.02		
- Dieldrin	ND	ND	ND - 0.01	n	maximum not over 0.1		
- Aldrin	ND	ND	<0.01	n	maximum not over 0.1		
- Heptachlor epoxide	ND	ND	0.28	n	maximum not over 0.2		
- Endrin	ND	ND	ND	n	Not detected		

Remarks :
- 1/ = See TABLE 4.3-4
- n = Natural
- n' = Natural but variable not more than 3°C
- * = Hardness not more than 100 mg/l as $CaCO_3$
- ** = Hardness more than 100 mg/l as $CaCO_3$
- ND = Non-detectable

June,1995

Water Quality Index	Station No. 1-5	Station No. 6-9	Station No. 10-15	Water Quality Standard Type 1	Type 2	Type 3	Type 4
Temperature,°C	30.3 - 31.5	30.0 - 33.0	28.0 - 32.0	n	n'	n'	n'
pH	7.4 - 7.8	7.7 - 7.9	7.4 - 8.3	n	5-9	5-9	5-9
Dissolved Oxygen, mg/l	1.7 - 6.1	6.1 - 7.3	6.1 - 7.7	n	>6.0	>4.0	>2.0
BOD, Mg/l	1 - 2	1 - 2	1 - 2	n	<1.5	<2.0	<4.0
Nitrate (NO_3 -N), Mg/l	0.29 - 0.96	0.19 - 0.35	0.01 - 0.34	n	<5.0	<5.0	<5.0
Coliform Bacteria, MPN/100ml							
- Total Coliform	>2,400	>2,401	> 2,400	n	<5,000	<20,000	
- Faecal Coliform	> 2,400	> 2,401	> 2,402	n	<1,000	<4,000	
Heavy Metals, mg/l							
- Copper (Cu)	0.007	0.006	0.006 - 0.017	n	maximum not over 0.1		
- Zinc (Zn)	0.251	0.182	0.110 - 0.302	n	maximum not over 1.0		
- Mercury (Hg)	ND	0.002	ND - 0.001	n			
- Cadmium (Cd)	ND	0.009	ND - 0.016	n	maximum not over 0.002*, 0.05**		
- Cromium (Cr)	0.02	ND	ND - 0.017	n	maximum not over 0.05		
- Lead (Pb)	ND	ND	ND - 0.018	n	maximum not over 0.05		
Pesticides, mg/l							
- DDT	0.02	0.02	ND	n	maximum not over 1.0		
- BHC	0.01	0.02	ND - 0.03	n	maximum not over 0.02		
- Dieldrin	ND	ND	ND - 0.02	n	maximum not over 0.1		
- Aldrin	ND	ND	ND	n	maximum not over 0.1		
- Heptachlor epoxide	ND	ND	ND	n	maximum not over 0.2		
- Endrin	ND	ND	ND	n	Not detected		

Remarks :
- 1/ = See TABLE 4.3-4
- n = Natural
- n' = Natural but variable not more than 3°C
- * = Hardness not more than 100 mg/l as $CaCO_3$
- ** = Hardness more than 100 mg/l as $CaCO_3$
- ND = Non-detectable

Classifications	Objective/Condition & Beneficial Usages
Class 1	Extra clean fresh surface water resources used for : (1) conservation, not necessary pass through water treatment processes require only ordinary process for pathogenic destruction (2) ecosystem conservation where basic organisms can breed naturally
Class 2	Very clean fresh surface water resources used for : (1) consumption which requires ordinary water treatment processes before use (2) aquatic organism of conservation (3) fisheries (4) recreation
Class 3	Medium clean fresh surface water resources used for : (1) consumption, but passing through an ordinary treatment process before using (2) agriculture
Class 4	Fairy clean fresh surface water resources used for : (1) consumption, but requires special water treatment process before use (2) industry
Class 5	The resources which are not classified in class 1-4 and used for navigation

Table 1.5.1 (1/2) MAIN IRRIGATION FACILITIES OF RIVERS AND CANALS IN CHAO PHRAYA RIVER BASIN (IN DOWNSTREAM)

Water Course	Name of Structure	Location (Province)	Structural Features					Retention Level (m MSL)	Flood Level (m MSL)		Design Flow (m3/s)
			Type	Number	Width (m)	Height (m)	Sill Elevation (m MSL)		Upper	Lower	
Yom River	Mae Yom Weir	Phrae	Fixed Weir & Rubber Dan	5	68.80	3.50	+178.00	+181.50	183.75	183.00	3,000
Nan River	Phitsanulok Diversion Weir (Naresuan Dam)	Phitsa-nulok	Movable Radial Gate	5	12.50	7.60	+40.20	+47.80	+50.35	+49.75	1,600
Thap Salao River	Thap Salao Diversion Weir	Uthai Thani	Fixed Weir	6 2 2	8.0 9.9 3.0	3.00	+71.00	+74.00	+77.25	+76.40	700
Yom to Nan River (Curtain Canal)	Control Regulator	Phitsa-nulok	Radial Gate	2	6.0	4.00	+33.975	/1	37.675	36.750	85
Yom to Nan River (DR 15.8 Canal)	Control Regulator No. 1	Phitsa-nulok	/1	/1	/1	/1	/1	/1	/1	/1	60
	Control Regulator No. 2	Phitsa-nulok	/1	/1	/1	/1	/1	/1	/1	/1	60

Note: /1 Data not available yet.

Table 1.5.1 (2/2) MAIN IRRIGATION FACILITIES OF RIVERS AND CANALS IN CHAO PHRAYA RIVER BASIN (IN UPPER AND MIDDLE STREAM)

Water Course	Name of Structure	Location (Province)	Structural Features				Full Supply Level (m MSL)		Flood Level (m MSL)		Design Flow
			Gate			Sill Elevation					
			Type	Number	Width (m)	(m MSL)	Upper	Lower	Upper	Lower	(m3/s)
Chao Phraya River	Chao Phraya Dam (Barrage)	Chai Nat	Radial Gate	16	12.50	+9.00	+16.50	+7.50	+18.50	+16.00	3,300.0
			Miter Gate	1	14.00	+9.00					
Suphan River	Phonlatep Head Regulator	Chai Nat	Slide Gate	4	6.50	+7.50	+16.50	+13.90	+19.40	+15.86	320.0
	Ban Thabot Regulator	Chai Nat	Radial Gate	4	6.00	+8.75	+13.50	+9.80	+13.73	+13.68	318.0
	Sam Chook Regulator	Suphan Buri	Slide Gate	2	12.50	+2.50	+9.15	+6.30	+9.52	+9.31	318.0
	Pho Phraya Regulator	Suphan Buri	Slide Gate	2	12.50	+0.20	+6.00	+0.75	+5.91	+5.82	318.0
Noi River	Boromma-that Head Regulator	Cai Nat	Radial Gate	4	6.00	+9.60	+16.00	+15.10	+18.24	+16.20	260.0
	Channasut Regulator	Sing Buri	Radial Gate	4	6.00	+5.72	+11.60	+9.73	+11.84	+11.40	260.0
	Yang Mani Regulator	Sing Buri	Radial Gate	4	6.00	+2.32	+7.74	+6.16	+7.74	+7.30	260.0
	Phak Hai Regulator	Ayutthaya	Radial Gate	3	6.00	+2.00	+3.50	+3.30	+3.50	+3.30	150.0
Chai Nat-Pasak Canal	Manorom Head Regulator	Chai Nat	Radial Gate	6	6.00	+12.80	+16.472	+16.142	+20.00	+16.142	210.0
	Chongkae Regulator	Chai Nat	Radial Gate	6	6.00	+9.50	+13.390	+13.150	-	-	207.0
	Koke kathiem Regulator	Lop Buri	Radial Gate	4	6.00	+6.29	+10.79	+10.59	-	-	174.1
	Reong Rand Regulator	Saraburi	Radial Gate	3	6.00	+3.97	+8.53	+8.27	+9.810	+9.810	131.0
Chai Nat-Ayutthaya Canal	Maharaj Head Regulator	Chai Nat	Radial Gate	3	4.00	+11.60	+16.00	+15.50	+18.00	-	75.0
Makamthao-Uthong Canal	Makamthao-Uthong Head Regulator	Chai Nat	Slide Gate	6	1.75	+13.75	+16.10	+15.95	-	-	35.0
Pasak River	Rama VI Barrage	Saraburi	Slide Gate	6	12.50	+0.10	+7.50	-	+9.81	-	Unknown

Table 1.6.1 CROSS SECTION DATA

River Name	Interval	Agency	Year
Chao Phraya River (rivermouth to Pathum Thani)	5 km	AIT	1983
Chao Phraya River (Pathum Thani to In Buri)	5 km	JICA	1998
Chao Phraya River (In Buri to Chainat)	3~5 km	JICA	1988
Chao Phraya River (Chainat to Nakhon Sawan)	5 km	JICA	1997
Noi River	5 km	JICA	1997
Pasak River	5 km	JICA	1990
Tha Chin River	1 km	RID	1990
Lop Buri River	5 km	JICA	1997
Nan River	10 km	JICA	1997
Yom River	10 km	JICA	1997
Khlong Bang Bal	5 km	JICA	1998
Khlong Bang Luang	5 km	JICA	1998
Khlong Bang Keao	5 km	JICA	1998
Khlong Bang Phra Mo	5 km	JICA	1998

Table 1.6.2 ESTIMATED FLOW CAPACITIES OF RIVERS

River Name	Flow Capacity (m3/s)
Chao Phraya River (rivermouth to Pathum Thani)	3,200 - 3,600
Chao Phraya River (Pathum Thani to In Buri)	1,000 - 4,400
Chao Phraya River (In Buri to Chainat)	3,700 - 5,000
Chao Phraya River (Chainat to Nakhon Sawan)	1,500 - 4,500
Noi River	150 - 1,200
Pasak River	1,000 -2,000
Tha Chin River	200 - 400
Lop Buri River	300 - 600
Nan River	800 - 2,500
Yom River	100 -1,100
Khlong Bang Bal	160 - 500
Khlong Bang Luang	700 - 1,000
Khlong Bang Keao	450 - 850
Khlong Bang Phra Mo	Approx. 300

Table 2.2.1 PROBABLE UNDER FULL CONFINEMENT CONDITION

River	Station	Probable Discharge(m^3/s)					
		2yr	5yr	10yr	25yr	50yr	100yr
Ping	P.17(B.Phisai)	1,230	1,830	2,150	2,650	3,000	3,350
Yom	Y.4(Sukhothai)	870	1,400	1,750	2,490	2,550	2,880
	Y.17(Sam Ngam)	1,080	1,620	2,000	2,520	2,870	3,220
Nan	N.5A(Pitsanulok)	1,080	1,640	2,010	2,530	2,870	3,200
	N.7(Pichit)	1,270	1,900	2,320	2,860	3,230	3,610
Chao Phraya	C.2(Nakhon Sawan)	3,400	4,600	4,900	5,150	5,350	5,500
	C.13(Chainat)	3,250	4,350	4,680	5,100	5,400	5,700
	C.7A(Ang Thong)	2,340	2,950	3,250	3,600	3,900	4,200
	C.34(Ayutthaya)	1,560	1,770	2,120	2,300	2,500	2,650
	Bang Sai	3,960	5,040	6,000	7,150	8,000	8,700
Pasak	RamaIV Barrage	900	1,260	1,490	1,830	2,080	2,280

Table 2.2.2 ISSUES OF RIVER IMPROVEMENT MEASURES IN CHAO PHRAYA RIVER BASIN

Issues	Heightening of Existing Dike Construction of Dike Newly	Deepening of Riverbed	Widening of Channel Width
Change of Water Level	Water level is increased.	Water Level is lowered.	Water Level is lowered.
	Damage potential is also increased.	Damage potential is also lowered.	Damage potential is also lowered.
Land Acquisition	Small	Medium	Large
		Land acquisition for revetments for stablizing channel slope is required.	A lot of land acquisition and house evacuation is required.
Reconstruction or Reinforcement of Bridge	Approach ramps	Foundation of pier and abutment	Expansion of bridge length
	It is necessary to only improve approach ramps to bridge because the elevations of surface of existing bridges are enough high.	Dredging of riverbed might affect foundations of bridges.	Widening of river channel might require expansion of bridge length. reconstruction.
Maintenance Work	Small	Large	Small
		Periodical maintenance dredging is necessary.	

Table 2.2.3 EFFECTIVENESS OF MEASURES WHEN SOLELY APPLIED

Type	Alternative Measures		Discharge at Nakhon Sawan*1 in 1995 Flood (m3/s)	Discharge at Bang Sai in 1995 Flood (m3/s)	Water Level at Samsen (C.12) in 1995Flood (m MSL)	Water Level at Mem. Bridge (C.4) in 1995Flood (m MSL)	Total Inundation Volume in 1995 (billion m3)	Flood Damage in 1995 (mil. Baht)	Decrease of Damage in 1995 (mil. Baht)	Cost*2 (mil.Baht)	Decrease of Damage in 1995 by Cost
Future Basin Condition in 2018 (Without Project)			4,110	3,980	2.62	2.45	14.1	143,535	-	-	-
Non-structure	Modification of Dam Operation Rule	Case1: Flood Control Capacity of 4,400 mil. m^3	4,020	3,960	2.59	2.43	13.7	132,829	10,706	minimum	infinite
		Case2: Flood Control Capacity of 6,700 mil. m^3	3,890	3,950	2.58	2.42	13.4	125,467	18,068	185*3	97.66
		Case3: Flood Control Capacity of 9,100 mil. m^3	3,820	3,920	2.57	2.41	13.1	112,987	30,548	1,853*3	16.49
Structure	River Improvement from Nan and Yom to Pathum Thani	Case1: 2-year Return Period	4,250	4,570	2.97	2.97	13.2	540,234	-396,699	10,430	-38.03
		Case1: 3-year Return Period	4,290	5,200	3.33	3.33	13.9	1,543,899	-1,400,364	15,240	-91.89
		Case3: 5-year Return Period	4,350	5,400	3.46	3.46	13.7	2,034,769	-1,891,234	21,710	-87.11
	River Improvement from Chainat to Pathum Thani	Case1: 5-year Return Period	4,110	4,350	3.01	2.52	13.8	398,755	-255,220	3,490	-73.13
		Case2: 10-year Return Period	4,110	4,690	3.11	2.67	13.9	874,567	-731,032	4,170	-175.31
		Case3: 25-year Return Period	4,110	4,860	3.12	2.75	14.3	1,093,588	-950,053	4,850	-195.89
	Pasak-Raphipat-Sea Diversion	Case1: Q= 500 m3/s	4,110	3,750	2.47	2.33	13.5	89,651	53,884	19,100	2.82
		Case2: Q=1,000 m3/s	4,110	3,450	2.39	2.32	13.4	53,465	90,651	32,000	2.83
		Case3: Q= 1,500 m3/s	4,110	3,320	2.39	2.32	13.3	52,258	91,538	45,000	2.03
	Chainat-Pasak-Raphipat-Sea Diversion	Case1: Q= 500 m3/s	4,110	3,790	2.51	2.35	12.9	98,527	45,008	33,000	1.36
		Case2: Q=1,000 m3/s	4,110	3,540	2.38	2.24	11.9	46,397	97,138	60,000	1.62
		Case3: Q= 1,500 m3/s	4,110	3,170	2.18	2.13	10.9	43,049	100,486	88,000	1.14
	Ayutthaya-East-Sea Diversion	Case1: Q= 500 m3/s	4,110	3,550	2.38	2.31	13.7	51,543	91,992	19,700	4.67
		Case2: Q=1,000 m3/s	4,110	3,190	2.22	2.19	13.4	45,359	96,100	31,400	3.06
		Case3: Q= 1,500 m3/s	4,110	2,670	2.10	2.10	13.3	41,254	101,414	49,000	2.07

*1: C.2 Station

*2: Financial Capital Cost (exclusive of price contingency)

*3: Net Present Value of Annual Financial Cost

Table 2.2.4 REQUIRED CAPACITY OF AYUTTHAYA-EAST-SEA DIVERSION

Capaciy of AES Diversion (m3/s)	Combination of Applicable Measures			Discharge at Nakhon Sawan*1 in 1995 (m3/s)	Discharge at Bang Sai in 1995 (m3/s)	Water Level at Samsen (C.12) in 1995 (m MSL)	Water Level at Memorial Bridge (C.4) in 1995 (m MSL)	Total Inundation Volume in 1995 (billion m3)
	Dam	Retarding	River Training					
800 m3/s	14,600 mil. M3	5,600 km2	10yr (Chainat to Pathum Thani)	3,820	3,230	2.26	2.20	12.4
1,100 m3/s	14,600 mil. M3	5,600 km2	25yr (Chainat to Pathum Thani)	3,820	3,490	2.32	2.18	11.6

Note : The required capacity has been estimated so that the water levels at Samsen and the Memorial Bridge could be lowered below the actual levels in 1995, namely 2.32 and 2.20 m MSL respectively.

Table 3.1.1 IMPLEMENTATION SCHEDULE OF FLOOD PROTECTION AND DRAINAGE SYSTEM OF MAJOR URBAN AREA (NAKHON SAWAN TO NONTHABURI)

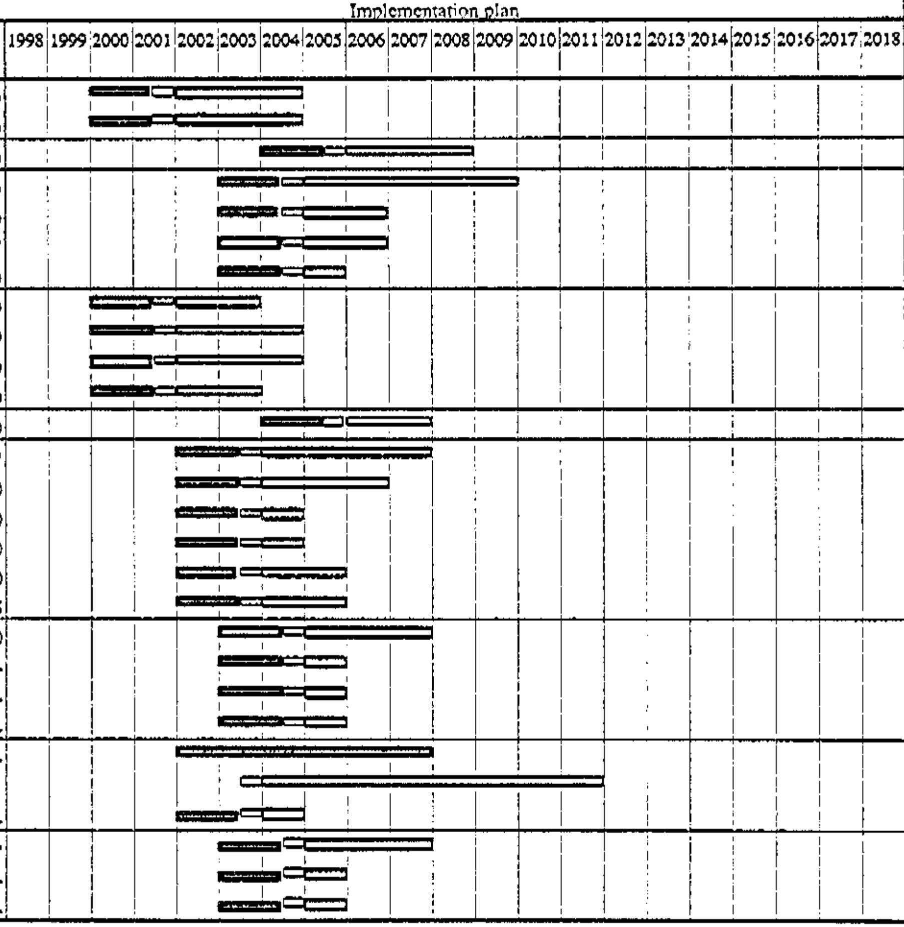
No.	Protection Area	Description	Exist. Facility: Facilit	Exist. Facility: Return Period	Exist. Facility: Dike El.(msl)	Flood Protection Plan: Facility	Flood Protection Plan: Return Period	Flood Protection Plan: Dike El.(msl)	Flood Protection Plan: F. board (m)	P. Area (km²)	Implementation plan (1998–2018)	C. Cost (Mil. Baht)	Remarks
1	N. Sawan (West Bank)	P. Muni.	Dike		24.4~28.7	Polder	100	28.0~29.0	0.4	21.0		1,475.1	
	Muang N. Sawan									103.8		2,690.0	
	Chumsaeng	Muni.				Polder	100	-	-	2.4		90.0	F/S, D/D required
	Krok Phra	S. D.				Polder	100	-	-	2.8		48.7	F/S, D/D required
	Phayuha Khiri	S. D.				Polder	100	-	-	1.8		48.6	F/S, D/D required
2	Chai Nat / East								0.5	11.2		136.2	
	A. Muang Chai Nat	P. Muni.	Dike		17.6~18.7	Polder	100	18.7~19.0		4.0		82.0	
	Ban Kluay	East bank	Dike		17.0~17.8	Polder	100	18.1~18.6		7.2		54.2	
	Chai Nat / West		Dike		17.5~18.6					6.4		120.4	
	Tha Chai	West bank	Dike		17.6~18.2	Polder	100	18.5~18.9		3.1		63.5	
	Had Tha Sao	West bank	Dike		18.2~19.2	Polder	100	19.0~19.15		3.3		56.9	
	Wat Sing	Muni.	Road		18.5~18.6	Polder	100	20		0.5		62.4	
3	Sing Buri	P. Muni.	Dike		13.06 *	Polder	100	13.25	0.5	11.98		2,009.8	
	Sub-area	1&5								6.15		1,144.0	
	Sub-area	7&8								4.99		636.0	
	Sub-area	2&6								0.69		82.5	
	Sub-area	3								0.15		147.3	
	In Buri					Polder	100	-	-	3.32		754.8	F/S, D/D required
	Sub-area	2&3								1.71		474.1	
	Sub-area	4								0.51		135.4	
	Sub-area	1								1.10		145.3	
	Phrom Buri									2.37		465.4	
	Bang Nam Chio		Dike		RID D.								
	Sub-area	1,2				Polder	100	-	-	1.23		165.0	F/S, D/D required
	Pak Bang												
	Sub-area	2				Polder	100	-	-	0.51		147.1	F/S, D/D required
	Sub-area	1&3								0.63		153.3	
4	Ang Thong									12.87		2,000.6	
	Talat Luang (W. bank)	P. Muni.	Dike		8.3~8.75	Polder	100	9.0	0.2	5.28		726.7	
	Bang Kaeo (E. bank)	P. Muni.			8.3~8.4	Polder	100	9.0	0.2	6.07		949.8	
	Talat Kruat	P. Muni.				Polder	100	9.0	0.2	1.52		324.1	D/D required
	Pamok (S.D)	Pamok				Polder	100	-	-	7.88		804.2	F/S, D/D required
	Bang Plakot (S.D)					Polder	100	-	-	7.80		1,029.8	F/S, D/D required
5	Ayuthaya									18.4		591.4	
	Ko Muang	P. Muni.	Road		4.6~6.1	Road	100	6.0		13.0		419.4	
						Dike	100	6.3~6.5	0.3~0.5				
	Ayothaya		Road		4.7~6.1	Road	100	6.0		5.4			
						Dike	100	6.3~6.5	0.3~0.5			172.0	
6	Pathum Thani									119.4		1,636.8	
	Muang Pathum T.	Polder	Rd., Dike		2.0~2.6	Polder	100	3.7~4.0	0.4/0.6**	8.8		292.9	
	B. Luang / Chieng Rak	Polder	Road		2.5~3.4	Polder	100	3.7~4.0	0.4/0.6**	39.5		725.5	
	B. Pho Tai / B. Luang	Polder	Road		2.4~2.7	Polder	100	3.7~3.8	0.4/0.6**	71.1		618.4	
7	Nonthaburi									232.5		3,715.3	
	Pak Kret	East bank	Road		2.6					82.5*			Completed 1997
	Pak Kret	East bank	D / W	100	3.15								
	Nonthaburi	East bank	Road										
	Nonthaburi	East bank	-		1.33~1.98	Polder	100	2.85~3.0	0.5***	3.0		275.5	
	B. Kruai, B. Bua Thong	West bank	-		1.43~2.23	Polder	100	2.85~3.15	0.5***	150.0		2,681.6	
	Extra Area	West bank								-		758.2	
8									total	566.4	total	17,679.5	

Note: ▭ Detailed Design, ▭ Bidding, ▬ Under Construction, ▭ Implementation, * Total area of East Bank, ** 0.4 : Concrete dike, 0.6 : Ear *** Including land subsidence : 0.2m

P. Area = Polder Area, P.Mini. = Provincial Municipality, Muni.= Municipality, S.D. = Sanitary District, D / W = Dike & Wall, C.Cost = Costruction Cost(Price level : 1997), F. board is depends on the local situation along the dikes

Table 3.1.2 IMPLEMENTATION SCHEDULE OF FLOOD PROTECTION AND DRAINAGE SYSTEM OF SECONDARY URBAN AREA

o	Location	Description	Flood Protection Plan: Facility	Return Period: Drain.	Return Period: Flood	No. of Pump St.	P. Capa. (cms)	Implementation plan (1998–2018)	C. Cost (Mil. Bahts)	Remarks
1	Sukhothai	P. Muni.	Polder	5	100	3	24.0		312.3	
	Sawankhalok	Muni.	Dike	5	100	2	16.0		331.2	
2	Uttaradit	P. Muni.	Polder	5	100	1	10.0		341.3	
3	Phitsanulok	P. Muni.	Polder	5	100	3	59.0		766.5	
	B. Rakham	S.D.	Polder	5	100	2	6.0		141.2	
	B.Krathum	S.D.	Polder	5	100	1	8.5		137.3	
	Phrom Phiram	S.D.	Polder	5	100	1	1.0		81.5	
4	Phichit	P. Mini.	Polder	5	100	2	14.0		275.1	
	Taphan Hin	Muni.	Polder	5	100	2	10.0		312.7	
	B. Mun Nak	Muni.	Polder	5	100	3	14.0		325.4	
	Pho Thale	S.D.	Polder	5	100	3	12.0		174.3	
5	Uthai Thani	P. Muni.	Polder	5	100	1	14.0		230.1	
6	Suphan Buri	P. Muni.	Polder	5	100	*	*		645.0	
	Songpeenong	Muni.	Polder	5	100	3	6.0		317.0	
	Phai Khong Din	S.D.	Polder	5	100	2	2.0		95.8	
	Ban Leam	S.D.	Polder	5	100	2	2.0		85.6	
	B. Pla Ma	S.D.	Polder	5	100	2	2.0		136.9	
	Khok Khram	S.D.	Polder	5	100	3	2.5		174.9	
7	Nakhon Phathom	P. Muni.	*	5	100	1	3.0		332.5	
	Rang Krathum	S.D.	Polder	5	100	Nil	-		34.6	
	B. Luang	S.D.	Polder	5	100	Nil	-		14.9	
	B. Leng	S.D.	Polder	5	100	Nil	-		49.5	
8	Samut Sakhon	P. Muni.	Polder	5	100	?	-		3,968.2	
	Om Noi		Dike	5	100	Nil	-		58.7	
9	Lop Buri	P. Muni.	Dike	5	100	**	**		393.4	
	Tha Wung	S.D.	Polder	5	100	Nil	-		40.7	
	Tha Khlong	S.D.	Polder	5	100	Nil	-		32.5	
10								total	9,809.1	



Note; Feasibility Study & Detailed Design, Implementation, P. Muni. = Provincial Municipality, Muni. = Municipality, S.D. = Sanitary District,
C.Cost = Construction Cost (Price level : 1998)

Table 3.1.3 FEATURES OF NEW REGULATORS IN LOP BURI RIVER WITH KHLONG BANG KAEO

Location	River/Canal	Lopburi	Bang Kaeo	Lopburi	Bang Phra Khru
	Point	2+832	15+080	31+950	Beginning Point
Objective		Storage of Water in Dry Season			
Gate	Number of Gate	4	4	5	3
	Width of Gate (m)	6	6	6	6
	Design Discharge (m3/s)	270	250	400	190
Elevation (MSL)	Ground Sill	3	-1.5	-0.5	-1.5
	Top of Gate	7.05	4.5	6.8	4.5
	Embankment	13	7	9.5	6.5
Schedule	Budget (mil Baht)	60	60	74	48
	Completion (Year)	1999 (under construction)	1999 (under construction)	1999 (under construction)	1999 (under construction)

Table 3.1.4 CHARACTERISTICS OF BARRAGE KM. 205 AND BARRAGE KM. 345

Item	Barrage km. 205	Barrage km. 345
River around Headwork Area	T. Phra Ngam A. Phrom Buri C. Sing Buri	T.Nam Song A. Phayuha Khiri C. Nakhon Sawan
Elevation of River Bank (m. MSL)	9-10	21-22
Elevation of River Bed (m. MSL)	-1	12.5
River Width (m)	150	200
Headwork Area		
Width of Diversion Canal (m)		
Upstream/Downstream	215/235	410/305
at Barrage Site	244	370
Flow Control Structure		
No. of Control Gates	12	20
Width of Control Gate	12.5	20
Sill Level (m. MSL)	-1	12.5
Level of Upper Edge of Sluice Gate when Closing (m. MSL)	10	22
Level of Lower Edge of Sluice Gate when Closing (m. MSL)	13	23
Drainage Capacity (m3/s)	4120	4564
Level of Roadway Bridge Surface	15.3	26.9
Width of Roadway Bridge	6	6
Max. Storage Level (m. MSL)	12.03	21.72
Storage Level (Dry/Rainy Season) (m. MSL)	9.00/8.00	21.00/20.00
Min. Downstream Water Level (m. MSL)	1.15	15.5
Max. Downstream Water Level (m. MSL)	11.9	21.5
Max. Flow (50 years return period (m3/s))	4120	4560
Designed Flow for Downstream Demand (m3/s)	80	200
Navigation Lock (number)	1	1
Width (m)	14	14
Length of Lock Chamber (m)	165	135
Downstream Sill Level (m)	-3	11
Fish Ladder (Number)	2	2
Width (m)	4	4
Slope	1:10	1:10
Hydropower Plant		
Type of Turbine	pit turbine	pit turbine
Designed Head (m)	6	4
Designed Flow (m3/s)	160	440
Installed Capacity (MW)	8.05	14.76
Average Hydropower (million units/year)	47.15	98.6
Closure Dam		
Crest Level (m. MSL)	13.5	22.8
Width of Road on the Crest (m)	6	6

Table 3.2.1 Summary of Flow Capacity

River	Storetch Name	Location	Minimum Flow Capacity			
			left		right	
			(m^3/s)	Return Period (yr)	(m^3/s)	Return Period (yr)
Chao Phraya	Chao-1	Chao Phraya Dam to Lop Buri River	3,670	12	3,570	9
	Chao-2	Lop Buri R. To K. Bang Kaeo	3,220	7	3,300	8
	Chao-3	K. Bang Kaeo to K. Bang Luang	2,240	4	2,790	17
	Chao-4	K. Bang Luang to K. Bang Bal	1,760	7	2,000	20
	Chao-5	K. Bang Bal to Pasak R.	1,340	5	900	1.8
	Chao-6	Pasak R. to Noi R.	2,820	4	2,300	2.5
	Chao-7	Noi R to Pathum Thani	2,990	1.9	2,520	1.3
Lop Buri	Lop-1	Chao Phraya R. to K. Bang Kaeo	200	2.5	280	6
	Lop-2	K. Bang Kaeo to Pasak R.	480	4	280	1.7
Pasak	Pas-1	Rama VI Barrage to K. Bang Phra Khru	1,010	4	970	3.5
	Pas-2	K. Bang Phra Khru to Lop Buri River	1,170	5.5	1,150	5
	Pas-3	Lop Buri R. to Chao Phraya R.	2,000	10	1,700	5
Noi R.	Noi-1	K. Bang Luang to K. Bang Phra Mo	1,020	25	1,020	25
	Noi-2	K. Bang Phra Mo to K. Bang Phra Mo	630	13	530	5
	Noi-3	K. Bang Phra Mo to K. Bang Bal	630	1.9	800	5
	Noi-4	K. Bang Bal to Chao Pharaya R.	960	2.5	1,140	6
K. Bang Kaeo	BK	Chao Phraya R. to Lop Buri River	590	4	580	4
K. Bang Phra Khru	BPK	Lop Buri R. to Pasak R.	330	5	330	5
K. Bang Luang	BL	Chao Phraya R. to Noi R.	720	8	820	15
K. Bang Bal	BB	Chao Phraya R. to Noi R.	350	6	160	1.3
K. Bang Phra Mo	BPM	Noi R. to Noi R.	300	20	280	6

Note : Flow capacity was estimated at the level which is 30 cm below the dike level.

Table 3.2.2 DESCRIPTION OF PROTECTION AREA

No.	Location	Area (km2)	Return Period of Existing Flow Capacity			Protection Level of Area (yr)	Main Land Use
			River Stretch	Left/Right	(yr)		
1	Area surrounded by Lop Buri and Pasak Rivers, Chainat-Pasak Canal and Khlong Bang Phra Khru	410	Lop-1	Left	2 to 3	2 to 3	Rice (HYV, DWR, FR)
			BPK	Left	5 to 10		
			Pas-1	Right	3 to 5		
2	Area surrounded by Pasak River and RID left dike of Chao Phraya River	850	Pas-1	Left	3 to 5	3 to 5	Rice (HYV, DWR, FR)
			Pas-2	Left	5 to 10		
3	Area surrounded by Lop Buri and Pasak Rivers and Khlong Bang Phra Khru	70	Lop-2	Left	3 to 5	3 to 5	Rice (DWR)
			BPK	Right	5 to 10		
			Pas-2	Right	5 to 10		
4	Area surrounded by Chao Phraya and Lop Bur Rivers, and Khlong Bang Kaeo	180	Chao-3	Left	3 to 5	less than 2	Rice (DWR)
			Lop-2	Right	less than 2		
			BK	Right	2 to 3		
5	Area surrounded by Chao Phraya and Noi Rivers, and Khlong Bang Luang and Bang Bal	45	Chao-4	Right	10 to 25	less than 2	Rice (DWR)
			Noi-3	Left	less than 2		
			BL	Left	5 to 10		
			BB	Right	less than 2		
6	Area surrounded by Chao Phraya and Noi Rivers, and Khlong Bang Bal	180	Chao-5	Right	less than 2	less than 2	Rice (DWR, FR)
			Chao-6	Right	2 to 3		
			Noi-4	Left	2 to 3		
			BB	Left	5 to 10		
7	Area surrounded by Chao Phraya River and RID right dike of Chao Phraya River	120	Pas-3	Left	3 to 5	less than 2	Rice (DWR)
			Chao-6	Left	2 to 3		
			Chao-7	Left	less than 2		
8	Area surrounded by Chao Phraya and Thachine Rivers and Khlong Phraya Ban Lu	1,100	Chao-7	Right	less than 2	2 to 3	Rice (HYV)

Table3.3.1 EFFECTIVENESS OF RIVER IMPROVEMENT

Case	Protection Level	Protection Area	Benefit (mil baht)*			Capital Cost (mil.baht)	Benefit by Capital Cost	Remarks
			Protected	Unprotected*	Total			
5-1	5-yr	Area-1	120	-40	80	390	0.21	Economically Viable
5-2	5-yr	Area-1 to 2	201	-60	141	500	0.28	Economically Viable
5-3	5-yr	Area-1 to 3	201	-60	141	630	0.22	Economically Viable
5-4	5-yr	Area-1 to 4	203	-96	107	910	0.12	
3	3-yr	All Areas	221	0	221	1234	0.18	Economically Viable

* : Average Annual Damage Decrease by River Improvement in 2006 Condition

Table 3.3.2 FLOOD DAMAGE AMOUNT AND INUNDATION VOLUME IN EACH PROBLEM AREA

(1) Inundation Volume

(a) 1957 Flood (3-year Flood)

(mil m^3)

Case	Area-1	Area-2	Area-3	Area-4	Area-5	Area-6	Area-7	Area-8	Total
WOP	187	674	30	114	137	225	87	275	1,729
Case5-1	111	677	30	136	138	243	88	286	1,708
Case5-2	111	623	30	143	141	249	90	287	1,674
Csae5-3	111	623	30	143	141	249	90	287	1,674
Csae5-4	111	623	30	102	154	283	101	290	1,695
Case3	112	683	30	104	90	172	82	209	1,481

(b) 1996 Flood (5-year Flood)

(mil m^3)

Case	Area-1	Area-2	Area-3	Area-4	Area-5	Area-6	Area-7	Area-8	Total
WOP	209	316	45	95	73	323	96	134	1,291
Case5-1	22	321	80	228	74	329	98	136	1,288
Case5-2	22	266	92	245	74	338	98	144	1,280
Csae5-3	22	266	28	263	74	348	99	152	1,251
Csae5-4	22	267	28	46	102	391	142	228	1,226

(2) Damage

(a) 1957 Flood (3-year Flood)

(mil.baht)

Case	Area-1	Area-2	Area-3	Area-4	Area-5	Area-6	Area-7	Area-8	Total
WOP	558	1,389	19	70	140	256	135	1,436	4,002
Case5-1	319	1,389	19	75	140	271	135	1,494	3,841
Case5-2	319	1,139	19	80	150	284	142	1,520	3,653
Csae5-3	319	1,139	19	80	150	284	142	1,520	3,653
Csae5-4	319	1,139	19	53	164	317	157	1,568	3,735
Case3	319	1,389	19	53	91	140	88	924	3,023

(b) 1996 Flood (5-year Flood)

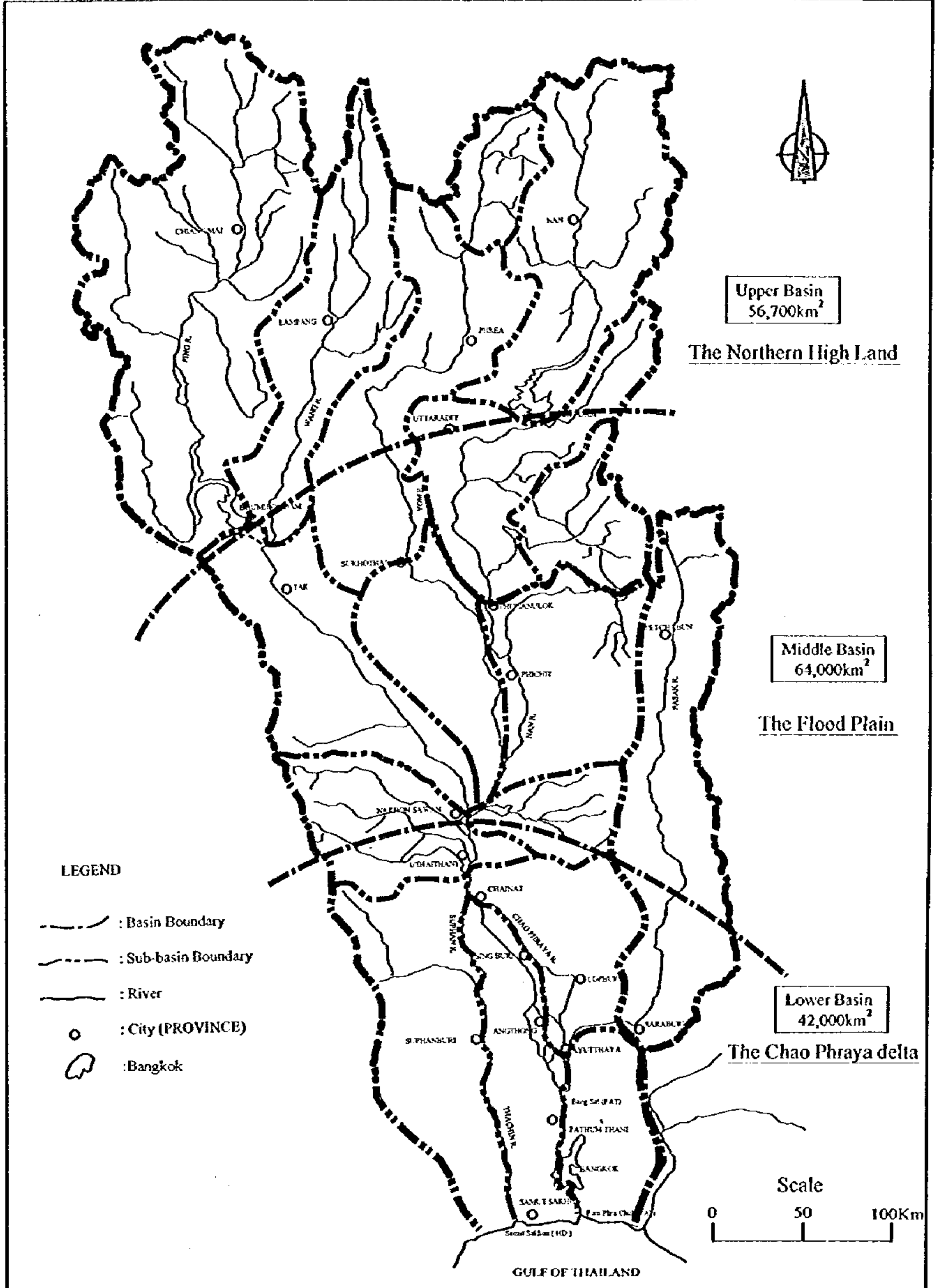
(mil.baht)

Case	Area-1	Area-2	Area-3	Area-4	Area-5	Area-6	Area-7	Area-8	Total
WOP	768	428	5	56	79	351	163	591	2,441
Case5-1	50	438	38	138	83	364	174	677	1,961
Case5-2	50	325	40	142	83	379	174	679	1,872
Csae5-3	50	325	5	154	84	394	174	687	1,872
Csae5-4	50	325	5	43	96	424	184	833	1,960

WOP : without project

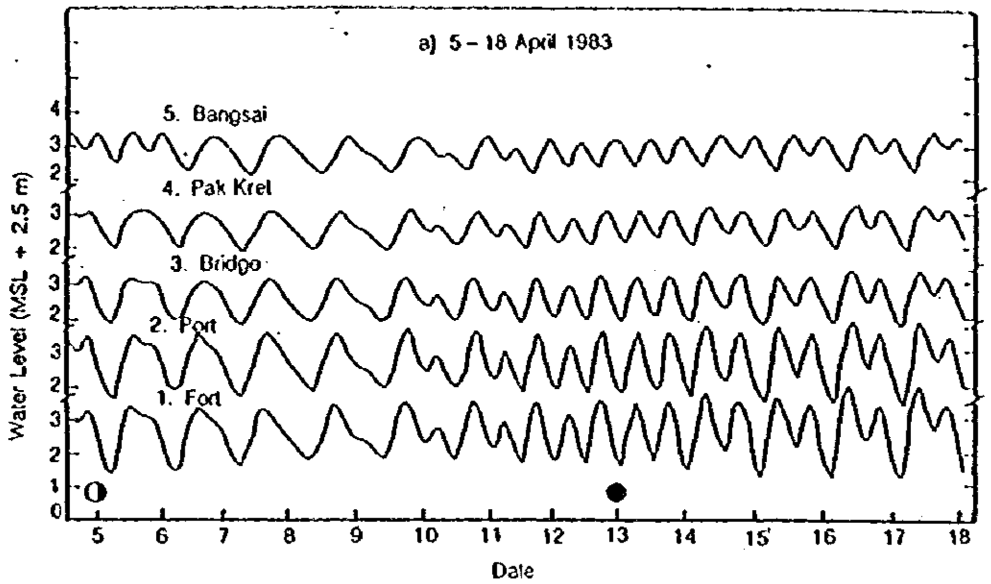
Protected Area (shaded)   Unprotected Area (unshaded)

Figures

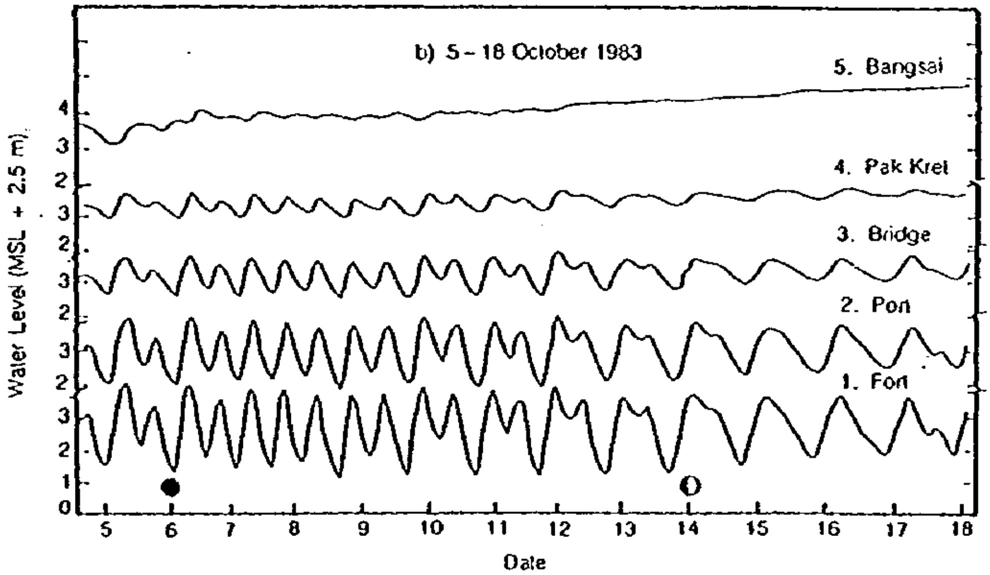


STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig. 1.1.1 THE DIVISION BY HYDROLOGICAL FEATURES IN CHAO PHRAYA RIVER BASIN
CTI ENGINEERING CO., LTD AND INA CORPORATION	

DRY SEASON

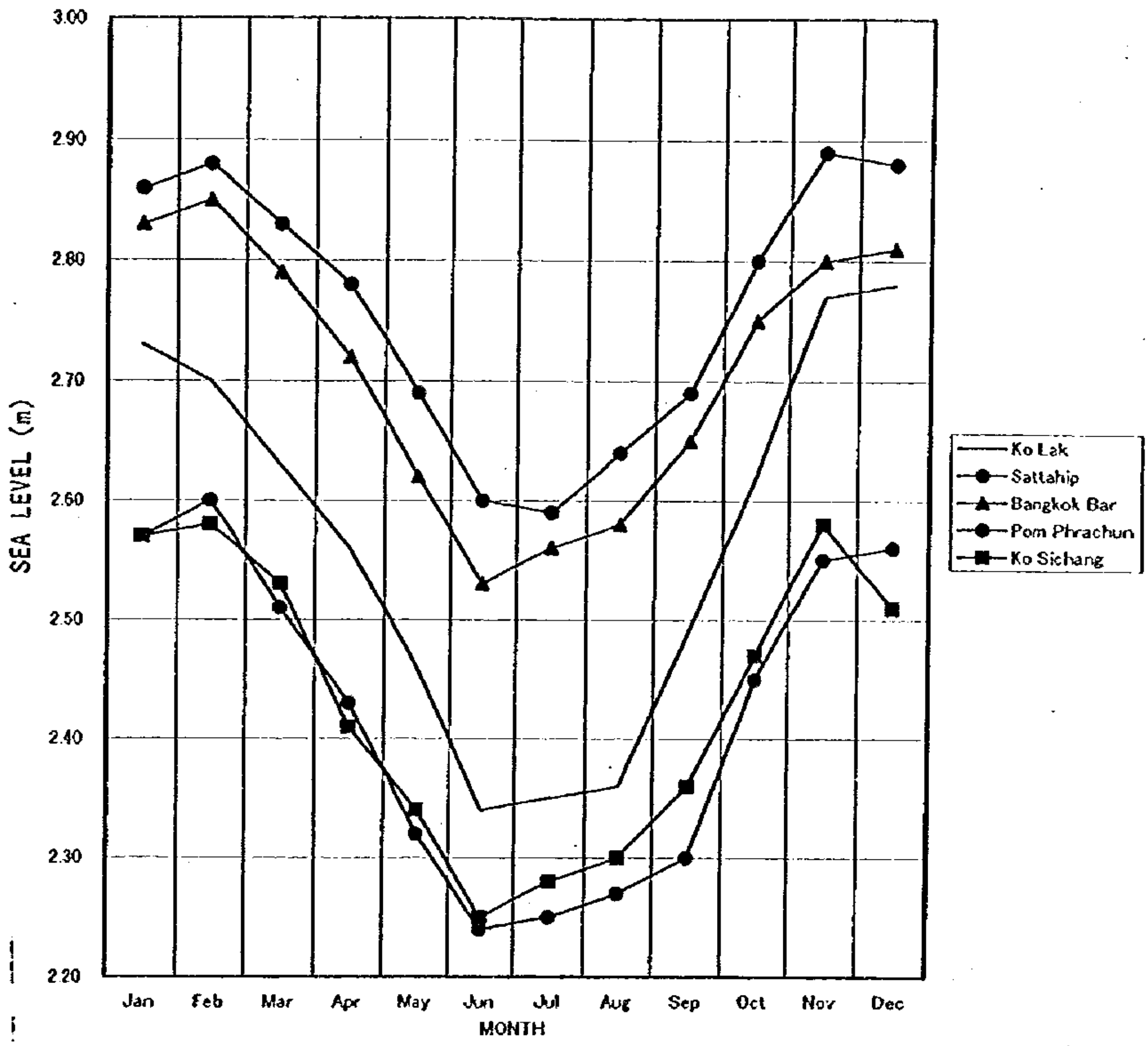


RAINY SEASON



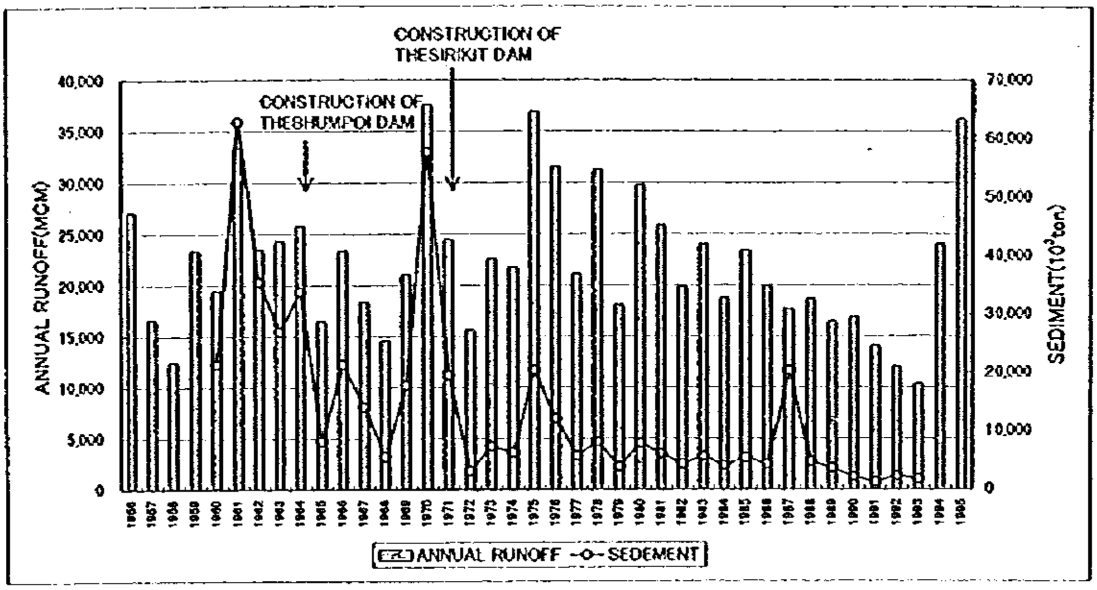
Data Source: "Lecture Note on Tidal hydraulics and Pollution Analysis in Estuaries by Prof. Suphat Vongvisessomjai, AIT"

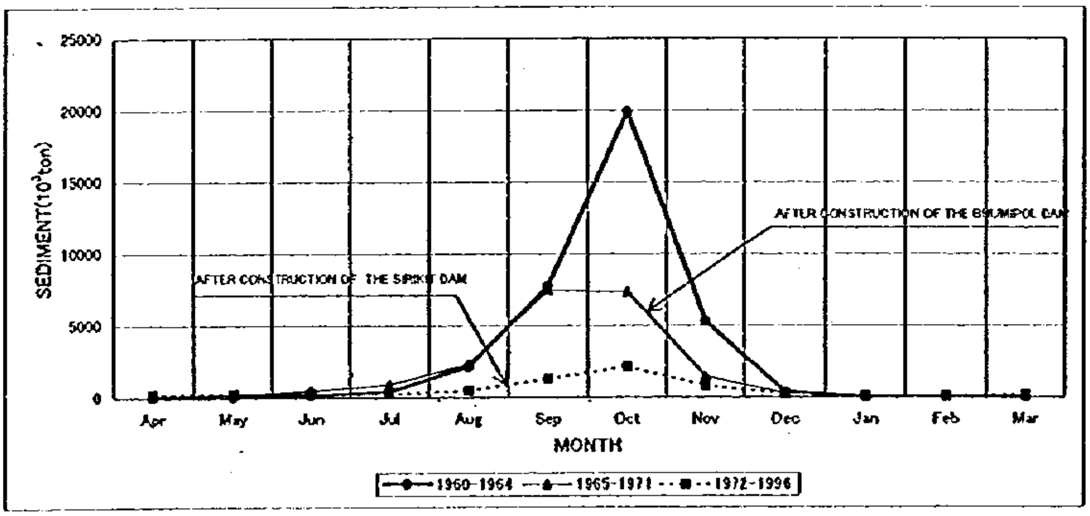
STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig.1.2.1
CTI ENGINEERING CO., LTD AND INA CORPORATION	OBSEVED TIDAL WAVE IN LOWER CHAO PHRAYA RIVER



Data Source: Hydrographic Dept., Royal Thai Navy

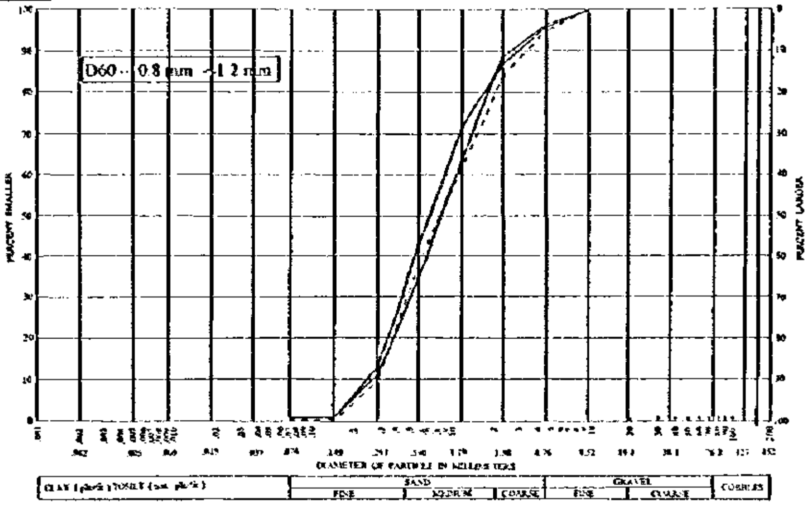
STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig.1.2.2
CTI ENGINEERING CO., LTD AND INA CORPORATION	SEASONAL VARIATION OF SEA LEVEL



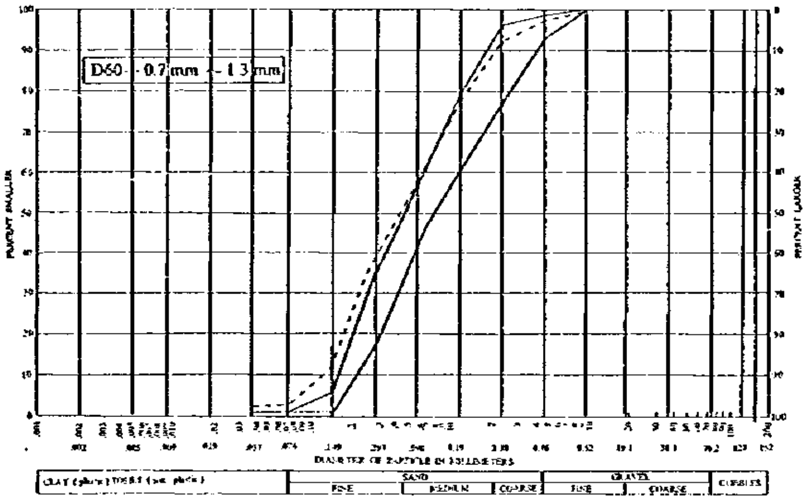


STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig. 1.3.1 ANNUAL SEDIMENT RUNOFF AT NAKHON SAWAN (STA.C2)
CTI ENGINEERING CO., LTD AND INA CORPORATION	

CHAO PHRAYA (C2)



PING (7A)



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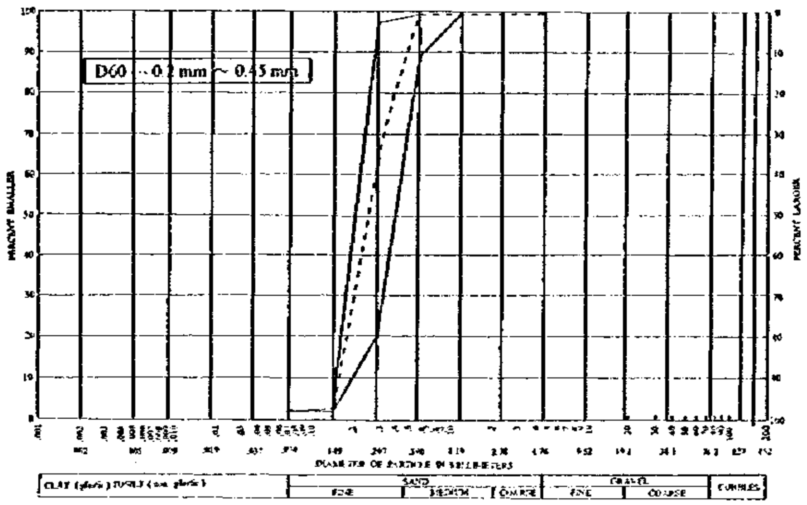
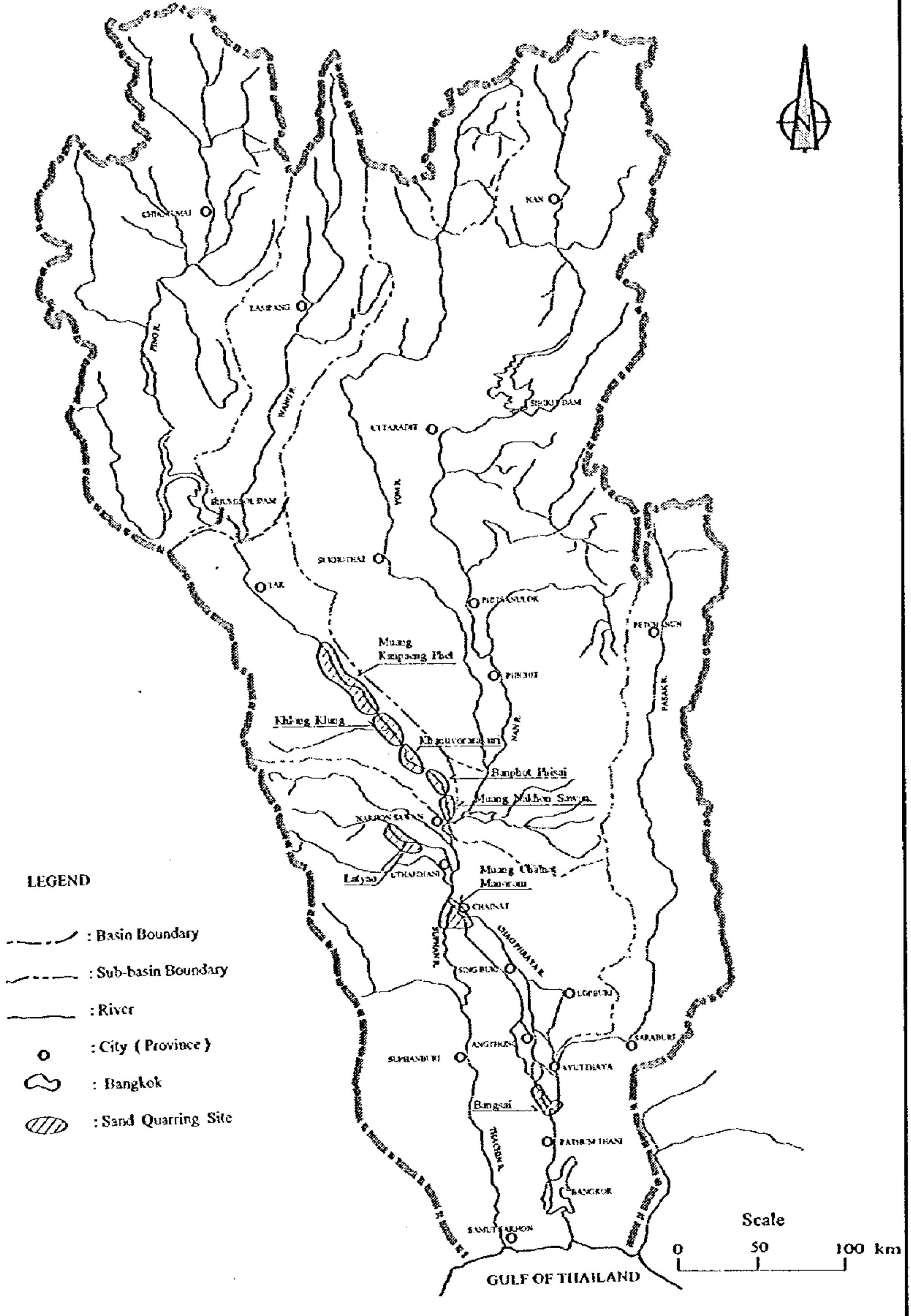
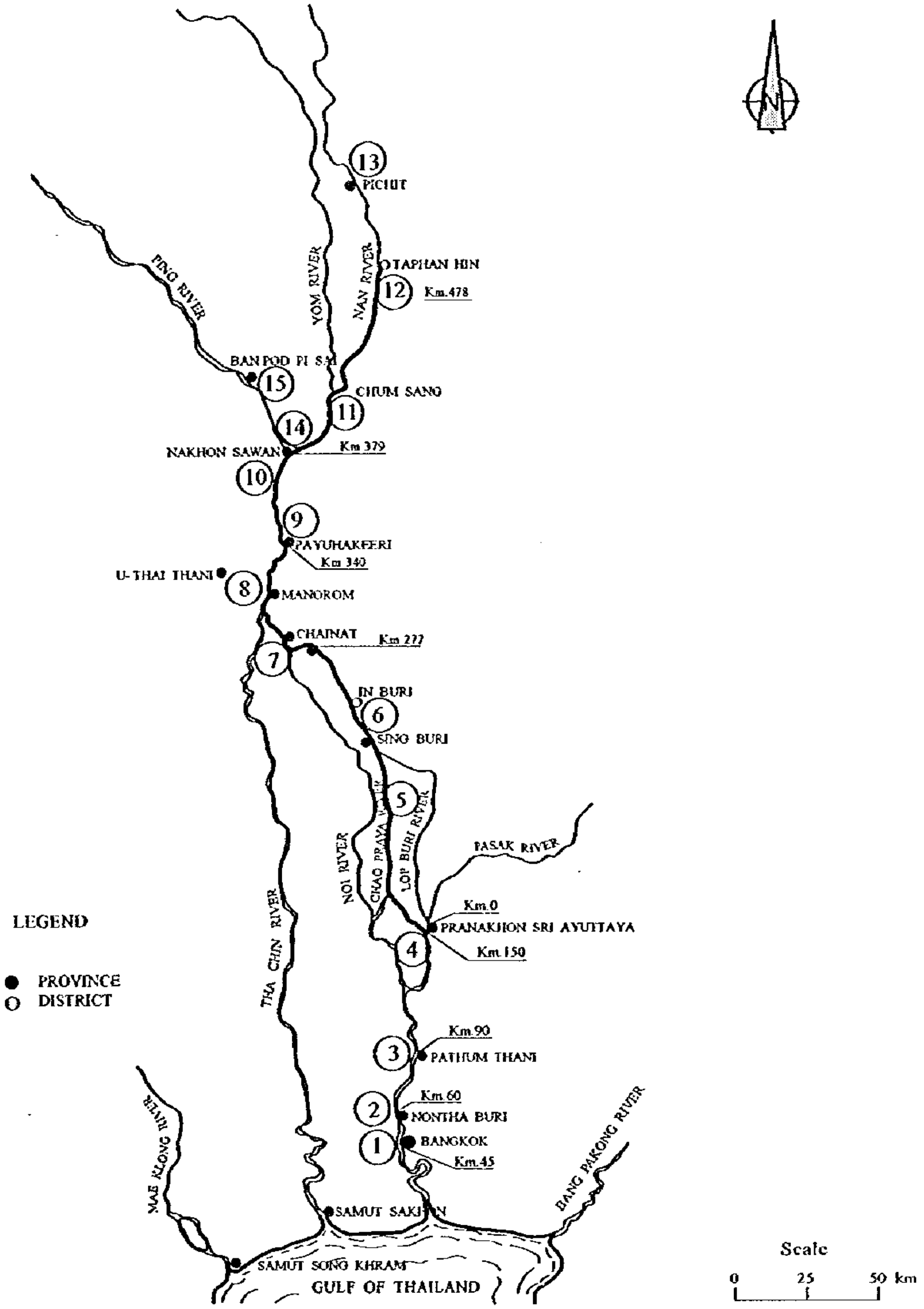


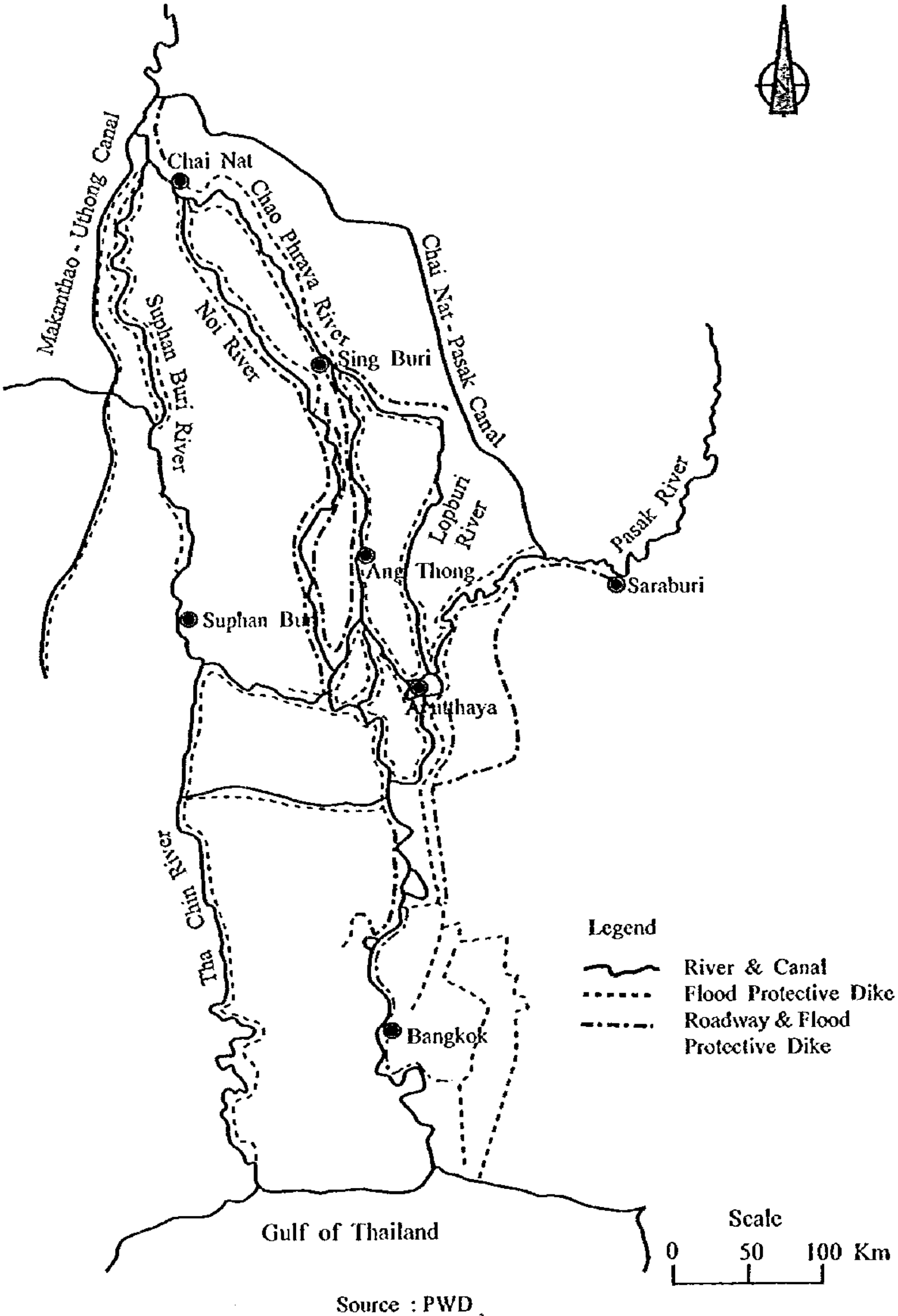
STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig. 1.3.2 GRADATION CURVE OF RIVERBED MATERIAL
CTI ENGINEERING CO., LTD AND INA CORPORATION	



STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig. 1.3.3 LOCATION OF THE SAND QUARRING SITE
CTI ENGINEERING CO., LTD AND INA CORPORATION	

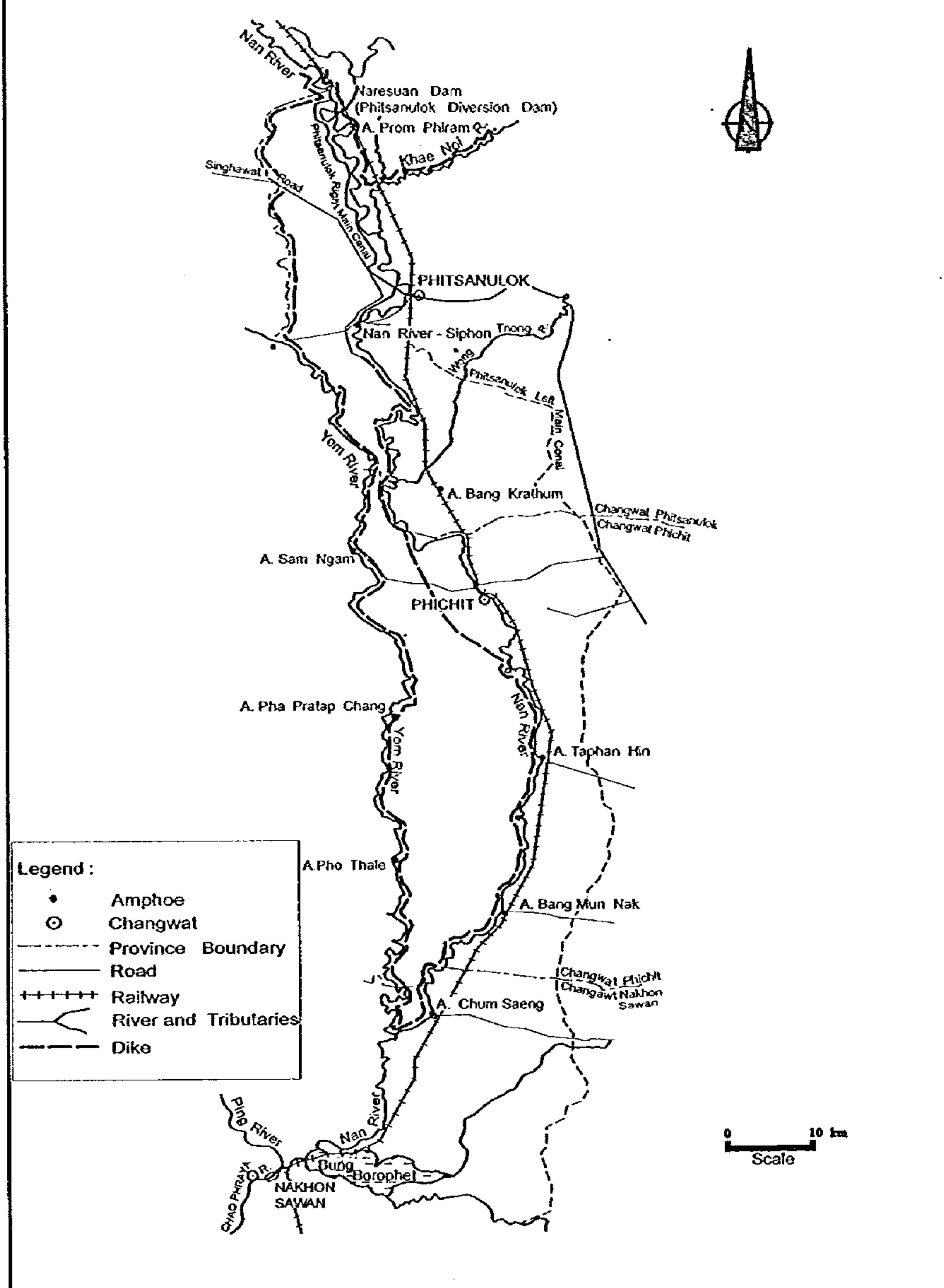


STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig. 1.4.1 LOCATION OF WATER SAMPLING STATION
CTI ENGINEERING CO., LTD AND INA CORPORATION	

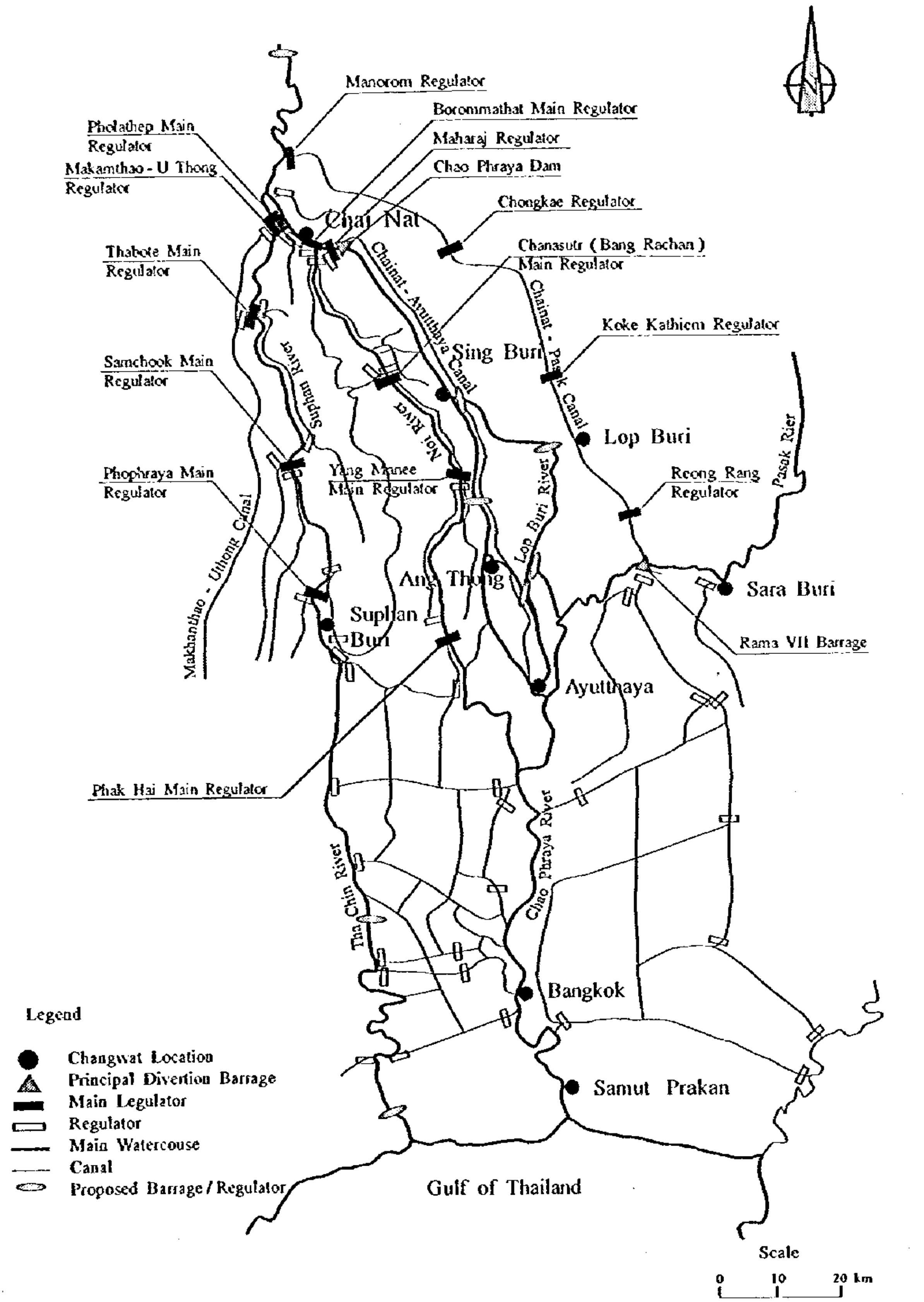


Source : PWD

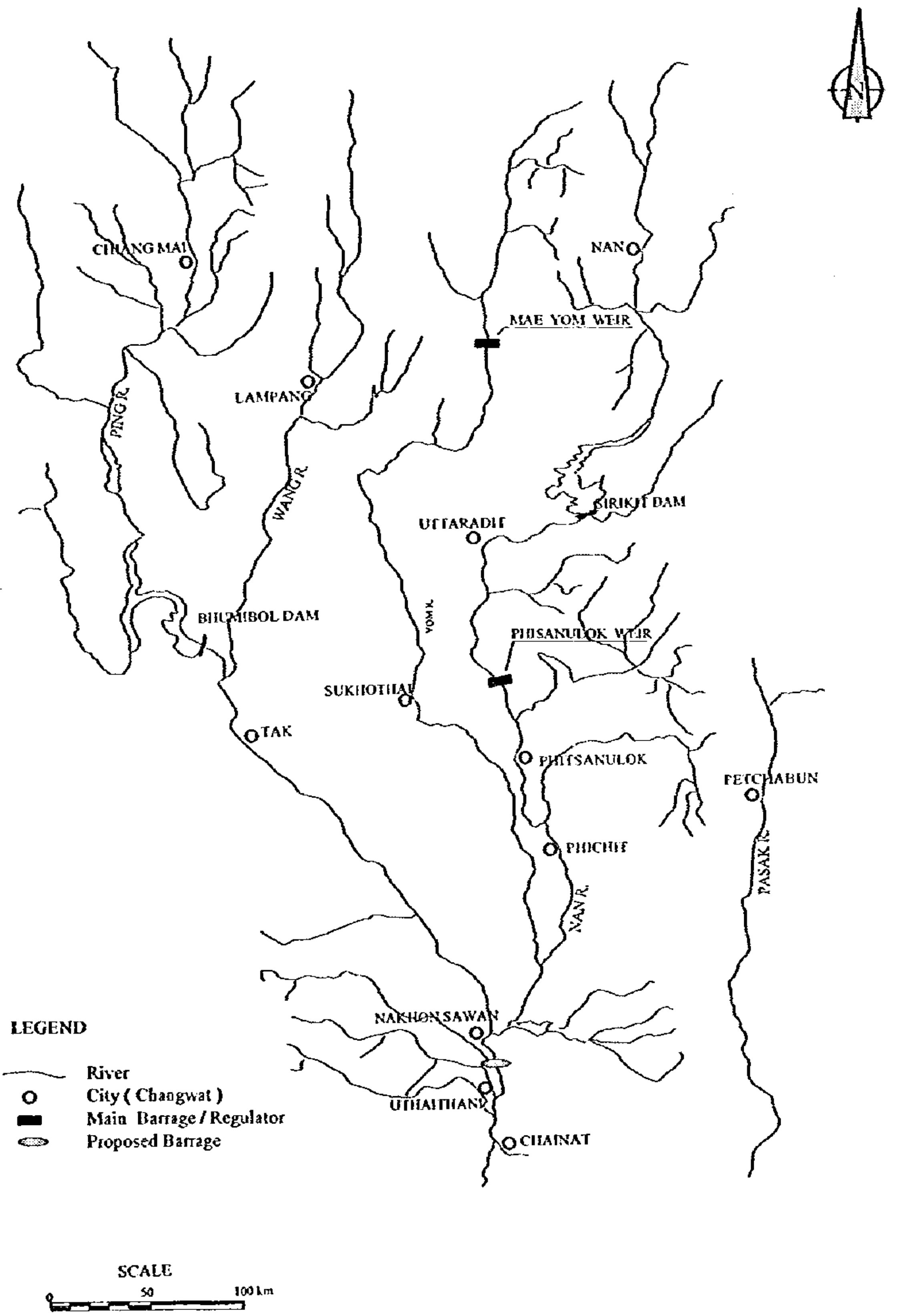
STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig . 1.5.1(1/2) EXISTING DIKE ALIGHMENT
CTI ENGINEERING CO., LTD AND INA CORPORATION	



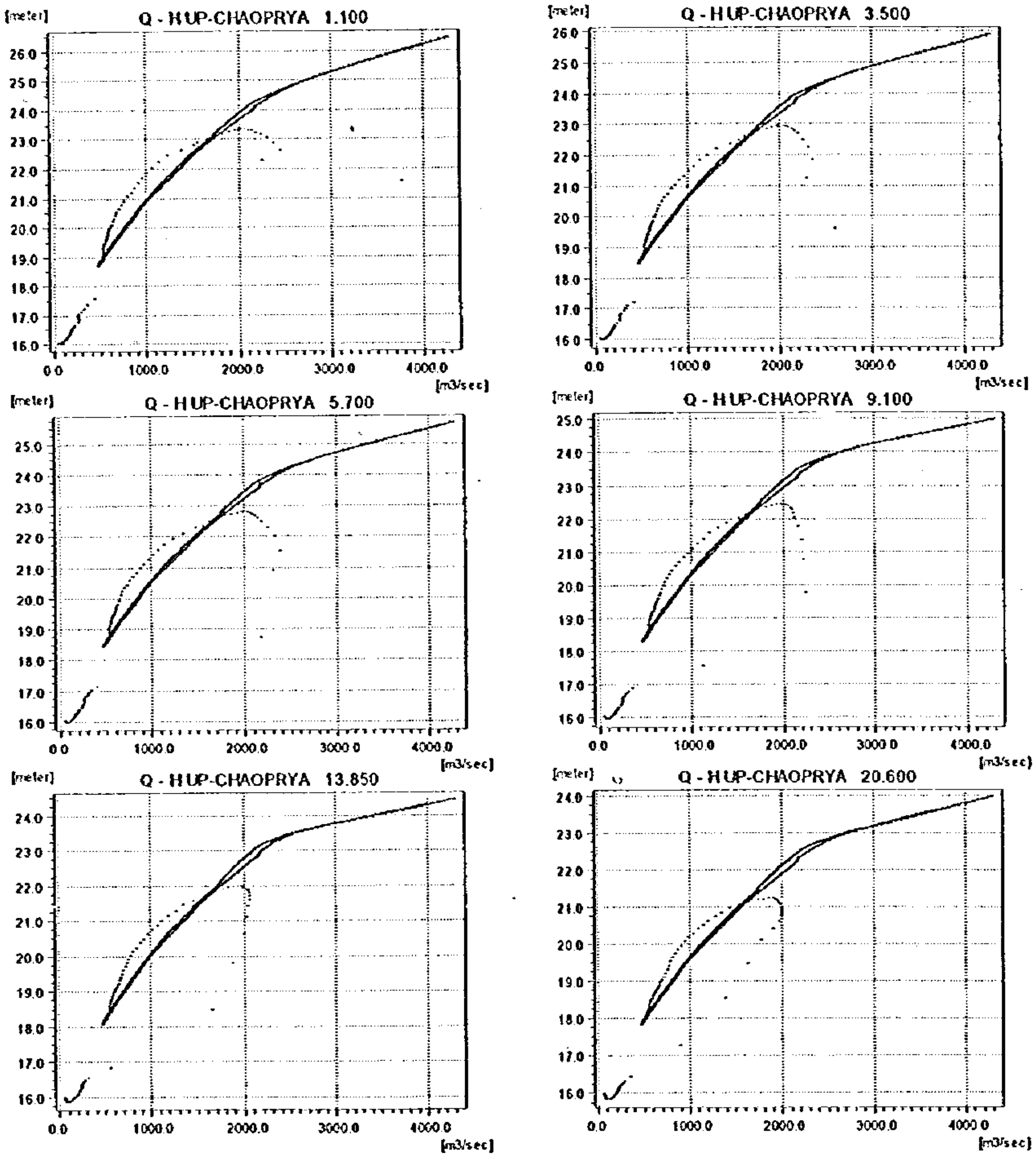
STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig. 1.5.1(2/2) EXISTING DIKE ALIGHMENT
CTI ENGINEERING CO., LTD AND INA CORPORATION	



STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig. 1.5.2 (1/2) LOCATION OF EXISTING AND PROPOSED WEIR / BARRAGE / REGULATORS
CTI ENGINEERING CO., LTD AND INA CORPORATION	

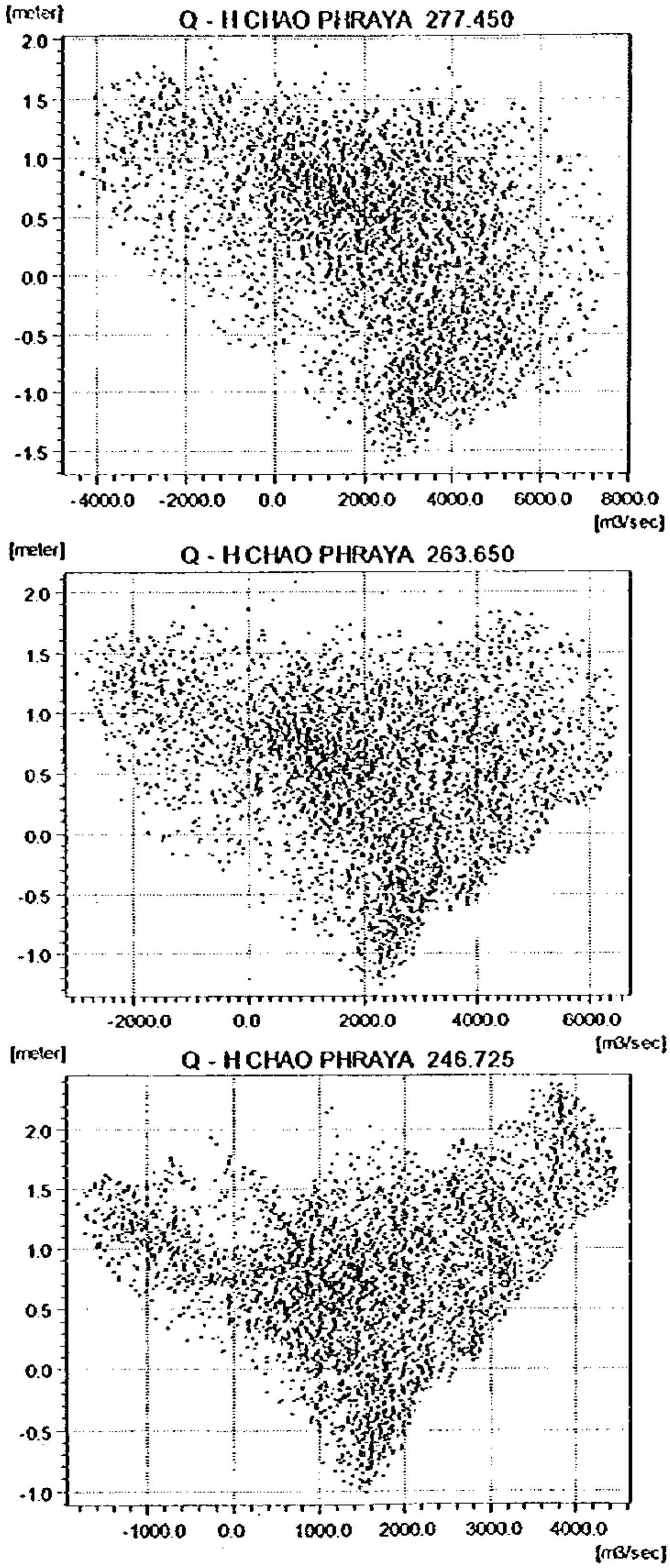


STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN CTI ENGINEERING CO., LTD AND INA CORPORATION	Fig . 1.5.2 (2/2) LOCATION OF EXISTING AND PROPOSED WEIR / BARRAGE / REGULATORS



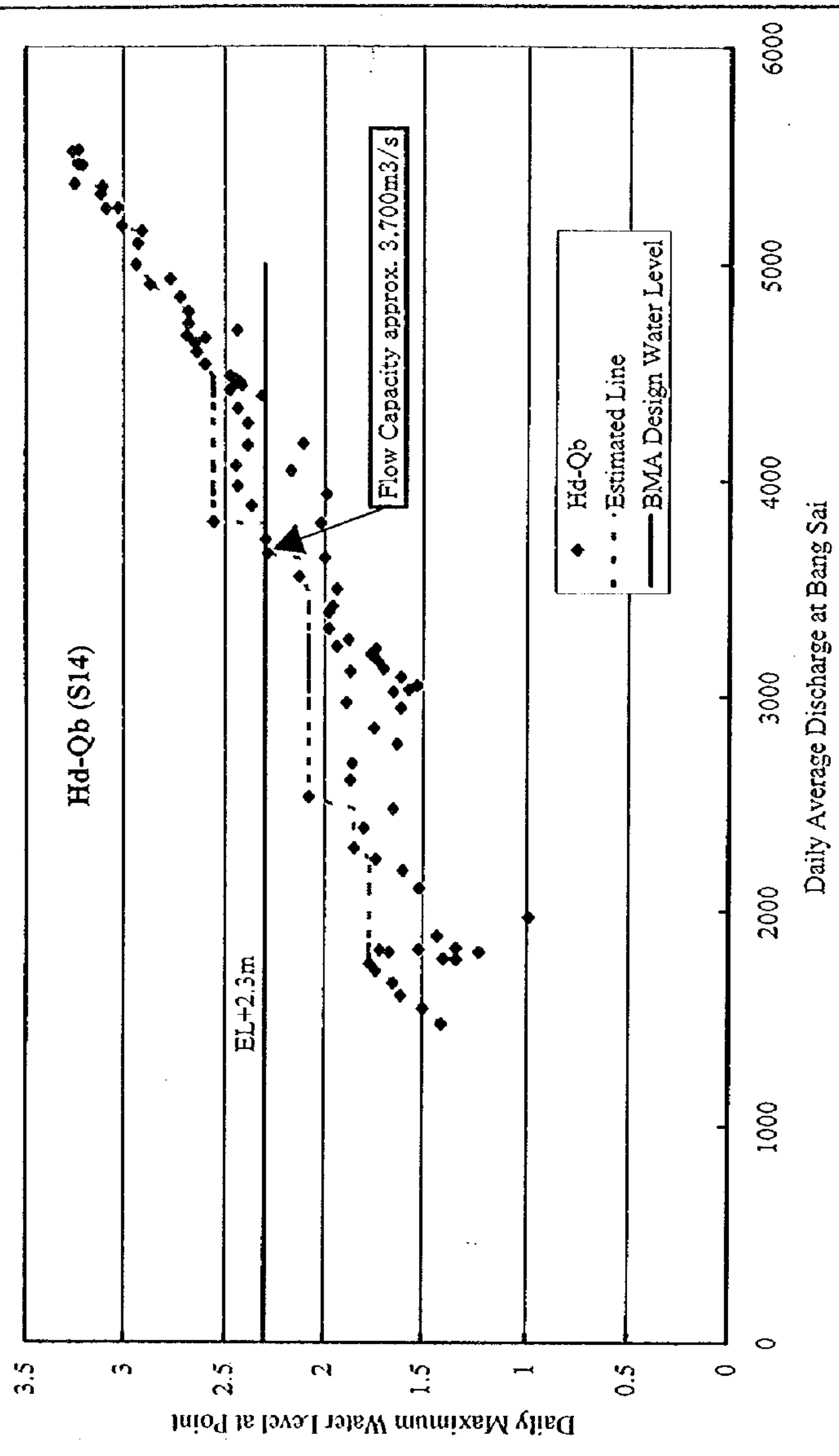
REACH FROM CHAINAT TO NAKHONSAWAN AS A SAMPLE

STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig.1.6.1 (1/2) GRAPH OF RELATION BETWEEN DISCHARGE AND WATER LEVEL
CTI ENGINEERING CO., LTD AND INA CORPORATION	



REACH OF LOWER CHAO PHRAYA AS A SAMPLE

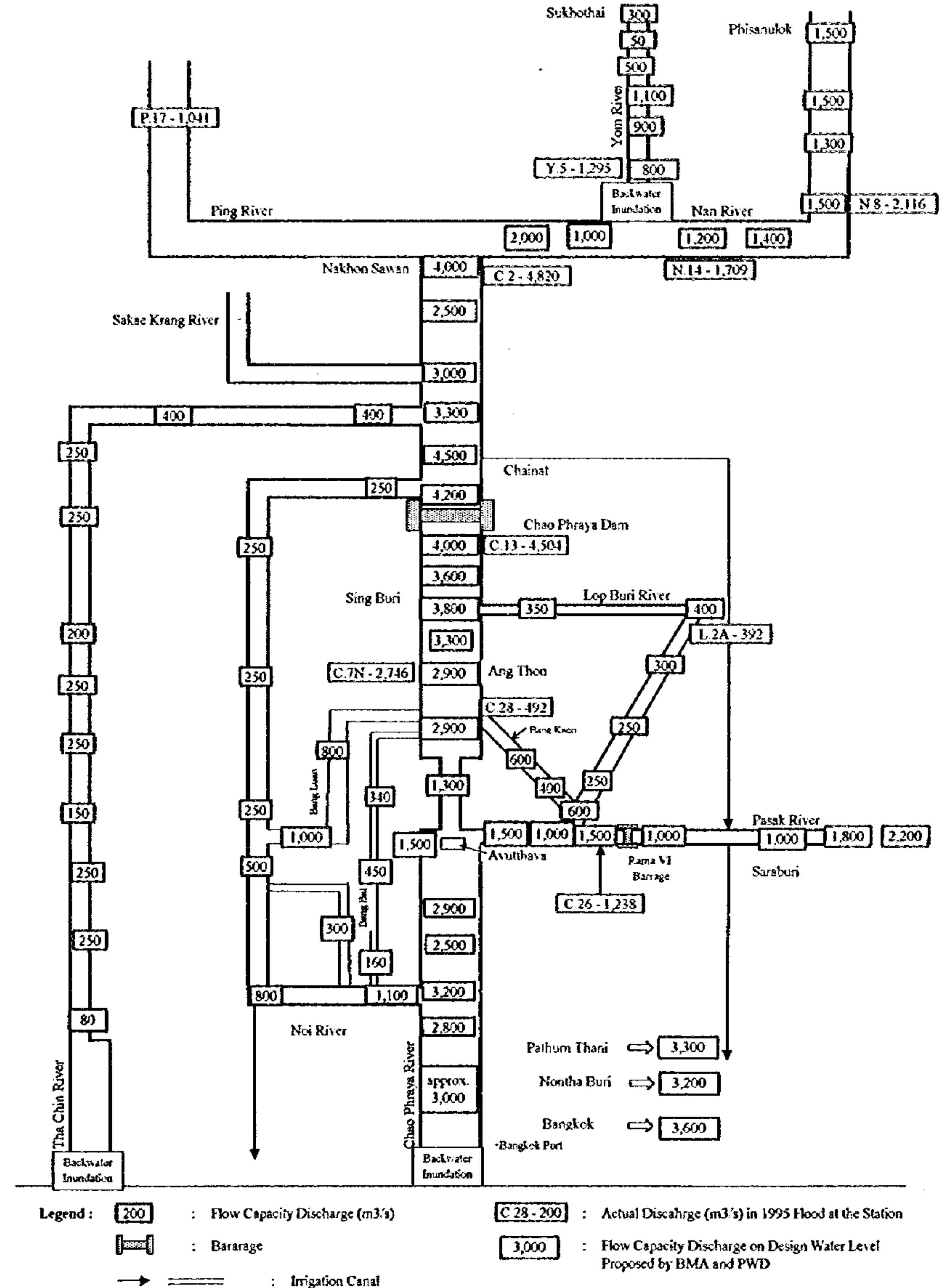
STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig.1.6.1 (2/2) GRAPH OF RELATION BETWEEN DISCHARGE AND WATER LEVEL
CTI ENGINEERING CO., LTD AND INA CORPORATION	



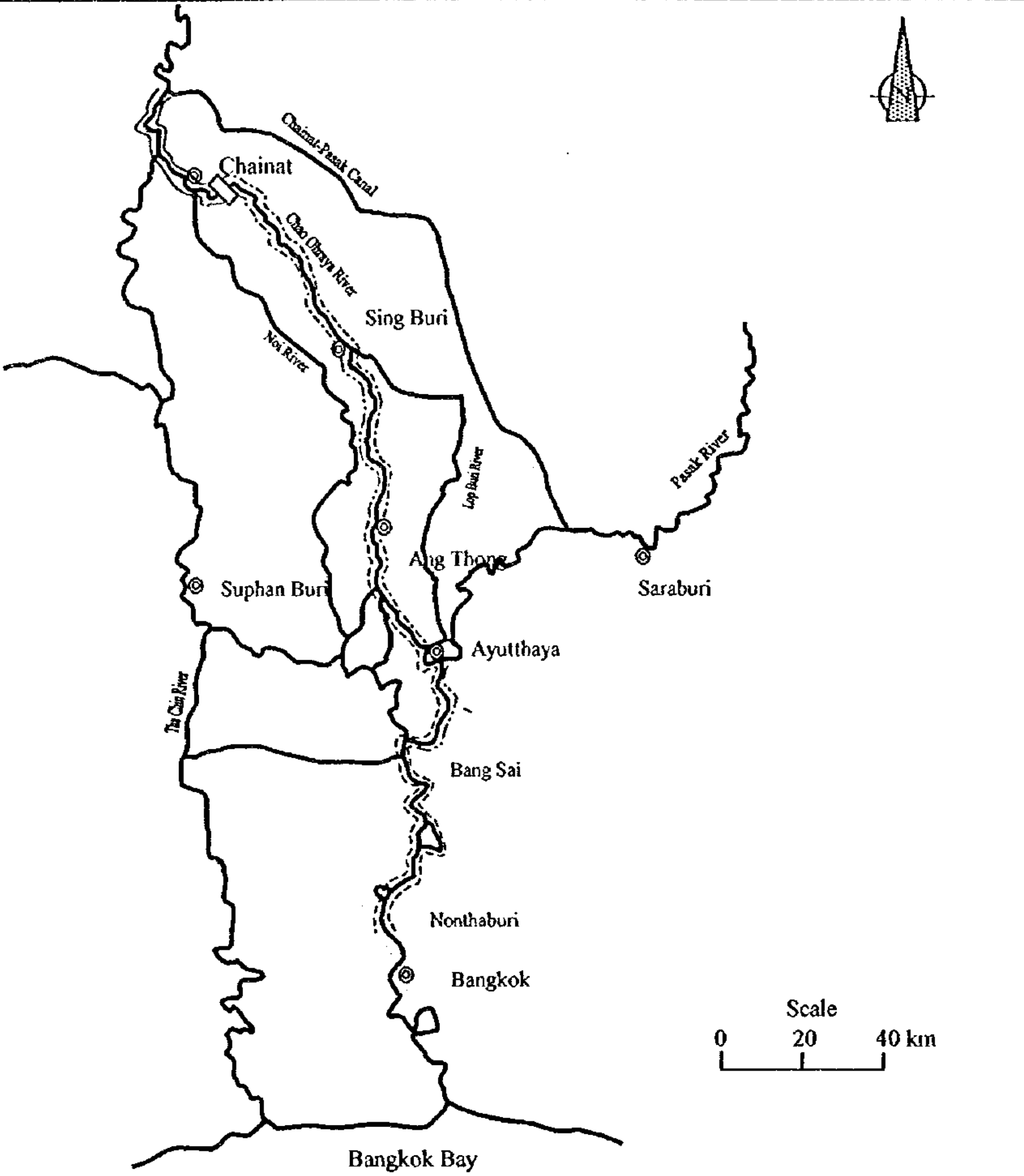
S-14 POINT AS A SAMPLE

STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig.1.6.2 HD-QB GRAPH AT LOWER REACH
CTI ENGINEERING CO., LTD AND INA CORPORATION	

Flow Capacity of Present River Condition in Chao Pharya River Basin in High Tide



STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig. 1.6.3
CTI ENGINEERING CO., LTD AND INA CORPORATION	FLOW CAPACITY OF PRESENT RIVER CONDITION IN CHAO PHRAYA RIVER BASIN IN HIGH TIDE



River Improvement of Chao Phraya River

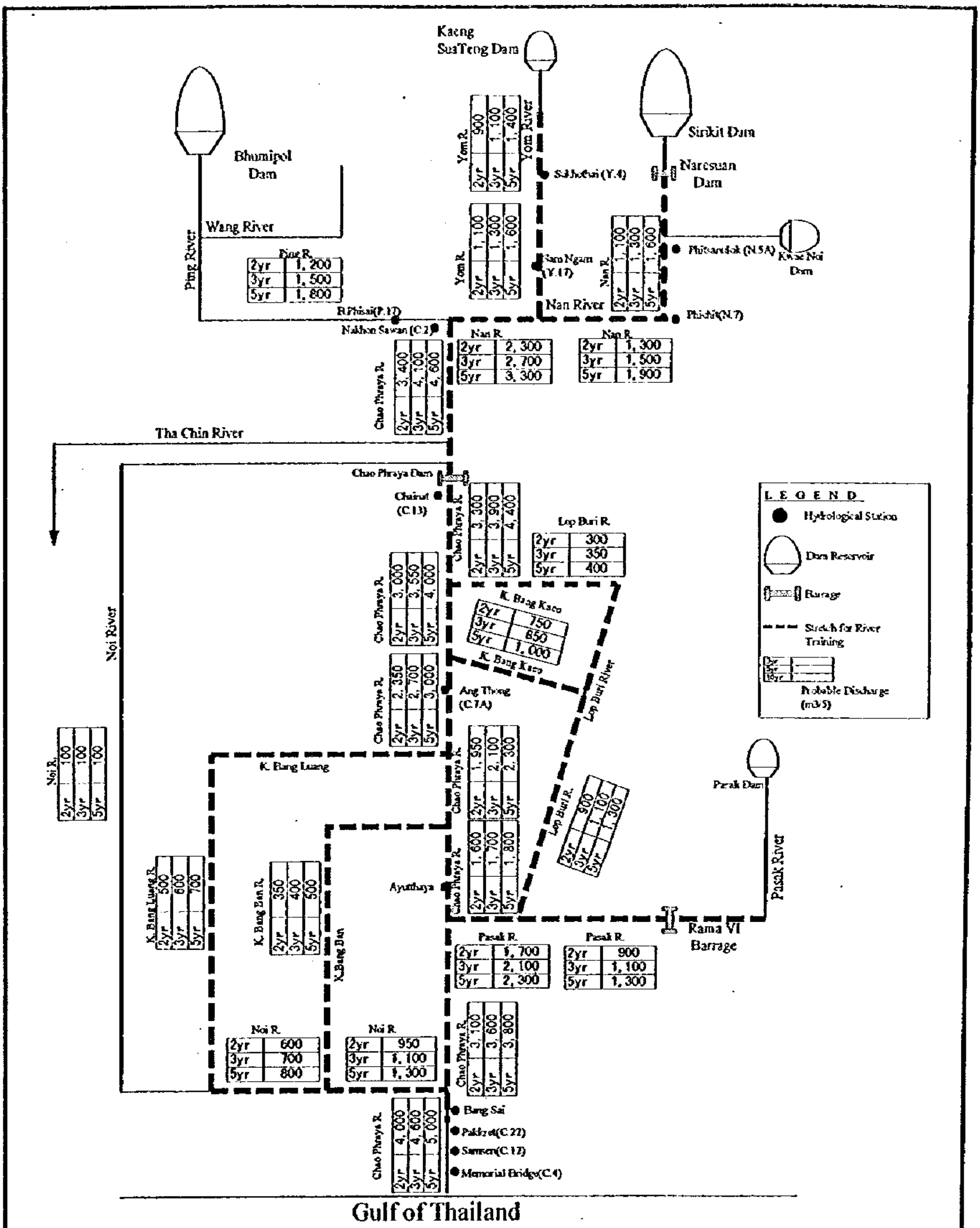
Line	Improvement Section Downstream	Improvement Section Upstream	Provability	Design Crown Level (MSL)	Line	Improvement Section Downstream	Improvement Section Upstream	Provability	Design Crown Level (MSL)
————	CP. Dam	Manorom	25-year	17.0 - 21.0	————	CP. Dam	Manorom	25-year	17.0 - 21.0
-·-·-·-	Ayutthaya	CP. Dam	25-year	5.8 - 17.0	-·-·-·-	Sing Buri	CP. Dam	25-year	12.0 - 17.0
—··—··	Bang Sai	Ayutthaya	25-year	4.2 - 5.0	—··—··	Ang Thong	Sing Buri	25-year	7.0 - 12.0
------	Nonthaburi	Bang Sai	25-year	3.0 - 4.2	------	Nonthaburi	Ang Thong	25-year	3.0 - 7.0

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

CTI ENGINEERING CO., LTD AND INA CORPORATION

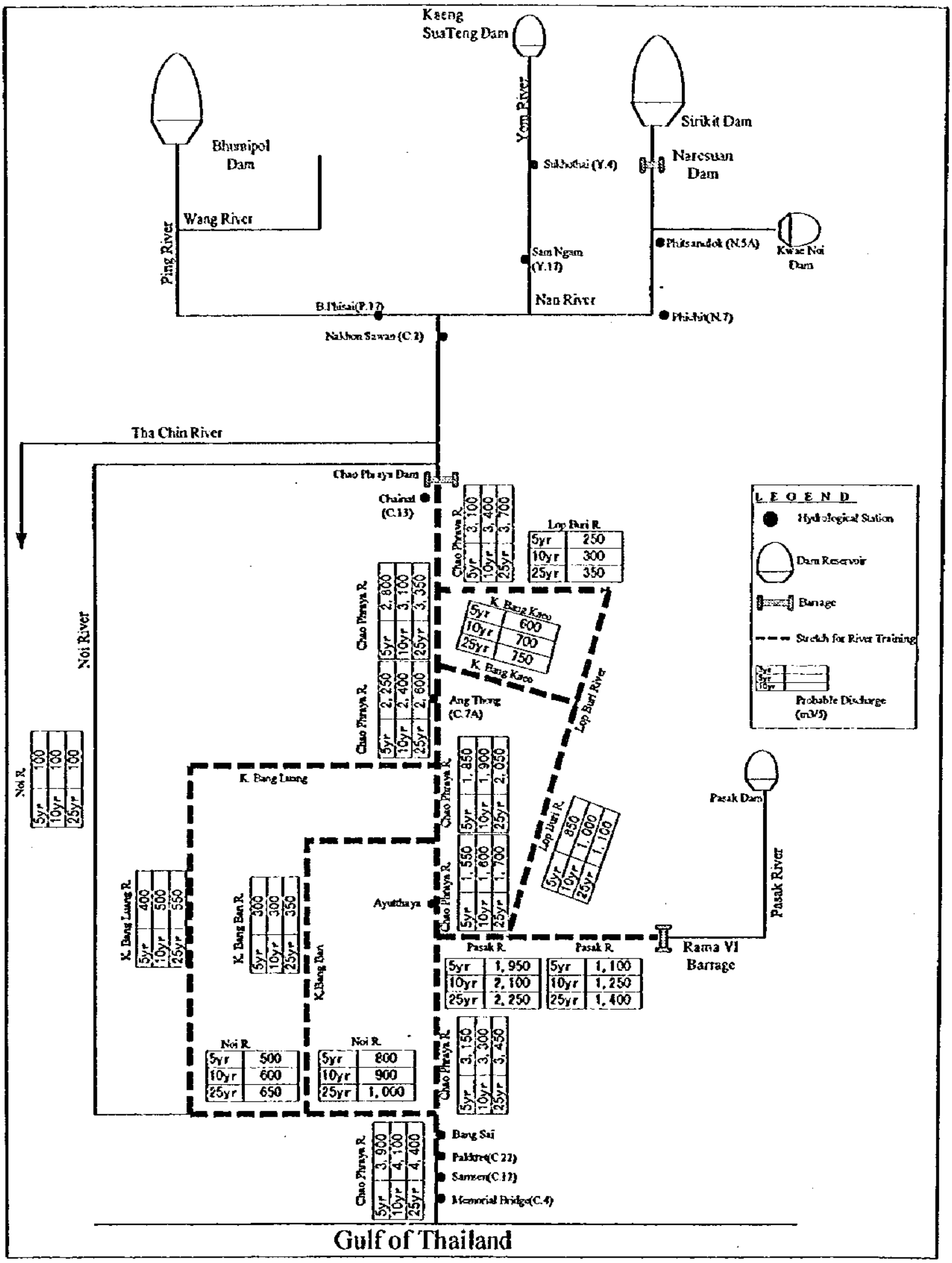
Fig.2.2.1

RIVER IMPROVEMENT OF RID



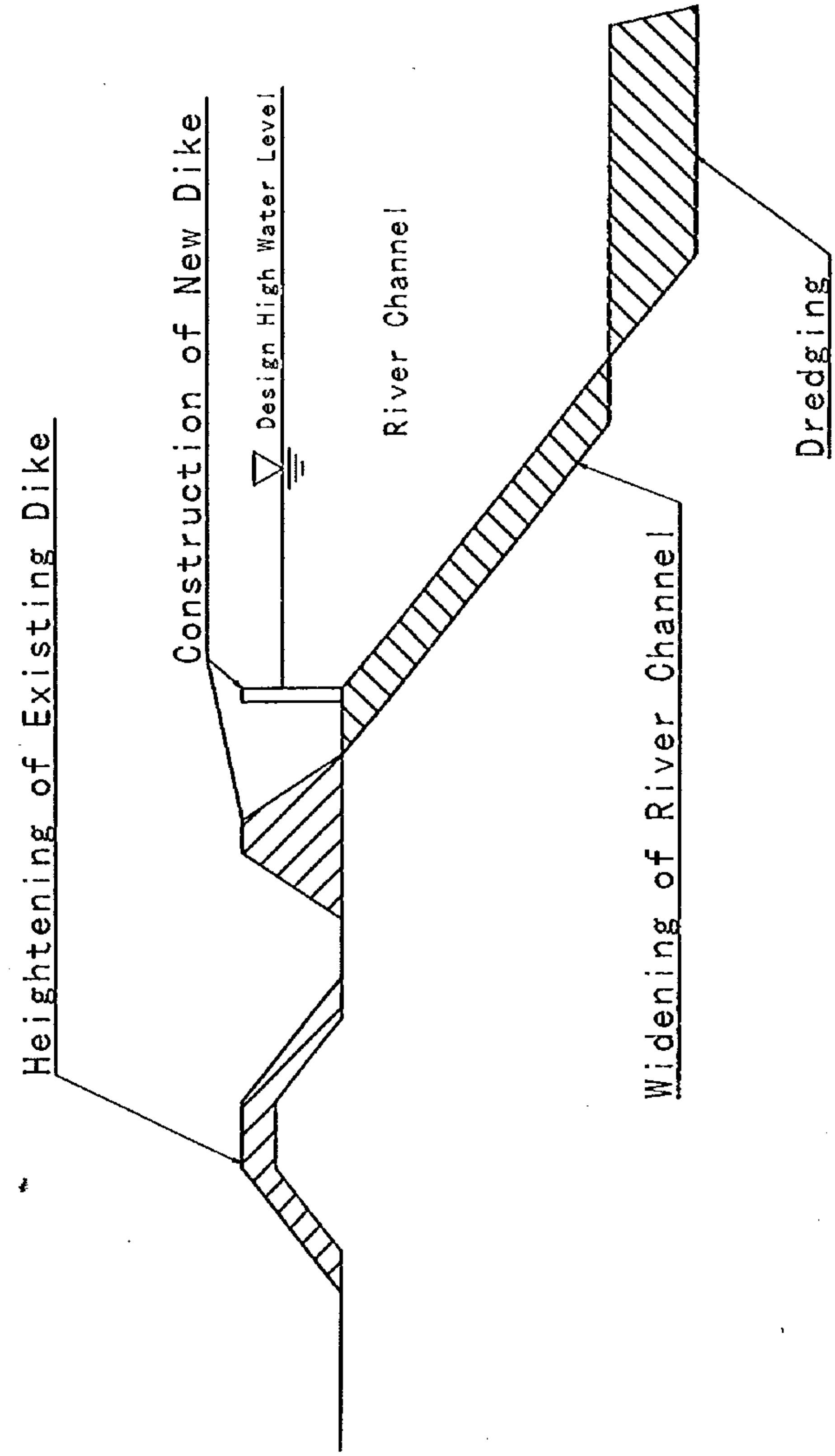
FROM PATHUM THANI TO NAN AND YOM

STUDY ON ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAOPHRAYA RIVER BASIN	Fig. 2.2.2(1/2) DISCHARGE DISTRIBUTION FOR RIVER IMPROVEMENT
CTI ENGINEERING CO., LTD & INA CORPORATION	



FROM PATHUM THANI TO CHAINAT

STUDY ON ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAOPHRAYA RIVER BASIN	Fig. 2.2.2(2/2) DISCHARGE DISTRIBUTION FOR RIVER IMPROVEMENT
CTI ENGINEERING CO., LTD & INA CORPORATION	



STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig. 2.2.3 MEASURES OF IMPROVEMENT FOR RIVER IMPROVEMENT
CTI ENGINEERING CO., LTD AND INA CORPORATION	