社会開発協力部報告書

THE GOVERNMENT OF THE KINGDOM OF THAILAND

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

MAIN REPORT

JUNE 1988

JAPAN INTERNATIONAL COOPERATION AGENCY

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN MAIN REPORT JUNE 1988

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THE GOVERNMENT OF THE KINGDOM OF THAILAND

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MAIN REPORT

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JUNE 1988

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

In response to the request of the Government of the Kingdom of Thailand, the Japanese Government decided to conduct the study on Flood Forecasting System in the Chao Phraya River Basin and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Thailand a Study Team, headed by Mr. Katsuhisa Abe of CTI Engineering Co., Ltd., comprising members of CTI Engineering Co., Ltd. and Nippon Koei Co., Ltd., from February to March, June to August and November to December 1987.

The Team exchanged views on the Project with the officials concerned of the Government of the Kingdom of Thailand and conducted a field survey in the Basin. After the team returned to Japan, further studies were made and the present report has been prepared.

I hope that this report will serve for the development of the Project and contribute to the promotion of friendly relations between our two countries.

I wish to express my deep appreciation to the officials concerned of the Government of the Kingdom of Thailand for their close cooperation extended to the Study Team.

June, 1988

Kensuke Yanagiya

KENSUKE YANAGIYA
President
Japan International Cooperation Agency

June, 1988

Mr. Kensuke Yanagiya
President
Japan International Cooperation Agency
Tokyo, Japan

Dear Sir,

LETTER OF TRANSMITTAL

It is our pleasure to submit to you the Final Report of the Study on Flood Forecasting System in the Chao Phraya River Basin.

The field survey and study have been conducted during the period from February 1987 to March 1988.

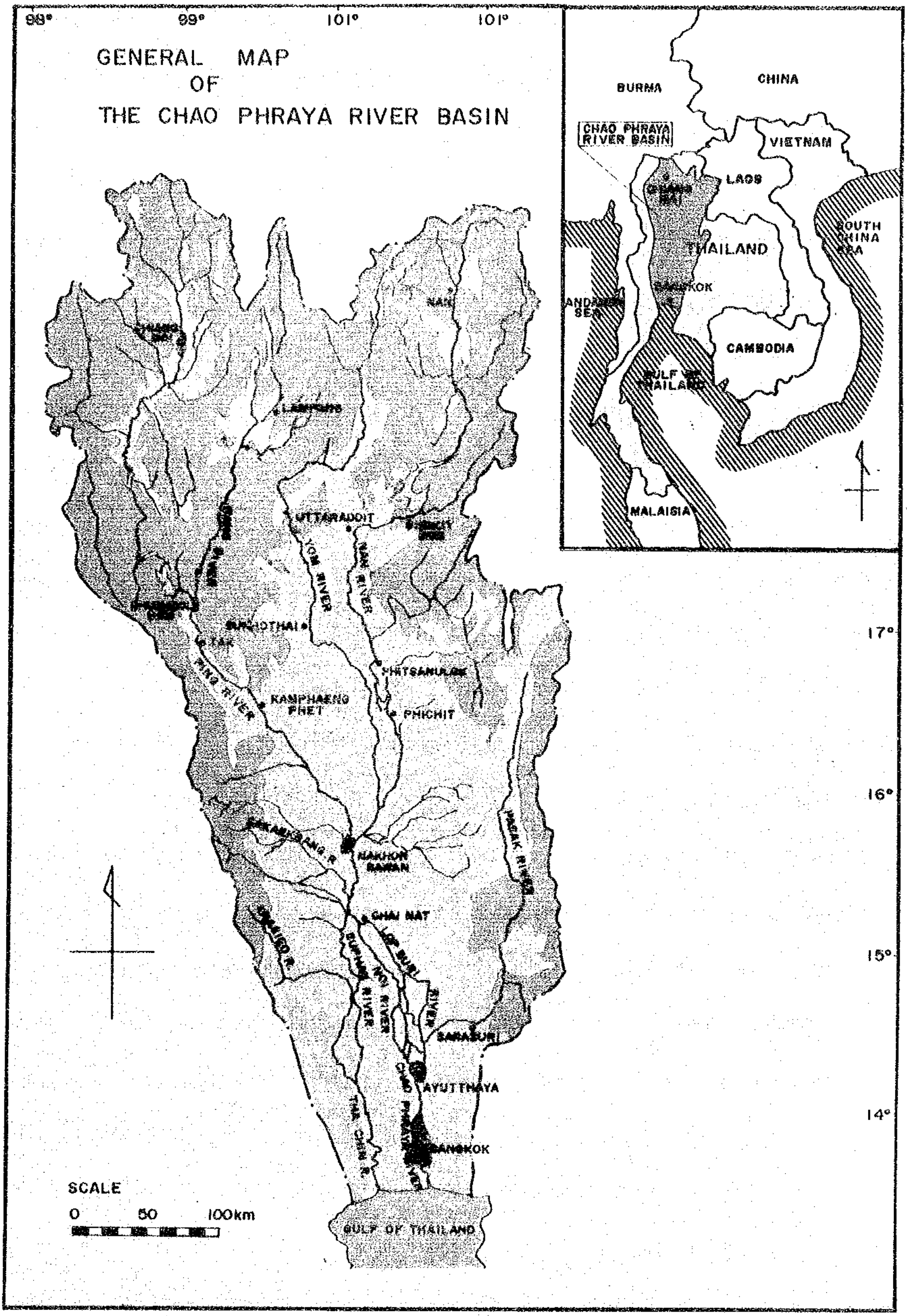
This Report consists of three volumes: VOLUME I - Executive Summary of the Study providing the summary and recommendations; VOLUME II - Main Report of the Study describing the results of survey and analysis; VOLUME III - Supporting Report providing information on the technical and socio-economic aspects.

We hope that realization of the proposed schemes would greatly contribute to the flood damage mitigation in the Basin.

Finally, we take this opportunity to express our sincere gratitude to Japan International Cooperation Agency, the Ministry of Foreign Affairs and the Ministry of Construction of the Government of Japan, the Embassy of Japan in Thailand, the Advisory Committee and the concerned officials of the Government of the Kingdom of Thailand which gave useful advice to the Study Team during the field survey and study periods.

Respectfully yours,

KATSUHISA ABE
Team Leader
for the
Study on Flood Forecasting System



GENERAL MAP OF THE CHAO PHRAYA RIVER BASIN
98°
99°
101°
101°
17°
16°
15°
14°
NAN
LAMPANG
UTTARADOIT
SUKHOTHAI
TAK
PING RIVER
YOM RIVER
NAN RIVER
PHITSANULOK
KAMPHAENG PHET
PHICHIT
NAKHON SAWAN
CHAI NAT
PASAK RIVER
LOP BURI RIVER
NOI RIVER
SARABURI
AYUTTHAYA
THA CHIN R.
CHAO PHRAYA RIVER
BANGKOK
GULF OF THAILAND
SCALE
0
50
100km
BURMA
CHINA
CHAO PHRAYA RIVER BASIN
VIETNAM
LAOS
THAILAND
SOUTH CHINA SEA
CAMBODIA
MALAISIA

S U M M A R Y

1. General Description

The Chao Phraya River, which has the catchment area of 162,000 km^2, rises among the northern mountains of the country. It flows through fertile rice fields and after passing through Bangkok Metropolis, pours finally into the Gulf of Thailand.

The basin, particularly the delta in the downstream, has long been enjoying much agricultural production and urban development. However, the massive agricultural and urbanization developments have brought a decrease in the basins's inherent flood retarding capacity, and Bangkok Metropolis experiences serious land subsidence due to excessive groundwater extraction. These circumstances have aggravated the flood damage condition in the basin.

To mitigate flood damage, flood control works such as dam construction, river improvement, diversion channel construction, etc., are essential. However, it will take a long time and require an enormous construction cost to realize a flood control plan due to the large area of the basin. Under this situation, the formulation of a flood forecasting system was requested to cope urgently with the flood damage problem.

2. Objectives of the Study

The study objectives are as follows:

(1) To formulate the flood forecasting system in the following two steps:

Step 1: Flood forecasting system utilizing existing facilities with the introduction of supplemental equipment.

Step 2: Flood forecasting system with updated facilities having high reliability of flood prediction results.

(2) To carry out the preliminary design and cost estimates of the above two systems.

3. Study and Target Areas

3.1 Study Area

Situated in central and northern Thailand, the Chao Phraya River Basin can be divided broadly into two (2) basins at Nakhon Sawan from the aspect of river channel system. These are the mostly mountainous upper reaches covering 70% of the total basin area and the lower reaches consisting of flat land.

Some of the plains scattered in the upper reaches such as Chiang Mai, Sukothai and Phitsanulok have developed into urban areas. The rest is agricultural land which sometimes function as retarding basin during flood time.

In the flat land of the lower reaches, the Chao Phraya River forms a complex watercourse network of diversion channels and canals. A vast agricultural land, as well as the urban areas of Bangkok, Ayutthaya, Chai Nat and others, exists in this flat land area. The agricultural land that is divided into districts by local ring levees, roads, railway lines, etc., also functions as retarding pond for the inland waters in the districts and the flood waters from the main tributaries during flood time. The riverbed gradient of this portion varies between 1/10,000 and 1/50,000.

The Chao Phraya River Basin is located in the tropical monsoon region which has distinct dry and rainy seasons. The annual rainfall in the basin ranges from 1,000 mm in the western area to 1,400 mm in the northeastern area. About 85 percent of the annual rainfall occurs during the rainy season from April to October and during a tropical cyclone, one day precipitation sometimes exceeds 100 mm. Temperature ranges from 27 to 32°C during the rainy season, while it fluctuates between 20 and 27°C during the dry season.

The river flow discharge shows a seasonal variation in accordance with the aforesaid distinctive precipitation in the rainy and dry seasons. According to the records of the stream gauging station at Nakhon Sawan, the maximum discharge was observed after construction of the Bhumibol and the Sirikit dams, at 4,355 m^3/s in 1975 and at 4,320 m^3/s in 1980. Among the recently recorded floods, those that occurred in 1975, 1978, 1980 and 1983 had inflicted severe damage especially in the downstream.

The tidal compartment is regarded approximately until Bang Sai on the Chao Phraya River and the Rama VI Dam on the Pasak River. Mean high water and mean low water spring tides are approximately 2.2 m and -1.8 m above MSL, which are observed at the river mouth.

3.2 Target Areas

The target areas of the study cover the following:

(1) Bangkok Metropolis and urban areas in Nakhon Sawan, Chai Nat, Sing Buri, Lop Buri, Ang Thong and Ayutthaya; and

(2) The agricultural areas along the Chao Phraya River between Ang Thong and Ayutthaya, and along the Pasak River between Ayutthaya and Rama VI Dam.

Among these areas, top priority for the establishment of a flood forecasting system is given to Bangkok Metropolis in view of its significant economic and political role in Thailand.

4. Step 1 Flood Forecasting System

4.1 Function and Facilities

The Step 1 Flood Forecasting System consists of four works: data collection, data transmission, data management and data dissemination. Utilized for data collection are the existing 31 water level gauging stations that include a tidal gauging station and the 34 rainfall gauging stations located in the lower reaches of Bhumibol Dam and Sirikit Dam. Most of the gauging stations are managed by RID and the rest by MD and PAT.

As for data transmission, hydrological data observed at gauging stations under RID's Regional Offices are transmitted through RID's Communication Division to RID's O&M Division, and those of MD are collected at its head office in Bangkok by its own telecommunication system. Therefore, the telecommunication network to be newly connected to this system covers the portion between RID's Head Office and (a) the hydrological gauging stations managed by RID's Hydrology Division, for data collection; (b) the head offices of related agencies, for collection of data and/or dissemination of prediction results; and (c) the tidal gauging station of PAT, for data collection.

The telecommunication system to be newly established is by means of the radio line and voice communication that utilizes the VHF and/or the HF/SSB band of the simplex line. The proposed telecommunication network is summarized as follows:

Related Agencies	Portions of Network: Gauging Station ===== Head Office of Related Agency	Head Office of Related Agency ====== Head Office of RID	Head Office of RID
MD	HF/SSB*	VHF**	Data collection /2
PAT	HF/SSB** /1		- do -
RID (O&M Division)	VHF; HF/SSB*	VHF; HF/SSB*	- do -
RID (Hydrology Division)	HF/SSB** /1		- do -
LAD		VHF**	Dissemination /2
BMA		VHF**	- do -
EGAT		VHF**	Data Collection/ Dissemination /2

Note: * Existing; ** Proposed
/1 Direct connection between gauging station and RID Head Office.
/2 Contents of communication.

For the management of data concerned, such as rainfall, water level, flood damage, etc., the system is equipped with functions such as data filing and processing by manual operation, flood prediction, hydrological analysis, and displaying computation results. The required equipment for this system is the engineering work station (EWS) and its peripherals such as data storage equipment, printer, color hard copy unit and video projector.

The flood prediction results consist of the daily and the hourly water stages during flood prediction time at the flood prediction points. Aside from RID's Regional Office Nos. 7 and 8, the information will be disseminated daily to the related government agencies such as LAD, BMA and EGAT.

4.2 Justification of the Proposed System

The Step 1 Flood Forecasting System can perform short term flood prediction 5.3 days in advance, which is the minimum time necessary for the flood forecasting works such as processing of predicted flood water level and flood fighting. The accuracy of the short term flood prediction results is not so high, with errors ranging approximately from 10 cm to 30 cm; however, flood prediction by the system is practically feasible. The maximum error of 30 cm occurred in the prediction for Sathu Pradit on October 21, 1978.

4.3 Implementation Schedule

The flood forecasting system can be broadly classified into two phases, namely, installation of flood forecasting system and development of the system. The total implementation time required for the proposed project is 36 months.

The establishment of the flood forecasting system, which includes detailed design, pre-construction, construction/ installation, preparation of operation and maintenance manual, and flood prediction programming, will require 12 months.

The development of the system including training of the staff concerned will further require 24 months. This development phase shall cover calibration and modification of flood prediction models, on-the-job training and overseas training.

4.4 Cost Estimates

The total cost of the proposed system is estimated at US$2,786,000 composed of the cost of establishment of the system and the cost of developing it amounting to US$1,731,000 and US$1,055,000, respectively.

5. Step 2 Flood Forecasting System

5.1 Function and Facilities

Since it may take quite a long time to establish the system with updated facilities that will cover the whole basin, the project is proposed to be executed stepwisely in accordance with the priority of the target area.

Rainfall data collection shall be undertaken by gauging measures which are roughly classified into two types, i.e., the point rainfall gauge type and the radar gauge type. The point rainfall gauging network shall be primarily established prior to the radar gauge network. Succeedingly, the radar gauge network will be installed to supplement the accuracy of areal annual rainfall estimation, subject to the real-time calibration of point rainfall gauges.

Eighty-four (84) point rainfall gauging stations shall be installed all over the whole basin of the Chao Phraya River. Two (2) radar gauge stations shall be installed at approximately 14°40'N latitude and 100°30'E longitude (south of Lop Buri) and at 16°15'N latitude and 100°15'E longitude (near Taphan Hin) to grasp the rainfall condition over the downstream area.

Forty-five (45) water level gauging stations including a tidal gauging station shall also be set up in this system. The installation of gauging stations is divided into five stages in accordance with the priority of the target area and the work volume.

For data transmission and communication, the facilities for the flood forecasting system shall include the following:

(a) Radio transmission link for exclusive use to assure reliability and speed of data transmission;

(b) On-line system with character transmission for data transmission to prevent occurrence of errors due to manual intervention; and

(c) Off-line system with voice communication for easier communication of comments and instructions.

The telecommunication network for Step 2 Flood Forecasting System is composed of trunk lines and branch lines. The trunk lines, which will utilize the TOT UHF microwave line, shall be provided between the Flood Forecasting Center (FFC) at the RID Head Office and the substations in RID's Regional Offices. To connect the substation and FFC to the terminal station of TOT, an approach line with no exchanger will be installed.

The branch lines between the substations and the gauging stations will be newly installed in this system, utilizing the VHF band of the simplex line. The branch line between FFC and the related agencies is newly installed as well, utilizing the UHF microwave band.

Regarding data management, the functions reinforced from those of Step 1 Flood Forecasting System are real-time data filing and processing, real-time flood prediction, displaying visual information, and monitoring basin conditions. The composition of the required facilities for this system is the same as that of Step 1, but the capacity and quality of some of the facilities such as the EWS and the display equipment are upgraded.

5.2 Justification of the Proposed System

The short term prediction time required for the Step 2 Flood Forecasting System is assumed to be 3 days for flood mitigation. The 3-day prediction will minimize errors to less than 20 cm on all prediction points.

As for the long term prediction time, 10-day prediction for Bangkok Metropolis and 6-day prediction for other target areas are the maximum prediction times estimated on the basis of the flood lag time. Errors of the 10-day and 6-day predictions are also within 20 cm, except in the prediction at Memorial Bridge in the 1983 flood where the error is 30 cm.

Under the above circumstances, flood prediction by the Step 2 Flood Forecasting System is also practically feasible.

5.3 Implementation Schedule

The required implementation period for this system is 11 years. This consists of 1.5 years for the integrated study, 1.5 years for the acquisition of necessary funds, 0.5 year for the procurement of consultant, 2.0 years for the detailed design, 0.5 year for the pre-construction, and 5.0 years for the construction of facilities and installation of equipment.

As for the construction and installation, the works shall be implemented in five phases according to the priority of the target areas in consideration of the large work volume. The required period for each phase of construction/installation works is estimated at 12 months, which include the period of 8.0 months for the procurement of equipment, 8.0 months for the construction of civil works, and 4.0 months for the installation and adjustment of equipment.

5.4 Cost Estimates

The total cost of the proposed Step 2 system is estimated at US$55,947,500 consisting of US$3,882,800 for Detailed Design, US$11,582,000 for Phase 1 Works, US$5,249,500 for Phase 2 Works, US$5,212,400 for Phase 3 Works, US$5,222,500 for Phase 4 Works, and US$24,798,300 for Phase 5 Works.

6. Socio-Economic Impact

The Chao Phraya River and its tributaries have caused serious flood damage in the past to immovable and movable properties, business activities and traffic. With the flood forecasting system, hydrological data covering the vast area of the Chao Phraya River Basin are collected and processed in a more precise manner with a longer quantity and a higher quality. It will practically be possible to predict flood discharge and water stage at target points, and based on such prediction, damage caused by flood is expected to be remarkably reduced.

In addition to the above damage mitigation, the proposed telecommunication network for Step 2 Flood Forecasting System can be utilized for common administration and communication in a more expeditious manner.

7. Recommendation

(a) In this study, the Step 2 Flood Forecasting System is formulated in a manner of master plan study stage for the installation of updated facilities. Since the study on water management system where some of the facilities will be utilized in common with the flood forecasting system is still under way, adjustment between both studies may be finally necessary. In this connection, it is recommended that further study of this flood forecasting system be commenced as early as possible after completion of the water management system study.

(b) To cope urgently with the flooding problems, a flood forecasting system utilizing the existing facilities is formulated as the Step 1 system. This system can directly proceed to the detailed design and construction phase and it requires only one (1) year for it to be established, though its effectiveness is not so high compared with Step 2.

Aside from promoting the study on the Step 2 system, it is recommended that the Step 1 system be executed with the least lapse of time to fulfill the objectives of flood forecasting until the Step 2 system is established.

PRINCIPAL FEATURES OF THE PROPOSED SYSTEM

A. STEP 1 SYSTEM

1. Hydrological Gauging Station

Existing

(a)	Rainfall Gauging Station	(RID)	16 places
		(MD)	18 places
	Total		34 places
(b)	Water Level Gauging Station	(RID)	27 places
		(MD)	2 places
		(PAT)	1 place
	Total		30 places

New Installation

(a)	Water Level Gauging Station	(RID)	1 place

2. Telecommunication

Existing

(a) HF Radio Station for Gauging Station (RID) — 4 places

Frequency Band	3-15MHz
RF Output Power	100W
Antenna	Dipole
Power Supply (Commercial)	220V, 50Hz

(b) HF Radio Station for Gauging Station (MD) — 20 places

Frequency Band	6MHz
RF Output Power	150W or 130W
Antenna	Dipole
Power Supply (Commercial)	220V, 50Hz

New Installation

(a) HF Radio Station for Gauging Station with Housing — 30 places

Frequency Band	3-15MHz
RF Output Power	100W
Antenna	Dipole
Power Supply (Engine Generator)	2 kVA
Housing Space (Floor Area)	3 m^2

(b) VHF Radio Station for Gauging Stations with Housing — 3 places

Frequency Band	150MHz
RF Output Power	10W
Antenna	3-element Yagi
Power Supply (Engine Generator)	0.5 kVA
Housing Space	3 m^2

(c) VHF Radio Station for Agencies Concerned — 4 places

Frequency Band	150MHz
RF Output Power	10W
Antenna	3-element Yagi

3. Data Management

New Installation

Engineering Work Station with CRT Display (32 bit CPU, 5 MB main memory)	1 unit
Hard Disk Drive (100 MB memory capacity)	1 unit
Magnetic Tape Drive	1 unit
Line Printer	1 unit
Video Projector	1 unit
CVCF (3 kVA capacity)	1 unit
Operating System Software	1 set
Application Program	1 set

B. STEP 2 SYSTEM

1. Hydrological Gauging Station

New Installation

(a) Rainfall Gauging Station	65 places
(b) Water Level Gauging Station	26 places
(c) Rainfall/Water Level Gauging Station	19 places
(d) Radar Raingauge	2 places

2. Telecommunication

New Installation

(a) VHF Radio Station for Gauging Station with Housing — 110 places

Frequency Band	150MHz
RF Output Power	10W
Antenna	3-element Yagi

Power Supply	12V, 8.5W (solar cell); and DC 12V, 40AH (battery)
Housing Space (Floor Area)	3 m^2
Tower Height	20 m

(b) UHF Radio Station for Radar Raingauge with Housing — 2 places

Frequency Band	1.5GHz
RF Output Oower	1 Watt
Channel Capacity	4 ch
Antenna	8-element Yagi
Power Supply (Commercial Power)	AC 200V, 50 Hz,
Power Supply (Engine Generator)	200 kVA
Housing Space (Floor Area)	300 m^2

(c) VHF Repeater Station with Housing — 15 places

Frequency Band	150MHz
RF Output Power	10W
Antenna	3-Stage Colinear
Power Supply	12V, 20W (solar cell); and DC 12V, 80AH (battery)
Housing Space	3 m^2
Tower Height	30 m

(d) Substation with Housing — 5 places

For VHF Radio Station to collect hydrological data — 5 places

Frequency Band	150MHz
RF Output Power	10W
Antenna	3-Stage Colinear

For UHF Radio Station to collect radar raingauge data — 2 places

Frequency Band	1.5 GHz
RF Output Power	1 Watt
Antenna	8-element Yagi

For UHF Radio Station to connect TOT Terminal Station — 5 places

Frequency Band	1.5 GHz
RF Output Power	1 Watt
Antenna	8-element Yagi
Channel Capacity	3 ch or less

Common Use for VHF, UHF Radio Station

Power Supply (Commercial Power)	AC 220V, 50Hz
Power Supply (Engine Generator)	75 kVA
Housing Space (Floor Area)	100 m^2
Tower Height	30 m

(e) Terminal Station of TOT without Housing — 6 places

Frequency Band	1.5GHz
RF Output Power	1 Watt
Antenna	8-element Yagi
Channel Capacity	3 ch or less

(f) Flood Forecasting Center

For VHF Radio Station to connect Gauging Station — 1 place

Frequency Band	150MHz
RF Output Power	10W
Antenna	3-Stage Colinear

For UHF Radio Station to connect Substations — 1 place

Frequency Band	1.5GHz
RF Output Power	1 Watt
Channel Capacity	16 ch
Antenna	8-element Yagi

For UHF Radio Station to connect Agencies Concerned — 1 place

Frequency Band	1.5GHz
RF Output Power	1 Watt
Channel Capacity	9 ch
Antenna	3-Stage Colinear

Common Use for VHF and UHF Radio Stations

Power Supply (Commerical Power)	AC 220V, 50Hz
Power Supply (Engine Generator)	200 kVA
Housing Space (Floor Area)	600 m^2
Tower Height	30 m

(g) UHF Radio Station for Data Dissemination without Housing — 3 places

Frequency Band	1.5GHz
RF Output Power	1 Watt
Channel Capacity	3 ch
Antenna	8-element Yagi

3. Data Management

New Installation

Engineering Work Station (32 bit CPU, 5 MB main memory)	3 units
Hard Disk Drive (100 MB memory capacity)	3 units
Magnetic Tape Drive	1 unit
Line Printer	1 unit
Color Hard Copy	1 unit
Video Projector	1 unit
Mimic Board	1 unit
Electronic Filing System	1 set
Video Tape Recorder	1 set
Telephone	13 sets
Facsimile	9 sets
Remote Terminal Monitor	5 sets

FLOOD FORECASTING SYSTEM
IN THE CHAO PHRAYA RIVER BASIN

MAIN REPORT

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ACRONYMS AND ABBREVIATIONS

ABBREVIATION OF ORGANIZATIONS

AIT	:	Asian Institute of Technology
BMA	:	Bangkok Metropolitan Administration
CAT	:	Communication Authority of Thailand
DDS	:	Department of Drainage and Sewerage, BMA
DOH	:	Department of Highways
DPW	:	Department of Public Works
DTEC	:	Department of Technical and Economic Cooperation
EGAT	:	Electricity Generating Authority of Thailand
HD	:	Harbour Department
IEC	:	Irrigation Engineering Center, RID
LAD	:	Local Administration Department
MD	:	Meteorological Department
NEA	:	National Energy Administration
NEB	:	National Environment Board
NESDB	:	National Economic and Social Development Board
NSO	:	National Statistical Office
PAT	:	Port Authority of Thailand
PTD	:	Post and Telegraph Department
RID	:	Royal Irrigation Department
SRT	:	State Railway of Thailand
TOT	:	Telecommunication Organization of Thailand
FFC	:	Flood Forecasting Center
JICA	:	Japan International Cooperation Agency

ABBREVIATIONS OF MEASUREMENT

Length

mm	:	millimeter(s)
m	:	meter(s)
km	:	kilometer(s)

Area

ha	:	hectare(s)
km^2	:	square kilometer(s)
rai	:	0.16 ha
taran war	:	4 square meters

Volume

m^3	:	cubic meter(s)
MCM	:	million cubic meter(s)

Time

s, sec	:	second(s)
h, hr	:	hour(s)

Other Measurements

HWL	:	High Water Level
MSL	:	Mean Sea Level
°	:	degree
'	:	minute
"	:	second
%	:	percent
°C	:	degree centigrade
m^3/s	:	cubic meter per second
KB	:	kilobyte
MB	:	megabyte
RAD	:	radian
bps	:	bit per second
BPI	:	bit per inch
AH	:	Ampere Hour

ABBREVIATION OF TELECOMMUNICATION AND COMPUTER TERMS

FM : Frequency Modulation
HF : High Frequency
SSB : Single-Side Band
VHF : Very High Frequency
UHF : Ultra-High Frequency
KHz : kilohertz
MHz : megahertz = 10^3 KHz
GHz : gigahertz = 10^3 MHz
CCU : Communication Control Unit
CPU : Central Processing Unit
MPU : Main Processing Unit
MONITOR: Remote Terminal Monitor
FAX : Facsimile
TEL : Telephone
BPPI : Bright PPI Display
SV/RC : Radar Supervisory/Remote Control Equipment
T/R : Transmitter/Receiver
SIG : Signal Processor
MUX : Multiplex Terminal Equipment
TSE : Telemetering Supervisory Equipment
MT : Magnetic Tape
MD : Magnetic Disk
LP : Line Printer
UPS : Uninterrupted Power Supply
AC : Alternating Current
UNIVAC : Universal Automatic Computer
PPI : Plan Position Indicator

OTHER ABBREVIATIONS/ACRONYMS

GDP : Gross Domestic Product
GNP : Gross National Product
GRP : Gross Regional Product
GPP : Gross Provincial Product
R/O : Regional Office
O&M : Operation and Maintenance

INTELSAT : International Communications Satellite Consortium

CHAPTER 1. INTRODUCTION

1.1 General Description

Chao Phraya River, the biggest river in Thailand, rises among the northern mountains of the country, flows through fertile rice fields and the Bangkok Metropolis, then pours into the Gulf of Thailand. Its catchment basin is 162,000 km^2, more or less, which is almost 1/3 of the area of the whole country.

The basin, particularly the delta in the downstream, has long been enjoying much agricultural production and urban development. However, recurrent floods had inflicted serious damage to the basin, particularly, the deltaic area.

The massive agricultural and urbanization developments of the basin bring about a decrease in its inherent flood retarding capacity, and the Bangkok Metropolis experiences serious land subsidence due to an excessive groundwater extraction. These circumstances have aggravated the flood damage condition in the basin.

Up to the present, no comprehensive flood control project covering the whole Chao Phraya River Basin has been prepared, while flood control works have been executed either locally or with a secondary purpose only. It is, therefore, imperative that effective flood control measures be figured out on the basis of a long-term and wide-viewed strategic plan.

It will take a long time to realize a comprehensive flood control plan due to the large area of the basin; however, the flooding problem should be urgently resolved. Under this situation, the formulation of a flood forecasting system was requested to cope urgently with the flood damage problem.

1.2 Study Area

The study covers the whole Chao Phraya River Basin, as shown in the General Map.

1.3 Objectives of the Study

The study objectives are as follows:

(1) To formulate the flood forecasting system in the Chao Phraya River Basin; and

(2) To carry out the preliminary design and cost estimate of the system.

1.4 Study and Staffing Schedules

The Study, in principle, has been carried out in accordance with the schedule shown in Fig. 1-1. The Staffing Schedule is presented in Fig. 1-2.

Study Item	1987												1988					
Month	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6
1. Preparatory Work																		
2. Field Reconnaissance, Data Collection, and Basic Analysis																		
3. Provision of Premises for Flood Forecasting System (Selection of Target Area, etc.)																		
4. Study on Availability of Existing Flood Forecasting System																		
5. Formulation of Flood Forecasting System																		
6. Preliminary Design and Cost Estimation																		
7. Project Evaluation																		
8. Reporting		*					*				*				*			*
		IC/R					P/R				IT/R				DF/R			F/R

LEGEND

- ▬ : Study in Project Site
- ▭ : Study in Japan
- * : Submittal of Report

IC/R : Inception Report
P/R : Progress Report
IT/R : Interim Report
DF/R : Draft Final Report
F/R : Final Report

Fig. 1-1. STUDY SCHEDULE

FLOOD FORECASTING SYSTEM
IN THE CHAO PHRAYA RIVER BASIN
JAPAN INTERNATIONAL COOPERATION AGENCY

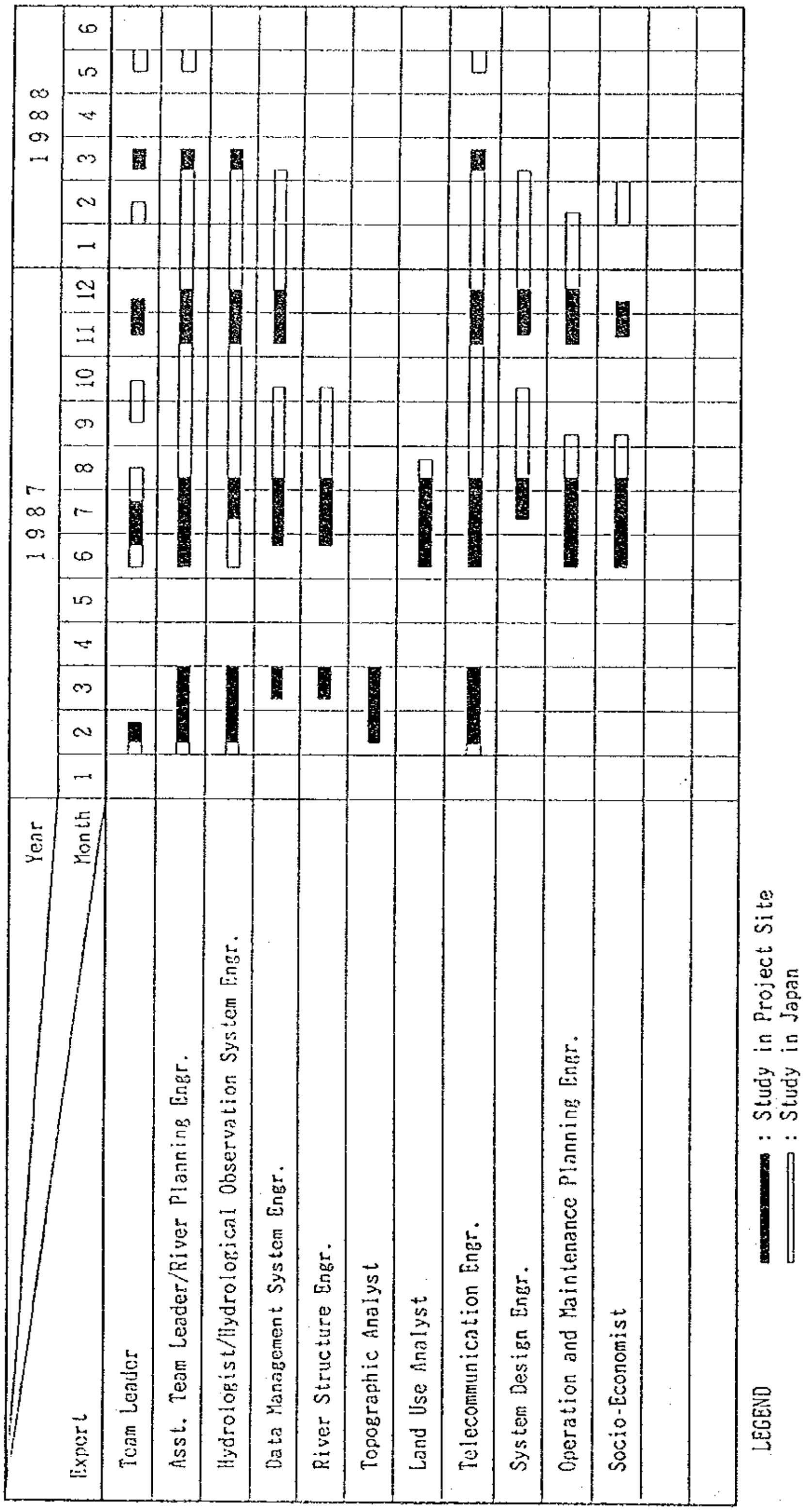

Fig. 1-2. STAFFING SCHEDULE

FLOOD FORECASTING SYSTEM
IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

CHAPTER 2. PROJECT BACKGROUND

2.1 National Development Policy

2.1.1 Results of Past Development Plans

Since 1961, the Kingdom of Thailand has been achieving a notable development in the national economy and the living standard of the people under the five economic and social development plans for the past 25 years. Actually, the Gross National Product (GNP) increased 18 times from 58,900 million baht in 1961 to 1,047,500 million baht in 1985, while the per capita income rose almost 10 times from 2,150 baht in 1961 to 20,420 baht in 1985. In the field of social development, the level of public services has risen; especially, a remarkable improvement has been achieved in both the fields of education and health which are basic services for the improvement in the quality of life of the Thai people.

Although the economy of Thailand has achieved a remarkable growth as mentioned above, its growth rate has gone down during both periods of the Fourth and the Fifth National Economic and Social Development Plans (1976-1980 and 1981-1986) due to world recession, intensified international trade competition and protectionism. For example, during the Fifth Plan period, the economic growth of Thailand averaged only 4.4% per annum against 7% per annum for the Fourth Plan period, and it was also lower than 6.6% per annum targeted for the Fifth Plan period. In addition to such a dull economic growth, Thailand had many problems and hindrances which should be solved at the end of the Fifth Plan, namely, increase in labor force, decrease in employment opportunities, trade and budget deficits, congestion of Bangkok Metropolitan Area, low growth in rural economy, deterioration in the quality of environment due to unsystematic utilization of natural resources, etc. The solution of these problems became a pressing matter on the national policy.

2.1.2 Sixth National Economic and Social Development Plan (1987-1991)

The major objectives of the Sixth Plan are to raise the country's level of development for future progress and prosperity, while working to solve problems accumulated from the past. In the light of this objective, the economic and social targets have been set; the economic target is to maintain at least the economic growth rate of 5% per annum (somewhat higher than the actual growth rate in the Fifth Plan) so as to absorb the new entrants into the labor market which is probably more than 3.9 million people, and the social target is to promote the development of the living conditions of the people so as to enable social progress and foster peace and equality.

Table 2-1 shows the macroeconomic targets of the Sixth Plan, compared with results of the Fourth and Fifth plans. In the Sixth Plan, the economic growth during the period is expected to be 5% per annum for GDP and 6.6% per annum for the manufacturing/industrial sector, especially. Concerning population growth and consumer price escalation, the Sixth Plan is designed to maintain the low rates of 1.3% and 2.3% per annum, respectively.

When the above economic targets are realized at the end of the Sixth Plan period, it is expected that Thailand will establish a fairly high position in the economic aspect among the Southeast Asian Countries. In this case, per capita income will rise from 21,000 baht in 1986 to 28,000 baht in 1991.

2.2 Administrative Divisions

The country is geographically divided into six regions: the Central, the Eastern, the Western, the Northeastern, the Northern, and the Southern region. Administratively, Thailand is divided into 73 provinces (changwat) which are composed of 733 districts (amphoe and king amphoe), 6,430 towns (tambon) and 57,415 villages (muban).

The Study Area on socio-economic sector is defined as all the 29 provinces in and/or related to the Chao Phraya River Basin (refer to Fig. 2-1). Twenty-four (24) of these provinces are wholly situated in the basin, while the five provinces of Chiang Mai, Tak, Phayao, Kamphaeng Phet and Uthai Thani are only partly situated. The 29 provinces are administratively composed of 270 districts which include 22 sub-districts, 2,461 towns and 19,552 villages. The total area of these provinces is 194,479 km^2, which includes the basin area of about 162,000 km^2 corresponding to 31.5% of the whole country area (refer to Table 2-2).

In the Study Area, the Bangkok Metropolitan Area composed of the Bangkok Metropolitan Administration (BMA) and the five provinces of Nonthaburi, Pathum Thani, Sumut Prakan, Nakhon Pathom and Samut Sakhon forms a greater community, and public works such as water supply, sewage and electric supply systems are administratively operated as a large unit on an area of 4,700 km2.

2.3 Economic Structure and Budget

2.3.1 General

The traditional industry of Thailand is agriculture which is based on rice cultivation. However, in recent years the demand for rice has decreased in both aspects of domestic and external uses, and the result appeared as the decrease in farmer's income and in exports.

To eliminate such an unfavorable situation, the Government encouraged the increase in production of upland crops such as maize, cassava, etc. The Government has also promoted the development of light industries which produce substitutes for daily goods to be imported. Currently, the light industrial products, together with some agricultural crops, have come to play a more important role than ever in export goods.

Despite the rise in exports owing to the increased production of light industrial products and some agricultural crops, the external trade of Thailand indicates that imports still exceed exports. The majority of such a trade deficit have been covered by the capital investments from abroad, and as a result the international payments of Thailand have kept a favorable balance in recent years. However, in the balance of international payments in 1986, it is noted that the balance of current account in addition to the capital account turned to a surplus, supported by the prosperity of export and service accounts.

2.3.2 Gross National Product (GNP) and Gross Domestic Product (GDP)

In 1985, the GDP and GNP of Thailand amounted to about 1,048,000 million baht and 1,010,000 million baht at current market prices, respectively, and the per capita GNP indicated about 20,000 baht. During the period from 1981 to 1985, the average annual growth rate of Thailand's economy was about 5% for GDP and GNP, and about 3% for per capita GNP (refer to Table 2-3).

In the Study Area (consisting of 29 provinces), the Gross Provincial Product (GPP) in 1985 amounted to about 668,000 million baht which corresponded to 64% of the GDP (1,048,000 million baht) of the Kingdom. Of this value, that in Bangkok City amounted to 389,000 million baht which accounted for 58% of that in the Study Area or 37% of the Kingdom's GDP. The growth in GPP in the Study Area for the 1981-1985 period was 5% or the same rate as the average growth rate of GDP in the whole country.

Per capita GPP in the Study Area in 1985 was estimated at about 30,000 baht which corresponds to about 1.5 times of that in the whole country. Especially, Bangkok, Samut Prakan and Pathum Thani showed a fairly high GPP per capita which amounted to 68,000 baht, 63,000 baht and 48,000 baht, respectively.

2.3.3 External Trade

In 1985, the external trade of Thailand amounted to about 444,000 million baht which comprised exports of 193,000 million baht and imports of 251,000 million baht, and the trade deficit showed 58,000 million baht. Such a trade deficit has continued every year in recent years, despite the rise in exports at the fairly high rate of 6% or more per annum since 1985.

Among exports, the aggregate sum of foods, crude materials and manufactured goods accounted for 73% of the total exports, i.e., 142,000 million baht in 1985. On the other hand, imports represented by machinery, mineral fuel, manufactured goods and chemicals amounted to about 205,000 million baht in 1985, or 82% of the total imports.

2.3.4 Balance of International Payments

Since 1981, the international payments of Thailand have kept a favorable balance every year except 1983, in spite of the trade deficit, owing to the positive balance of invisible trade consisting of capital, transfer and service accounts. For example, in 1986 the balance of international payments came to a surplus of about 33,600 million baht which comprised the deficit of 16,500 million baht for the trade balance, the surplus of 10,800 million baht for the capital account, the surplus of 5,800 million baht for the transfer account, the surplus of 16,600 million baht for the service account and the other surplus of 16,900 million baht.

2.3.5 Government Budget

The Government Budget of Thailand increased at the average rate of 14% per annum during the past two decades, and in 1985 the public revenue and expenditure amounted to 159,000 million baht and 183,000 million baht, respectively. Although the finance deficit continued every year during the said period, it has indicated a reducing tendency since 1982. Statistics on revenue and expenditures are shown in Table 2-4.

2.4 Population and Households

2.4.1 Population

The population census of Thailand has been conducted every 10 years since 1960, and it showed the population of 26.258 million in 1960, 34.393 million in 1970 and 44.825 million in 1980. The average annual rate of population growth for both periods of 1960-1970 and 1970-1980 was 2.74% and 2.68%, respectively. The population in 1985 amounted to 51.795 million according to the report of the National Statistical Office, and the growth rate was estimated at 2.93% per annum during five years from 1980 to 1985 (refer to Table 2-5).

The population in the Study Area rose from 18.254 million in 1980 to 21.158 million in 1985 which accounted for about 40% of the population of the whole country, and during the 1980-1985 period the population growth showed a rate of 3% per annum. Among them, the population of Bangkok City in 1985 amounted to nearly 5.400 million and the growth rate indicated 2.69% per annum during the 1980-1985 period.

The population density in 1985 was estimated at 101 persons per square kilometer on the average in the whole country and 109 persons per square kilometer in the Study Area. In the Study Area, Bangkok City had the population density of nearly 3,500 persons per square kilometer in the same year.

2.4.2 Households

According to the 1980 Census, Thailand had about 8.419 million households at the average rate of 5.2 persons per household, and in the Study Area the number of households amounted to about 3.464 million (or 43% share in the whole country) at the rate of 5 persons per household. Details on the number of households in the Study Area are described in the Supporting Report.

2.5 Price Index and Household Income

2.5.1 Price Index

The consumer price of Thailand has been stable for the last few years, reducing gradually the rate of price escalation, i.e., the rise in consumer price was only 2.4% in 1985 against 5.2% in 1982. During the 1981-1985 period, the average rise rate of the price was about 3% per annum, and there was not so much disparity among regions.

On the other hand, the producer price of Thailand showed a downward trend rather than stability, i.e., the producer price index in the whole Kingdom fell from 169.5 in 1981 to 169.0 in 1985 (100 in the base year 1976) at the average rate of -0.1% per annum. In the Central and Northern regions which include a majority of the Study Area, the producer price index fell at the average rate of -2% or more per annum during the same period.

2.5.2 Household Income

According to a Socio-Economic Survey for the whole Kingdom which was conducted in 1981 by the National Statistical Office, the average annual household income was estimated at 40,536 baht for the whole Kingdom for the said year. Among households by region, the households in the Bangkok Metropolitan Area had the highest average annual income of 71,664 baht per household, and was followed by the Central Region, the Southern Region and the Northern Region, which amounted to 43,980 baht, 39,072 baht and 34,632 baht, respectively.

2.6 Infrastructures

2.6.1 Transportation

Inland transport in Thailand depends mainly on the highway transport. Share in the transport volume in 1985 accounted for approximately 85% on the highway, 13% on the railway, 1% on the waterway and 1% on the airway.

Highway

Among highways, the national and provincial highways account for the majority of transport. The total length increased from 14,175 km in 1981 to 15,132 km in 1985 for the national highways, and for the provincial highways from 15,841 km in 1981 to 21,017 km in 1985, at the increase rate of 1.6% and 7.3% per annum, respectively. The highway network in the Study Area in 1985 amounted to about 20,000 km in total length, which accounted for more than a half of the length of the whole country's highway network.

Railway

Railways in Thailand, which are at present operated by a governmental authority, the State Railway of Thailand, have the total length of 3,735 km consisting of the single track of 3,645 km and the double track of 90 km.

The number of passengers transported by railway rose from 74.3 million people in 1980 to 81.5 million people in 1984 at the average growth rate of 9.7% per annum. However, the growth since 1982 has declined gradually, and the freight transport also showed a downward trend during the period 1980-1984, i.e., 6.23 million tons in 1980 and 5.57 million tons in 1984.

Port

Thailand has the Bangkok Port and three other trading ports, Sattahip, Songkhla and Phuket, which are administered by the Port Authority of Thailand (PAT). Bangkok Port located on the downstream of the Chao Phraya River is the most important trading port and has accounted for over 90% of cargoes handled at all ports in Thailand. Water depth in the port is about 8.5 m below mean sea level, and it is possible to enter a vessel with 8.2 m draft, 12,000 DWT and 170 m long in the port.

The quantity of goods loaded at the Bangkok Port reached 1,975 million tons in 1984, corresponding to about twice the 1,017 million tons in 1980. On the other hand, the quantity of goods unloaded was 4,151 million tons in 1984, or 1.15 times the 3,586 million tons in 1980. During the 1980-1984 period, the average annual growth rate of the quantity of cargoes handled showed 18.05% for the loaded goods and 3.73% for the unloaded goods. In recent years, the quantity of goods loaded rose remarkably, supported by the increase in the export of light industrial goods, etc. However, the quantity of unloaded goods still exceeded that of the loaded goods during the said period.

2.6.2 Telecommunication

The telecommunication business of Thailand is at present operated by two agencies, namely, the Telephone Organization of Thailand (TOT) and the Communications Authority of Thailand (CAT), which are under the control of the Posts and Telegraph Department (PTD). TOT provides all of the domestic telephone services and CAT conducts telegram, telex, postal and international telephone services.

The number of telephone line capacity rose from 423,000 in 1980 to 571,000 in 1984 at an average rate of 7.8% per annum, and the number of subscribers increased from 366,000 in 1980 to 519,000 in 1984 at a high average rate of 9.2% per annum.

According to the Fifth Development Plan of TOT (1984-1991), it is expected that the ratio of subscribers in the whole Kingdom will increase from one (1) set per 97 persons in 1984 to one (1) set per 37 persons at the end of 1991.

2.6.3 Water Supply

The waterworks of Thailand are mainly conducted by two agencies, namely, the Metropolitan Waterworks Authority (MWA) and the Provincial Waterworks Authority (PWA). MWA, which was established in 1967, has conducted the water supply activities in four (4) municipalities (Bangkok, Thonburi, Nonthaburi and Samut Prakan) in the Bangkok Metropolitan Area. The water quantity supplied by MWA amounted to 820 million m^3 (MCM) in 1986 against 620 MCM in 1981 at the average increase rate of 5.8% per annum during the said period, and the population served in 1986 reached 4.71 million spreading over the served area of 475 km^2. According to the future plan of MWA, in the year 2000 it is expected that water supply will amount to about 1,400 MCM per annum for the served population of 7.8 million.

PWA, since its establishment in 1979, has carried out the waterworks in 183 municipalities with a population of 5,000 or more, except the MWA area. The total quantity of water supplied by PWA in 1985 amounted to 260 MCM for the served population of 2 million. In the Study Area except the BMA area, the supplied water quantity came to about 100 MCM for the served population of 0.8 million in the same year. According to the development plan of PWA, it is expected that the water supplied will amount to about 300 MCM in 1991 for the served population of 2.2 million.

Despite efforts of the said agencies, the served population does not exceed 20 million in the whole country, or the served ratio is below 50%. Therefore, the spread of water supply system is a matter of vital importance for the Thai people, especially in the rural areas.

2.6.4 Electric Power Supply

The electric power supply business in Thailand is mainly operated by three agencies, namely, the Electricity Generating Authority of Thailand (EGAT), the Metropolitan Electricity Authority (MEA) and the Provincial Electricity Authority (PEA). EGAT has since 1969 conducted construction, operation and maintenance of power plants and the electric supply to MEA, PEA, and some factories. MEA and PEA have carried out supply services for the general users. The MEA service area is the Bangkok Metropolitan Administration (BMA) and the two provinces of Nonthaburi and Samut Prakan; other areas are served by PEA.

The total generation capacity in Thailand increased from 3,800 MW in 1980 to 6,200 MW in 1984 at an average growth rate of 13% per annum. Share of the capacity by generation origin in 1984 showed 27% for hydroelectric plants, 59% for steam power plants and 14% for other power plants. The actual power generation made was about 22.0 billion kWH in 1984, against about 15.1 billion kWh in 1980. During the period from 1980 to 1984, the growth rate of generation was 10% per annum on the average.

Consumption of electric power in the whole country, except a distribution loss, amounted to 18,500 kWh in 1984, against 13,000 kWh in 1980 at an average growth rate of 9% per annum. Share of the consumption by sector in 1984 indicated 26% for both residential and commercial uses, and 47% for industrial use. In the MEA area, the consumption increased from 8.0 billion kWH in 1980 to 10.0 billion kWH in 1984 at the average annual growth rate of 6% which was somewhat low compared with that in the whole country.

2.7 Topography and Geology

2.7.1 Topography

The Chao Phraya River Basin is situated in central and northern Thailand. It extends from the Thai-Burma border in the north down to the Gulf of Thailand in the south.

Rivers merge into the Chao Phraya River somewhere around Nakhon Sawan at the transition zone from the mostly mountainous area in the north to the flat land in the south, and then diverge again into several channels. Therefore, the Chao Phraya River Basin can be broadly divided into two (2) basins at Nakhon Sawan from the aspect of river channel system, i.e., the upper reaches covering 70% of the mostly mountainous total basin area and the lower reaches consisting of flat land.

From West to East, the upper reaches can in turn be subdivided into four (4) basins that correspond to the main river channels in the area. These are the Ping River Basin, the Wang River Basin, the Yom River Basin and the Nan River Basin, each one forming a feather-shaped configuration (refer to Fig. 2-2). The catchment areas of the four basins are 45,900 km^2, 10,400 km^2, 21,400 km^2 and 33,200 km^2, and the river lengths are 500 km, 220 km, 500 km and 490 km, respectively. The river channels form a relatively gentle riverbed gradient of from 1/1,700 to 1/8,300.

Some of the plains scattered in the upper reaches have developed into urban areas such as Chiang Mai, Sukothai and Phitsanulok. The rest is agricultural land which sometimes plays the role of retarding basin during flood time.

In the flat land in the lower reaches, the Chao Phraya River with a catchment area of approx. 51,000 km^2 and river length of 360 km forms a complex watercourse network of diversion channels and canals. At around the beginning of the flat land, it diverts into four irrigation canals, the

Chai Nat-Pasak Canal, the Chai Nat-Ayutthaya Canal, the Noi River and the Suphan River. Further downstream, it gives off four other diversion channels, the Lop Buri, the Bang Kaeo, the Bang Ban and the Bang Luan rivers. Except the Suphan River, these diversion channels and canals rejoin the Chao Phraya River near Ayutthaya and Bang Sai.

In the lower reaches, the Chao Phraya receives some tributaries such as the Sakae Krang River with the catchment area of 4,600 km^2 and the Pasak River with 14,000 km^2. The riverbed gradient of the Chao Phraya River varies between 1/10,000 and 1/50,000. (Refer to Fig. 2-3.)

A vast agricultural land, as well as urban areas such as Bangkok, Ayutthaya, Chai Nat and others, exists in the flat land area. The agricultural land is divided into districts by local ring levees, roads, railway lines, etc., that sometimes interrupt inland drainage in the districts and the flow of flood water into main tributaries during flood time. From this condition, it can be said that the agricultural land plays the role of retention area for local rainfall and inundation water from the Chao Phraya River.

2.7.2 General Geology

Landforms in the mountainous area in the upper reaches are believed to have been formed during Tertiary and Quaternary times. It has been reported that the late Mesozoic and early Tertiary seem to have been periods of erosion and peneplanation. Probably a younger granite was emplaced thereafter, succeeded by intense fracturing and accumulation of limnic and terrestrial deposits in down faulted areas.

The landforms are formed in widely variable rocks of igneous and sedimentary origin that are more or less metamorphosed in places, trending N-S. Many portions are known to contain great thickness of lacustrine and fluviatile Cenozoic sediments, mainly Miocene and Quaternary. Remnants of old peneplanation situated at different levels exist. Terrace gravels and calcareous tufa, a few basalt occurrences as well as alluvial deposits, account for the latest geologically recorded events.

In the flat land area in the lower reaches, the landforms which are characterized by strong undulation with alternating swells and swales can be geomorphologically classified into three categories: floodplain, terrace and peneplain. Floodplain deposits along the Chao Phraya river course have a surface of 3 m to 5 m above the present stream bed in the lower part and consist of the natural levee and the back swamp with a surface of more than 10 m in the higher part.

The terraces develop along the present and abandoned river courses, forming a narrow belt and/or zonal strip formed by sediment deposition which reaches to 13 m above the present riverbed at the part adjacent to the mountainous area. Some portions are marked by heavily weathered sediments with a thin lateritic cap, or consist of thin laterite bed in the upper part of the deposit.

2.8 Land Use

Flood damages to agriculture and inhabitants occur in the wet season. Therefore, the following description presents the general information on land use in the wet season.

2.8.1 Land Use in the Whole Basin

The present land use in the Chao Phraya River Basin, which has an aggregate area of 162,000 km^2, can be categorized into five (5), namely, built-up land, cultivated land, forest land, water area and other lands, as shown in Fig. 2-4. Each categorized area is estimated by province in Table 2-6.

Among the five categories, forest land which spreads over the mountainous area and the cultivated land which is situated mainly in the flat plain along the river courses occupy 51% and 43% of the whole Chao Phraya River Basin, or 83,000 km^2

and 70,000 km^2, respectively. The remaining 6%, or an area of about 9,000 km^2, is composed of the built-up land situated mainly along the river courses, the water area, and the other lands which are scattered in the basin.

The cultivated land is further divided into four (4) categories, namely, paddy field, field crop land, perennial crop land and nursery pond, as shown in Table 2-6. The present rates of paddy field and field crop land compared to the whole area of the cultivated land are 63% and 33%, or 44,500 km^2 and 23,000 km^2, respectively, which are about 27% and 14% of the whole basin area. The other 4% or 2,500 km^2 of the cultivated land is composed of perennial crop land and nursery pond.

From the aspect of irrigation system, 22,300 km^2 of the cultivated land is irrigated under the large/medium scale projects, small scale projects and royal development projects. Almost all of the irrigation systems are installed in paddy fields, so that about half of all paddy fields in the basin are already irrigated.

As a whole, the rates of land use mentioned above will not vary much in the future, although the rate among the four categories of cultivated land will vary gradually for higher productivity, as noted in the forest conservation being carried out as one of the national policies.

2.8.2 Land Use in the Downstream

Among the cultivated land which spreads widely along the river course from Uttaradit to the estuary as presented in Fig. 2-4, the area of about 45,000 km^2 situated downstream from Nakhon Sawan where land utilization is highly developed has been considered for the selection of the target area.

The flat plain in the downstream from Nakhon Sawan is well developed; thus, the rate of cultivated land in this area reaches up to 70% of this downstream area, or about

31,500 km^2. Out of this cultivated land area, 70% or 22,000 km^2 is paddy field. The paddy field consists of 80% or 17,800 km^2 of lowland rice field and 20% or 4,200 km^2 of deepwater/floating rice area which is mainly cultivated nearby the river courses as shown in Fig. 2-5.

Forest lands along the east and west boundaries of the basin occupy only 20% or about 9,000 km^2 of the downstream area, which is much lower than the average rate of forest land in the whole basin. The remaining 10% or about 4,500 km^2 of the downstream area consists of built-up land, water area and other lands, and this rate is almost double the average rate for the whole basin because the residential and industrial areas are well developed in the downstream.

The rate of irrigated area in the downstream is much higher than the average rate for the whole basin, i.e., 50% of the cultivated area or 15,700 km^2 is already irrigated. This comprises about 70% of the paddy field area of 22,000 km^2.

2.9 Meteorology and Hydrology

The Chao Phraya River Basin is located in the tropical monsoon region which has distinct dry and rainy seasons. The rainy season is brought by the southwest monsoon coming from the Indian Ocean during the period from April to October. The monsoon is laden with high moisture content and provides high values of precipitation and humidity.

During the rainy season, tropical cyclones often occur in the South Pacific Ocean and move into the basin, especially in September and October. Due to the tropical cyclonic disturbances, more widespread precipitation of longer duration can happen in the basin.

The dry season continues from November until March during which a dry and cold air mass is brought by the northwest monsoon from the China Mainland (refer to Fig. 2-6).

Consequently, the dry season provides low values of precipitation and humidity.

The annual rainfall in the basin varies from 1,000 mm in the western area to 1,400 mm in the northeastern area. About 85 percent of the annual rainfall occurs during the rainy season and during a tropical cyclone, one-day precipitation sometimes exceeds 100 mm.

Temperature ranges from 27 to 32°C during the rainy season, while it drops to 20 to 27°C during the dry season (refer to Fig. 2-8). As for the areal variation, the temperature is rather uniform, except in the mountainous region around Chiang Mai.

Evaporation in the basin is normally at its highest in April and lowest in August to September (refer to Fig. 2-7). According to the records of a pan evaporation gauge, the average monthly evaporation varies from about 100 mm to 250 mm with annual totals of about 1,200 mm observed in the northeastern area to 2,000 mm in the inland areas.

The river flow discharge shows a seasonal variation in accordance with the aforesaid distinctive precipitation in the rainy and dry seasons. It usually starts to increase in April, and reaches its peak in either September or October when an intensive precipitation is caused by the tropical cyclonic disturbances.

The stream gauging station at Nakhon Sawan (Sta. C2) is regarded as a key station to overview the flood discharges from Ping, Yom and Nan. According to the records at the station, the maximum discharge was observed after construction of the Bhumibol and the Sirikit dams at 4,355 m^3/s in 1975 and the second at 4,320 m^3/s in 1980. 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 the large retarding effects, the extremely wide drainage area, and the gentle slope of the basin.

The tidal compartment is regarded approximately until Bang Sai on the Chao Phraya River and the Rama VI Dam on the Pasak River. The mean high water and the mean low water spring tides are approximately 2.2 m and -1.8 m above MSL observed at the river mouth.

2.10 Inundation and Flood Damage

Major flood damages along the Chao Phraya river course are caused by flood discharge from the Chao Phraya River and its main tributaries during the rainy season. Flood damages in certain areas of the basin are caused by inundation due to local heavy rainfall.

The collected data indicate that flood inundation occurred both in the upper reaches and the lower reaches from Nakhon Sawan. In the upper reaches, the flood inundation area is mostly along the right side bank of the Yom River, although some small inundation areas are dotted along the river course. Flood inundation in the lower reaches is widely seen along the Chao Phraya river course, especially in the area near Ayutthaya.

According to the statistical data on the number of population that received aid from the social welfare flood rescue fund and the flood damaged irrigation area during the period from 1975 to 1985, those in the upper reaches amount to 395,000 people and 33,000 ha, while those in the lower reaches are 1,132,000 people and 250,000 ha, respectively. From these data, it is gathered that flood damage is more serious in the lower reaches from Nakhon Sawan.

Among the recently recorded floods, those that occurred in 1975, 1978, 1980 and 1983 had inflicted severe damage in the downstream, as described in the following paragraphs.

1975 Flood

The flood in 1975 that had the discharge of about 4,400 m^3/s and 3,900 m^3/s at Nakhon Sawan and Chai Nat water gauging stations, respectively, brought about inundation to the agricultural land on the right bank side of Chao Phraya downstream of Ang Thong, although the inundation area is not clear. In Bangkok Metropolis, flood damage amounted to 1,100 million baht. (Refer to Table 2-7.)

1978 Flood

The flood discharge observed at Nakhon Sawan and Chai Nat stations were about 3,500 m^3/s and 3,700 m^3/s, respectively, while that at Ang Thong Station in the lower reaches of Chai Nat marked 2,800 m^3/s only. From these observed data, it is believed that flood discharge overtopped the bank between Chai Nat and Ang Thong, as verified from the inundation map in Fig. 2-8(1/3).

The data on flood damage indicate that inundation occurred in the agricultural area between Sing Buri and Ayutthaya and in the Ayutthaya urban area. The maximum flood discharge in the basin of Pasak River, a tributary of the Chao Phraya River, was 3,200 m^3/s. This was almost equal to that in the Chao Phraya River Basin, and flood damage on the agricultural area along the Pasak River has been reported. Flood damage caused by local rainfall was also detected, especially in the area along the Chai Nat-Pasak Irrigation Canal and the Lop Buri River, and flood damage on the Bangkok Metropolis has been reported as that of an average flood.

1980 Flood

In this flood, damage occurred in several places in the lower and upper reaches due to inundation by local rainfall and the flood discharge from the main channel which inflicted a more severe damage. Discharges of about 4,400 m^3/s and 3,700 m^3/s observed at Nakhon Sawan and Chai Nat, respectively, inundated both sides of the Chao Phraya river course between Chai Nat and Ayutthaya, so that the agricultural area suffered from tremendous damage [refer to Fig. 2-8(2/3)]. Several cities along the main river course such as Nakhon Sawan, Chai Nat and Ayutthaya were also exposed to danger by flooding water of the river channel. In the Bangkok Metropolis, flood damage was reported at 450 million baht.

1983 Flood

The peak discharge of 2,300 m3/s in the upper reaches from Nakhon Sawan during the flood in 1983 is not so large compared with the previous three floods. However, in the lower reaches the peak discharge surged to 3,300 m3/s at Chai Nat and 3,700 m3/s at Ang Thong. The flood also brought inundation to the area along the river course between Chai Nat and Ayutthaya, and inundation caused by local rainfall occurred also in the lower reaches near Bangkok Metropolis, as shown in Fig. 2-8(3/3).

During the year, flood damage in Bangkok Metropolis amounted to 6,500 million baht due to multiple causes such as flood discharge from the Chao Phraya River, high tide, local rainfall and inflow discharge from the outer area.

The road network along the Chao Phraya river course was also reported to have been damaged in the lower reaches but not in the upper reaches, as shown in Fig. 2-9, while the railway has not been interrupted by floods for the past 10 years.

Table 2-1. MACRO ECONOMIC TARGETS OF THE SIXTH PLAN COMPARED WITH RESULTS OF THE FOURTH AND FIFTH PLANS

Item	Fourth Plan (1977-1981) (Actual)	Fifth Plan (1982-1986) (Actual)	Sixth Plan (1987-1991) (Targets)
1. Real Economic Growth (%) (Average Rate Per Annum)			
1.1 GDP	7.1	4.4	5.0
1.2 Agriculture	3.5	2.1	2.9
1.3 Manufacturing	8.7	5.1	6.6
1.4 Mining	10.1	6.1	6.4
1.5 Electricity	11.7	8.0	6.1
1.6 Construction	9.5	3.6	5.1
1.7 Services	8.2	5.6	5.3
2. Real Expenditure Growth (%) (Average Rate Per Annum)			
2.1 Consumption			
- Private Sector	5.5	4.3	3.7
- Public Sector	10.2	3.3	5.3
2.2 Investment			
- Private Sector	8.6	-0.8	8.1
- Public Sector	12.9	1.8	1.0
3. Export & Import of Goods			
3.1 Real Growth Rate Per Annum (%)			
- Export	20.0	8.4	10.7
- Import	24.8	2.9	9.5
3.2 Average Value Per Annum (Current Prices)			
- Export (Million Baht)	-	177,500	290,700
- Import (Million Baht)	-	233,100	326,700
3.3 Trade Deficit (Million Baht)	45,000	55,600	36,000
4. Current Account Deficit (Average Value Per Annum)	37,400	36,000	11,800
5. Government Finance/GDP (%)			
5.1 Revenue	14.2	14.6	15.2
5.2 Expenditure	17.5	18.2	17.3
5.3 Financial Deficit	3.3	3.6	2.1
6. Population Growth Rate Per Annum (%)			
6.1 Whole Country	-	1.7 /1	1.3 /2
6.2 Bangkok Metropolitan Area	-	2.7 /1	2.5 /2
6.3 Other Areas	-	1.4 /1	0.8 /2
7. Consumer Price Escalation Per Annum (%)	10.6	2.9	2.3
8. Per Capita Income (Baht)	-	21,395 /1	27,783 /2

Note: /1 In 1986.
/2 In 1991.

Source: Summary of the Sixth National Economic and Social Development Plan (1981-1991), NESDB.

Table 2-2. ADMINISTRATIVE DIVISIONS IN THE STUDY AREA

Province	Area (km^2)	Number of Subdivisions			
		Amphoe/2	Tambon	Village	Municipality
Whole Kingdom	513,115	733	6,430	57,415	124
Study Area	194,479	270	2,461	19,552	48
Central Region	20,308	91	857	6,298	17
1. Bangkok	1,565	24	150	727	-
2. Chai Nat	2,470	6	49	417	2
3. Nonthaburi	622	6	50	394	2
4. Pathum Thani	1,526	7	58	512	1
5. Ayutthaya	2,557	16	208	1,457	3
6. Lop Buri	6,200	8	117	1,010	3
7. Saraburi	3,577	11	109	935	3
8. Sing Buri	823	6	43	349	1
9. Ang Thong	968	7	73	497	2
Eastern Region	1,004	5	44	467	2
10. Samut Prakan	1,004	5	44	467	2
Western Region	27,881	29	328	2,479	6
11. Kanchanaburi /1	19,483	10	85	632	1
12. Nakhon Pathom	2,168	6	100	802	1
13. Samut Sakhon	872	3	40	283	2
14. Suphan Buri	5,358	10	103	762	2
Northern Region	145,286	145	1,214	10,308	23
15. Kamphaeng Phet	8,608	7	61	642	1
16. Chiang Mai /1	20,107	20	184	1,491	1
17. Tak /1	16,407	8	52	418	2
18. Nakhon Sawan	9,598	12	117	1,075	3
19. Nan	11,472	11	86	681	1
20. Phayao /1	6,335	7	54	594	1
21. Phichit	4,531	8	82	629	3
22. Phitsanulok	10,816	9	84	785	1
23. Phetchabun	12,668	11	91	967	2
24. Phrae	6,539	7	64	445	1
25. Lampang	12,534	13	87	643	1
26. Lamphun	4,506	6	48	412	1
27. Sukhothai	6,596	9	80	612	2
28. Uttaradit	7,839	9	62	440	2
29. Uthai Thani /1	6,730	8	62	474	1

Note: /1 The watershed boundary line of Chao Phraya River passes through this province.
/2 Includes king amphoes.

Source: Statistical Yearbook 1985-1986, National Statistical Office

Table 2-3. GROSS DOMESTIC PRODUCT AND GROSS NATIONAL PRODUCT AT CURRENT MARKET PRICES (1981-1985)

Unit: Million Baht

Industrial Origin	1981	1982	1983	1984	1985
Agriculture	187,886	188,742	204,443	193,438	182,279
Mining and Quarrying	13,373	14,807	16,480	21,291	29,279
Manufacturing	158,272	164,659	176,200	196,793	207,691
Construction	42,008	43,040	47,129	52,772	53,758
Electricity and Water Supply	10,743	14,454	16,319	18,884	21,645
Transportation and Communications	57,281	63,133	73,708	83,588	96,254
Wholesale and Retail Trade	150,293	159,849	165,812	181,993	190,676
Banking, Insurance and Real Estate	52,025	61,021	71,722	80,577	89,751
Ownership of Dwellings	8,441	9,912	11,210	12,337	13,706
Public Administration and Defence	30,645	37,349	42,551	43,182	47,058
Services	75,229	89,170	98,680	106,704	115,467
Gross Domestic Product (GDP)	786,166	846,136	924,254	991,559	1,047,564
Net Factor Income	-21,787	-26,376	-25,370	-31,776	-37,081
Gross National Product (GNP)	764,379	819,760	898,884	959,783	1,010,483
Per Capita GNP (Baht)	16,096	16,906	18,174	19,044	19,697

Source: Statistical Yearbook 1985-1986, National Statistical Office

Table 2-4. BREAKDOWN OF REVENUE AND EXPENDITURES OF THE GOVERNMENT (1981-1985)

Unit: Million Baht

Particulars	1981	1982	1983	1984	1985
Revenue	110,392	113,848	136,604	147,846	159,196
Taxes and Duties	95,496	100,261	118,613	130,015	138,525
Direct Taxes	21,580	24,436	26,705	31,454	34,157
General Sales Tax	21,661	22,697	25,429	30,434	30,711
Specific Sales Tax	26,508	30,343	32,434	34,557	40,161
Consumption Goods Tax	23,023	27,161	30,200	32,200	36,547
Natural Resource Tax	3,485	3,182	2,234	2,357	3,614
Import and Export Duties	24,964	21,545	27,805	32,819	31,826
Fees and Permits	782	1,239	6,175	750	1,669
Others	1	1	5	1	1
Sales of Goods and Services	2,920	3,496	4,066	4,222	4,602
State Enterprises	6,220	4,895	6,248	6,312	9,009
Miscellaneous	5,756	5,196	7,677	7,297	7,060
Expenditures	135,295	156,387	173,938	179,371	182,942
Economic Services	25,869	29,907	31,568	39,790	26,471
Education	28,228	33,525	36,244	37,559	35,926
Public Health and Utilities	20,040	15,744	18,194	20,228	21,089
Defence	27,319	30,955	34,246	35,297	31,166
Internal Security	7,293	8,172	9,130	9,735	9,704
General Administration	5,555	4,414	4,968	5,060	5,751
Debt Services Payment	16,858	20,469	27,088	33,385	44,394
Others	4,133	13,201	12,500	8,317	8,441

Source: Statistical Yearbook of Thailand, 1985-1986, National Statistical Office.

Table 2-5. POPULATION AND HOUSEHOLDS BY PROVINCE IN THE STUDY AREA IN 1980 AND 1985

Province	1980			1985		Average Annual Growth Rate
	Population	Number of Households	Persons Per Household	Population	Population Density (persons/km²)	(1980-85) (%)
Whole Kingdom	44,824,540	8,419,238 /1	5.3	51,795,651	101	2.93
Study Area	18,254,195	3,643,563	5.0	21,158,260	109	3.00
1. Bangkok	4,697,071	906,591	5.2	5,363,378	3,427	2.69
2. Nonthaburi	369,777	67,455	5.5	504,424	811	6.41
3. Pathum Thani	319,674	60,011	5.3	384,713	252	3.77
4. Ayutthaya	602,021	120,570	5.0	652,977	255	1.64
5. Ang Thong	256,706	54,256	4.8	270,941	280	1.09
6. Saraburi	432,875	85,734	5.0	489,056	137	2.47
7. Lop Buri	571,713	117,819	4.8	695,992	112	4.01
8. Sing Buri	198,574	43,231	4.6	215,021	261	1.60
9. Chai Nat	318,068	66,717	4.8	339,478	137	1.31
Sub-total	7,766,479	1,522,384	5.1	8,915,980	439	2.80
10. Samut Prakan	484,829	95,258	5.1	662,612	660	6.45
11. Samut Sakhon	247,168	43,592	5.7	315,373	362	4.99
12. Nakhon Pathom	525,906	94,229	5.6	609,316	281	2.99
13. Suphan Buri	709,432	140,284	5.1	779,703	146	1.91
14. Kanchanaburi	481,776	92,155	5.2	620,033	32	5.18
Sub-total	1,964,282	370,260	5.3	2,324,425	83	3.42
15. Nakhon Sawan	942,068	190,081	5.0	1,042,936	109	2.06
16. Uthai Thani	225,632	47,093	4.8	283,074	42	4.64
17. Phetchabun	680,315	124,567	5.5	905,262	71	5.88
18. Kamphaeng Phet	507,532	99,284	5.1	621,243	72	4.13
19. Phichit	537,774	107,529	5.0	553,913	112	0.59
20. Phitsanulok	632,218	126,805	5.0	735,052	68	3.06
21. Sukhothai	500,140	102,628	4.9	566,915	86	2.54
22. Uttaradit	401,165	78,998	5.1	441,730	56	1.95
23. Tak	272,483	53,654	5.1	318,844	19	3.19
24. Lampang	649,006	137,802	4.7	737,145	59	2.58
25. Phrae	420,546	90,379	4.7	475,238	73	2.48
26. Nan	361,609	68,924	5.2	417,344	36	2.91
27. Phayao	418,228	86,524	4.8	480,420	76	2.81
28. Lamphun	335,039	75,713	4.4	398,292	88	3.52
29. Chiang Mai	1,154,850	265,680	4.3	1,277,835	64	2.04
Sub-total	8,038,605	1,655,661	4.9	9,255,243	64	2.86

Note: /1 Excluding collective household.

Source: 1980 Population & Housing Census, National Statistical Office.
Statistical Yearbook 1985-1986, National Statistical Office.

Table 2-6(1/2). PRESENT LAND USE IN PROVINCES IN THE CHAO PHRAYA RIVER BASIN

(Unit: km^2)

	Province	Provincial Area	Build-Up Land /2	Cultivated Area: Paddy /3	Cultivated Area: Field Crop /4	Cultivated Area: Perennial Crop /5	Cultivated Area: Nursery Pond /6	Cultivated Area: Total	Forest /7	Water Area /8	Other Areas /9
1	Bangkok Metropolis	1,565	605.3	678.6	79.5	99.8	75.3	933.2	-	8.4	18.1
2	Chai Nat	2,470	122.4	1,734.4	149.7	0.5	-	1,184.6	428.5	16.2	18.3
3	Nontha Buri	622	119.1	409.6	16.8	70.5	0.4	497.3	-	5.6	-
4	Pathum Thani	1,526	64.1	1,282.5	7.3	124.0	1.3	1,415.1	6.0	9.2	31.7
5	Ayutthaya	2,557	254.9	2,300.6	-	-	-	2,300.6	1.5	-	-
6	Lop Buri	6,200	162.1	1,694.5	3,012.5	83.2	-	4,790.2	895.7	26.1	325.9
7	Sara Buri	3,577	305.9	1,210.9	1,104.0	44.8	-	2,359.7	849.7	9.6	52.1
8	Sing Buri	822	497.7	323.1	-	-	0.4	323.5	-	0.7	0.1
9	Ang Thong	968	138.3	808.5	13.8	3.3	-	825.6	0.4	3.2	0.5
10	Samut Prakarn	1,004	159.2	396.1	0.5	51.5	349.4	797.5	29.1	16.2	2.1
11	Kanchanaburi /1	3,000	53.1	132.8	650.0	40.0	-	822.8	1,890.5	138.8	179.9
12	Nakhorn Pathom	2,168	161.0	1,703.1	220.2	83.7	-	2,007.0	-	-	-
13	Samut Sakhorn	872	70.6	222.4	0.2	211.2	198.7	632.5	112.3	9.1	47.5
14	Suphan Buri	5,358	336.6	2,839.4	1,260.8	1.5	0.1	4,101.7	822.7	77.2	19.8
15	Kamphaeng Phet	8,608	123.7	1,981.7	1,059.8	252.0	-	3,293.5	5,096.0	-	94.8
16	Chiang Mai /1	17,584	268.7	1,347.4	110.9	372.5	-	1,830.8	15,185.8	70.5	228.2
17	Tak /1	7,400	58.7	370.5	537.8	3.6	-	911.9	6,260.1	109.0	60.3
18	Nakhon Sawan	9,598	281.1	4,985.1	1,818.1	52.3	-	6,855.5	1,844.5	64.7	552.1
19	Nan	11,472	106.1	687.1	102.3	43.8	-	833.2	10,399.2	56.9	76.6
20	Phayao /1	3,200	83.7	829.9	46.6	0.4	-	876.9	2,095.1	15.4	128.9
21	Phichit	4,531	224.1	3,708.2	486.0	43.0	-	4,237.2	24.8	34.3	10.6
22	Phitsanulok	10,816	271.9	2,924.1	3,117.1	449.6	-	6,490.8	3,903.8	63.4	86.1
23	Phetchabun	12,668	239.5	1,999.0	5,489.8	29.9	-	7,518.7	4,735.8	6.5	167.5
24	Phrae	6,539	98.2	5,474.0	430.6	1.8	-	5,906.4	524.6	-	9.8
25	Lampang	12,534	189.4	1,259.1	320.1	26.1	-	1,605.3	10,718.2	18.9	2.2
26	Lamphun	4,506	117.0	642.1	79.2	65.8	0.3	787.4	3,462.8	4.3	134.5

Table 2-6(2/2). PRESENT LAND USE IN PROVINCES IN THE CHAO PHRAYA RIVER BASIN

(Unit: km^2)

Province	Provincial Area	Build-Up Land /2	Cultivated Area: Paddy /3	Cultivated Area: Field Crop /4	Cultivated Area: Perennial Crop /5	Cultivated Area: Nursery Pond /6	Cultivated Area: Total	Forest /7	Water Area /8	Other Areas /9
27 Sukhothai	6,596	113.3	394.1	1,736.0	0.2	2.1	2,132.4	4,281.8	7.8	60.9
28 Uttaradit	7,837	116.1	962.4	687.2	2.8	-	1,652.4	5,535.8	306.5	225.3
29 Uthai Thani /1	5,400	34.2	1,153.5	311.7	3.3	-	1,468.5	3,807.5	56.6	33.2
Total (Chao Phraya Basin)	162,000	5,376.0	44,454.7	22,805.7	2,149.4	627.9	70,037.7	82,884.3	1,135.1	2,566.9
Percentage (%) /10	100	3.3	(63.5)	(32.5)	(3.1)	(1.0)	43.2 (100.0)	51.2	0.7	1.6

Note: The whole area of the Kingdom of Thailand is 513,115 km^2.

Data on provinces and their area were taken from the Statistical Yearbook for 1985-1986 published by the National Statistical Office.

The estimation of area of each land category is based on the interview survey with the Land Development Department of the Ministry of Agriculture and Cooperatives.

/1 The watershed boundary line of the Chao Phraya River Basin passes through the province.
/2 Cities, towns, villages, commercial land, industrial land and roads.
/3 Low-yield and high-yield varieties, traditional variety and deepwater/floating rice variety.
/4 Corn, sugarcane, beans, etc.
/5 Coconut, mango, orange, etc.
/6 Fish and shrimp ponds, saltbeds.
/7 Dense and sparse forest lands.
/8 Rivers, lakes and ponds.
/9 Rocky and wasteland.
/10 Percentages in parenthesis refer to the categories of Cultivated Land only.

Table 2-7. FLOOD DAMAGE CONDITION IN BANGKOK

Flood Year	Area	Investigated Item	Estimated Cost of Damage (in million Baht)	Source of Estimate
1975 Flood	Bangkok	Direct damage, indirect damage and utility losses.	1,100	Water Resources Committee, NESDB
1980 Flood	Central Bangkok Area	Direct damage, indirect damage and flood prevention cost.	450	Burkhard
Normal Flood Between 1975 and 1982	Central Bangkok Area	Damage and losses to households, small and large establishments, institutions, public utilities, road users, tourism sector and environmental conditions.	800	NEDECO
1983 Flood	Greater Bangkok Area	---	6,597	National Statistical Office

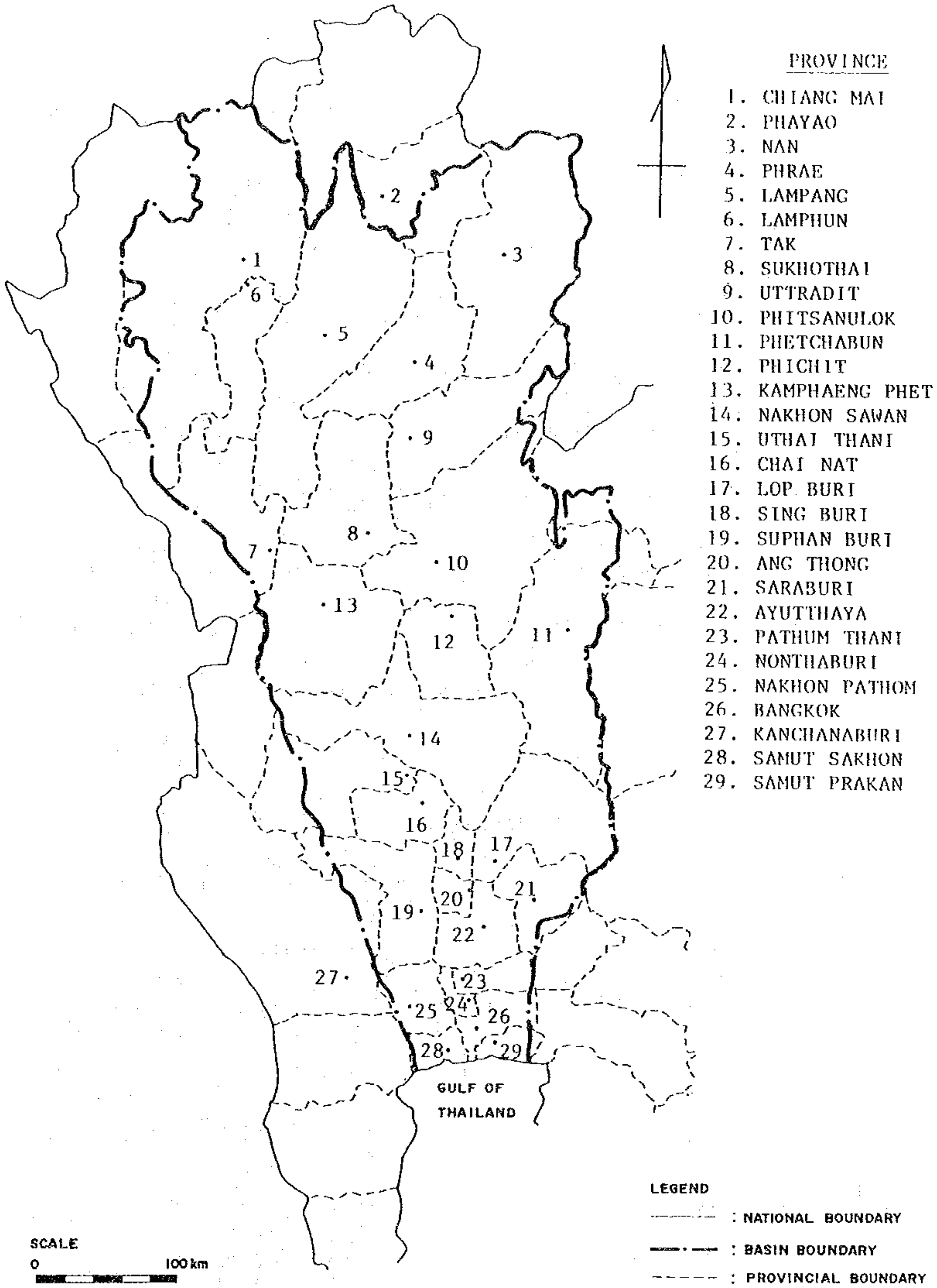

Fig. 2-1. ADMINISTRATIVE DIVISIONS

FLOOD FORECASTING SYSTEM
IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

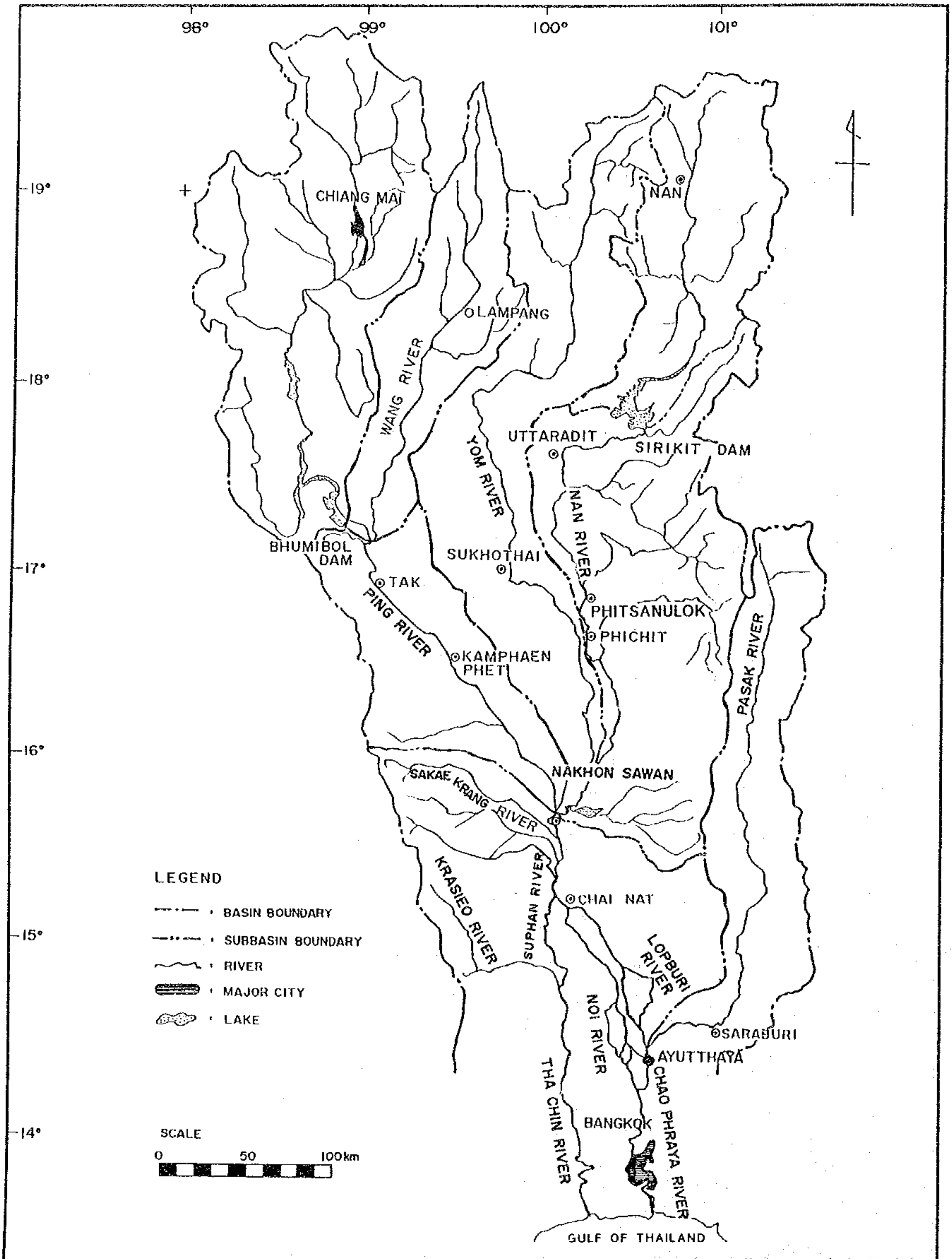

Fig. 2-2. SUBBASIN BOUNDARY

FLOOD FORECASTING SYSTEM
IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

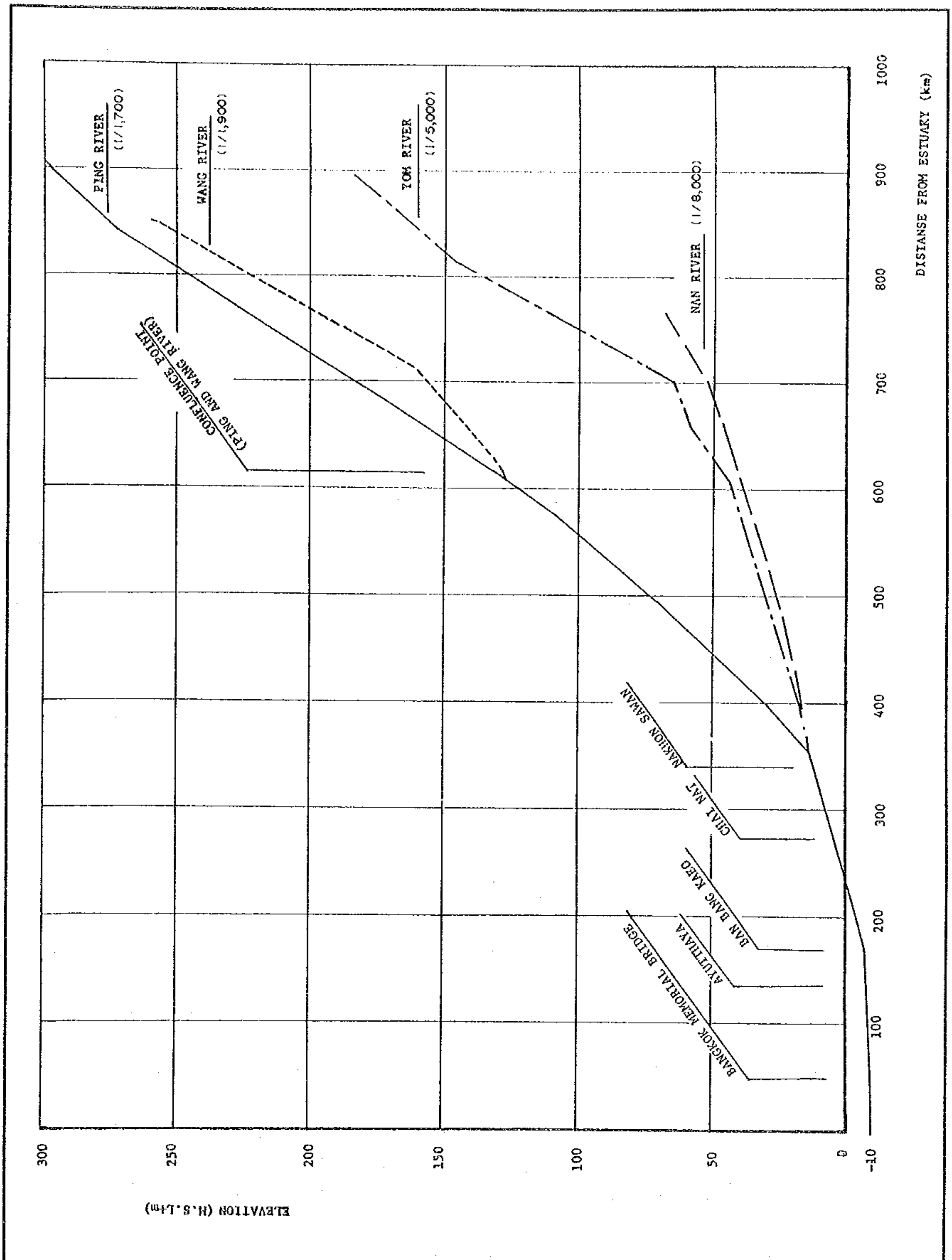

Fig. 2-3. LONGITUDINAL PROFILE OF THE CHAO PHRAYA RIVER

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

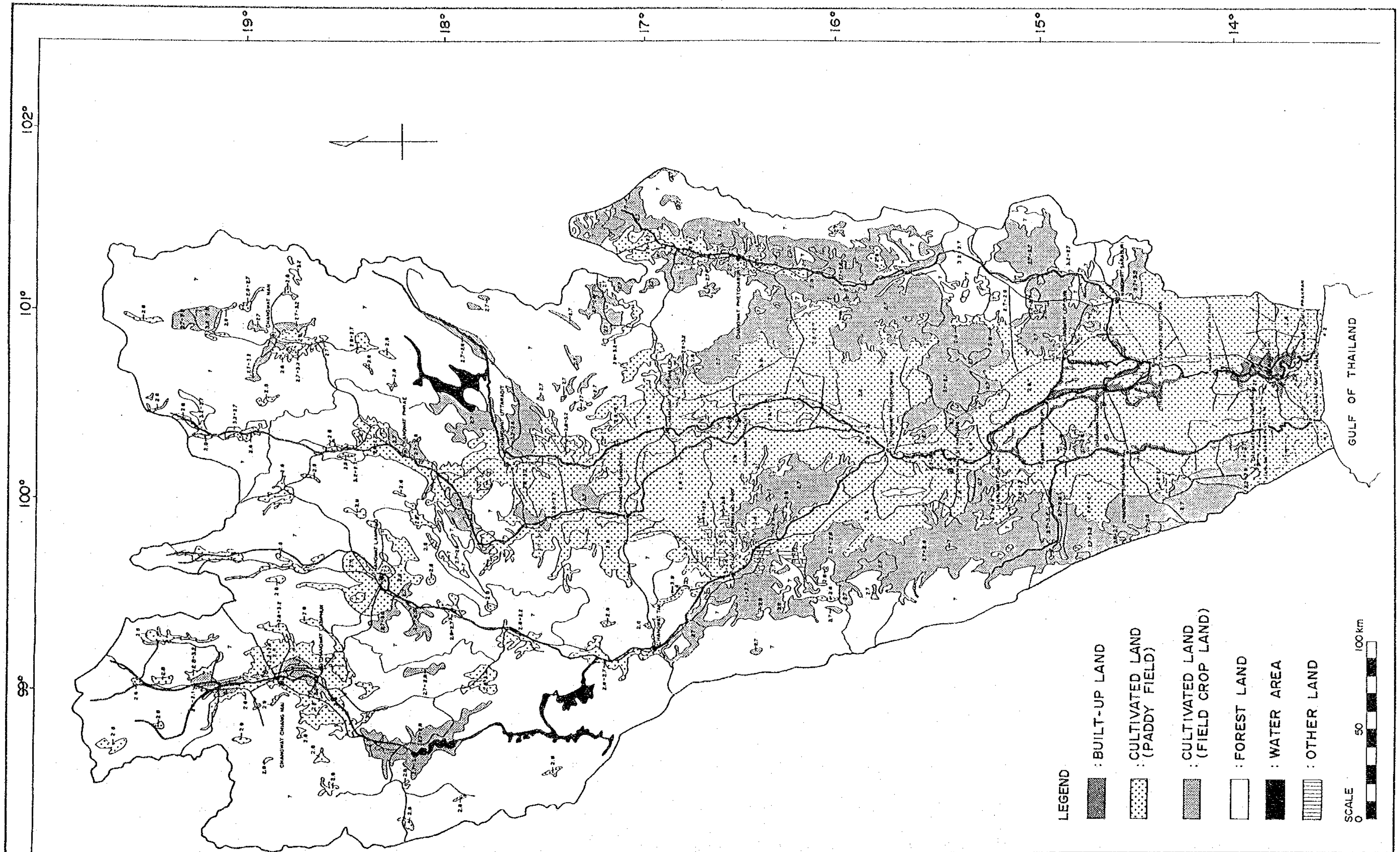

Fig. 2-4. PRESENT LAND USE IN THE CHAO PHRAYA RIVER BASIN

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

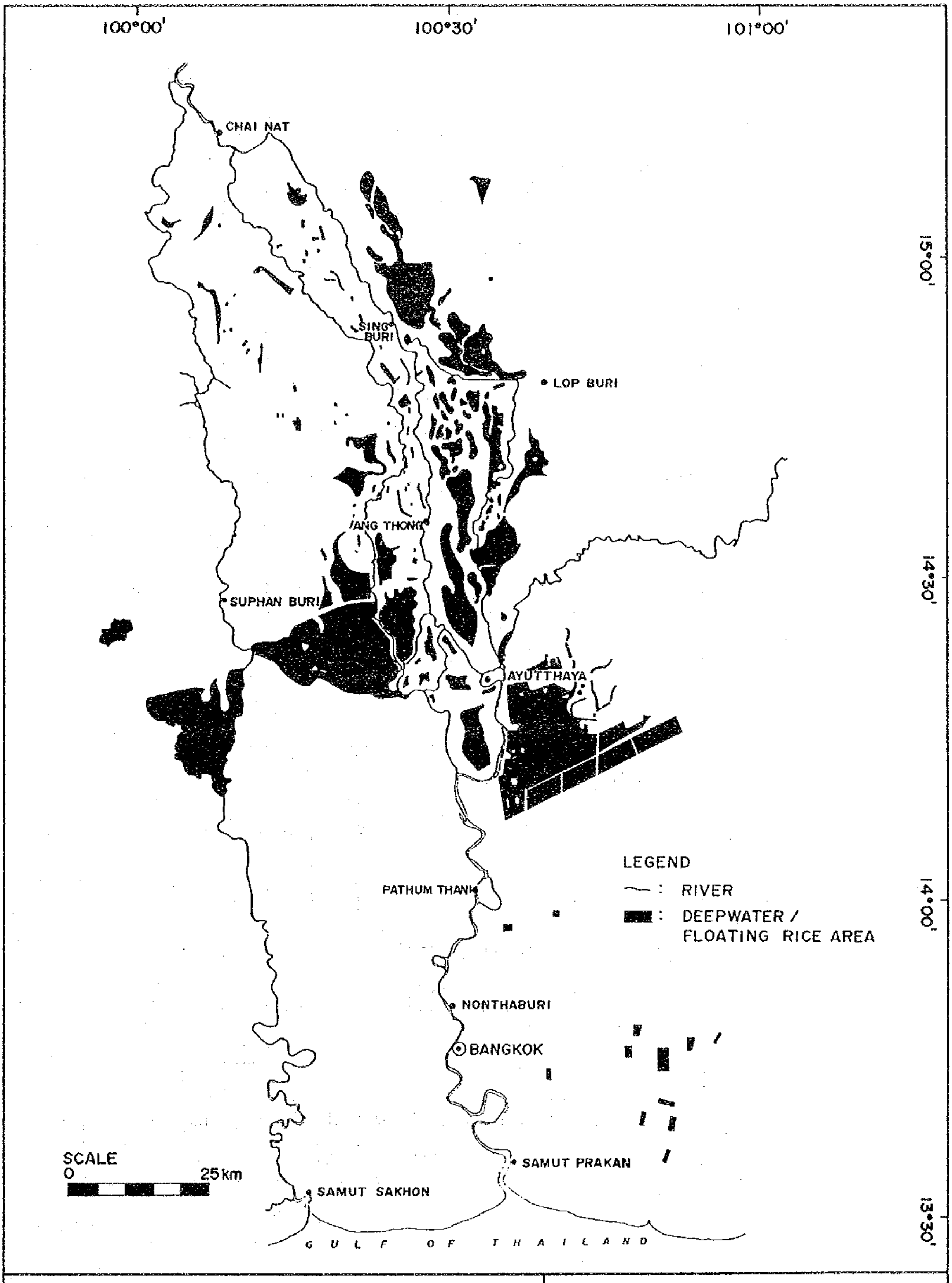

Fig. 2-5. PLANTATION AREA OF DEEPWATER/ FLOATING RICE

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

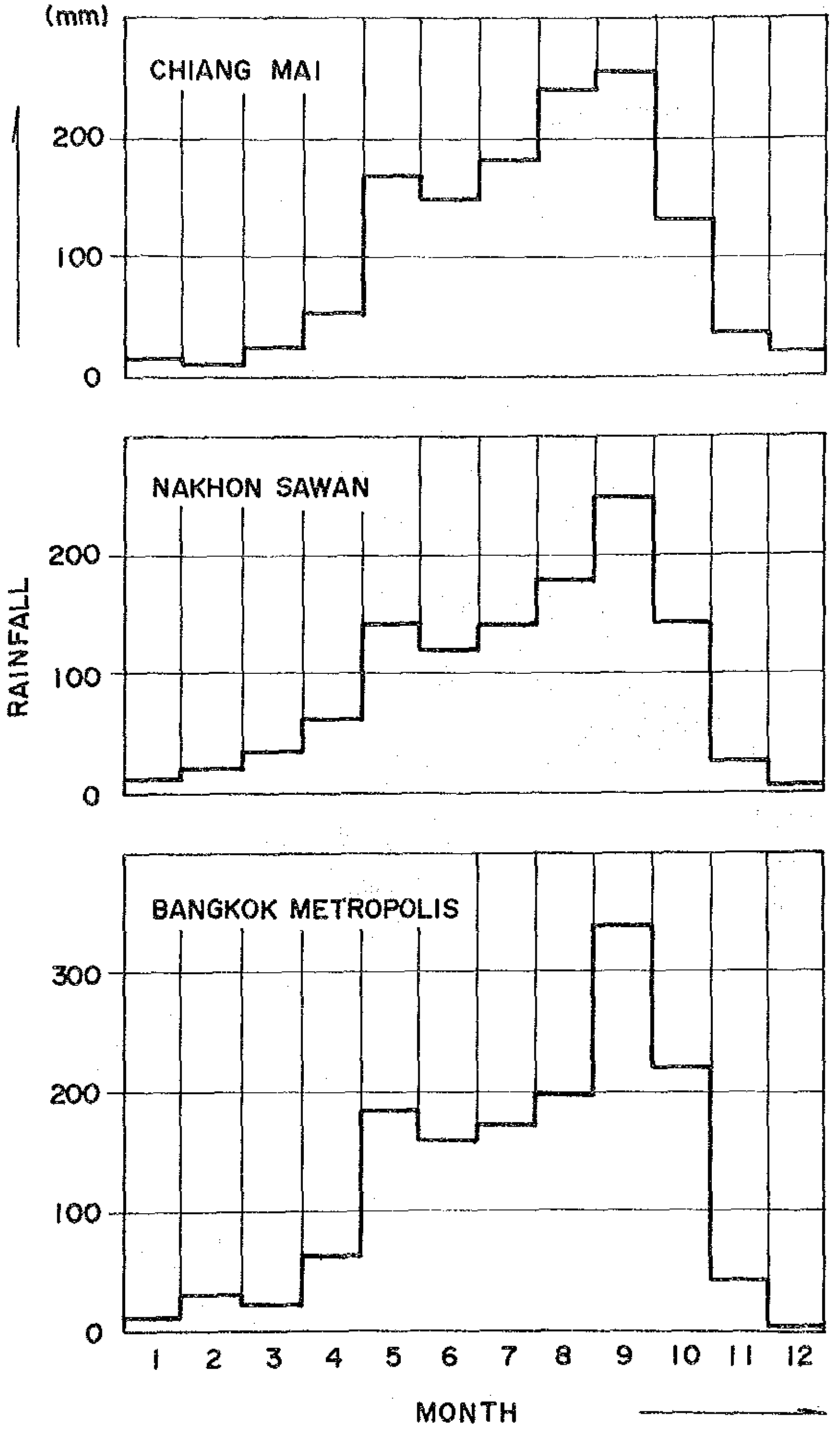

Fig. 2-6. MONTHLY VARIATION OF AVERAGE RAINFALL (1951 - 1980)	FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY

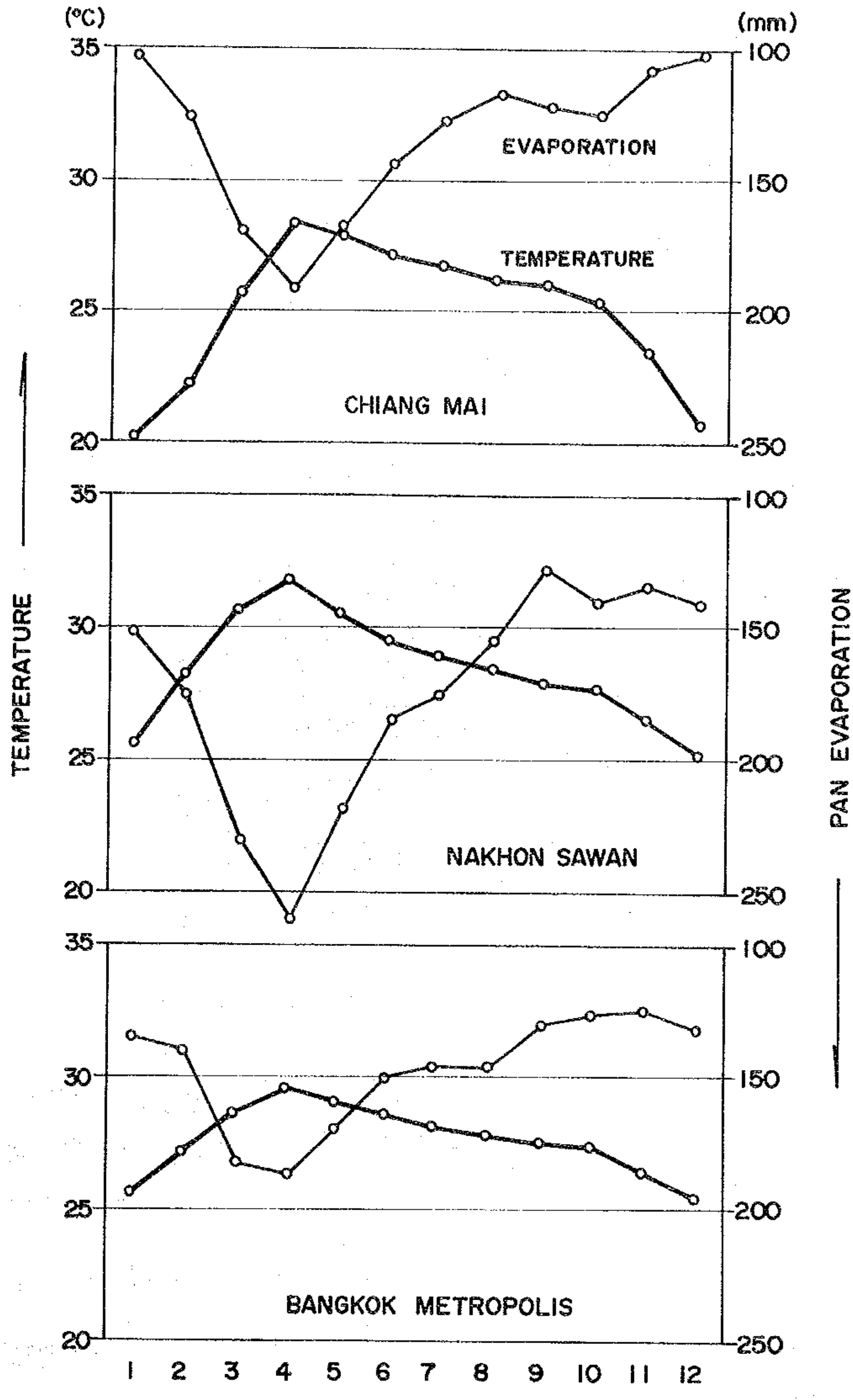

Fig. 2-7. MONTHLY VARIATION OF AVERAGE TEMPERATURE AND EVAPORATION (1951 - 1980)	FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY

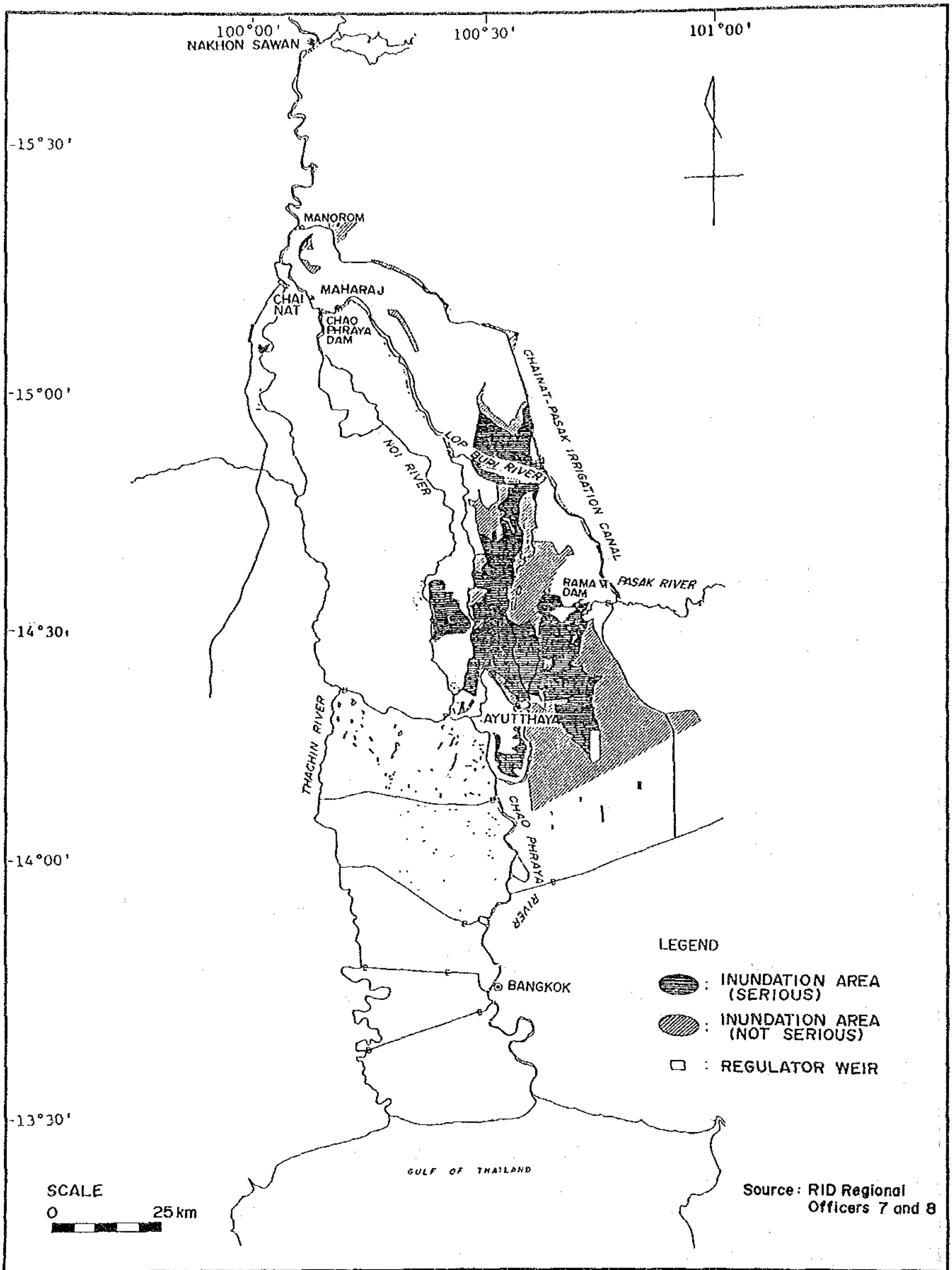

Fig. 2-8(1/3). FLOOD INUNDATION AREA (1978 FLOOD)	FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY

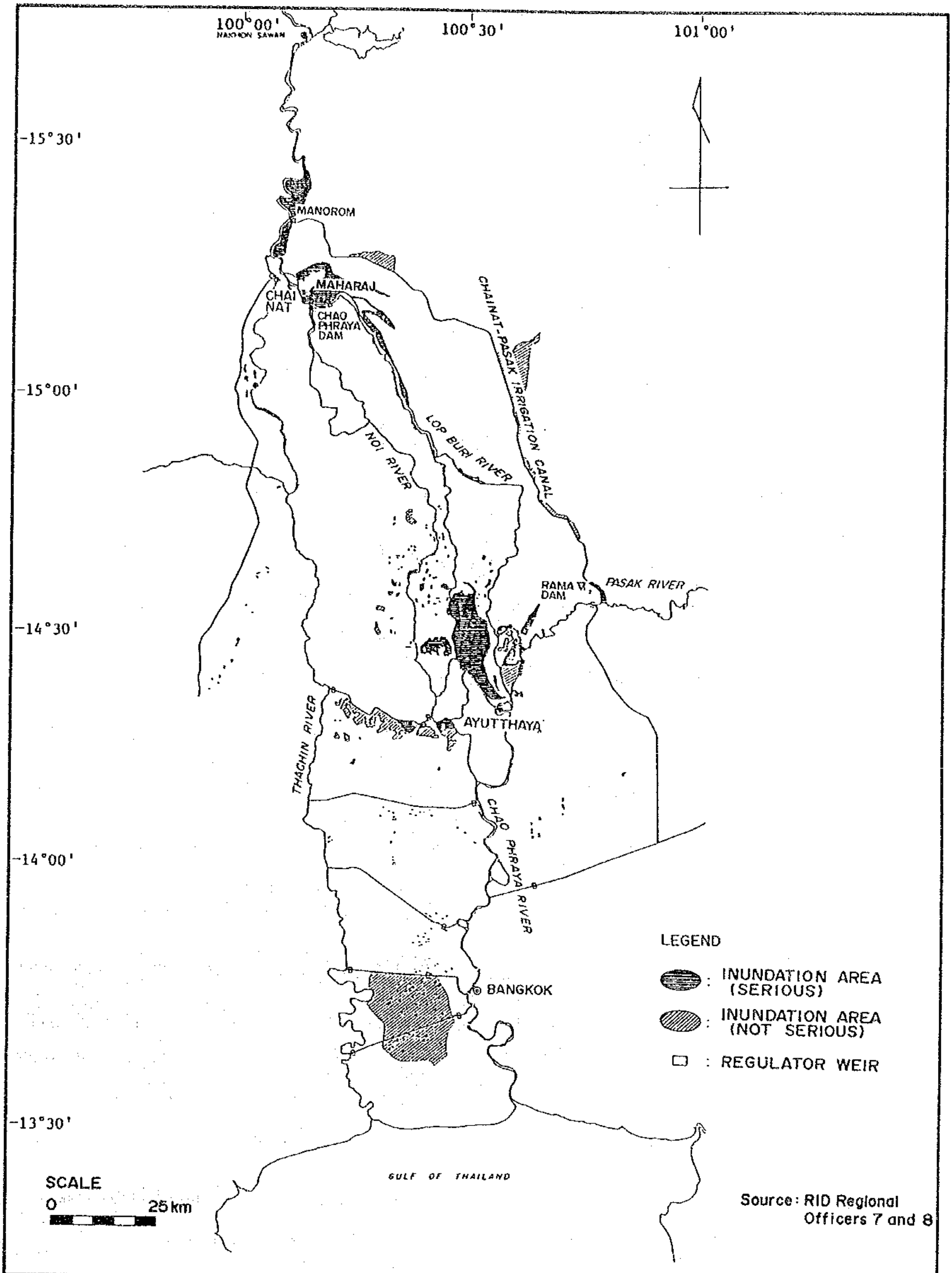

Fig. 2-8(2/3). FLOOD INUNDATION AREA (1980 FLOOD)

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

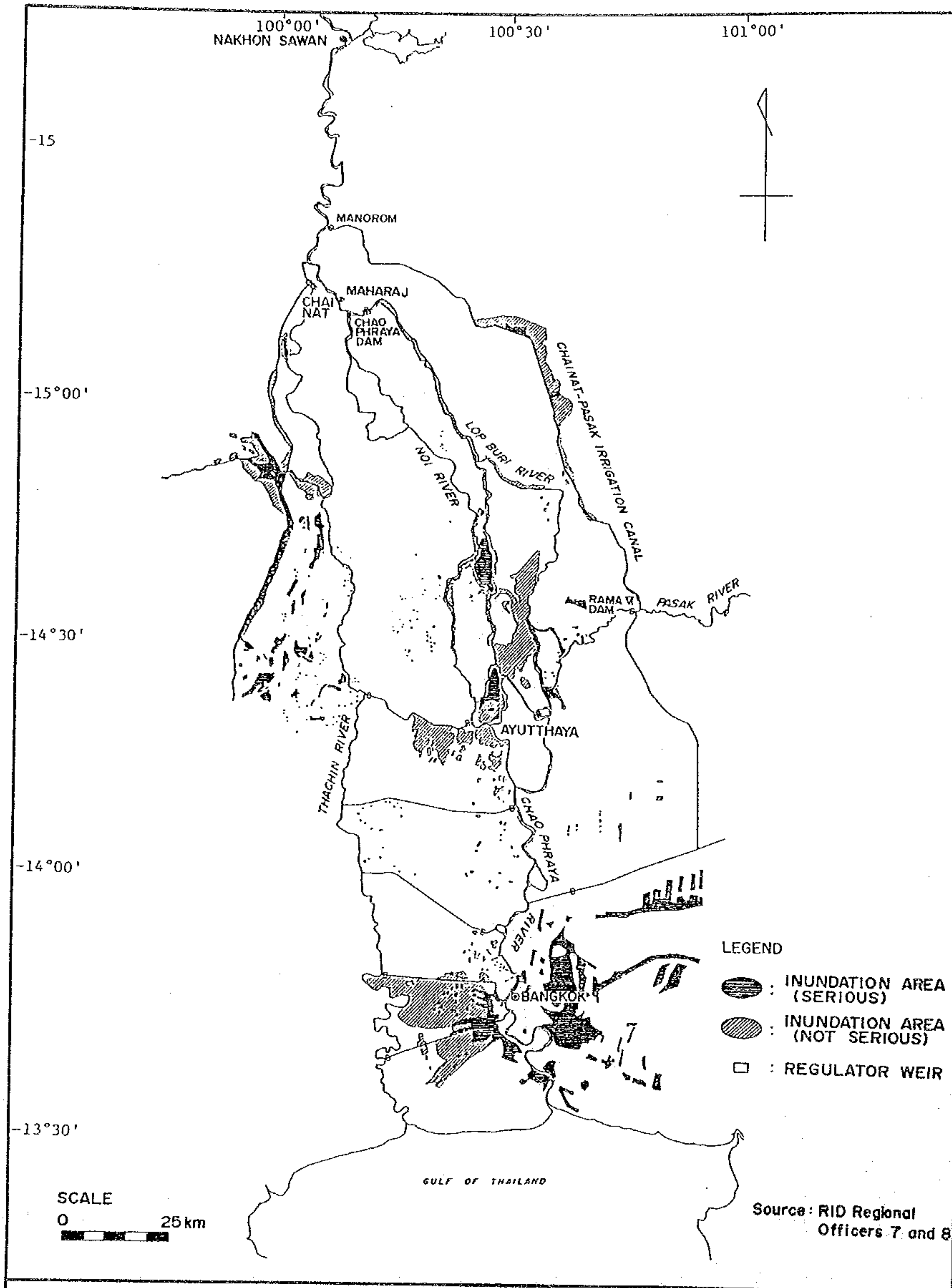

Fig. 2-8(3/3). FLOOD INUNDATION AREA (1983 FLOOD)

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

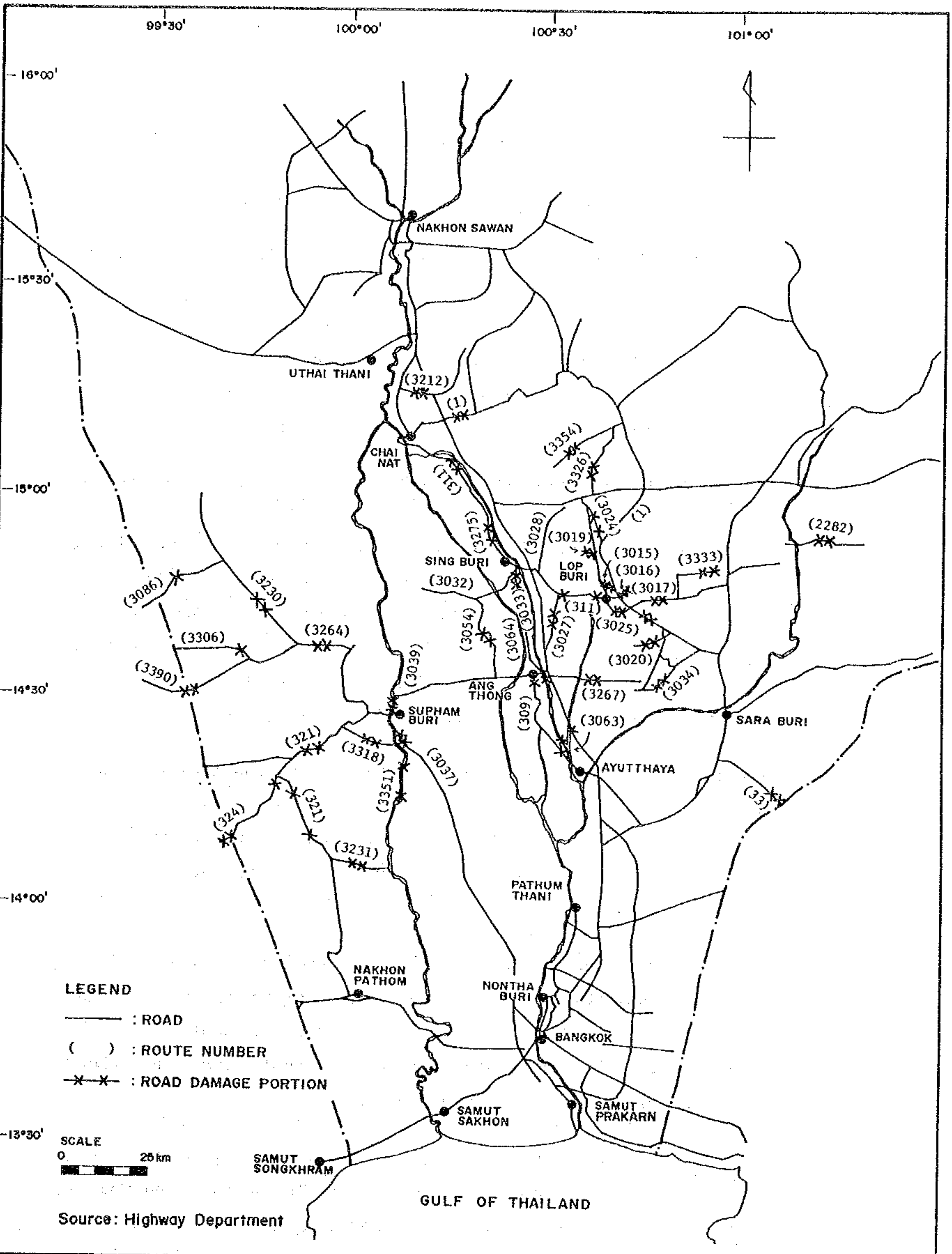

Fig. 2-9. PORTIONS OF ROAD NETWORK INUNDATED BY 1983 FLOOD

FLOOD FORECASTING SYSTEM
IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

CHAPTER 3. EXISTING FACILITIES RELATED TO FLOOD FORECASTING SYSTEM

3.1 Hydrological Observation Network

3.1.1 Rainfall Observation

The rainfall observation network in the Chao Phraya River Basin consists of about 600 point gauging stations (refer to Fig. 3-1), about half of which are operated by RID and the other half by MD. In addition to these stations, some point gauging stations are operated by other agencies such as NEA, EGAT and PWD.

The gauging stations of RID are mostly installed nearby the irrigation structures and biased to the deltaic areas in the lower reaches from Nakhon Sawan, while those of MD are almost equally distributed in the upper and the lower reaches from Nakhon Sawan. Consequently, although about 400 gauging stations concentrate on the lower reaches within an area of about 50,000 km^2, only about 200 gauging stations are in the upper reaches of about 110,000 km^2.

Gauging stations equipped with telecommunication data transmission facilities are rather scarcely distributed in the upper reaches from Nakhon Sawan. Accordingly, difficulty is foreseeable in the collection of gauging data within a short period.

On the other hand, telecommunication facilities are provided to more than 100 gauging stations in the lower reaches from Nakhon Sawan. Most of them are, however, useful for the management of irrigation water but not for the flood forecasting of the Chao Phraya River.

In addition to the aforesaid point rainfall gauging stations, MD also operates radar gauging stations at Bangkok and Chiang Mai. The information from radar gauges are only for qualitative analysis of precipitation in the basin and not for determination of quantitative areal precipitation.

3.1.2 Water Stage and Discharge Observation

There are 224 water stage gauging stations along the Chao Phraya River and its tributaries, which are operated by RID, MD, HD, EGAT and NEA. Among them, 107 stations have periodical flow discharge measurements also by a current meter.

Judging from the location of existing gauging stations, the 39 stations operated by RID are regarded as the key stations to comprehend the flood runoff condition on the Chao Phraya main channel and its major tributaries, that is, Ping, Wang, Yom, Nan and Pasak. Other key stations are also pointed out to be the two stations operated by MD in the middle reaches of the Pasak River Basin, but their discharge data have not been provided since 1981. In the estuary of the Chao Phraya River Basin, tidal information is presently provided by six stations operated by PAT. The location of all these key gauging stations are shown in Fig. 3-2.

For the observation of flood discharges on the Chao Phraya and its major tributaries, the present observation network mentioned above is judged to have blind spot areas, especially in the Pasak and the Sakae Krang river basins where the gauging stations are scarcely distributed. The Pasak and the Sakae Krang river basins have the first and second largest drainage areas in the lower reaches from Nakhon Sawan, and the flood discharges in both basins are directly drained into the Chao Phraya River. Thus, the flood discharges are considered to have a large influence on the river.

Telecommunication facilities are scarcely provided to the water stage/discharge gauging stations in the upper reaches from Nakhon Sawan and will not be useful to forecast flood discharges from the Ping, Wang, Yom and Nan river basins; while, in the lower reaches from Nakhon Sawan, telecommunication facilities are provided to numerous gauging stations located along the irrigation canals. The observation data from the gauging stations in the lower reaches are, however, not effective to forecast the flood discharges on the Chao Phraya River and its major tributaries.

3.2 River Structures

River structures related to flood control can be classified into the following four groups, in consideration of their functions, structural features, scale and importance:

(1) Dams and reservoirs on main tributaries in the upper basin;

(2) Diversion weirs/barrages across the main rivers;

(3) Regulators/gates installed on the main canals; and

(4) Flood protection dikes along the main rivers.

In the Chao Phraya River Basin, the existing river structures are being operated for the purpose of irrigation, hydropower generation, municipal water supply, navigation, flood control, salinity control, and so on. Among these purposes, irrigation and hydropower generation are given priority importance. The location of existing river structures is shown in Fig. 3-3 and schematized in Fig. 3-4.

3.2.1 Bhumibol and Sirikit Dams

There exist six (6) multi-functional dams in the Chao Phraya River Basin. Among these dams, the Bhumibol and Sirikit Dams are much larger in scale and affect the basin to a great deal. The general structural features of these two dams are presented in Table 3-1.

Management and Operating Principles

Bhumibol and Sirikit dams/reservoirs are managed by EGAT and RID, in coordination with each other, to satisfy the requirements of power and downstream water demands. EGAT is responsible for power generation, while RID is primarily responsible for irrigation and released water activities such as municipal water supply, navigation and salinity control.

In practice, actual gate operation of both dams is made by EGAT. EGAT controls the water releases from the reservoirs to meet hydroelectric generation needs, taking into account the required water releases for irrigation requested by RID.

Operation Rule

The storage level and reservoir release from each dam are managed through the upper and lower operation rule curves established for each reservoir by EGAT. The operation rule curves for both dams, together with the recent storage level records, are presented in Fig. 3-5.

With reference to flood control function, both dams control flooding water by using the capacity between the Normal High Water Level and the Upper Operation Rule Curve Level. The present operation rules are summarized as follows:

(1) When reservoir levels are above the Upper Rule Curve, extra energy is generated to avoid unproductive spill.

(2) When reservoir levels are between the upper and the lower rule curves, EGAT releases water primarily to satisfy downstream demands requested by RID.

(3) When reservoir levels are below the Lower Rule Curve, water releases are reduced. In this case, releases are made to meet the minimized request for downstream water demand.

Operating Practice and Reservoir Records

The recent operating policy on Bhumibol and Sirikit dams is to increase storage as much as possible during the rainy season by minimizing releases for hydropower so as to assure water for irrigation in the dry season. This operating policy contributes directly to the promotion of flood control by the dams.

The reservoir records of recent flood years on storage level and the relationship between inflow and outflow are shown in Fig. 3-6. The records indicate that the respective flood control effects of these two reservoirs roughly represent inflow reductions of 1,000 to 1,500 m^3/s. Nevertheless, a higher regulation effect than those indicated can be expected substantially on both reservoirs.

3.2.2 Barrage and Regulators

There are five (5) major diversion weirs/barrages in the Basin (refer to Fig. 3-3), which are operated primarily for irrigation. The structural features of these structures are shown in Tables 3-2 and 3-3.

Management and Operating Principles of Barrage and Regulators

River structures related to water control are managed by RID through the coordination among its head office (O&M Division) in Bangkok, its regional offices and project offices. The executive body for management varies depending on purpose, scale and importance of structures.

The basic operating principles of structures is established based on the irrigation water supply. The head office (O&M Division) periodically obtains hydrological data, crop data, water demands, etc., (flooding data in times of flood) of each project through communication with each regional and project office. Water allocation is determined on the basis of these data and the simulated output of the water management model developed by RID. Depending on the water allocation determined, each river structure is operated; major ones by regional offices, small scale ones by project offices.

Operating Practice of Barrage and Regulators

(1) The Chao Phraya Dam and Head Regulators

There is no prescribed form of regulation, but the basic operation rule that has been observed is to divert the design flow into each main watercourse by gate operation of the Chao Phraya Dam and other head regulators, and to release any surplus water into the Chao Phraya River. At the time of an extraordinary flood, surplus water beyond the allowable flow capacity is released through the emergency spillway behind the dam to the retarding basin. Recently, however, use of the spillway has been avoided.

The above flow distribution system is presented in Fig. 3-4. Practically, these operations are made by RID's Regional Office No. 7 according to the instructions on water allocation by the head office.

Some of the specific operations on the Dam are as follows:

(a) The water level behind the dam is managed to remain at EL +16.50 m MSL to assure the diversions into each main watercourse.

(b) A water head between the upstream and the downstream is controlled at less than 9.5 m for the assurance of structural stability.

(c) A minimum discharge of 75 m^3/s is needed for navigation, salinity control and municipal water supply.

At the time of the major floods in 1975, 1978, 1980 and 1983, all of the peak discharges exceeded the design flow of 3,300 m^3/s, and they had been passed through the gate openings without using the emergency spillway.

(2) Major Regulators

Major regulators on each main watercourse and canal are operated by the regional or project offices in accordance with the water operation rule curves established for each regulator. In time of flood, in addition to the operation rule curve, flooding condition and growing condition of rice in each project area are considered. Gate operation is made through the coordination among the head office and each regional and project offices.

In connection with gate operation, the records of maximum discharge from the head regulators, together with the discharge from the Chao Phraya Dam, are given in Table 3-4. When peak flood flows occur in the Chao Phraya River, releases from each head regulator are nearly commensurate with the design flow, although some excess flows are observed at the Manorom Regulator.

(3) Other Major Barrages

The normal gate operation of Rama VI Dam and the Phitsanulok Weir is to adjust the upstream water level to enable the stable intake for irrigation. The former water level is maintained at about EL +7.50 m MSL and the latter, at about EL +47.5 m MSL. At the time of flood, both gates are supposed to be fully opened to pass the flood flow safely.

3.2.3 Flood Protection Dikes

Up to the present, flood protection dikes are constructed mainly along the Chao Phraya River and the lower portion of the Pasak River. Fig. 3-7 shows the existing dike alignment, including the flood protection dikes in the lower reaches from Nakhon Sawan.

Upper Reaches from Ayutthaya

Flood protection dikes in the upper reaches were constructed on the basis of the development of irrigation system. In general, dikes of irrigation canals running in parallel with the Chao Phraya River are used as the river dikes which are to prevent flood damage in the agricultural area. Besides, some portions of roads also serve as flood protection dikes.

The height of dike in the upper reaches was designed based on the high water level of a 25-year return period flood, considering the freeboard of about 0.5 m. However, in 1983 the lower portion of the upper reaches was seriously damaged by the high flood water level in the river. Correspondingly, the dike elevation was raised higher than the water level of the 1983 flood with the freeboard ranging from 0.5 m to 1.0 m. Raising work on dikes is still underway.

Lower Reaches from Ayutthaya

In the lower reaches between Ayutthaya and Bangkok Metropolis, dikes of both the drainage channel and feeder road running in parallel with the river function as the flood protection dike. In the area of Bangkok Metropolis, circle levees/dikes were constructed to prevent not only the overflow from the Chao Phraya River, but also the inflow from the north and east areas. In the urban west bank area, a polder system is under feasibility study and detail design as well.