JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

ROYAL IRRIGATION DEPARTMENT
KINGDOM OF THAILAND

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

FINAL REPORT

Vol. 2 : MAIN REPORT

AUGUST 1999

CTI ENGINEERING INTERNATIONAL CO., LTD.
INA CORPORATION

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

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

US$1.00 = Thai Baht 36.5 = Japanese Yen 115.7

As of December 1998

COMPOSITION OF FINAL REPORT

Vol. 1 EXECUTIVE SUMMARY

Vol. 2 MAIN REPORT

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

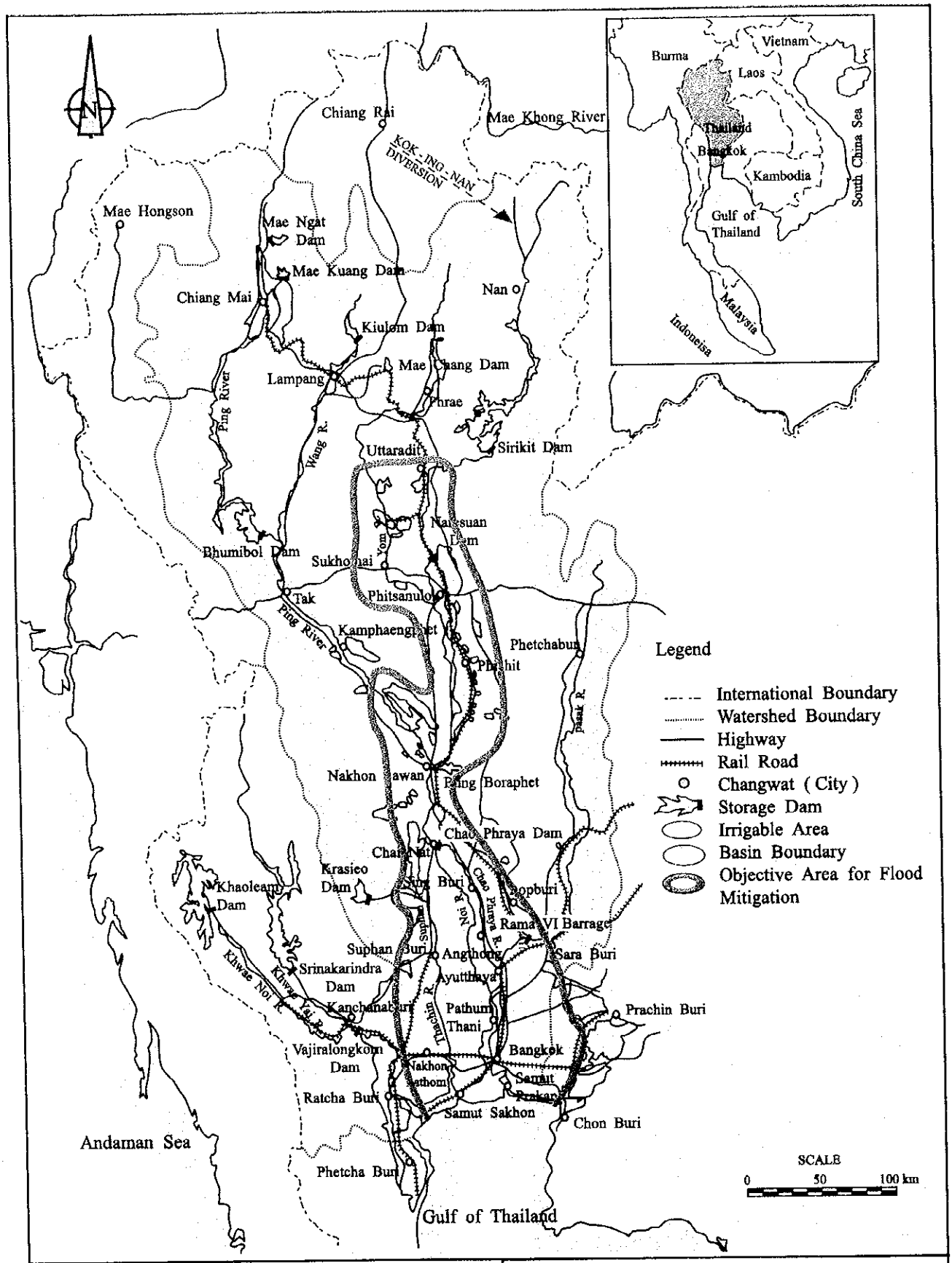
SECTOR	I	HYDROLOGY AND FLOOD SIMULATION
SECTOR	II	SOCIOECONOMY
SECTOR	III	LAND USE
SECTOR	IV	GEOLOGY AND SOIL MECHANICS
SECTOR	V	FLOOD DAMAGE
SECTOR	VI	FLOOD MITIGATION PLAN

Vol. 4 SUPPORTING REPORT (2/2) (SECTOR VII to XV)

SECTOR	VII	RIVER IMPROVEMENT PLAN
SECTOR	VIII	INTEGRATED DAM OPERATION PLAN
SECTOR	IX	FARMLAND WATER MANAGEMENT PLAN
SECTOR	X	URBAN DRAINAGE PLAN
SECTOR	XI	INSTITUTION AND ORGANIZATION
SECTOR	XII	PRELIMINARY DESIGN, COST ESTIMATE AND CONSTRUCTION PLAN
SECTOR	XIII	ECONOMIC EVALUATION
SECTOR	XIV	ENVIRONMENTAL CONSIDERATION
SECTOR	XV	TOPOGRAPHIC SURVEY

Vol. 5 DATA BOOK

Vol. 6 EXECUTIVE SUMMARY (in Thai)



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

GENERAL MAP

CTI ENGINEERING CO., LTD. AND INA CORPORATION

PREFACE

In response to a request from the Government of the Kingdom of Thailand, the Government of Japan decided to conduct the Development Study on Integrated Plan for Flood Mitigation in Chao Phraya River Basin and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA selected and dispatched a study team headed by Mr. Katsuhisa Abe of CTI Engineering International Co., Ltd., and consisting of members from CTI Engineering International Co., Ltd. and INA Corporation, to Thailand, five (5) times between December 1996 and August 1999. In addition, JICA set up an advisory committee headed by Mr. Hidetomi Oi, Development Specialist, JICA, between November 1996 and August 1999, which examined the study from specialist and technical points of view.

The team held discussions with the officials concerned of the Government of Thailand, and conducted field surveys at the study area. Upon returning to Japan, the team conducted further studies and prepared this final report.

I hope that this report will contribute to the promotion of this project and to the enhancement of friendly relationship between our two countries.

Finally, I wish to express my sincere appreciation to the officials concerned of the Government of Thailand for their close cooperation extended to the team.

August 1999

Kimio Fujita
President
Japan International Cooperation Agency

August, 1999

Mr. Kimio Fujita
President
Japan International Cooperation Agency
Tokyo, Japan

Letter of Transmittal

We are pleased to submit herewith the Final Report on the "Study on Integrated Plan for Flood Mitigation in Chao Phraya River Basin" in the Kingdom of Thailand.

Under contracts with JICA, CTI Engineering International Co., Ltd. in association with INA Corporation conducted the Study during the period from December 1996 to August 1999. In conducting the study, particular attention was paid to the formulation of an integrated master plan with the target year 2018, with due consideration on the present situation of Thailand. A feasibility study was also conducted on the urgent and/or priority projects identified through the master plan study.

We would like to take this opportunity to express our sincere gratitude to the officials concerned of JICA, the Ministry of Foreign Affairs, the Ministry of Construction, and the Ministry of Agriculture, Forestry and Fisheries, all of Japan. We would also like to express our gratitude to the officials concerned of the Thai Government, as well as the JICA Thailand Office and the Embassy of Japan in Thailand for their cooperation and assistance extended to us during our investigation and study.

Finally, we hope that this report will contribute to the further promotion of the project.

Very truly yours,

Katsuhisa Abe
Team Leader
Study Team on
Integrated Plan for Flood Mitigation in
Chao Phraya River Basin
CTI Engineering International Co., Ltd.

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

FINAL REPORT

VOL. 2 MAIN REPORT

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

Thailand Government / Agencies

AIT	:	Asian Institute of Technology
ALRO	:	Agricultural Land Reform Office
BMA	:	Bangkok Metropolitan Administration
CAT	:	Communication Authority of Thailand
DDS	:	Department of Drainage and Sewerage, BMA
DEDP	:	Department of Energy Development and Promotion
DF	:	Department of Fisheries
DIW	:	Department of Industrial Works
DOH	:	Department of Highway
DOLA	:	Department of Local Administration
DPW	:	Department of Technical and Economic Cooperation
DTCP	:	Department of Town and Country Planning
EGAT	:	Electricity Generating Authority of Thailand
GOT	:	Government of the Kingdom of Thailand
HD	:	Harbor Department
H&D	:	Hydrographic Department
IEC	:	Irrigation Engineering Center, RID
LAD	:	Local Administration Department
MD	:	Meteorological Department
MOAC	:	Ministry of Agriculture and Cooperative
MOI	:	Ministry of Interior
MOSTE	:	Ministry of Science, Technology and Environment
NESDB	:	National Economic and Social Development Board
NEB	:	National Environmental Board
NSO	:	National Statistic Office
OARD	:	Office of Accelerated Rural Development
OEPP	:	Office of Environmental Policy and Planning
PAT	:	Port Authority of Thailand
PTD	:	Post and Telegraph Department
PWD	:	Public Works Department
RFD	:	Royal Forest Department
RID	:	Royal Irrigation Department
SRT	:	State Railway of Thailand
TOT	:	Telecommunication Organization of Thailand
FFC	:	Flood Forecasting Center

Japanese Government and International Organizations

GOJ	:	Government of Japan
JICA	:	Japan International Cooperation Agency
MAFF	:	Ministry of Agriculture, Forestry and Fisheries, Japan
MOC	:	Ministry of Construction, GOJ
ADB	:	Asian Development Bank
IBRD	:	International Bank for Reconstruction and Development (World Bank)

Units of Measurement

(Length)

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

(Area)

mm^2	:	square millimeter(s)
cm^2	:	square centimeter(s)
m^2	:	square meter(s)
km^2	:	square kilometer(s)
ha	:	hectare(s)
rai	:	0.16 ha

(Volume)

cm^3	:	cubic centimeter(s)
m^3	:	cubic meter(s)
l	:	liter(s)
mcm or MCM	:	million cubic meter(s)

(Speed/Velocity)

cm/sec, cm/s	:	centimeter per second
m/sec, m/s	:	meter per second
km/hr, km/h	:	kilometer per hour

(Stress)

kgf/cm^2	:	kilogram per square centimeter
$tonf/m^2$	:	ton per square meter

(Discharge)

l/sec, *l*/s	:	liter per second
m^3/sec, m^3/s	:	cubic meter per second
m^3/yr, m^3/y	:	cubic meter per year

(Note : Other combined units may be constructed similarly as above)

(Weight)

g, gr.	:	gram(s)
kg	:	kilogram(s)
ton	:	ton(s)

(Time)

s, sec	:	second(s)
min	:	minute(s)
h (hrs)	:	hour(s)
d (dys)	:	day(s)
y, yr (yrs)	:	year(s)

(Electrical Units)

W	:	watt(s)
kW	:	kilowatt(s)
MW	:	megawatt(s)
kWh	:	kilowatT-3-hour
MWh		megawatT-3-hour
GWh	:	gigawatT-3-hour
V	:	volt(s)
kV	:	kilovolt(s)

Monetary Terms

¥, YEN	:	Japanese Yen
Bht, Baht	:	Thai Baht
US$	:	United States Dollar

Other Measurements

HWL	:	High Water Level
MSL	:	Mean Sea Level
°	:	degree
′	:	minute
″	:	second
%	:	percent
°C	:	degree centigrade
KB	:	kilobyte
MB	:	megabyte
RAD	:	radian
bps	:	bit per second
BPI	:	bit per inch
AH	:	Ampere Hour

CHAPTER 1. INTRODUCTION

1.1 Background

Every effort has been made to mitigate flood damage in the Chao Phraya River Basin through the construction of dam reservoirs, dikes and pump stations. In spite of these, however, flooding problems persist due to the increase of flood discharge as a result of deforestation, expansion of farmlands, etc., in line with the economic growth.

The flood damage potential is increasing due to rapid urbanization and land development in downstream areas, particularly, the Bangkok metropolitan area and other municipalities along the Chao Phraya River. A disastrous flood occurred in October 1995, resulting in the extensive damage to properties and loss of human lives.

Flood mitigation in the Chao Phraya River Basin is thus recognized as a priority issue for which measures should be taken as early as possible to sustain the social and economic development. With the initiative of His Majesty, King Bhumibol, after the 1995 flood, the Government of the Kingdom of Thailand had requested the Government of Japan to conduct "The Study on the Integrated Plan of Flood Mitigation in the Chao Phraya River Basin" (the Study) under the technical cooperation program of the Japan International Cooperation Agency (JICA). JICA then dispatched a Study Team to Thailand at the beginning of December 1996.

1.2 Objectives of the Study

The objectives of the Study are:

(1) To formulate an integrated master plan of flood mitigation in the Chao Phraya River Basin, taking flood damage, agricultural land conservation, water use, land use management and so on into consideration;

(2) To conduct a feasibility study on the urgent and/or priority project identified through the master plan study; and

(3) To carry out technology transfer to the Thai counterpart personnel in the course of the Study.

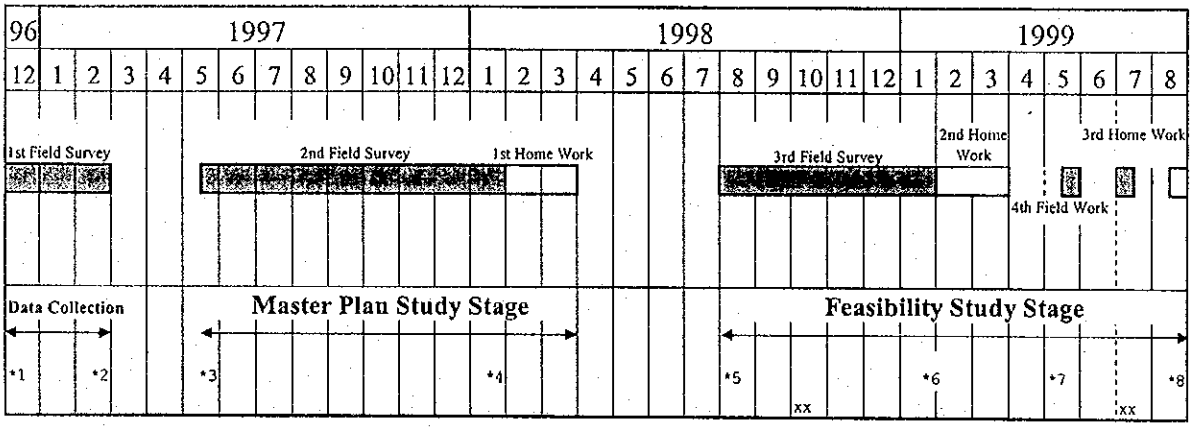
1.3 Study Area

The study area is the whole Chao Phraya River Basin of 163,000 km^2 (see General Map). The Chao Phraya Delta and the lower reaches of the Nan and Yom rivers are the target areas for flood mitigation, giving high priority to the Chao Phraya Delta including the Bangkok Metropolitan Area (BMA) because of its social and economic significance.

1.4 The Study Schedule

The Study is as shown in the chart below. The study was started at the beginning of December 1996 and was completed on August 1999.

STUDY SCHEDULE



Work in Thailand

Work in Japan

*1 : Inception Report
*2 : Progress Report 1
*3 : Methodology Report
*4 : Progress Report 2
*5 : Interim Report
*6 : Progress Report 3
*7 : Draft Final Report
*8 : Final Report
xx : Seminar

CHAPTER 2. GENERAL BACKGROUND OF THE STUDY AREA

2.1 Natural Conditions

2.1.1 Climate

The climate of the study area belongs to the tropical monsoon. The annual rainfall is between 1,000 and 1,400 mm and it registers higher in the northeastern region of the basin. According to the rainfall pattern, about 85% of the annual rainfall is registered in the period between April and October (refer to Fig. 2.1.1). Tropical cyclones occur between September and October and may strike the Chao Phraya River Basin. In this case, rainfall continues for a long period of time in a relatively wide area due to climatic disturbances. The peak river discharge is registered in October, the end of the rainy season, and serious flood damage may arise with high tide in this period. Detailed data on the above is compiled in the Supporting Report, "Hydrology".

2.1.2 Topography

(1) General Topography

The Central Plain formed by the Chao Phraya River (Study Area) is a strip of land of over 500 km long and 100-200 km wide. (See Fig. 2.1.2.)

The Central Plain can be divided into three areas; namely, the Upper Central Plain, the Nakhon Sawan Area, and the Lower Central Plain. In the Upper Central Plain, three big rivers; namely, Ping, Yom and Nan, traverse the plain and join together at Nakhon Sawan to form the Chao Phraya River (refer to Fig. 2.1.3). The typical feature in the Upper Central Plain is the combination of well defined meander belts and many scars of abandoned river courses with numerous small swamps; whereas, on the higher lands, dissected terraces and peneplains with sandy ground surface are predominant. The Upper Central Plain is subdivided into the Yom-Nan basin in the east and the Ping basin in the west.

In the Nakhon Sawan area, a number of isolated mountains and mountainous groups stand out clearly from the plain, just like monadnocks. This monadnock area continues for about 50 km from Nakhon Sawan to Chai Nat in the N-S direction.

From Chai Nat, the Chao Phraya River flows southwards to the Gulf of Thailand, traversing the Lower Central Plain. With a flat to very slightly undulating broad depositional surface dominating the topography of the area, the Chao Phraya River gives off many effluent branches. Among them the Tha Chin River (Suphan Buri River), the Noi River and the Lop Buri River are important.

(2) Geomorphologic Features of the Study Area

The main geomorphological features in the study area are summarized below according to these figures. (Takaya, Ohya, Haruyama, et al)

(a) Alluvial Fans

Alluvial fans are scarcely seen in the plain along the Chao Phraya River. When the area is flooded, it is inundated by sheet floods but the water drains off well. There are several fans at the outskirts of the plain, consisting of sand and gravel covered by laterite.

(b) Natural Levees and Back-marshes

The natural levees in the plain are divided into two groups: the higher natural levee and the lower one. The higher natural levee has developed along 145 Km. At its head, the levee is about 15 meters above MSL and at the lower end it is about 2 meters (see Fig. 2.1.4).

Back-marshes occupy spaces between one natural levee and another. The relative heights of the higher natural levees are generally 2.5 to 3.5 m, but the maximum is 6 m. The relative heights of the lower levee are generally 1.8 to 2 m, but only 0.5 m in the lowest reaches.

(c) Delta

The Chao Phraya Delta is very flat, i.e., its gradient is 1 to 2/100,000. The delta is divided into a higher delta (old delta), lower delta, active delta and sub-aquatic delta. The higher delta is well developed between Chai Nat and Ayuthaya, and has higher natural levees on it. It has the feature of the lacustrine delta. The lower delta is distributed along the Suphan Buri, Chao Phraya and Bang Pakong rivers.

From the lower delta to the south, the coastal topographies consisting of sand spits (banks) and mud spits has developed. Marine clays are seen at the ground surface. The active delta or tidal flat consists of fine clay, and the area is utilized for the culture of shrimp and for salt fields.

(3) Aquifer and Land Subsidence

The Central Plain lies on the area underlain by thick alluvial and deltaic sediments from the Chao Phraya River. The Department of Mineral Resources (DMR) defined and named 8 aquifers within the 550 m depth which constitute sandy and gravely aquifer intercalated by clayey layers as illustrated in Fig. 2.1.5. The higher aquifers up to about 100 m below sea level such as the Bangkok aquifer and the Phrapradaen aquifer are not potable due to their high salinity. The main aquifer for groundwater abstraction in the Bangkok area is the high, permeable Nakhon Luang aquifer of quality water, about 150 m below sea level, with an approximate thickness of 50 to 70 m.

However, the groundwater level of this aquifer has shown significant draw-down in recent years (30 to 60 m by 1996) due to excessive pumping. This draw-down had induced extensive land subsidence in Bangkok and vicinity at a maximum of 1.5 m in the last 20 years, as shown in Fig. 2.1.6. (DMR, 1997 and JICA/DMR, 1995)

2.2 Socio-Economy

2.2.1 Administration

The country is usually divided into six (6) regions; namely the Central, Eastern, Western, Northern, Northeastern and Southern regions. The Central Region is again divided into Bangkok Metropolis, Bangkok Vicinity and the other area in many cases, e.g., in statistics books. Administratively, however, Thailand is composed of, first, provinces (changwat), then each province constituted by districts (amphoe and king amphoe), a district comprising Tambon, and finally each Tambon is divided into villages (muban). The number of each administrative level is 76, 868, 7,404 and 66,604, respectively (refer to Table 2.2.1).

2.2.2 Demography

(1) Population

Population of the provinces sharing the study area was 18.95 million in 1980, and 22.79 million in 1990 accounting for about 41.8% of the total population of the country. In the study area, Metropolitan Bangkok and its vicinity, i.e., Bangkok Metropolis, Nonthaburi, Phathum Thani, Samut Prakan and Samut Sakon, showed, during 1980's, high increase rates of 2.3 to 4.7% per annum. Other provinces in the study area that showed high increase rates were Uthani Thani with the rate of 2.7%, Phechabun with 2.5%, and Kamphaeng Phet with 2.4%.

On the other hand, shown in Table 2.2.2 is the official population projection made by the Human Resources Planning Division, NESDB. The projection states that the total population in the study area will be 26.48 million in 2005.

(2) Households

According to the registration record in 1995, in the study area, the number of households amounted to about 7.1million with an average of 3.6 persons per household. (Refer to Table 2.2.3.)

2.2.3 Economic Indexes

(1) General

An economic depression occurred in ASEAN countries in mid-1997 and had prevailed over the East Asian countries. The Thai economy is confronting today's difficulties, downsizing the economic target figures of the Eighth National Economic and Social Development Plan (1997-2001).

The projects under study shall be carried out and realized in the stable social and economic conditions. The Thai economy shall certainly recover in due course. Therefore, hereinafter, the economic situations before the economic disturbance are mainly described as a witness to the power of Thai economy, which shall be linked with the potentialities of the Thai economy after recovery.

(2) Gross Domestic Products (GDP)

The GDP of Thailand, at the current market prices, was 3,601 billion Bath in 1994, increasing at an average growth rate of 14.2% from 1989. The per capita GNP also grew at an annual growth rate of 12.8% during the period and became 61,335 Bath in 1994. In terms of GDP by industry, agriculture shares 369 billion Bath (10.2%), manufacturing 1,015 billion Bath (28.2%), trade, banking, services and others 2,217 billion Bath (61.6%). (Refer to Table 2.2.4.)

The gross regional products (GRP) of the provinces sharing the study area, as shown in Table 2.2.5, amounted to 2,541 billion Bath in 1994, which was 70.6% of the whole kingdom. Within the GRP of the study area, that of Bangkok Metropolis and its vicinity accounted for about 73%. Per capita GRP in 1994 was also high in Bangkok Metropolis and its vicinity; namely, 203,650 Bath in Bangkok Metropolis, 248,216 Bath in Samut Sakhon, and 245,555 Bath in Phthun Thani. The annual growth rate during 1989-1994 was 12.7% in Bangkok Metropolis, 19.0% in Samut Sakhon and 29.4 % in Samut Prakan. (Refer to Table 2.2.4.)

On the other hand, Table 2.2.6 is the revised GDP projection up to the year 2001 worked out by NESDB in September, 1997. According to the projection, the GDP in 2001 will be 7,481 billion Bath in the whole country.

(3) Government Budget

The budgetary expenditure of the Government of Thailand increased at an average rate of 13.5% during the period 1990-1994, and in 1994 the revenue and expenditures amounted to 655,992 million bath and 625,000 million bath, respectively. The majority of revenue was accounted for by taxes and duties, which in 1994 for instance amounted to 573,662 million bath, or 87.4% of the total revenue. As for the expenditures, education payments showed the highest figure of 124,460 million bath or 20.0% of the total expenditure in 1994, followed by the maintenance of internal peace and order, maintenance of national security, and general services (refer to Table 2.2.7).

2.3 River Condition

2.3.1 River System

The Chao Phraya River Basin is as large as one-third (162,800 km^2) of the whole territory of Thailand (514,000 km^2). The basin is often divided into three according to hydrological features: (1) the upper basin of northern highland; (2) the middle basin of the flood plain with the surrounding watersheds; and (3) the lower basin of the Chao Phraya Delta, as shown in Fig. 2.3.1.

The Chao Phraya River system consists of four (4) principal tributaries; namely, Ping (36,018 km^2), Wang (11,708 km^2), Yom (24,720 km^2), and Nan (34,557 km^2), all originating in the northern highland. The Wang and Yom rivers join the Ping and Nan rivers in the middle basin, respectively. Then, the Ping and Nan rivers join to

form the Chao Phraya River at Nakhon Sawan, which flows down to the lower basin through Chai Nat, Ayuthaya and Bangkok, then finally pours into the Gulf of Thailand. The Pasak River(15,806 km^2), a tributary, joins the Chao Phraya River in the lower basin, while the Tha Chin River diverges from the Chao Phraya at the main stream.

2.3.2 Riparian Structures

(1) Dikes/Levees

In the ancient times the Chao Phraya River formed the low alluvial ridge area adjoining the channel, named the *Natural Levee*. Most people had lived on the natural levee and had cultivated rice in general in the hinterland lower than the natural levee. The natural levee is protected from small to medium flooding.

Nowadays, flood protection dikes are constructed mainly on the natural levees along the Chao Phraya River, the Tha Chin River and the lower portion of the Pasak River. On the other hand, in actual floods, the banks of canals for irrigation or embankments of roads on the natural levee and the hinterland along the river have taken the role of flood protection dikes for the river. Fig. 2.3.2 shows the existing dike alignment in the Basin.

(2) Diversion Weir and Regulator

There are five (5) major diversion weirs/barrages in the Basin, which are operated primarily for irrigation. Their structural features are shown in Table 2.3.1. (Refer to Fig. 2.3.3.)

On the other hand, RID has formulated a plan, named the Upper and Lower Tha Chin River Project, to construct two (2) new barrages along the Tha Chin River. One of them, named Site 6, is 100 km upstream from the river mouth, and the other, named Site 1A, at the lower reach 20 km upstream from the mouth. (Some details of the project are explained in Subsection 2.6.3.)

The Harbor Department has also formulated a plan, named the Damming Chao Phraya Project, to construct two (2) new barrages along the Chao Phraya River. Some details of the project are explained in Subsection 2.6.3 (refer to Fig. 2.3.3).

Table 2.3.1 gives the features of main regulators, while Fig. 2.3.3 shows the location of main regulators in the Basin. In the Chao Phraya River basin including that of the Tha Chin River, a lot of regulators have been installed along rivers and canals. Among these regulators, Phonlatep Head Regulator and Manorom Head Regulator are more important for flood mitigation, because floodwaters in the Chao Phraya River can be diverted to the Tha Chin River and the Chainat-Pasak Canal, respectively, with the gates of regulators open.

2.4 Agriculture Activities

2.4.1 Agriculture

(1) Statistical Data on Agriculture

Agriculture had kept a leading position in the gross domestic product (GDP) for a long time, but the sector occupied only 15% of the GDP in 1991 because of the rapid growth and expansion in sectors of manufacturing and commerce. The per capita of GDP in the agricultural sector was as low as 10% of the non-agriculture sectors. Nevertheless, the agricultural population is still a majority, accounting for about 60% of the total population in 1991.

The present agricultural features in the Chao Phraya River Basin are summarized in Tables 2.4.1 to 2.4.3 which give the yield of agricultural main products, agricultural land use and rice cultivation, respectively.

(2) Cropping Pattern

The cropping patterns of typical crops in the Chao Phraya River Basin are presented in Fig. 2.4.1. In Thailand, the cropping patterns are compiled in the Agricultural Extension Manual issued by the Agricultural Extension Division in each agricultural region. Regional agricultural extension staff lead farmers in each region based on the manual and the latest technical information.

As further information, the relationship between the reducing percentage of rice yield and the period of flood inundation is given in Table 2.4.4 according to a study report of RID Regional Office VII.

(3) Deepwater and Floating Rice Cultivation

The area for deepwater and floating rice cultivation has reduced by one-half since ten years ago, and cultivation is practiced currently in about 5% of the total rice cultivation area in Thailand. The cultivation areas are scattered in the flood plains of the Chao Phraya, Mekong, Mae Klong and Bang Pakong rivers.

In the Chao Phraya River Basin, deepwater and floating rice are planted in Sinburi, Ang Thong and Ayuthaya provinces (refer to Table 2.4.5). The recent areas planted with floating rice in each irrigation project in the Chao Phraya River Basin are given in Tables 2.4.5 and 2.4.6 and Fig. 2.4.2.

2.4.2 Irrigation System and Water Demand

(1) Irrigation System

The river and canal network in the Chao Phraya River Basin is presented in Fig. 2.4.3. Among various facilities, the Chao Phraya Dam (or Chainat Barrage) is the most important barrage constructed at the upstream portion of the Chao Phraya River and it supplies irrigation water to an area of nearly 1 million ha through the Chainat-Pasak and Makamtao-Uthong canals, Tha Chin River, Noi River, etc. The operation and maintenance work for major

irrigation and related facilities in the Chao Phraya River Basin is conducted by the respective regional offices of RID.

The jurisdictional boundaries of the regional offices are shown in Fig. 2.4.4. Irrigation projects and the existing main facilities managed by RID are listed in Tables 2.4.7 and 2.3.1, respectively, and their location maps are presented in Figs. 2.4.5 and 2.3.3.

(2) Irrigation Water Demand

Irrigation in the study area relies, to a great extent, on the water released from the Bhumibol and Sirikit dam reservoirs. The weekly water demand program for the irrigation projects throughout the coming dry season is made by RID at the beginning of the season, and is submitted to EGAT which actually operates the two huge dam reservoirs.

After considering various factors such as the remaining vacant volumes in the reservoirs, EGAT decides the quantities of water release. The RID's water demand submitted to EGAT for the dry season in 1997 is shown in Fig. 2.4.6.

As of January 1997, the released water volumes from the two dams were almost the same as scheduled. If a regional office requests an extra water volume, the RID head office adjusts the request and informs the amended demand data to EGAT. Then, a final decision is made by EGAT. On the other hand, the water allocation to each irrigation project in a regional area is controlled by the regional offices of RID.

2.5 Flood and Damage

2.5.1 Major Flood Events

As far as people in Thailand could remember, the biggest flood was the 1942 flood. In the flood, the highest water level marked at the Memorial Bridge in Bangkok was 2.27 m MSL (refer to the Table 2.5.1), and the entire area of Bangkok City suffered catastrophic damage.

In the last two decades where data and information are more available, years 1978, 1980, 1983, 1995 and 1996 are rated as flood years, among which the 1983 and 1995 floods were most serious. Spatial distribution of 5 months rainfall from July to December and flood inundation areas in these years are given in Figs. 2.5.1 and 2.5.2. The following are descriptions of the respective flood events listed in the above table.

(1) 1942 Flood

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

almost non-existing, and natural habitation on its flood plain was much smaller than at present.

(2) 1978 Flood

Heavy rainfall took place in the Nam, Yom, Ping and Pasak river basins, resulting in swelling of the Chao Phraya River in October 1978. At Nakhon Sawan (C.2) and Chainat (C.13), maximum flood discharges of 3,500 m^3/s and 3,800 m^3/s, respectively, were recorded. Floodwaters overtopped the riverbanks at many locations and spread into klongs between Chainat and Ayuthaya, resulting in extensive flood inundation in the adjacent flood plains, as shown in Fig. 2.5.2(1/5). At Ang Thong, the river discharge decreased to 2,900 m^3/s.

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

(3) 1980 Flood

Inundation took place at several places by local rainfall, spilling and distribution from rivers. Flood discharges of 4,400 and 3,800 m^3/s were observed at Nakhon Sawan and Chainat, respectively. Serious inundation occurred on both sides of the Chao Phraya River between Chainat and Ayuthaya as shown in Fig. 2.5.2(2/5), inflicting tremendous damage to the agricultural areas. In addition, urban areas along the Chao Phraya River including Nakhon Sawan, Chainat, Sing Buri, Ang Thong and Ayuthaya were also exposed to floodwaters.

(4) 1983 Flood

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

In the lower basin, heavy rainfall in August (434 mm compared to 170 mm on the average) caused local flooding. After that, the total rainfall from September to November was recorded at 405 mm (215 mm on the average), which resulted in the peak water level of 2.04 m at Memorial Bridge in November and extensive inundation in and around Bangkok, as shown in Fig. 2.5.2(3/5).

(5) 1995 Flood

The flood in 1995 caused inundation to an extensive area of nearly 15,000 km^2 from the Nan and Yom upper to lower reaches, as shown in Fig. 2.5.2(4/5). The difference with the other cases of flooding was that Bangkok was practically free from floodwaters, and hence did not suffer much damage in contrast with the heavy damage outside of the city. The infrastructure damage

inflicted by the flood was estimated at about 6.4 billion Bath on the assumption that the damage equals the repairing cost for damaged roads, bridges, riparian structures and other infrastructures recorded at the 21 provincial offices in the study area. No statistical data on the damage to houses, crops, industrial activities, etc., was available.

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

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

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

(6) 1996 Flood

A big flood occurred in 1996 consecutively with extensive flood inundation by local rainfall, as well as spilling and distribution from the rivers, as shown in Fig. 2.5.2(5/5). The flood magnitude was rather smaller than that of the 1995 flood, but discharge of over 3,000 m^3/s was observed at Nakhon Sawan and Chainat. The two huge dam reservoirs, Bhumibol and Sirikit stored 3.4 and 2.7 billion m^3 of floodwater, respectively, without any spillage. Heavy local rainfall in the west of Tha Chin River filled the Krasieo Dam Reservoir and spilled water caused inundation along the river in Supan Buri Province.

The damage to infrastructures was estimated at about 1.5 billion Bath on the same assumption as above.

2.5.2 Features of Flood Damage

Based on the previous flood records especially those in 1983, 1995 and 1996, the characteristic features of flood damage in the Chao Phraya River basin are summarized as follows:

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

In the upstream of Nakhon Sawan, the geographic features are characterized by valley plain between hilly areas with gentle slope in the east and west sides.

In this area, inundation caused by overtopping of the Yom and Nam rivers widely spread along these river courses.

The total inundation area was about 5,000 km^2 in the 1995 flood. The inundation period lasted for as long as 2 to 3 months, and in some depressed areas inundation continued for more than 3 months up to January the following year.

Although the inundation depth was between 0.5 m and 3 m, areas with inundation depths greater than 1 m were dominant. Some of the inundation water got detained for a long time and gradually drained into the river when the river water level went down. Some of it went downstream as overland flow.

In the area, the major flood damage was brought to the agricultural area where paddy fields with traditional varieties such as floating rice, deepwater rice and others were dominant. High yield rice varieties were observed in a certain irrigation area protected by dike, and 50% of the area was protected from flood damage. The other areas including the traditional variety area were damaged.

The urban areas such as Sukho Thai, Phitsanulok and Phichit, as well as public facilities such as roads, irrigation facilities and canal embankments, also suffered from serious flood damage.

(2) Nakhon Sawan Area between Nakhon Sawan and Chainat

In the Nakhon Sawan area between Nakhon Sawan and Chainat, the geographic condition is characterized by a narrow valley plain with a number of isolated mountains. In this area, inundation water is caused by overland flow from upstream and overtopping from the Chao Phraya River. The inundation water widely spreads and some of the water is detained in the area and some flow downstream as overland flow.

The inundation area was about 500 km^2 in the 1995 flood. The inundation period did not last as long as 1 to 2 months compared with the other areas and the inundation depth was between 0.5 m and 3 m.

In the area, major flood damage was brought to both agricultural and urban areas. In the agricultural areas, 30,000 ha of paddy fields where the traditional rice variety was dominant were damaged. The urban areas such as Nakhon Sawan and Uthai Thani, as well as public facilities such as roads, irrigation facilities and canal embankment, also suffered from serious flood damage.

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

In the higher delta in the lower central plain between Chainat and Ayuthaya, the geographic condition is characterized by natural levees and back marshes. In this area, the inundation water is caused by overland flow from upstream and overtopping and breaches along the Chao Phraya River, Lopburi River, Tha Chin River and so on. The inundation water widely spreads and some of the water is detained in the area and some flow downstream as overland flow.

The inundation area was about 4,600 km^2 in the 1995 flood. The inundation period also lasted for as long as 2 to 3 months, and in some depressed areas, inundation continued for more than 3 months up to January the following year. The inundation depth was between 0.5 m and 4 m.

In the area, major flood damage was brought to both agricultural and urban areas. In the agricultural areas, paddy fields with high yield rice varieties were dominant, but floating rice and deepwater rice were planted in the habitual inundation area.

The urban areas such as Chainat, Sing Buri, Angthong, Ayuthaya and Suphan Buri, as well as public facilities such as roads, irrigation facilities and canal embankments, suffered from serious flood damage.

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

In the lower delta in the lower central plain (downstream of Ayuthaya), the geographic condition is characterized as very flat lowland. In this area, the inundation water is caused by overland flow from upstream and overtopping and breaches along the Chao Phraya and Tha Chin rivers. The inundation water widely spreads and most of the water is detained for 2 to 3 months and naturally or artificially drains into the river or the sea.

The inundation area was about 4,700 km^2 in the 1995 flood. The inundation depth was between 0.5 m and 2 m.

In the area, major flood damage was brought to both agricultural and urban areas. In the agricultural areas, paddy fields with high yield rice varieties were dominant.

The urban areas such as Pathum Thani and Nonthaburi, as well as public facilities such as roads, irrigation facilities and canal embankments, suffered from serious flood damage. In the 1995 flood, the Bangkok metropolitan area was relieved from severe flood damage.

The features of flood damage are summarized in Table 2.5.2.

2.6 Flood Mitigation and Drainage Works

2.6.1 Previous Plans

To cope with the repeated flooding as presented in Section 2.5, the agencies responsible for flood mitigation and drainage works have made every effort to prepare several plans as listed in Table 2.6.1 whose major features are shown in Table 2.6.2. As can be seen in the table, the first study for the protection of Bangkok was in 1960, and most of the plans also focused on the protection of the Bangkok metropolitan area and the adjacent flood plain. These plans, in general, proposed the following measures:

(1) Polder system together with the improvement of drainage systems including pump facilities;

(2) Dikes along the river courses; and

(3) Diversion channels.

Of these plans, a polder system with drainage system improvement covering the Bangkok metropolitan area has been developed, and diking has progressed continuously along the Chao Phraya River even in rural areas.

Among the previous studies, the study on "Chao Phraya Flood Management Review" conducted by World Bank in 1996, which is much related to this study, recommended to take the following actions:

(1) Local Management

Drainage and flood exclusion works should be developed continuously to manage runoff from direct rainfall and to prevent flooding by overflow from adjacent streams on local community basis in the following manner:

- The current work programs of PWD, BMA, RID and other national government agencies as well as provincial and local governments to provide local drainage should continue. Local drainage and protection programs should consider land use program as one of the tools of local drainage and flood protection design. In some locations the local flood protection works must be adjusted to suit the changing local flood regime due to regional effects of large-scale developments.

- Flood risk mapping should be undertaken throughout the basin to identify areas where flood resistant design standards, land use restriction and flood forecasting and warning programs should be applied.

- Flood forecasting and warning systems and codes for flood tolerant design and construction standards should be developed for use by local communities.

(2) Regional Flood Management in the Upper Basin

Two activities are recommended for clarification of flood management interactions in the upper basin:

- The operating objectives of small and medium sized reservoirs should each be analyzed and flood control priorities defined.

- The overall effects of the large area protected by dike in the upper basin should be listed for moderate and large-scale flood events.

(3) Regional Flood Management in the Lower Basin

The framework of a series of activities leading to design and implementation of flood management actions specifically recognizing the large degree of interaction among land use, flood control and flooding processes is recommended in the lower basin:

- Background studies to set up design criteria for flood protection and relief, to enable prediction of the effects of changes in land use on flood severity and to evaluate the technical, social, political and environmental implications of alternative flood management measures.

- Evaluation of the five alternative themes for flood management in the basin applying the identified large and medium scale actions in various combinations at the feasibility study level.

- Evaluation of the other actions on a small scale at the feasibility level.

- Selection of the theme of flood control based on the works mentioned above.

- Designing and financial and administrative arrangement for the selected flood management program.

- Implementation of program elements in the short, medium and long terms.

For the implementation of these programs, it is proposed to establish a River Basin Authority.

2.6.2 Works in Urban Areas

(1) General

The flood protection and drainage facilities provided for typical urban areas such as Bangkok Metropolis and provincial cities in the Chao Phraya River Basin have not been well installed. After the 1995 flood, however, substantial improvement works were made or are being designed for many of such cities as briefly described below. Regular improvement and maintenance works not described herein are carried out by the related agencies.

(2) Bangkok Metropolis

Based on the various studies as listed in Table 2.6.1, BMA has continuously made vital efforts to protect the Metropolis from flood and to improve the drainage condition. Such efforts have concentrated on the construction of (a) polder dikes along the periphery of the urban areas of both right and left banks of the Chao Phraya River; (b) flood barriers along both banks; (c) drainage pumping stations with flood forecasting center; and (d) improvement of drainage channel. Fig. 2.6.1 shows the location of polder dikes, flood barriers and pumping stations.

At present, BMA is constructing a flood barrier along both banks to protect the urban area of about 890 km^2 (650 km^2 for the left bank and 240 km^2 for the right bank) as shown in Table 2.6.3. The location is as presented in Fig. 2.6.2.

The crest elevation (EL. 2.75 - 3.00m) was determined in consideration of the probable high water level of 100-year return period (EL. 1.90 - 2.50 m),

freeboard (0.50 m) considering estimated land subsidence (20 cm in 2006), and public opinion with respect to convenience and aesthetic condition.

As shown in the same table and figure, the total capacity of the drainage pump of BMA is 692 m^3/s, i.e., 452 m^3/s for the left bank and 240 m^3/s for the right bank, most of which are directly discharged into the Chao Phraya River.

On the other hand, RID has a plan to increase the flow capacity of the Chao Phraya River at Bangkok Port by lop-cut. (Refer to Fig. 2.6.3.)

(3) Provincial Urban Areas Located Downstream of Bangkok

Samut Prakan Province, located between the southern part of Bangkok metropolitan area and the Gulf of Thailand, is divided by the Chao Phraya River into East and West. The ground level of the province is generally low and the area is always affected by flood mainly caused by high tide in the rainy season.

The PWD is presently carrying out the flood protection works along the Chao Phraya River, 236 km^2 in the East and 124 km^2 in the West. A polder system together with gates and pumps has been adopted to protect the area, as shown in Fig. 2.6.4.

(4) Provincial Urban Areas Located Upstream of Bangkok

After the serious damage in major urban areas in the study area, PWD is presently carrying out some remedial measures for flood protection in some provincial capitals along the Chao Phraya River. On the other hand, PWD had selected seven (7) provinces; namely, Nakhon Sawan, Chainat, Sing Buri, Ang Thong, Ayuthaya, Pathum Thani and Nonthaburi, for feasibility study and detailed design works which were generally completed by November 1997.

In the study mentioned above, the urban areas to be protected were generally selected through the screening of urban areas in each province in due consideration of the importance of the urban areas, the amount of damage from floods, the number of population, quantity of work for countermeasures, etc. Thus, provincial capitals, several municipalities and sanitary districts were chosen for the feasibility study as shown in Table 2.6.4 and Fig. 2.6.5. The expansion of urban areas, one of the factors affecting the flood condition, was taken into account, especially in the provincial capitals.

PWD/AIT has also been conducting a master plan study for 67 provinces in the country (except Samut Prakan, Bangkok and the 7 provinces mentioned above). The final report was expected to be available in January or February of 1998, with higher priority placed on some provinces in the study area such as Sukhothai, Phitsanulok and Phichit.

2.6.3 Works in Rural Areas

(1) Present Situation

The present flood prone areas are the lowlands of the Chao Phraya Delta and the Yom-Nan basin where one paddy cropping per year is predominant. Once these areas are flooded, the farmers lose the total income of one crop-year. To protect these areas, RID had established the following three (3) regional offices in the study area to execute the protection works and water management for major irrigation facilities (refer to Figs. 2.6.6 and 2.6.7):

- Regional Office 7 which consists of 17 project offices at the right bank of the Chao Phraya River.
- Regional Office 8 which consists of 12 project offices at the left bank of the Chao Phraya River.
- Regional Office 3 which consists of 4 project offices under the Phitsanulok Irrigation Project.

Provincial irrigation offices have also been established for each province to carry out construction and maintenance works that are not covered by the above project offices. The provincial irrigation offices function under the RID Regional Office and work for the province under the Provincial Governor. The main budget is allocated by the RID Regional Office and is supplemented by one from the provincial office.

Amounts disbursed by RID for flood protection and drainage improvement for Fiscal Year 1995 and 1996 are given in Table 2.6.5. According to RID, the disbursements for the Chao Phraya River Basin in 1995 and 1996 were far larger than normal years which required limited disbursements for regular works. The regular works consist of regular maintenance work (one-half) and rehabilitation of damage by the 1995 flood.

(2) Monkey Cheek on the West Bank and the East Bank

The west and east banks on Bangkok Metropolis which extend over 2,000 km^2 between the Chao Phraya and Tha Chin rivers and 2,000 km^2 between the Chao Phraya and Bang Pakon rivers, respectively, are called water conservation areas and have long played a vital role to protect Bangkok during extreme floods (Takaya, 1982). However, the recent rapid change in land use and lifestyle of inhabitants have made it difficult to expect such a role in some areas. RID, thus, commenced the detailed design for the regional drainage project for each bank, named the Monkey Cheek by His Majesty King Bhumibol, focusing particularly on flood control and drainage improvement in these regions.

The present major drainage canals and the location of pumping stations and regulators are presented in Fig. 2.6.8. The total capacities of the RID pumps in the West Bank and the East Bank are, thus, estimated at 126 m^3/s along Tha Chin River, 405 m^3/s in the East Bank and 130 m^3/s along Chao Phraya River.

(a) Monkey Cheek Project in the West Bank

The project was conceived in accordance with His Majesty King Bhumibol's suggestion at Mahachai-Senamchai Khlong in the 1995 flood as shown in Fig. 2.6.9. The suggestion is summarized as follows:

- Flood control and drainage improvement, at first by regulators, then pumps, or effective combination of them. Retarding will enhance the flood mitigation effect.
- Dams are effective for flood control. Flood diversion is also possible by a new route or expansion of the existing facilities.
- Land use in the vicinity of Bangkok is changing and urbanized which should be provided with flood protection and drainage improvement. Land raising and soil improvement are to be considered.
- Environmental consideration particularly for improvement of water quality through provision of regulators and effective operation thereof.

These guidelines or policies have been observed by RID for application to the ongoing projects discussed below.

(i) Mahachai-Senamchai Project

This project aims to prevent floods and to improve drainage conditions in an area of 46 km^2 downstream of the West Bank, as shown in Fig. 2.6.10, by the provision of 13 regulators and 6 pumping stations with a total capacity of 138 m^3/s. This project is expected to improve the water quality through flushing deteriorated water by tidal phenomena.

(ii) Upper Tha Chin and Lower Tha Chin Project

The West Bank with an area of 2,400 km^2 (80 km N-S and 30 km wide as shown in Fig. 2.3.3) have long played the role of retarding basin to protect Bangkok from floods. However, urbanization is recently encroaching into the area from the southern end. The Upper Tha Chin Regulator and the Lower Tha Chin Tidal Barrage projects (location and plan are shown in Fig. 2.6.10) have been designed with water use as primary objective. The Upper Tha Chin project is ready for construction, and the Lower Tha Chin project is at its final stage of detailed design. A preliminary study has been made for the stream flow of the canal network in this area, as presented in Fig. 2.6.11.

(b) Monkey Cheek Project in the East Bank

(i) Cholahan Phichit 2 Drainage Pump Project

The project aims at improvement of drainage condition of the eastern suburban area adjoining the BMA territory for an approximate area of

2,500 km^2 which is bounded on the west by the King's Dike, on the east by the Bang Pakong River, on the north by the Rangsit Canal and on the south by the Gulf of Thailand (refer to Fig. 2.6.12). The existing main drainage canals are Khlong Phalonk Chaiyanuchit and Khlong Bang Chalok, with widths of 40-60 m. Both canals originate from Rangsit Canal and flow toward south to the sea, being used for drainage and navigation. Excessive water during the flood season is drained out to the sea by nine (9) pumping stations equipped with 101 pumps in total or a capacity of 303 m^3/s installed along National Road No. 3. The existing Chola Han Phichit Drainage Pump Station is among these stations. On the other hand, along the Bang Pakong River, there are six (6) pumping stations equipped with 34 pumps in total or a capacity of about 102 m^3/s, which drain water to the Bang Pakong River.

The Project aims at drainage improvement by provision of main drainage canal with a bottom width of 100 m and a length of 63 km from Rangsit to the sea, and construction of a new and large pumping station named Chola Han Phichit 2 Pumping Station with a total capacity of 200 m^3/s for five (5) vertical axial flow pumps.

(iii) Eastern Bangkok Drainage System Study

In response to the implementation of the Second Bangkok International Airport, RID is planning a scheme for the Eastern Bangkok Drainage System Study which covers an area wider than studied by the above Cholahan Phichit 2 Project at master plan and feasibility study levels.

(3) Proposed Flood Protection Dike by RID

RID has planned reconstruction of existing dikes, whose elevation is from 2.0 m to 4.0 m (MSL), between Ayuthaya and Pathum Thani along the Chao Phraya River. The design crest elevation of these dikes is 4.0 m (MSL). These dikes will be completed in the near future based on the results of the present Study.

(4) Projects which Relate with Flood Mitigation

The Harbor Department has planned a project for construction of two barrages in the Chao Phraya River reaches. The main objective of the project is to increase the least available depth, LAD, for navigation so that the size of cargo ships and their tonnage can be increased. The general features of the two barrages are as tabulated below. The locations of the two barrages are as shown in Fig. 2.3.3.

Barrage at Km. 205	The barrage will be located at Km. 205, along the Chao Phraya River from the river mouth in Amphoe Phrom Buri, Changwat Sing Buri. (Refer to Table 2.6.6 for more daitails.)
Barrage at Km. 345	The barrage will be located at Km. 345, along the Chao Phraya River from the river mouth in Amphoe Phayuha Khiri, Changwat Nakhon Sawan. (Refer to Table 2.6.6 for more details.)

2.7 Land Use

The recent land use condition of the Chao Phraya River Basin has been studied and prepared by several agencies. Among others, the basin-wide land use condition is well clarified by the Agricultural Land Use Map (Fig. 2.7.1) and the Changes of Land Use from 1980 to 1990 (Fig. 2.7.2) both prepared by the Center of Agricultural Information, MOAC.

2.7.1 Historical Changes in the Basin

Inhabitants of the Chao Phraya River Basin have had experiences on flood which, on one hand, had brought abundant water and fertile soil to their cultivation lands. However, at present, they can no longer avail themselves of such benefits of abundant water because of the social and economic developments all over the basin.

In agricultural land, the intensified agricultural practice giving emphasis on the conversion from the traditional local varieties like floating rice to the high yield varieties vulnerable to flooding has prevailed and flood damage potential has been enhanced. Further, cultivated areas, mostly with irrigation works, have increased from 7,000 km^2 before 1950's to 35,000 km^2 in the 1990's.

On the other hand, urbanization in the basin has progressed and the Bangkok Metropolitan Area of 51 km^2 before 1950's has grown to 528 km^2 at present. Consequently the flood damage potential has not only enlarged due to the increased population and assets, but flood discharge due to the decrease of runoff detention capacity has also become more serious. Moreover, the forest area has diminished to give way to various types of development from 166,000 km^2 before 1950's to 92,000 km^2 in the 1990's, which also resulted in the increase of flood discharge of the rivers. Such changes in the basin which possibly heightened the flood damage and enhanced the importance of flood mitigation works are summarized in Table 2.7.1.

2.7.2 Present Land Use in the Basin

The typical land use of the river basin with an area of 168,000 km^2 can be roughly classified, as shown in Table 2.7.2.

(1) Forest Land Use

Recent changes in land use are well clarified by Fig. 2.7.2 that compares the reduction of forest area and increase of farmland from 1980 to 1990. The forest area was reduced from 64% to 39% of the area of the Northern and Central regions (237,000 km^2) where most of the river basin extend. This marked reduction has paced down with a rate of only 2% for 5 years from 1988 to 1993 since the strict control and efforts on reforestation were made

after the Cabinet Resolution in 1985 which aims that 40% of the state land be covered by forest. The GOT plans in the 8th Five-Year Development Plan to reforest a total area of 11,600 km^2.

(2) Agricultural Land Use

The agricultural land in the Chao Phraya River Basin occupies 5.9 million ha mostly covered by paddy fields. The areas covered by irrigation facilities are 44% of the paddy field in the Yom-Nan Flood Plain and as high as 82% in the Chao Phraya Delta, compared with the national average of 42% as detailed in Table 2.7.3. However, actually harvested areas in the irrigated paddy fields are only 11% and 24% of paddy fields in Yom-Nan and Chao Phraya, respectively (see Table 2.4.3), mainly due to the limited water resources.

The expanding tendency of the agricultural land in the basin, paddy fields in particular, has ceased recently and some reduction is observed in the vicinity of Bangkok and the major towns, as shown in Table 2.7.1. Further agricultural land use information was studied by Kasesart University, ORSTOM in 1996, as presented in Fig. 2.7.3. The future regional agricultural land use plan for the West Bank and the East Bank of Bangkok were also studied by RID and NESDB (for SBIA, Second Bangkok International Airport), as presented in Figs. 2.7.4 and 2.7.5.

(3) Land Use for Urban Areas

Bangkok Metropolis with a total area of 1,577 km^2 has been urbanized rapidly since 1970 (180 km^2) to the present (528 km^2 estimated by AIT). The present land use was roughly classified according to BMA/JICA, 1996 which prepared a plan for the future land use as presented in Fig. 2.7.6.

There are several major cities in the flood plain. Land use maps have been prepared for these cities especially for the provincial capitals from 1980's to early 1990's, as shown in Tables 2.7.4 and 2.7.5.

(4) Land Use in Riverine Belts

As discussed in Subsection 2.1.2, natural levees are well developed in the flood plain. Most residences and buildings are situated in this elevated land mixed with farmland in rural areas, and commercial activities are concentrated in these areas because rivers had played an essential role as main transportation and communication means for a long time.

Such situation and the lifestyle of people in rural areas have been changing rapidly according to the construction of roads. Many roads and irrigation canals have been constructed alongside natural levees. These areas named riverine belts in this Study can be observed over the entire flood plain, even in the urban area as shown in Fig. 2.7.7, and are confined by the roads and canal dikes during flood.

2.7.3 Land Use Projection

The target year is 2018, which is 20 years ahead from the present. The area for projection is only inside the flood plain.

The flood plain is demarcated into four regions in accordance with their features. Four regions are made of: the Upper Central Plain; the Nakhon Sawan Area; the Higher Delta in the Lower Central Plain; and the Lower Delta in the Lower Central Plain. Fig. 2.7.8 shows this demarcation.

In the following, the methods and the stepwise procedure of how land use projection in the year of 2018 is made are explained:

(1) Setting of Present Land Use

The projection bases the present land use mostly on the GIS data made by the MOAC in 1997. The agricultural land use data in this GIS is based on the data collected in 1994. The present land use of the four regions is described in Table 2.7.6.

(2) Projection of Agricultural Land Use

Agricultural land can be classified into several categories by crop types. In the projection, it is classified into four: paddy, fruits & trees, vegetables & flowers, and field crops. There must be some types of crops that cannot belong to any of the four. Those types of crops, however, are classified as others that contain not only such other farm land but also other land use such as barren land, water, swamp, unclassified, etc. These four agricultural land use types are thought to cover the overall land use features in the flood plain.

Now the growth rates of these four types of agricultural lands are to be determined. For this purpose, it is decided that the growth rates in the projection be derived from the projection given by the JICA study for the Chao Phraya Delta named "The Kok-Ing-Nan Water Diversion Project". In addition, the report for the whole Study Area named "Chao Phraya Basin Water Management Strategy" is used to cover the whole flood plain.

In the projection of agricultural land use, the growth rates given by the Kok-Ing-Nan Water Diversion Project and the median scenario given by the Chao Phraya Basin Water Management Strategy are used for the projection of agricultural land use. The rates actually adopted here are shown in Table 2.7.6. For example, the growth rates in the flood plain as a whole are -1.0% for rice, 2.4% for fruits & trees, 3.6% for vegetables & flowers, and -1.1% for field crops. Concerning rice, its types are further analyzed in step (7) and the result is given in Table 2.7.7.

(3) Projection of Urban Land Use

For urban land use projection, the plans made by DTCP and PWD are used. For Bangkok, however, BMA's plan is used. In addition, major development plans and ongoing projects are integrated into the projection. For example, the

Bangkok Second International Airport and the Outer Ring Road are taken into account for the projection.

(4) Projection of Forest

Thailand has experienced a rapid reduction of forest. Observing the recent trend shown in Table 2.7.8; however, it is natural to think that no further reduction of the forest occurs in the future. Thus, in the projection, the forest area is estimated to remain the same in the future.

(5) Others (Residuals)

This classification includes several land use types. Others consists of farm holdings, water, fishpond, swamp, mangrove, barren land, and unclassified land. Since the agricultural lands of four major crops grow with fixed rates and the urban land also grows independently without any connection with the overall land use, there will be residuals generated in the flood plain.

(6) Calibration

Based on steps (1) to (5), the first calculation of the land use projection can be done. Because each land use type is set to change independently while the total land is fixed, the growth rates of others are to be set to those values which make the summation of all areas of the future land use types equal to the fixed whole area. Through iterative calculations, odd values given to others (residuals) are adjusted by re-distributing them to other land use types in proportion to their area sizes. By doing this, the future areas of others can be suppressed to an appropriate level. The result of the projection is shown in Table 2.7.6.

(7) Types of Rice

Since rice has a large share in land use, it is better to analyze the types of rice. In the Study, rice is demarcated into four: high yield variety (HYV), general traditional variety (GTV), deep water rice, and floating rice. The present land use types of rice are determined as shown in Table 2.7.7.

The area change in rice has been determined as in Table 2.7.6 and no further modification is to be made.

In the Upper Central Plain, there are some large/medium-scale irrigation projects and a number of small-scale irrigation projects planned by the RID. Those newly irrigated areas are assumed to be used for HYV.

In the Nakhon Sawan Area, there is no particular reason to reduce the area of HYV. That is, it is considered that the force of urbanization in this region is not so strong enough to convert the area of HYV into urban or other agricultural land use types. Thus it is assumed that the area of HYV remains the same. With regard to GTV, deep water rice, and floating rice, their future areas are determined by the same ways as described above in the Upper Central Plain.

In the Higher Delta in Lower Central Plain and the Lower Delta in Lower Central Plain, deep water rice and floating rice are focused. From Table 2.7.7, it is concluded that the floating rice area was decreased with -3.0%, which is the annual average growth rate from 1986 to 1995 in RID's Regions 7 and 8 (refer to Table 2.7.9). Hence it is assumed that the areas of deep water rice and floating rice decrease with this rate.

Table 2.7.7 shows the result of rice type projection.

The result of the land use projection is given in Tables 2.7.6 and 2.7.7, and the comparison of the present and the future land use is visualized in Fig. 2.7.9. In Tables 2.7.6 and 2.7.7, the projection of land use in 2005 is also given with the same annual growth rates.

As shown in these tables and figures, the most noticeable change is the dramatic reduction of paddy field in all four regions. This reduction is replaced mainly by the increase in fruits & trees as well as urban areas. It is concluded that not much profitable rice production will be decreasing while diversification of agriculture for seeking more profits and urbanization through industrialization will be taking place in the future.

2.8 Land Subsidence

2.8.1 Present Situation

The recent economic development of Thailand has brought about increases in water demands for industrial, commercial and domestic purposes, particularly in the Bangkok Metropolitan Area. In order to meet with the growing water demands, groundwater is pumped heavily, causing increased and more widespread land subsidence and saltwater intrusion in the area. Though land subsidence has slowed down in the central part of Bangkok due to regulations undertaken in the early 1980's, it is still progressing in the vicinity of the Bangkok Metropolitan Area.

The land subsidence not only damages roads, bridges, buildings and canals but also causes flood in the lowlands which bring large economic losses. Under such circumstances, various studies have been made and among them, the JICA study on Management of Groundwater and Land Subsidence in the Bangkok Metropolitan Area and its Vicinity (1995) has been one of the comprehensive and in-depth studies. The study reported the following with respect to the present situation of land subsidence in the area:

(1) The actual land subsidence in the area is estimated at 2 cm/year on average in Bangkok, 5-6 cm in Samut Prakan, 4-5.5 cm in Min Buri and Lat Krabang, and 3-4 cm in Pathum Thani and Samut Sakhon. These estimates correspond to the study results by BMA/NEDECO, 1996 for ESUB Project.

(2) The Study Area's total groundwater pumpage in 1992 was estimated from the well inventory database at 1.48 MCM/day. Pumpage has been

recently increasing in Bangkok's vicinity, e.g., Lat Krabang, Pathum Thani and Samut Sakhon.

(3) Groundwater levels of the main aquifer have declined from 30 m to 60 m below MSL. In the central area of Bangkok, groundwater level is again lowering because of the effect of the regional decline of groundwater level caused by over-pumping in the vicinity.

The Department of Mineral Resources (DMR) and the Royal Thai Survey Department (RTSD) have been monitoring land subsidence every year. Fig. 2.8.1 prepared by them reveals that (a) the annual subsidence in 1995 and 1996 are still in progress, and (b) areas affected by the land subsidence have extended toward north to Pathum Thani, west to Samut Sakhon and east to Samut Prakan. On the other hand, Fig. 2.8.2 (BMA, NEDECO et al) shows such marked subsidence has paced down along the Chao Phraya River near the city core of Bangkok.

The progress in (a) above is attributed mainly by the increase of groundwater abstraction in the area. The major users of groundwater are deemed to be the private sector such as industry. However, although the total pumping water is not so large, MWA also increased groundwater production rapidly from 16.9 MCM in 1991 to 68.4 MCM in 1995.

2.8.2 Future Prediction

With respect to the future prediction of land subsidence, the following are the latest study results:

(1) DMR/JICA (1995) focused on the groundwater declining and estimated future regional land subsidence for nine (9) scenarios, in terms of groundwater pumping control alternative, as presented in Fig. 2.8.3 which shows the future conditions: 2 m subsidence in 2017 at maximum under the most moderate control, and maximum 0.5 m under the most strict control (Refer to Fig. 2.8.4).

(2) BMA/NEDECO et al (1996) estimated the subsidence for the future 10 years to 2006 along the proposed flood barrier at 20 cm along the Chao Phraya River, 30 cm along King's Dike and 40 cm along the northern boundary of Bangkok.

2.9 Institutional Setup for River Management

2.9.1 Law and Regulations

The major laws and regulations related to river management in Thailand are presented in Table 2.9.1. Among the major laws and regulations, the People Irrigation Act and the State Irrigation Act are especially for river water utilization.

Although water resources development programs such as irrigation, hydropower and domestic water supply projects are promoted independently by the respective agencies, there is no law for the regulation and coordination of proposed water resources development for multipurpose use, except a coordinating committee

composed of members from the related agencies. Moreover, for flood control works, only the State Irrigation Act has some stipulations.

In such a situation, a Water Act was drafted in 1993 by the Law Section of the National Board of Research to clarify water rights and agencies for water resources management. The draft was submitted to the cabinet in 1997, but has yet to be enacted pending agreement among the agencies concerned. In this draft bill, the following are stipulated:

(1) *State Water Resources*: The state is entitled to develop public water resources by changing the size or enlarging the coverage area.

(2) *Water Rights*: Any person who owns a plot of land whether or not adjacent to water resources shall have the right to draw the water at a reasonable quantity for private use.

(3) *National Water Resources Board*: The National Water Resources Board shall be set up with authority and duties as follows:

   (a) To propose to the Cabinet a policy pertaining to the conservation, development, utilization and other related activities of water resources;

   (b) To suggest, review and coordinate water resources plans and projects with the government agencies and government enterprises;

   (c) To follow up and evaluate any activity pertaining to water resources; and

   (d) To guide, follow up and oversee the plans for flood protection and flood mitigation of the various river basin committees.

(4) *River Basin Committee*: The National Water Resources Board shall designate the River Basin Committee as the body responsible for the work in each river basin taking into account the geographical conditions of the water resources, the water utilization and the appropriate limit of responsibility.

2.9.2 Related Organizations

On the national level, there exist seven (7) ministries and two (2) national institutes for river management, including RID and PWD. To coordinate their management work, the National Water Resources Board was established in 1989.

On the local government level, local offices of RID and PWD and provincial governments are engaged in river management. Table 2.9.2 shows the organizations concerned in river management, while Table 2.9.3 shows those for the Chao Phraya River Basin.

(1) Flood Control

The Royal Irrigation Department (RID) implements water flow control and drainage works for the agricultural areas in consideration of the effect to Bangkok and the provincial urban areas. Drainage works for the Bangkok metropolitan area are executed by the Department of Drainage and Sewage (DDS) of the Bangkok Metropolitan Administration (BMA).

For the provincial governments, the Public Works Department (PWD) provides consulting services and executes the construction of ring dike and pumping stations for drainage works, while the Department of Local Administration (DOLA) manages flood fighting. The Electricity Generating Authority of Thailand (EGAT) and the Meteorological Department (MD) execute flood forecasting in a part of the Chao Phraya River Basin.

2.10 Environment

2.10.1 Thailand's National Policy on Environment

The Eighth National Economic and Development Plan (1997-2001) is set to counterbalance the "ordinary ways" of development. Technically, it supports more opportunities for local communities and organizations to manage natural resources. It also recommends economic instruments for controlling and supervising the development practices. The general idea of The Eighth National Economic and Development Plan is schematically illustrated in Fig. 2.10.1.

2.10.2 Environmental Act

In 1992, the Enhancement and Conservation of National Environmental Quality Act B.E. 2535 was proclaimed by repealing the Enhancement and Conservation of National Environmental Quality Act, B.E. 2518 (1975), the Enhancement and Conservation of National Environmental Quality Act (No. 2), B.E. 2521 (1978), and the Enhancement and Conservation of National Environmental Quality Act (No. 2), B.E. 2522 (1979). As a result of the revised Act, the National Environmental Board (NEB) was strengthened (Chapter I), the Environmental Fund was established (Chapter II), conservation and protected areas came under the central government (Chapter III), and the Environmental Impact Assessment process was clarified (Chapter IV). In all, the central government, especially MOSTE, is strengthened to play major roles in environmental concerns on the broader aspect.

2.10.3 Institutional Setup

The primary organization for maintaining environmental quality in Thailand is NEB. NEB consists of heads of related ministries. According to Section 19 of the Enhancement and Conservation of National Environment Quality Act B.E. 2535, NEB has the power to require government agencies, state enterprises, and other persons to submit documents relating to the impacts on environmental quality and documents or data concerning the projects or work plans planned.

As noted in Section 21 of the Enhancement and Conservation of National Environment Quality Act B.E. 2535, NEB may entrust the three departments under

MOSTE with the operation or preparation of propositions made to NEB. The three departments are the Office of Environmental Policy and Planning (OEPP), the Pollution Control Department, and the Department of Environment Quality Promotion. Among these departments, the Environment Impact Evaluation Division of OEPP is designated to be in charge of the environmental impact assessment process.

2.10.4 Environmental Impact Assessment (EIA)

(1) Outline of EIA

With the revised Enhancement and Conservation of National Environmental Quality Act B.E. 2535, as noted above, the environmental impact assessment process was newly affirmed. Its major procedure is shown in Fig. 2.10.2.

If a project or activity is required under the law to submit an EIA report (as mentioned later), the proponent has the duty to prepare an impact assessment report at the stage of conducting a feasibility study, and submit the EIA report to the Environmental Impact Assessment Division under OEPP, MOSTE for review, and must obtain a permission by the National Environmental Board (NEB) prior to construction or operation.

It should also be noted that the EIA report must be prepared by a person who is officially licensed as a specialist in environmental impact assessment. As of June 1993, 33 consultant firms have been issued a license which is valid for 3 or 5 years. Fig. 2.10.2 shows the EIA process for a project of a government agency, or of a state enterprise or to be jointly undertaken with a private enterprise which is required to be approved by the cabinet.

(2) Projects Required to Submit EIA Report

Projects or activities of a government agency, a state enterprise or a private person who is required to prepare the EIA report are specified by the Notification of the Ministry of Science, Technology and Environment in the name of Mr. Paijitra Auetaweekul, the Minister under the Enhancement of National Environment Quality Act B.E. 2535 (1992). The notification, shown in Table 2.10.1, was published in the Government Gazette, Vol. 109, No. 130 (October 8, 1992), and additional types of projects and activities in the Government Gazette, Vol. 109, No. 136 (October 22, 1992).

2.10.5 Other Conservation/Protection Acts

(1) Watershed Classification and Development Restrictions

The decline of forest areas has been a major concern of the public for environmental reasons as well as watershed value. The Cabinet approved the Classification for watersheds of the Ping and Wang rivers in 1985, and the Yom and Nan in 1986. The project implementing agencies must follow the measures and recommendations of land utilization applicable to each watershed class (see Table 2.10.2).

(2) Protected Land for Biological Purposes

About 10% of Thailand has already been declared as national park and wildlife sanctuaries to protect habitats of wildlife from development and their impacts. A map of national parks, wildlife sanctuaries and non-hunting areas is presented in Fig. 2.10.3.

2.11 Related Projects

2.11.1 Water Resources Projects

(1) Dams

In the Chao Phraya River Basin, seventeen (17) dams have been constructed and twenty-eight (28) construction plans are being implemented. Among the constructed dams, there are eight (8) large reservoirs whose effective volume exceeds 100 MCM and the others have less than 100 MCM.

Among the twenty-eight (28) planned dams, six (6) have large reservoirs and the remaining twenty-two (22) dams are classified as small ones. The general features of these dams are shown in Table 2.11.1 and the principal features and locations of the large scale dams are shown in Table 2.11.2 and Fig. 2.11.1, respectively.

The purposes of these large-scale dams are irrigation, power generation, and flood control. However, none of the dam reservoirs have an exclusive volume for flood regulation, and flood control has not been given priority in the determination of release and reservoir operations.

The two giant dam reservoirs, Bhumibol and Shirikit, however, can regulate flood runoff by using the vacant volume above the upper rule curve for reservoir operation which was established to maximize power generation. The other dam reservoirs may also regulate flood runoff to some extent as a result of impounding water. Figs. 2.11.2 and 2.11.3 show the upper rule curves and results of reservoir operation of Bhumibol and Sirikit reservoirs, respectively.

The flood regulation effect by these dam reservoirs depends upon the reservoir volume used for flood regulation, namely, the vacant volume of the reservoir at the beginning of the flood season (at the end of the dry season). The reservoir volumes of dams in the Chao Phraya River Basin are summarized in Table 2.11.3.

(2) Trans-Basin Water Diversion Plans

In order to fulfill the possible future water demand, NESDB/RID/JICA is conducting a feasibility study for the Kok-Ing-Nan Water Diversion Project which has been selected among some trans-basin plans including Salawin River to Bhumibol diversion and Mekong River to Sirikit and upper Pasak diversion (see General Map). The plan is summarized as follows:

(a) Background

The total inflow of the Sirikit Reservoir, operated since 1974, is 5 billion m^3 in normal years and 3.4 billion m^3 in drought years against the active storage of 6.7 billion m^3. However, the water actually released from the reservoir for water use in the downstream in dry season is as low as 2.7 billion m^3 and 1.6 billion m^3 in normal years and drought years, respectively, mainly due to inevitable carrying over storage of 2 to 3 billion m^3 to cope with the demand in the possible succeeding drought year. Improvement of this condition of the reservoir operation has long been expected by the agency concerned.

(b) Proposed Plan

The proposed plan aims to increase the released water to 5.7 billion m^3 as follows:

- To reestablish the carrying over storage at 1 billion m3;
- To divert water of the Sirikit Reservoir of a maximum of 2 billion m^3 (175 m^3/s) in flood season from the Kok and Ing rivers to the upstream tributary (Yao River); and
- To store at least 3.7 billion m^3 inflow from the Nan River Basin.

(c) Major Components of the Project

The major components of the project are:

- Kok Diversion Dam (125 m^3/s) and Kok-Ing Diversion Channel (20 km);
- Ing Diversion Dam (175 m^3/s), Lao Diversion Canal (12.4 km) and Ing-Yot Tunnel (50 km); and
- Yao Flood Control Dam (28 MCM) and Yao River Improvement (40 km).

(d) Flood Control Effect

It is expected that the project will bring an increase in flood control effect by reducing the carrying over storage from 2 billion m^3 to 1 billion m^3 that, in turn, increases the flood control storage. In addition, 2 billion m^3 of the diverted water may be regulated in case a flood damage is forecast in the downstream of the dam.

2.11.2 Other Projects

As the other projects, the following are specified:

(1) Second Bangkok International Airport

This project is to construct a new international airport at Nong Ngu Hao in the Samut Prakan province, 30 km east of Bangkok, because the existing international airport at Don Muang is forecasted to reach its full capacity by

the end of this century. The master plan and feasibility studies were done by the Office of the Second Bangkok International Airport Development Committee (OSBAC) and the NESDB by 1994, and the project commenced in 1998.

Along with this new airport construction, the surroundings and related infrastructure are significantly planned for development. Moreover, disturbance to the area designated to have a drainage function called "the Green Belt" might be caused due to the airport construction and subsequent development of the surroundings unless special attention is paid to drainage in the area. It is, however, also known that a drainage project called "the Chola Han Phitchit Project" is under consideration for improving drainage function around there.

(2) Outer Ring Road and Truck Route

Around Bangkok, the construction of the Outer Ring Road and the Truck Route as shown in Fig. 2.11.4 is ongoing or under consideration to improve the link among neighboring cities and to reduce the extreme concentration of all functions in Bangkok. This kind of development is observed in many places in the world and it is quite natural for it to be actually realized soon in line with the decentralization policy after the eccentric rapid growth of a big city like Bangkok.

The Outer Ring Road is an inner circle and makes the 11 existing cities the sub-centers by connecting them each other in order to absorb the future development in the suburban area of Bangkok. The Ring Road was proposed by the BMA as a part of its plan of metropolitan sub-centers. Its construction at the western side of Bangkok is almost completed.

The Truck Route will be an outer circle and link those cities that do not currently have the function of a sub-center, but will grow to have such a function later on.

Although the start and completion of these road projects is not clear at present, it is believed that definitely they will be implemented in the near future.

(3) Urban Development Planning in the Delta

In connection with the Second Bangkok International Airport Project and the Outer Ring Road and the Truck Route projects, there are some other development projects in the Delta. Other expressways and highways, as shown in Fig. 2.11.4 that was prepared by the DTCP, are under consideration to enlarge the Bangkok Metropolitan Region much wider than that envisaged in the Outer Ring Road and the Truck Route. For example, Saraburi, Lopburi and Suphanburi will be satellite towns that will be connected by a circular highway. This kind of development will take place in the future after the Outer Ring Road and the Truck Route projects are completed and related cities are well developed.