OFFICE OF NATIONAL ECONOMIC AND SOCIAL DEVELOPMENT BOARD (NESDB)

ROYAL IRRIGATION DEPARTMENT (RID)
MINISTRY OF AGRICULTURE AND COOPERATIVES (MOAC)

DEPARTMENT OF WATER RESOURCES (DWR)
MINISTRY OF NATURAL RESOURCES AND ENVIRONMENT (MNRE)

KINGDOM OF THAILAND

PROJECT
FOR
THE COMPREHENSIVE FLOOD
MANAGEMENT PLAN
FOR
THE CHAO PHRAYA RIVER BASIN

Final Report

Volume 2: Main Report

September 2013

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

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<u>**COMPOSITION OF FINAL REPORT**</u>

Volume 1: Summary Report

Volume 2: Main Report

Volume 3: Supporting Report (1/2)

Sector A. GIS Database

Sector B. Natural and Social Environment

Sector C. Hydrological Observation and Analysis

Sector D. Hydrological and Hydraulic Model Development and Analysis

Sector E. Evaluation of Countermeasures with Other Rainfall Pattern

Sector F. Study on River Channel Improvement

Sector G. Study on Efficient Operation of Existing Dam Reservoirs

Volume 3: Supporting Report (2/2)

Sector H. Construction of New Dams

Sector I. Retarding and Retention Area

Sector J. Construction of Diversion Channel

Sector K. Controlled Inundation

Sector L. Land Use Control in Inundation Area

Sector M. Inland Rain Storm Drainage

Sector N. Forest Restoration

Sector O. Cost Estimation

Sector P. Economic Evaluation

Sector Q. Environment

Sector R. Climate Change

Sector S. Storm Surge

Sector T. Examination of Observed Data by RID

Sector U. Materials of Workshop on July 16-17, 2013

Addendum Report: The Flood Analysis on the Chao Phraya River with RRI Model

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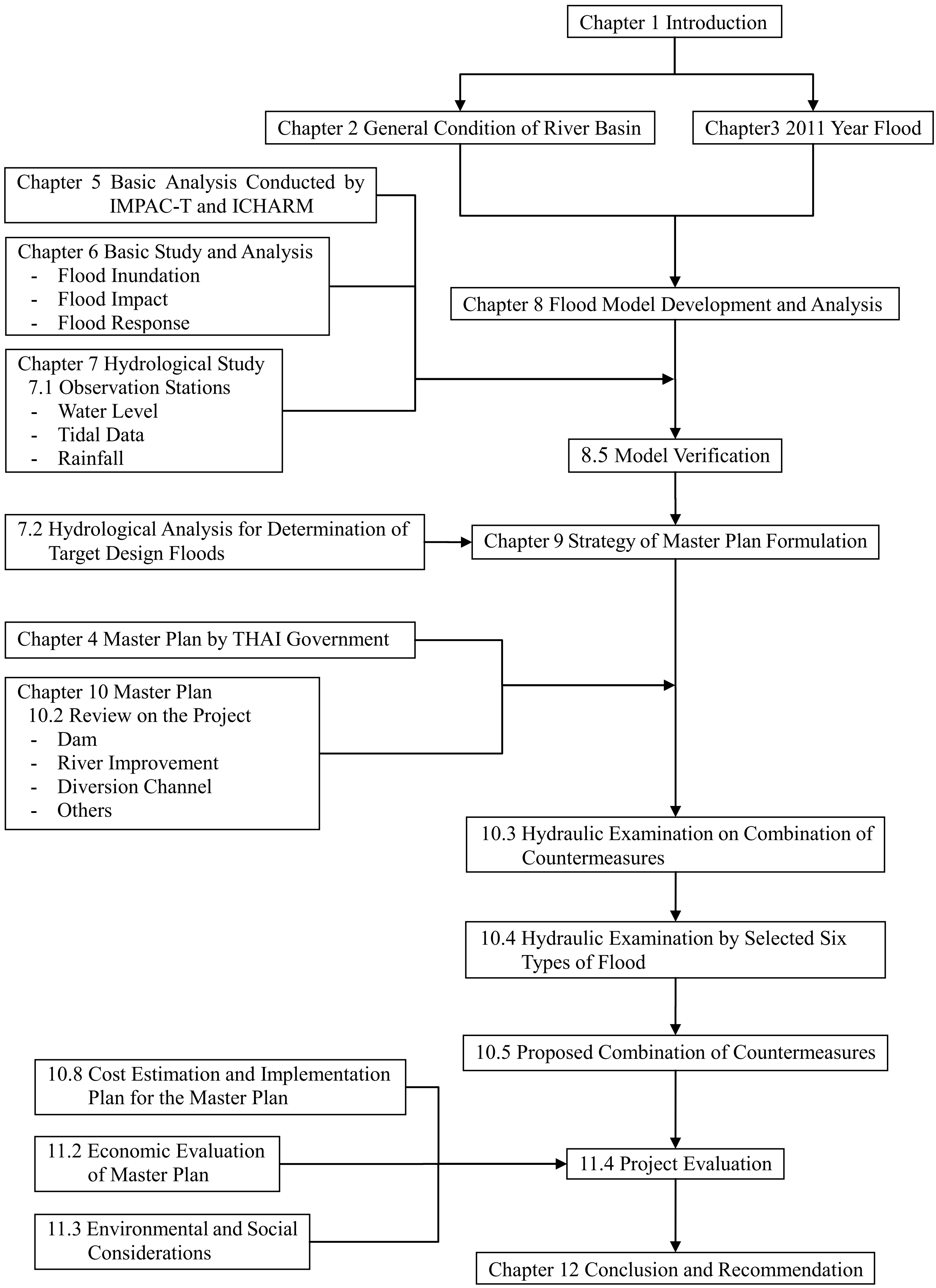

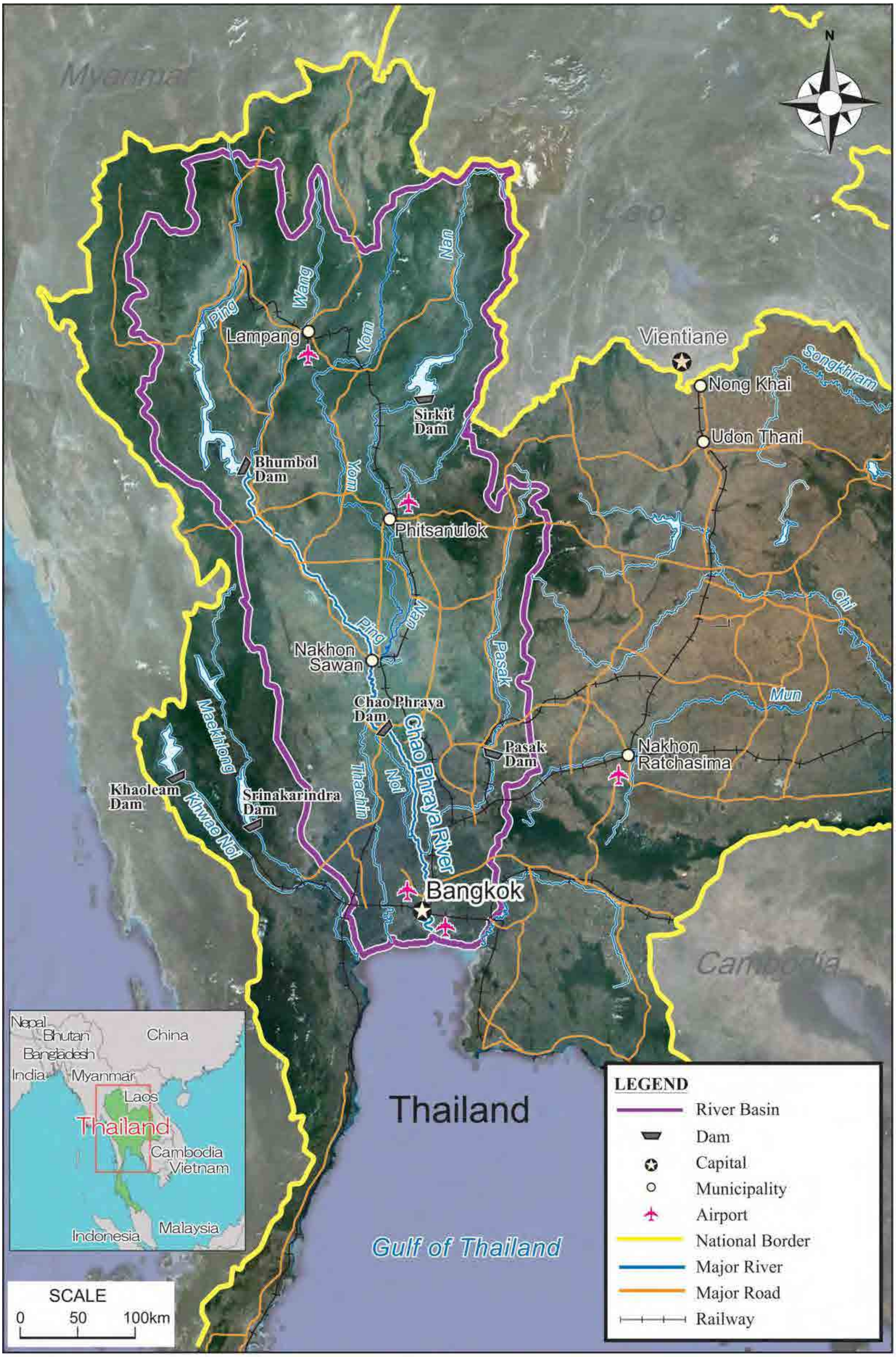

LOCATION MAP

PROJECT FOR THE COMPREHENSIVE FLOOD MANAGEMENT PLAN FOR THE CHAO PHRAYA RIVER BASIN

FINAL REPORT
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ABBREVIATIONS

AIT	Asian Institute of Technology
ALRO	Agricultural Land Reform Office
BMA	Bangkok Metropolitan Administration
CAT	Communication Authority of Thailand
CPB	The Crown Property Bureau
DDPM	Department of Disaster Prevention and Mitigation
DDS	Department of Drainage and Sewerage, BMA
DEDP	Department of Energy Development and Promotion
DF	Department of Fisheries
DGR	Department of Groundwater Resources
DIW	Department of Industrial Works
DOH	Department of Highway
DOLA	Department of Local Administration
DOR	Department of Rural Road
DPT	Department of Public Works and Town and Country Panning
DPW	Department of Technical and Economic Cooperation
DTCP	Department of Town and Country Planning
DWR	Department of Water Resources
EGAT	Electricity Generating Authority of Thailand
FFC	Flood Forecasting Center
GISTDA	Geo-Informatics and Space Technology Development Agency
GOT	Government of the Kingdom of Thailand
ICHARM	International Center for Water Hazard and Risk Management
IEC	Irrigation Engineering Center
IMPAC-T	Integrated Study Project on Hydro-meteorological Prediction and Adaptation to Climate Change in Thailand
JETRO	Japan External Trade Organization
LAO	Local Authority Organizations
MD	Marine Department
MI	Ministry of Industry
MOAC	Ministry of Agriculture and Cooperative
MOI	Ministry of Interior
MNRE	Ministry of Natural Resources and Environment
MOSTE	Ministry of Science, Technology and Environment
MOT	Ministry of Transport
MST	Ministry of Science and Technology
NDPMC	National Disaster Prevention and Mitigation Committee
NESDB	National Economic and Social Development Board
NEB	National Environmental Board
NWRFPC	National Water Resources and Flood Policy Committee
NWRC	National Water Resources Committee
NSO	National Statistic Office
OBI	Office of the Board of Investment
OCS	Office of the Council of the State

OEPP	Office of Environmental Policy and Planning
ONWRFPC	Office of National Water Resources and Flood Policy Committee
OPM	Office of the Prime Minister
OSCWRM	Office of Strategic Committee for Water Resources Management
PAT	Port Authority of Thailand
PCD	Pollution Control Department
RBC	River Basin Committee
RFD	Royal Forest Department
RID	Royal Irrigation Department
RTN	Royal Thai Navy
RTSD	Royal Thai Survey Department
SCRFD	Strategic Committee for Reconstruction and Future Development
SCWRM	Strategic Formulation Committee for Water Resources Management
SRT	State Railways of Thailand
THB	Thai Baht
TMD	Thai Meteorological Department
TOT	Telecommunication Organization of Thailand
WRFMC	Water Resources and Flood Management Committee
WT	Public Works Department

MEASUREMENT UNITS

(Length)			(Time)		
mm	:	millimeter(s)	s, sec	:	second(s)
cm	:	centimeter(s)	min	:	minute(s)
m	:	meter(s)	h, hr	:	hour(s)
km	:	kilometer(s)	d, dy	:	day(s)
			y, yr	:	year(s)
(Area)					
mm^2	:	square millimeter(s)	(Volume)		
cm^2	:	square centimeter(s)	cm^3	:	cubic centimeter(s)
m^2	:	square meter(s)	m^3	:	cubic meter(s)
km^2	:	square kilometer(s)	l, ltr	:	liter(s)
ha	:	hectare(s)	MCM	:	million cubic meter(s)
(Weight)			(Speed/Velocity)		
g, gr	:	gram(s)	cm/s	:	centimeter per second
kg	:	kilogram(s)	m/s	:	meter per second
ton	:	ton(s)	km/h	:	kilometer per hour

CHAPTER 1 INTRODUCTION

1.1 Background

In 1999, after the significant floods in 1995 and 1996, Japan International Cooperation Agency (JICA) proposed several flood mitigation measures composed of structural and nonstructural measures under the integrated flood mitigation study for the Chao Phraya River Basin (hereinafter referred to as "JICA 1999 Study"). In 2000, the Crown Property Bureau (CPB) also proposed short-term, mid-term and long-term plans on water resources management and development. Due to several reasons including the influence of the Asian Currency Crisis, however, almost no substantial measure has been implemented except for a loop-cut in the lowest Chao Phraya River since then. Nevertheless, land development and accumulation of assets and properties have proceeded in the river basin.

Under these circumstances, an exceptional flood took place in 2011. Four tropical storms and a typhoon associated with record rainfall hit Thailand one after another between June and October 2011. The prolonged flood in 2011 had caused more than 800 deaths and extensive damage and losses which amounted to THB 1.43 trillion. Out of this, THB 1 trillion was on the manufacturing sector.

In response to the request from the Royal Thai Government in November 2011, JICA has planned to conduct a flood management project; namely, the "Project for the Comprehensive Flood Management Plan for the Chao Phraya River Basin."

The Project Study has been conducted in accordance with the Minutes of Meeting dated December 22, 2011 and the Record of Discussion (R/D) dated January 13, 2012 and signed by the National Economic and Social Development Board (NESDB), the Royal Irrigation Department (RID), the Department of Water Resources (DWR), and JICA. The project is composed of three (3) components: Component 1 was subdivided into Subcomponent 1-1 and Subcomponent 1-2, and Component 3 was revised by the R/D in May 2012 as follows:

Component 1: Upgrading of "the Flood Management Plan" and the creation of a new and more precise topographic map.

Sub-component 1-1:

Creation of a new and more precise topographic map for Subcomponent 1-2.

Sub-component 1-2:

Upgrading of "the Flood Management Plan" with the creation of a new and more precise topographic map.

Component 2: Urgent rehabilitation works; installation of new water gates, and elevation of Route 9.

Component 3: Improvement of flood information system and development of Flood Forecasting System.

The study started in December 2011 and utilized the new and more precise topographic data (LiDAR data) provided from the results of Component 1-1 in August 2012. Component 1-2 proposed a draft of the Flood Management Plan in the Seminar on June 20, 2013 and compiled the Draft Final Report in June 2013.

This document presents the Final Report of Sub-component 1-2 that aims to review the Study on the Integrated Plan for Flood Management in the Chao Phraya River Basin.

1.2 Objectives of the Project

The objective of the Project is to prepare a comprehensive flood management plan for the Chao Phraya River Basin through scientific and engineering based analysis and design based on the Master Plan of Water Resources Management formulated by the Strategic Committee for Water Resources Management (SCWRM).

1.3 Basic Policy and Approach

The basic policy and approach is to collect actual data and information in order to assess the existing physical and socio-economic conditions as much as possible during the project through supplementary topographic surveys and questionnaire surveys, and to develop a GIS data base and river basin analysis model for the Chao Phraya River Basin for the project as decision support system.

1.4 Study Area

The study area is the whole Chao Phraya River Basin which covers 163,000 km^{2}and is composed of the tributaries such as the Ping, Wang, Yom, Nan, Chao Phraya, Sakae Krung, Pa Sak and Tha Chin Rivers shown in the Location Map. Since the Bang Pakong River in east side and the Mae Klong River in west side are other large river basins, they are not included in the study area of this study.

1.5 Project Implementation Structure

The organization structure for the implementation of the entire Project is summarized as follows:

(1) NESDB shall be responsible for coordinating the overall project and for maximizing the output of the Project.

(2) RID and DWR shall be responsible for the implementation of Subcomponent 1-2.

(3) The Japanese Advisor for SCWRM shall give necessary technical guidance and advice to the Thailand counterpart personnel on technical matters pertaining to the implementation of the Project.

(4) The Japanese Advisory Committee (hereinafter referred to as “AC”) chaired by Dr. Taikan OKI of the University of Tokyo has been established to confirm outputs provided by the Project from the technical viewpoint. AC was to convene whenever necessary. AC members, IMPAC-T (University of Tokyo) and ICHARM have been conducting studies including run-off analysis and flood inundation analysis to provide effective advice and to propose the direction of the Project.

(5) For the effective, successful and holistic implementation of the Project, RID had established the Technical Committee (hereinafter referred to as “TC”) and the Technical Working Group. The functions of TC are to guide the direction of the Project, to discuss and decide important issues and to make consensus on the results of the Project.

(6) The Consultant’s Team was to be engaged in detailed studies to fix contents of the long-term plan of the Master Plan proposed by SCWRM as directed by TC.

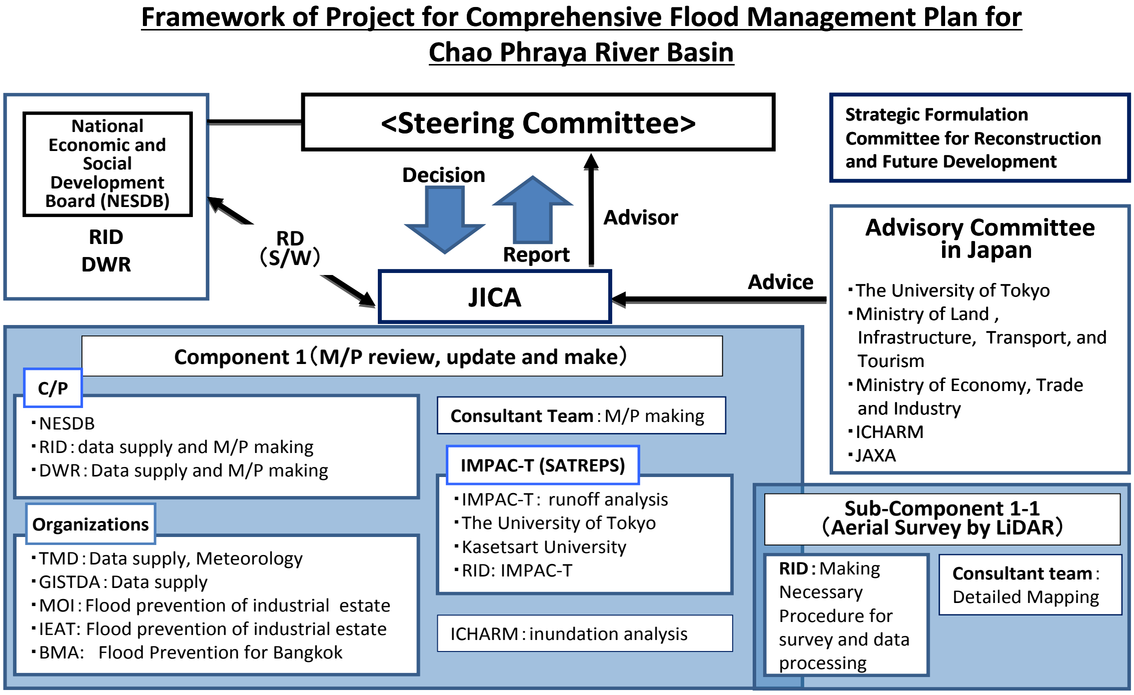


Figure 1.5.1 Implementation Structure of Entire Project

1.6 Counterpart Agencies

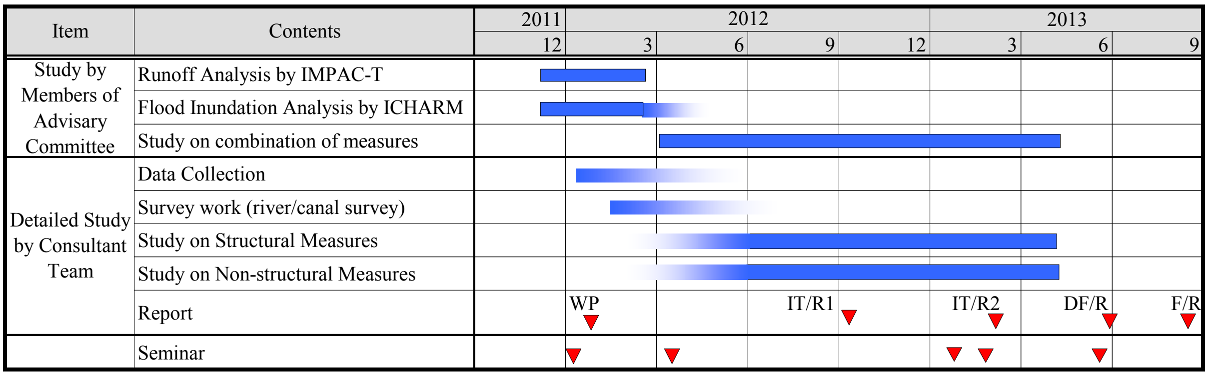
The counterpart agencies were the RID, DWR and NESDB and the executing agency was the RID which organized the “Technical Committee” and the “Technical Woring Group” for the Study in order to smoothly and effectively implement the Study on the Project.

1.7 Project Schedule

The Project Period is from December 2011 to October 2013. As explained in the preceding section, not only the Consultant’s Team but also some members of the Advisory Committee such as IMPAC-T (University of Tokyo) and ICHARM have conducted studies under JICA and JST. The Studies by the Advisory Committee members, which were conducted intensively at an early stage from January to April 2012, were generally preliminary but require special and/or broad know-how. Those by the Consultant’s Team are detailed ones that materialize contents of the master plan in the direction that is timely shown by SC in the course of the Project.

IMPAC-T (University of Tokyo) had conducted a runoff analysis for the Upper Chao Phraya River Basin, the outputs of which were input data to a flood simulation model that was established by ICHARM. The runoff model and the simulation model were further used to roughly examine the effectiveness of several measures (modification of dam reservoir operation, retarding basins (monkey cheek), floodway or flood diversion channels, etc.) proposed by SCWRM. These studies have shown certain effectiveness of the measures in a quantitative manner, and also gave some suggestions that the Consultant’s Team should follow in the succeeding study stages. The study results were presented to agencies concerned at a meeting on April 26, 2012.

The Consultant’s Team had conducted studies on the Master Plan according to the schedule shown in Figure 1.7.1.



WP: Work Plan, IT/R1: Interim Report 1, IT/R2: Interim Report 2, DF/R: Draft Final Report, F/R: Final Report

Figure 1.7.1 Project Schedule

1.8 Survey Items under Subcontract

In the course of the Study, a total of seven (7) surveys have been subcontracted to obtain necessary information and data as listed in Table 1.8.1.

Table 1.8.1 Survey Items under Subcontract

No.	Survey Title	Objective
1	Inundation Survey	To gather data and information with regard to the actual flooding impact in the study area as a preparation for the flood analysis.
2	River and Canal Survey (West)	To survey and collect data including (1) leveling check for existing benchmarks; (2) horizontal position establishment for cross-section lines; (3) river cross-section survey; (4) canal cross-section survey; and (5) drawing preparation for river and canal longitudinal profiles and cross-sections.
3	River and Canal Survey (East)	To survey and collect data including (1) leveling check for existing benchmarks; (2) horizontal position establishment for cross-section lines; (3) river cross-section survey, (4) canal cross-section survey; and (5) drawing preparation for river and canal longitudinal profiles and cross-sections.
4	Flood Response Operation Survey	(1) To identify the present operation mechanism and its problems on effective flood mitigation; (2) to study the new operation mechanism effective for flood mitigation; and (3) to prepare the flood information network required for an effective operation mechanism.
5	Questionnaire Survey	(1) To identify the actions taken by the residents and communities before and during the 2011 Flood; and (2) to collect data and information on the damages and losses as well as the damageable assets by the floods.
6	Flood Impact Survey	To obtain data and information on damages and losses in the manufacturing sector, particularly, the ten (10) industrial estates, including Saha Rattana Nakorn, Rojana, Hi-Tech, Factory Land, Bang Pa-In, Nava Nakorn, Bangkadi, Bang Chan, Lat Krabang and Bangpoo, which are located in the flooding area of the 2011 Flood.
7	Verification Survey on Water Level Data	To survey and collect data for the verification of observed water level data at RID hydrology stations.

CHAPTER 2 GENERAL CONDITION OF RIVER BASIN

2.1 Natural Condition

2.1.1 Climate

Climate at the Chao Phraya River basin belongs to the tropical monsoon. The annual rainfall is between 1,000 and 1,400 mm and it registers higher in the northeastern region of the basin. According to the rainfall pattern, about 85% of the annual rainfall is registered in the period between April and October. 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. Table 2.1.1 indicates 30-year average temperature and rainfall amount (1960-90) in Nakhon Sawan and Bangkok, respectively.

Table 2.1.1 Thirty-Year Average Temperature and Rainfall Amount

Nakhon Sawan

Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
°C	Max.	32.2	34.8	36.8	38.1	35.9	34.6	34	33.3	32.5	32.1	31.5	31.0
	Min.	18.1	21.7	24.1	25.7	25.4	25.0	24.5	24.3	24.0	23.6	21.3	18.2
Rainfall (mm)		9.8	14.9	30	60.9	139	117	134	195	232	144	35.3	7.3
Rainy days (d)		1	2	3	5	12	14	16	18	18	14	4	1

Bangkok

Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
°C	Max.	32.0	32.7	33.7	34.9	34.0	33.1	32.7	32.5	32.3	32.0	31.6	31.3
	Min.	21.0	23.3	24.9	26.1	25.6	25.4	25.0	24.9	24.6	24.3	23.1	20.8
Rainfall (mm)		9.1	29.9	28.6	64.7	220	149	155	197	344	242	48.1	9.7
Rainy days (d)		1	3	3	6	16	16	18	20	21	17	6	1

Source: Thai Meteorological Department (TMD)

2.1.2 Topography

Topography of the Chao Phraya River basin is composed of Highland, Upper Central Plain and Lower Central Plain. The Central Plain formed by the Chao Phraya River is a strip of land of over 500 km long and 100 to 200 km wide.

The Central Plain can be divided into two areas; namely, the Upper Central Plain upper Nakhon Sawan and the Lower Central Plain. In the Upper Central Plain, four big rivers; namely, Ping, Wang, Yom and Nan, traverse the plain and join together at Nakhon Sawan to form the Chao Phraya River. The typical feature in the Upper Central Plain is a 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-Wang 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, Tha Chin River (Suphan Buri River), Noi River and Lop Buri River are important.

2.1.3 Geo-Morphology

The main geo-morphological features of the Central Plain in the Chao Phraya River basin are summarized below:

(1) Alluvial Fans

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

(2) 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 the rivers. At its head, the levee is about 15 meters above MSL and at the lower end, it is about 2 meters.

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

(3) 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 between Chai Nat and Ayutthaya is well developed 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, coastal topographies consisting of sand spits (banks) and mud spits have 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.

2.1.4 River System

The Chao Phraya River Basin is as large as one third (163,000 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.

The Chao Phraya River system consists of four (4) principal tributaries; namely, Ping, Wang, Yom, and Nan, all originating in the northern highland. The Wang join the Ping and the Yom join the 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, Ayutthaya and Bangkok, then finally pours into the Gulf of Thailand. The Sakae Krung River from West and Pasak River from East, join the Chao Phraya River in the lower basin, while the Tha Chin River diverges from the Chao Phraya from the main stream at Chai Nat (refer to Figure 2.1.1).

Diversion		Area (km^2)
Upper Sub-Basin	1. Ping	34,537
	2. Wang	10,793
	3. Yom	24,047
	4. Nan	34,682
Sub-Total (Nakhon Sawan)		**104,059**
Lower Sub-Basin	5. Chao Phraya	23,873
	6. Sakae Krung	4,907
	7. Pa Sak	15,626
	8. Tha Chin	14,196
Sub-Total (Lower Basin)		**58,602**
Chao Phraya Basin Total		**162,661**

Figure 2.1.1 The Chao Phraya River System

The longitude profile of Chao Phraya River is shown in Figure 2.1.2. Main characteristics of the river are listed as following,

- The riverbed slope is very gradual. From the estuary to confluence of Noi River, the riverbed slope is flat, which indicates that this section is though to be tidal compatment and influenced by sea tide.
- In upstream of the river, the river flows hillside and there is no river dike.
- The riverbed after confluence of Noi River is extremely deep compared to up- and down-stream riverbed. Extrapolating from past inundation conditions and the plane configuration of the rivers, it could be said that river water of Noi River and inundated water returning to rivers/canals collides into the confluence of Chao Phraya River and Noi River, and induces the intense riverbed erosion.

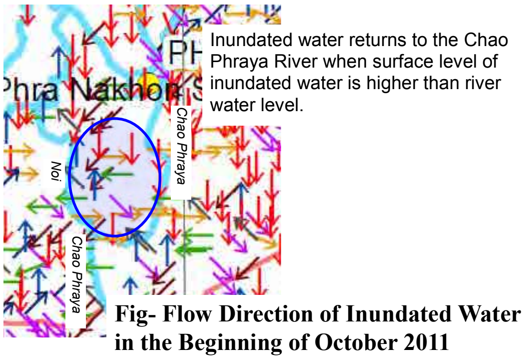


Fig- Flow Direction of Inundated Water in the Beginning of October 2011

- River embankment from 230km to 280km (near Chaophraya Dam) is low and the relative elevation between the top of embankment and river dike is large. In 2011yr flood, dike breaches occurred intensively in the sections which have the high relative elevation of that.
- The river width near the Ayutthaya is the narrowest. The river width widens with distahnce from Ayutthaya to upstream, which might be caused by decrease of river water due to the diversion of rivers and irrigation canals such as Bang Ban Canal, Phong Pheng Canal, Bang Kaew Canal, Lop Buri River etc.

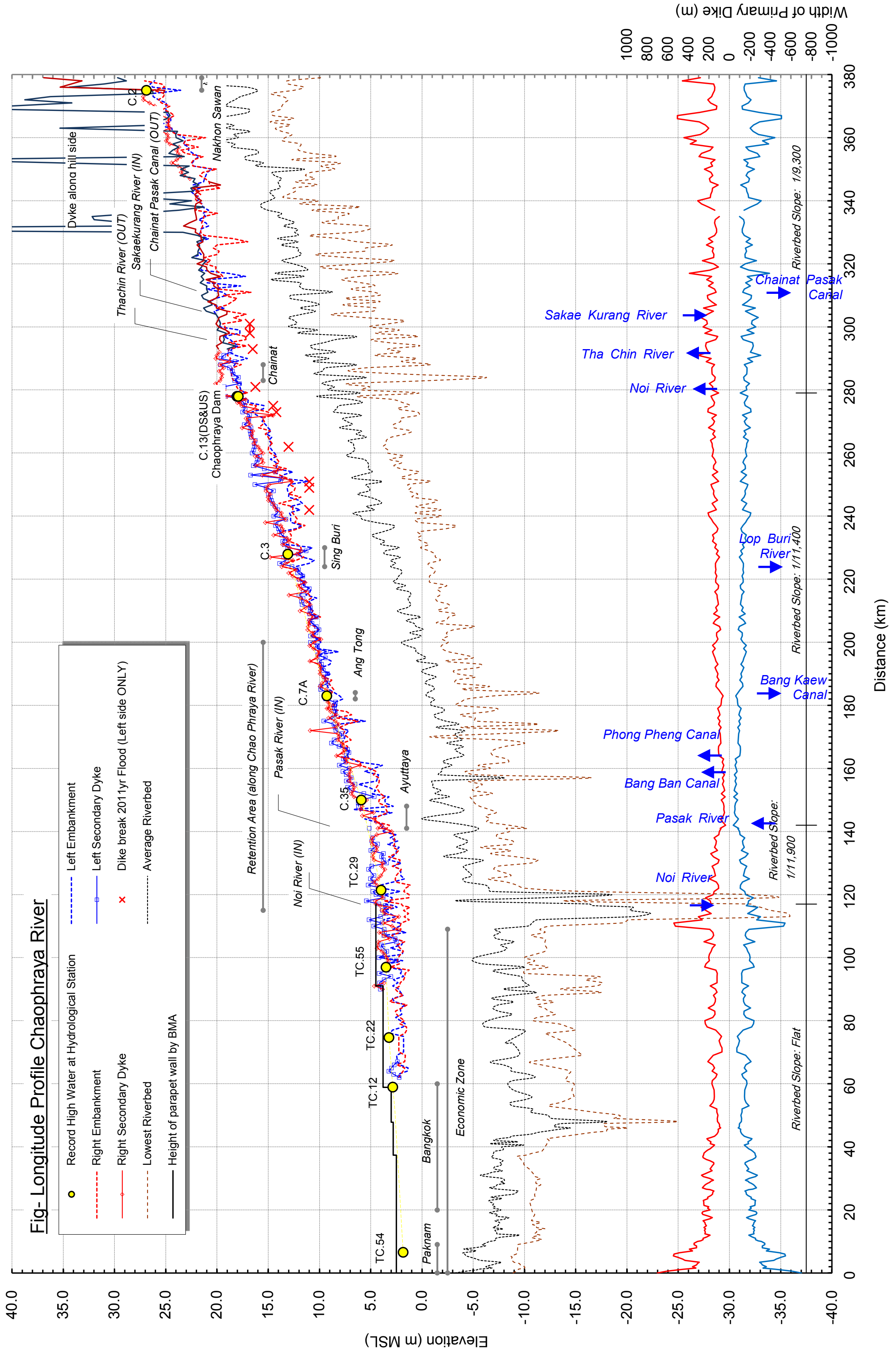


Figure 2.1.2 Longitude Profile of Chao Phraya River (Cross-section Data Obtained in 2005 - 2006)

2.2 Socio-economy

2.2.1 Demography

The population of Thailand is approximately 64 million, of which 9.3 million live in Bangkok and its vicinity. Ninety-four (94) percent of the population are Thai-speaking Buddhists. The national population growth rate is 0.68%, according to the 2006 Census. About 93% of the people in Thailand is functionally literate.

The Basin has some 40 percent of the country's population. The total population of the Chao Phraya Basin was 23 million inhabitants according to a survey in 1996. Approxi,ately half of the population (11.5 million) reside in the Lower Chao Phraya Basin. Approximately 68 percent of the total population of the basin is rural. The average population density is 136 inhabitants per km^2, but varies greatly from 44 in the Nan sub-basin to 533 inhabitants per km^2 in the Chao Phraya sub-basin. Bangkok and its vicinity have the highest population density, with 1,500 inhabitants per km^2.

2.2.2 Economy and Industries

Thailand experienced firm growth from 2000 to 2007, averaging more than 4% per year, thanks to the developed infrastructure, the free-enterprise economy, generally pro-investment policies, and strong export industries, after recovering from the Asian financial crisis of 1997-98.

After the global financial crisis of 2008-09, Thailand's economy expanded 7.8%, with the fastest pace since 1995 in 2010. However, steady economic growth at just below 4% for most of 2011 was interrupted by historic flooding in October and November in the industrial areas north of Bangkok.

The Chao Phraya River Basin employs 78% of the nation's work force and generates over two-thirds of the country's GDP. The BMA contributes 78% of the total GDP of the basin. Regarding the GDP distribution of industry in the basin, manufacturing is dominant for 33%, following wholesale and retail trade for 17%, while about 5% in agriculture.

Nominal GDP in 2011 marked at 10.5 trillion THB, corresponding to about 6% of nominal GDP in Japan. Regarding per capita GDP, 5,394 USD in 2011 corresponds to 10% of the index in Japan (45,920 USD).

2.2.3 Agriculture

Mountainous and hilly area predominates in the upstream basin of Chao Phraya River where the rate of irrigated farmland is limited to 2~10% and most lands remains rain-fed. Many dams are located, but their storage is released for far-downstream beneficiaries and the upstream area only depends on intake of stream water by weirs. Downstream areas are located at Suphanburi, Phitsanulok, Lopburi and further south provinces where alluvial plain is dominant, forming the so-called "Chao Phraya Delta". The major granary area develops here (27~100% of farmland is irrigated) in which double/triple rice cropping has been practiced. Limited upland is prepared by filling earth in paddy field for cultivating vegetables and fruit trees. This granary area wholly depends on stored water in two grand dams (Sirikit and Bhumipol). The area experienced flood damages 7 times, and 6 drought periods during these 40 years after both dam's construction. In this basin, annual precipitation tends to increase from the north (1,000mm) to the south (>2,000mm). In the downstream basin, south of Ayutthaya Province, drainage is a major issue where water drained from northern areas is utilized for irrigation.

Paddy cultivation consists of rain-season crop (from April/May to July/August), following flood rice and dry-season crop (from November/December to March/April). Recently, farmers tend to avoid cropping flood season rice as officially advised, reflecting an steady increase of dry season rice. Since 2000, cultivation of upland crops and perennial fruit trees has been increasing. In this basin, 1,665 thousand farm households are cultivating 10,390 thousand ha of farmland (6ha/household).

Table 2.2.1 Land Use in Chao Phraya River Delta and Its Hinterland

unit: rai =1/6.25 ha

Province	Land	Utility	Residenc	Paddy	Upland	Fruit tree	Vegetables	Forages	Wasted	Others	Forest	Water body
Phecha Bun	7,917.8	6,249.8	82,066	1,374.4	1,828,1	298,95	39,071	21,45	22,82	38,92	2,544.1	166.8
Phitsanulok	6,759.9	4,983.4	76,231	1,569.3	615.5	163,92	13,363	8,689	13,23	38,54	2,484.6	177.7
Phichit	2,831.8	2,049.1	61.9	1,621.5	190.6	118,09	10,206	6,287	5,546	27,00	8.0	78.3
Nakhon Sawan	5,998.3	4,568.3	106.3	2,394.4	1.3	110,73	36,216	39,86	9,370	35,20	550.6	143.0
Uthai Thani	4,206.4	3,568.4	39.9	554.6	0.7	82,297	8,228	15,74	8,170	19,70	2,170.6	63.8
Chainat	1,543.6	1,232.9	41.8	914.0	0.2	44,859	6,924	8,208	5,683	7,092	47.9	31.1
Lop Buri	3,874.8	3,031.8	46.4	954.0	1.2	71,587	24,030	26,68	10,68	11,62	684.8	84.3
Sara Buri	2,235.3	1,497.5	30.9	420.5	0.4	93,723	14,167	44,30	5,907	11,70	504.2	73.8
Suphan Buri	3,348.8	2,505.6	78.3	1,260.4	0.6	89,259	30,219	5,434	3,285	35,33	384.2	84.3
Ang Thong	605.2	485.0	24.1	378.9	17.6	51,332	6,999	1,622	1,742	2,658	0	12.0
Sing Buri	514.0	442.6	8.7	394.6	18.3	11,628	1,502	1,726	2,690	3,492	0	7,142
Kanchanabu	12,177.0	9,720.8	64.1	459.4	1,203.5	209.6	52,966	24,07	18,93	10,08	7,678.2	245.7
Pathum	953.7	470.8	15.8	336.0	233	92.9	16,190	0	1,321	8,317	0	48.3
Nakhon	1,326.3	971.9	14.3	461.1	120	74.0	6,370	1,559	1,961	12,48	400.0	35.4
Nakhon	1,355.2	727.3	39.9	376.6	89.4	94.6	50,658	2,448	4,112	69,68	0	62.8
Prachin Buri	2,976.5	2,021.9	32.4	743.9	188.0	132.5	16,983	5,436	15,88	20,40	866.4	95.5
Ayutthaya	1,597.9	1,112.4	41.8	1,015.5	392	36.9	6,848	1,396	1,635	7,848	0	48.6
Nonthaburi	388.9	176.3	3.4	119.0	0	32.1	18,496	0	984	2,300	0	21.3
Bangkok	978.3	115,922	4.3	95.5	0	10.7	3,987	5	75	872	0.4	86.2
Samut	545.2	167.7	4.2	23.1	0	79.4	3,696	0	41	33,61	23.8	37.8
Samut	627.6	187.2	81.2	39.6	0	14.2	372	0	41	39,05	12.6	44.0
Chachoeng	3,344.4	2,129.3	47.2	775.8	492.3	190.8	13,465	8,250	22,24	95,18	484.1	121.5
Total.	66,107.0	48,416.2	945.3	16,281.9	8,948,529	2,104.2	380,956	223.2	156.4	531.1	18,844	1,769.1

Source: Agricultural Statistics of Thailand Note: * estimated from sizes of cities, ** estimated from bovine heads, estimation of the area available for creating monkey cheek is made as 60% of the water area though 79% is obtained by measurement.

2.3 Land Use

2.3.1 Collected Data

Satellite images of LANDSAT-M photographed in 1996 and 2010 covering Upper Central Plain and the Lower Central Plain of the Chao Phraya River Basin have been collected and processed into land use maps as shown in Figure 2.3.1 and Figure 2.3.2, Table 2.3.1 and Table 2.3.2 present breakdowns by province for the 1996 and 2010 land use.

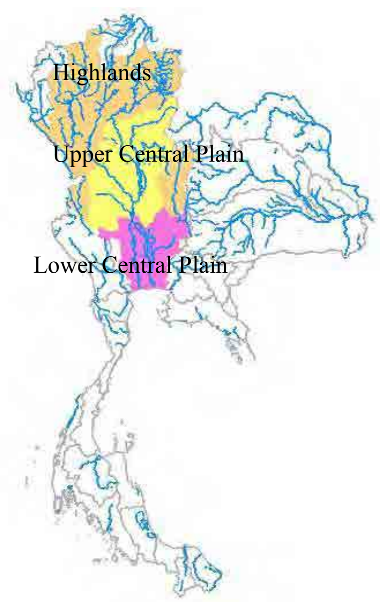


Figure 2.3.1 Divisions of Chao Phraya Basin

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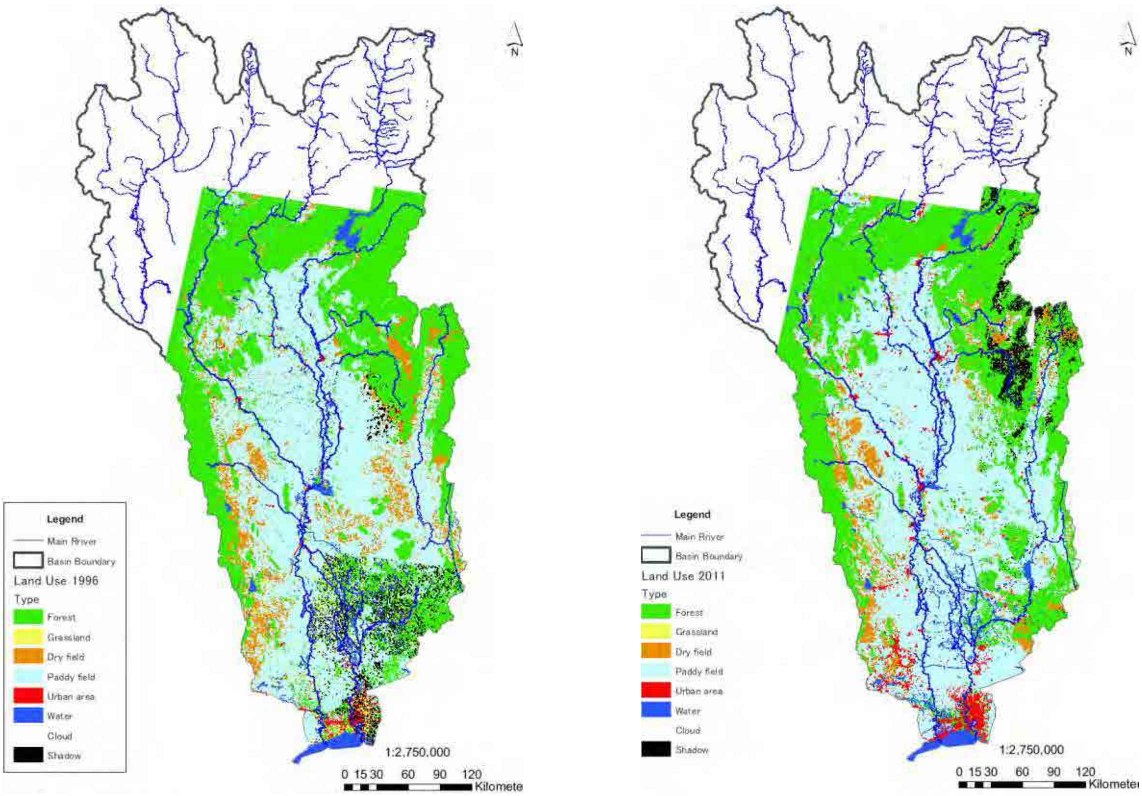
Oriental Consultants Co., Ltd.
Nippon Koei Co., Ltd.
CTI Engineering Co., Ltd.

2.3.2 Regional Land Use Conditions

Land Use conditions of the Study Area are preliminarily discussed as follows, from the viewpoint of comparison with the share of land use in 1996 and 2010.



(a) 1996 Land Use (b) 2010 Land Use

Figure 2.3.2 Comparison of Land Use Between 1996 and 2010

(1) The Upper Central Plain

The Upper Central Plain mainly consists of riverine terraces and alluvial fans, as well as flood plain along the major tributaries of the Chao Phraya River such as the Ping, Wang, Yom and Nan rivers. The share of dry field is significant with 39% in 1996, but it has a tendency of reduction, declined to 36% in 2010. On the other hand, paddy field, third share in the Area, has a tendency of increase from 27% (1996) to 30% (2010). Urban Area has also increased from 0.11% (1996) to 0.37% (2010).

Taking a look at the breakdown by province, paddy fields of Phichit and Nakhon Sawan are enormous with 63% and 49%, respectively, and have an increasing tendency. The increase of the share of urban area of Nakhon Sawan is also significant with the 306% of growth rate.

(2) The Lower Central Plain

The Lower Central Plain is said to be simply characterized as a delta. It is significant that the highest share was dry field with 37% in 1996 and replaced by paddy field with 38% in 2010.

Taking a look at the breakdown by province, there has been an increase in the share of paddy field in most provinces. Also seen is a significant increase of the share of urban area in most provinces. Elongation of the share of urban area in Suphan Buri, Nonthaburi and Samut Sakhon are particularly remarkable. The share of urban area in Bangkok is high, of course, has continued to increase, and in 2010 it has become 28%.

Table 2.3.1 Land Use in Chao Phraya River Basin (1996)

(Unit: ha)

Province	Unspecified due to clouds	Dry field	Forest	Grassland	Paddy field	Unspecified due to shadows	Urban area	Water	Grand Total
Upper Central Plain									
Sukhothai		274,300.72	185,678.70		203,275.14		739.53	2,462.91	666,457.01
Uttradit	2.32	145,705.19	466,785.27		120,818.15		216.54	26,760.61	760,288.08
Phitsanu Lok	15,410.91	401,957.75	421,895.30		214,245.34	1,433.34	1,194.59	3,521.74	1,059,658.96
Kampaeng Phet		426,573.31	197,708.91		222,104.95		1,206.00	3,493.89	851,087.05
Phichit	2,269.11	169,006.68	1,300.81		255,611.52	173.82	760.18	2,780.98	431,903.10
Nakhon Sawan	5,148.34	468,450.66	78,568.76	618.66	385,631.29	343.98	1,607.00	12,414.81	952,783.49
Uthai Thani	416.49	235,381.96	326,898.07	82.89	98,895.47		230.31	2,990.91	664,896.09
Sub Total	***23,247.16***	***2,121,376.27***	***1,678,835.81***	***701.55***	***1,500,581.86***	***1,951.14***	***5,954.15***	***54,425.85***	***5,387,073.78***
Lower Central Plain									
Chainat	197.20	113,909.69	3,022.47	1,033.20	128,939.70	249.01	716.12	2,458.86	250,526.24
Singburi	3,259.13	34,126.16	6,663.58	3,195.41	31,104.58	1,657.89	268.33	1,425.58	81,700.67
Lopburi	30,918.79	258,199.80	96,527.76	1,540.74	249,325.23	9,940.95	1,121.63	2,696.65	650,271.55
Suphan Buri	1,027.69	223,500.86	71,591.21	3,164.93	233,111.46	1,143.13	748.57	6,071.01	540,358.85
Ang Thong	3,802.34	38,052.68	3,418.07	3,148.00	41,093.31	4,029.01	310.49	1,195.77	95,049.68
Ayutthaya	8,530.15	40,130.56	6,216.64	2,798.85	185,033.34	5,529.07	1,829.26	4,666.89	254,734.78
Saraburi	38,719.46	114,980.35	70,215.32	104.56	106,899.95	14,772.26	1,711.26	1,414.55	348,817.71
Nakhon Pathom	503.52	71,350.66	4,411.93	1,700.88	131,585.43	438.38	2,545.45	1,428.30	213,964.55
Nonthaburi	543.35	11,688.51	2,782.58	457.58	45,377.84	1,122.06	1,005.73	662.39	63,640.05
Pathum Thani	10,155.63	23,028.63	7,035.08	941.38	105,237.33	3,122.74	1,517.26	1,041.99	152,080.04
Samut Sakhon	17.91	11,397.51	2,786.11	701.79	50,200.22	32.85	3,214.67	18,711.24	87,062.31
Bangkok	8,401.02	30,933.55	4,324.36	2,995.65	72,838.36	3,822.92	26,448.52	6,897.96	156,662.34
Samut Prakarn	8,161.66	15,915.88	6,220.83	1,608.95	36,735.23	5,680.77	6,772.35	15,615.94	96,711.61
Sub Total	***114,237.86***	***987,214.85***	***285,215.96***	***23,391.92***	***1,417,482.00***	***51,541.05***	***48,209.63***	***64,287.13***	***2,991,580.39***
Grand Total	***137,485.02***	***3,108,591.12***	***1,964,051.77***	***24,093.47***	***2,918,063.86***	***53,492.19***	***54,163.78***	***118,712.97***	***8,378,654.17***

Table 2.3.2 Land Use in Chao Phraya River Basin (2010)

(Unit: ha)

Province	Unspecified due to clouds	Dry field	Forest	Grassland	Paddy field	Unspecified due to shadows	Urban area	Water	Grand Total
Upper Central Plain									
Sukhothai	309.60	201,072.88	223,163.81		236,004.48		2,304.05	3,602.19	666,457.01
Uttradit	28,973.54	142,738.19	447,086.75	631.77	14,868.58	2,763.09	2,527.29	20,698.86	760,288.09
Phitsanu Lok	77,332.60	397,763.58	334,278.62	168.06	219,780.07	18,502.68	4,581.91	7,251.43	1,059,658.96
Kampaeng Phet	839.79	418,226.60	189,680.68	277.48	34,796.47		3,174.19	4,091.85	851,087.05
Phichit	108.00	154,233.66	3,006.37	59.04	271,264.99	59.73	1,051.02	2,120.30	431,903.10
Nakhon Sawan	1,769.18	380,008.95	86,019.02	654.39	471,130.22	180.34	4,993.74	8,027.65	952,783.49
Uthai Thani	491.43	248,431.86	340,275.22	13.32	70,879.13		1,165.65	3,639.48	664,896.09
Sub Total	***109,824.14***	***1,942,475.72***	***1,623,510.46***	***1,804.06***	***1,618,723.94***	***21,505.84***	***19,797.85***	***49,431.76***	***5,387,073.79***
Lower Central Plain									
Chainat	124.56	143,095.51	4,247.38	58.59	99,031.19		1,755.84	2,213.17	250,526.24
Singburi	14.53	23,628.04	242.89		56,036.64		158.94	1,619.63	81,700.67
Lopburi	2,137.14	200,165.77	102,915.15		328,918.16	805.39	1,283.76	14,046.18	650,271.55
Suphan Buri	425.79	245,342.35	59,372.45	41.85	220,141.63	14.94	8,898.83	6,121.0	540,358.85
Ang Thong	5.40	29,001.69	214.51		63,300.05		102.44	2,425.58	95,049.68
Ayutthaya	2,022.99	38,636.06	7,696.85		197,372.73		3,158.59	5,847.56	254,734.78
Saraburi	5,552.62	125,888.00	109,789.27		102,650.01	331.16	1,772.62	2,834.04	348,817.71
Nakhon Pathom	366.19	57,108.17	3,258.57	141.75	145,454.75		3,649.17	3,985.94	213,964.55
Nonthaburi	903.60	4,083.74	425.67		52,238.22	190.53	5,201.36	596.93	63,640.05
Pathum Thani	15,643.53	772.62	175.68		133,633.60	100.71	1,038.29	715.61	152,080.04
Samut Sakhon	204.27	4,449.17	812.41		56,125.63	2.25	7,599.77	17,868.82	87,062.31
Bangkok	14,883.80	6,774.98	2,265.79	81.54	82,252.11	120.65	43,545.58	6,737.89	156,662.34
Samut Prakarn	11,039.23	2,025.11	1,701.95	13.05	57,455.79	89.32	10,154.38	14,232.79	96,711.61
Sub Total	***53,323.66***	***880,971.20***	***293,118.58***	***336.78***	***1,594,610.50***	***1,654.95***	***88,319.57***	***79,245.15***	***2,991,580.39***
Grand Total	***163,147.80***	***2,823,446.92***	***1,916,629.04***	***2,140.84***	***3,213,334.44***	***23,160.80***	***108,117.42***	***128,676.91***	***8,378,654.18***

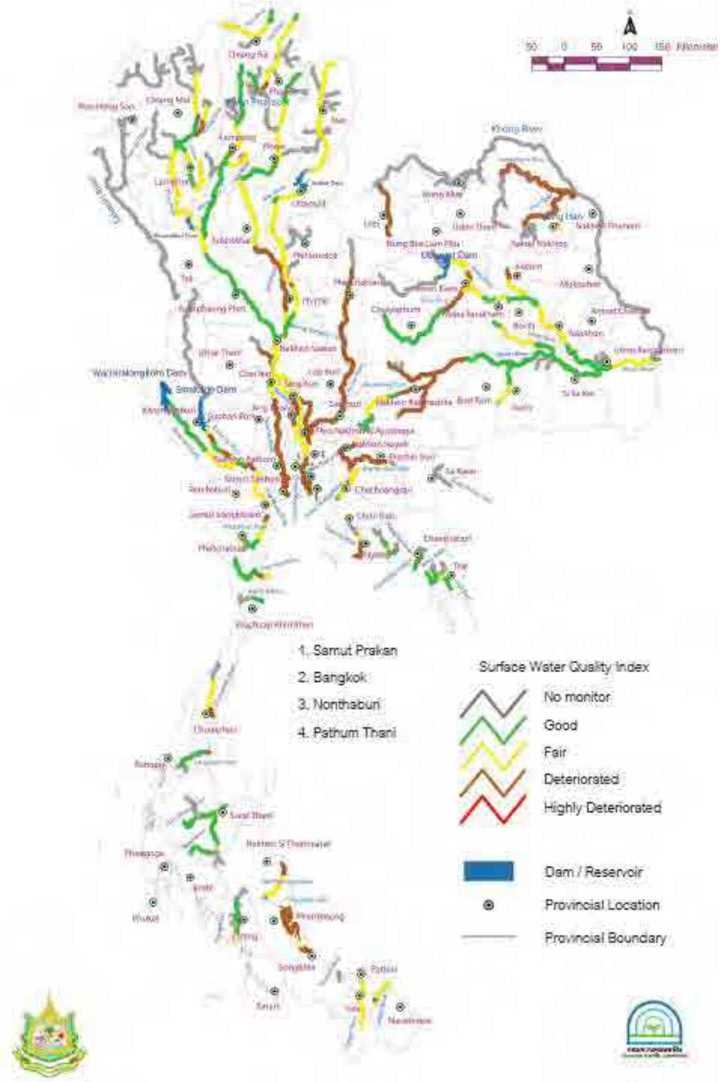
2.4 Environment

2.4.1 Ecology

The lowland areas of the Chao Phraya River Basin in the central plain have been designated as the Chao Phraya freshwater swamp forests, an area of about 400 km from north to south and 180 km wide. These forests have almost entirely been removed as the plain has been converted to rice paddies or urban areas like Bangkok. Then most of the wildlife that once inhabited these plains have disappeared, including a large number of fish in the river systems, birds such as vultures, the Oriental Darter, White-eyed River Martin (Pseudochelidon sirintarae) and the Sarus Crane, and animals such as tigers, Asian elephants, Javan Rhinoceroses and the much-hunted Schomburgk's Deer.

2.4.2 Water Quality

The water quality monitoring survey in 2010 by the Pollution Control Department (PCD) targeting 48 major rivers and 4 standing surface water resources (Kwan Phayao, Bueng Boraphet, Nong Han and Songkhla Lake) revealed that water quality in the level of good, fair and deteriorated conditions were in the proportion of 22%, 39% and 39%, respectively. However, the water quality became worse compared with those in the previous year. Possible reasons were frequent flooding, urbanization and insufficient water quality control. Focusing on the Chao Phraya River, the water quality in the upper basin marked "fair." However, in the central and lower basin along populated regions such as Bangkok the quality was worse and marked as "deteriorated". The map of surface water pollution in the main 48 rivers over the nation is shown in Figure 2.4.1.



Data Source: Thailand State of Pollution Report 2009

Figure 2.4.1 Surface Water Quality in Forty-Eight Rivers and Four Water Resources in 2009

2.5 National Development Plan

2.5.1 Vision and Mission

Thailand's national development plans have evolved in the context of global and domestic changes. During the Tenth Plan (2006-2011), the Philosophy of Sufficiency Economy was applied extensively in Thailand's development, resulting in greater resilience in various aspects of Thai society, enabling Thailand to cope effectively with the impacts of the 2008 global economic crisis.

The Eleventh Plan (2012-2016) is an indicative medium-term strategic plan aimed at achieving the vision of the year 2027 which was set out by all parties in Thai society that is: "Thai people are proud of their national identity, in particular, hospitality."

Even though Thailand will encounter more complicated domestic and external changes and fluctuations during the Eleventh Plan, the Plan has stipulated the following visions and missions to follow the path of Sufficiency Economy with democratic values and good governance.

(1) Vision

"A happy society with equity, fairness and resilience."

(2) Missions

- To promote a fair and quality society so as to provide social protection and security, to enjoy access to a fair judicial process and resources, and to participate in the development process under good governance.
- To develop people with integrity, knowledge and skills appropriate to their ages, and to strengthen social institutions and local communities for positive adaptation to changes.
- To enhance the efficiency of production and services based on local wisdom, knowledge, innovation and creativity by developing food and energy security, reforming the structure of the economy and consumption to be environmentally friendly, and strengthening relations with neighboring countries in the region for economic and social benefits.
- To build a secure natural resource and environmental base by supporting community participation and improving resilience to cushion impacts from climate change and disasters.

2.5.2 Development Strategies

The Plan has explicit development strategies in "5. Development Strategies" regarding the Comprehensive Flood Management Plan for the Chao Phraya River Basin for managing natural resources and environment toward sustainability and the purpose of this strategy.

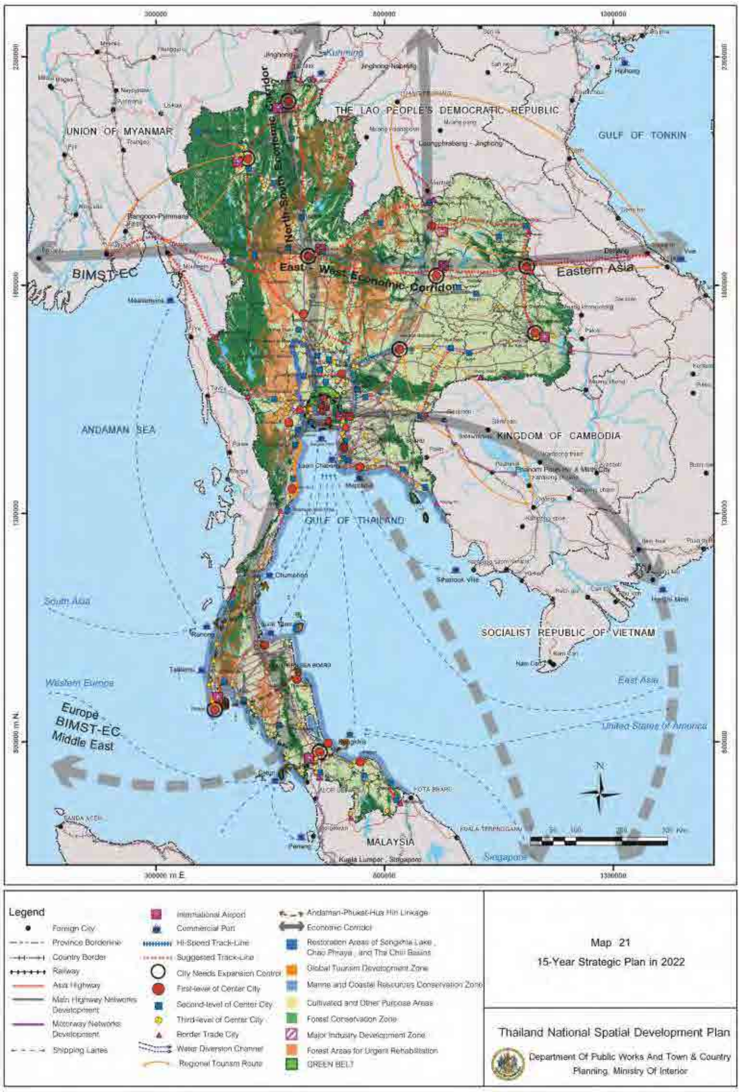
The guidelines related to the Comprehensive Flood Management Plan for the Chao Phraya River Basin are as follows:

- Ensure preparedness for natural disaster response. Maps and priority list of areas under risk will be prepared at the national, regional and provincial levels. Efficiency of disaster management will have to be improved. Furthermore, database system and telecommunication network will have to be developed. It is necessary to provide support for the development of science and technology in disaster management. The national volunteer work system will have to be developed to meet international standards. Moreover, encouragement will be given to private sector, enterprises, schools and local authorities to be well-prepared, and to develop action plan for disaster response.
- Foster resilience toward trade related measures associated with environmental conditions and climate change impacts. Efforts will be made for surveillance and monitoring measures related to environmental conservation that may have effects on international trade and investment. Measures will be introduced to cope with anticipated effects from trade measures and international agreements on environment and climate change. It will also be essential to conduct research on their effects, and to develop strategic plans along with alleviating measures for relevant products and businesses.

2.5.3 National Spatial Development Plan

(1) Background and Contents of the Plan

The national plan comprises a set of measures and strategies to address national development, urban systems, hierarchies, function, industry, infrastructure, and public facilities. The regional plans will be applied to six regions: Central Thailand, Bangkok, and the northern, eastern, northeastern, and southern regions of the country. On 9 July 2002, the Cabinet mandated the Department of Public Works and Town &Country Planning (DPT) to accelerate development of the urban plan to cover all areas throughout the country. In compliance with the aforesaid resolution, DPT had established a National Spatial Development Plan in order to set up the development policies, strategies, and measures as frameworks for spatial development and planning at all levels in line with each the area's features and potentiality. The plan was published on 2009 with cabinet approval, divided into three types: long-term (50 years), medium-term (10 to 15 years), and short-term (5 years) (refer to Figure 2.5.1).



Data Source: National Spatial Development Plan (2009)

Figure 2.5.1 Fifteen-Year Strategic Plan in 2022

(2) Flood Disaster Protection Policy

From the viewpoint of the Flood Management Plan for the Chao Phraya River Basin, the following have been stipulated as a Flood Disaster Protection Policy in the National Spatial Development Plan:

- Non-structural Flood Protection by classifying endangered areas from flooding into 3 levels (high/medium/low risks of recurrent flood), restoring forests upstream and solving problem of soil erosion.
- Applying city planning measures to protect urban areas from flood.
- Deepening and widening watercourses and ditches; Establishing efficient flood protection plans for urban areas.
- Organizing settlement with no water course encroachment permitted.

- Designating high-risk disaster areas free from buildings/structures as areas for natural catchment development.
- Constructing diversion channels for water released from the main waterway.
- Establishing an ad-hoc center for flood protection and mitigation in charge of formulating the action plans, monitoring water, circumstances and disseminating information to the public.
- Structural Flood Protection, e.g., Dams, Reservoirs, Weirs, Dikes, Embankment, etc., to slow down and release water for utilization when the areas face shortage of water supply.
- The structures will also be utilized as aquatic animal breeding sources as well as tourism and communication centers.
- A water diversion system will be developed to divert water from the main watercourse into channels or irrigation canals. The system will divert water that causes urban flooding into open areas or monkey cheeks for temporary retention.
- Flood diversion networks will also be developed for overflow release from the high-density areas with high economic values to the areas capable of receiving water.
- In addition, career structure adjustment and provision of flood insurance or compensation payment to residents in the areas allocated for receiving the overflow will also be necessary.

2.5.4 Large Scale National Development Plans

Among several large scale national development plans in Thailand, the following infrastructures are highlighted:

- High Speed Train
- Expressway

The outline of plans of these infrastructures is as follows:

(1) High Speed Train

(a) Background

High Speed Train has been planned in the Railway of Thailand (SRT)'s Railway Development Master Plan (2010) with investment of 176,808 million Baht in order to promote the rail mode as the nation's main commodity transportation mode connecting all the major production bases with Laem Chabang Port. The development of High Speed Rail System (HSR) is particularly needed in the plan to connect with neighboring countries in the sub-region with expected investment of 742,000 million Baht. The government plans to propose the draft of Loan Act for the country infrastructure investment.

(b) Overview

The development plan covers 4 main routes including:

- Northern Route (Bangkok-Chiang Mai)
- North-eastern Route. (Bangkok - Nong Khai and Bangkok - Ubon Ratchathani)
- Southern Route (Bangkok - Hat Yai - Padang Besar)
- Eastern Route (Bangkok – Chanthaburi and Aranyaprathet)

The government is expediting the HSR projects and offered implementation under the Public Private Partnership (PPP) scheme.

For the first phase of the project, the Bangkok-Nakhon Ratchasima route is in the preparation process for construction as a pilot project (refer to Figure 2.5.2).

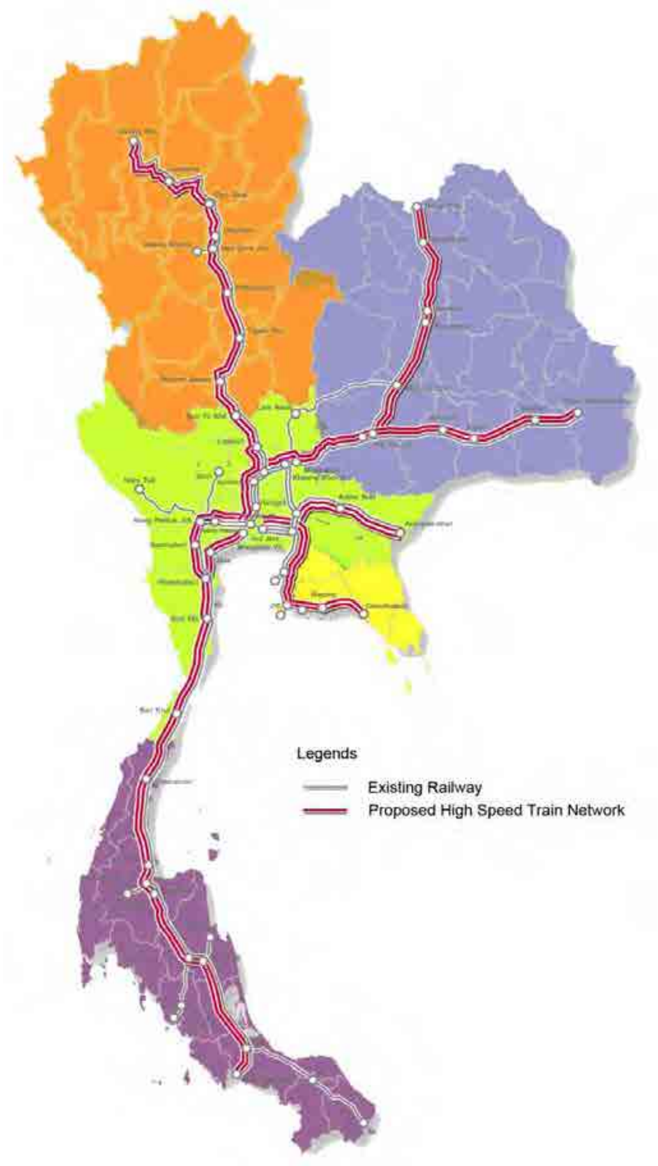


Figure 2.5.2 High Speed Train Network

(2) Expressway

(a) Background

The Expressway Authority of Thailand (EXAT) had implemented "The Study on Traffic Condition on Expressway and Future direction of EXAT" which was completed in August 2011. The study had proposed the future expressway network in the BMA region and the intercity network.

(b) Overview

(i) Expressway Plan in BMA

The expressway master plan in BMA comprised 3 phases totaling 22 projects with 347.40 km in length and total investment cost of THB 125,045.5 million (refer to Table 2.5.1).

- The short term plan included 5 projects to be constructed during fiscal year 2010-2020.

Table 2.5.1 List of Short Term Plan

Project	Construction Period	Operation Starting Year	Investment Cost (mil.THB)
1) Si rat expressway – BKK outer ring road	2010-2016	2016	27,050.5
2) 3rd northern expressway N1+N2+N3	2016-2022	2022	46,801.0
3) Western outer ring road elevated project section 1 (bang khun thian-bang yai)	2017-2023	2023	22,082.0
4) Dao khanong expressway - western outer ring road	2018-2024	2024	16,950.0
5) Si rat-Dao khanong expressway	2020-2025	2025	125,045.5

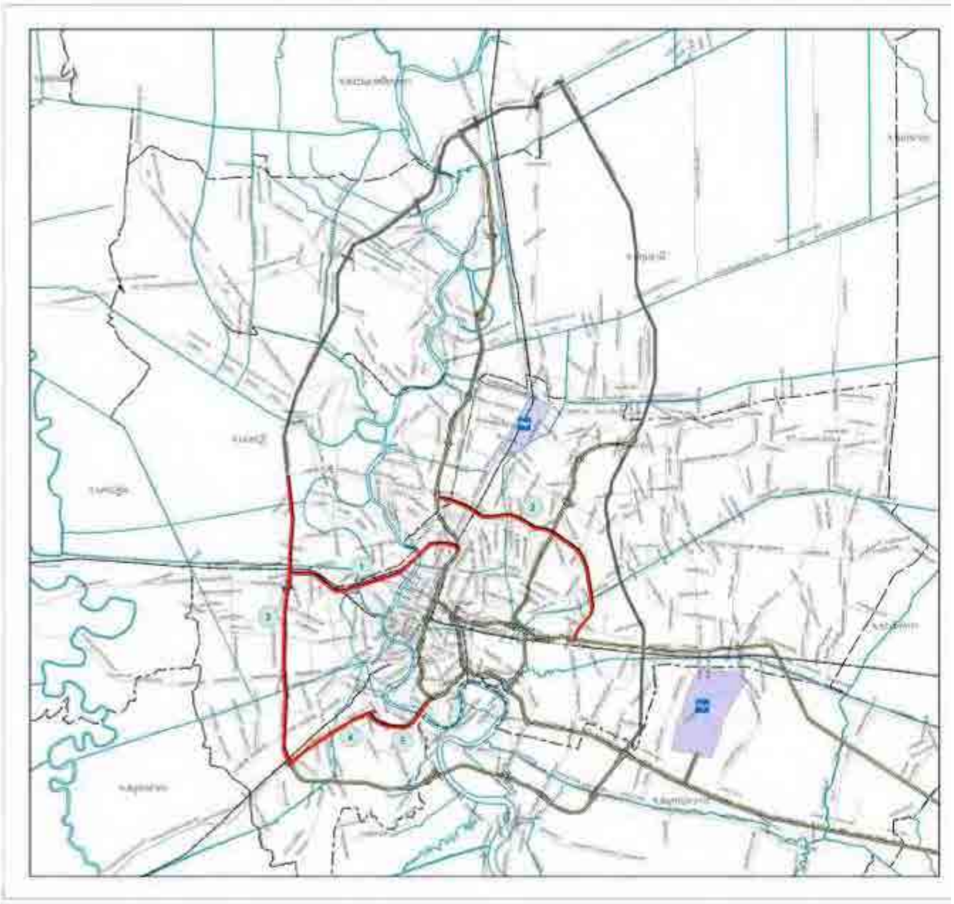


Figure 2.5.3 Short-Term Expressway Plan in BMA

- The middle term plan will be constructed during fiscal year 2021-2030 including 9 projects with 114.5 km in length and total investment cost of THB 236,563 million. (refer to Table 2.5.2 and Figure 2.5.4).

Table 2.5.2 List of Middle-Term Plan

Project	Construction period	Operation starting year	Investment cost (mil.THB)
1) Expressway project for traffic distribution	2021-2026	2026	9,079
2) Suwannaphum expressway section 1	2022-2028	2028	26,466
3) Sinakharin-bangna-samut prakan expressway	2023-2029	2029	30,529
4) 3rd expressway northern E-W corridor (East)	2024-2029	2029	8,219
5) bang phun-thanyaburi-outer eastern ring road	2025-2031	2031	21,778
6) bang khlo-industrial ring road	2026-2031	2031	7,836
7) 3rd expressway southern section S2 (bangna-samrong)	2027-2032	2032	20,882
8) Rama II expressway-phet kasem-nonthaburi	2028-2034	2034	58,374
9) Rama IV expressway- taksin-outer western ring road	2029-2035	2035	53,400

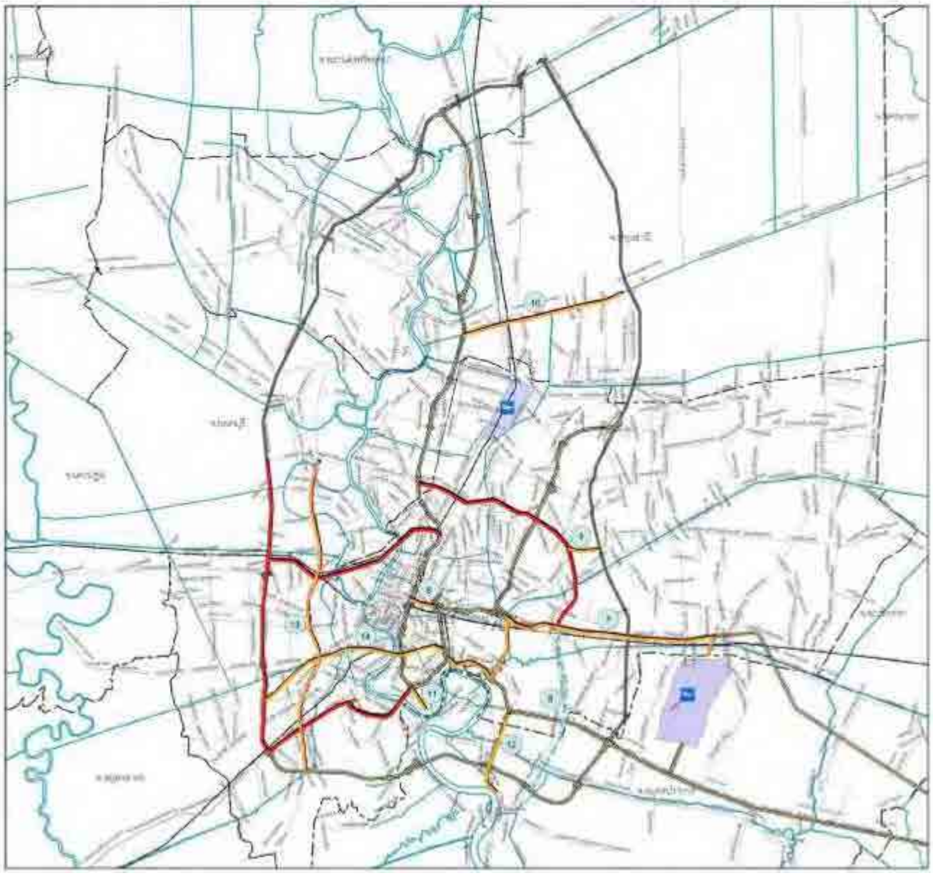


Figure 2.5.4 Mid-Term Expressway Plan in BMA

- The expressway projects under the long term plan including 8 projects with 156.8 km in length and total investment cost of 188,279 million THB will be constructed during fiscal year 2031-2040 as shown in Table 2.5.3 and Figure 2.5.5.

CTI Engineering International Co., Ltd.
Oriental Consultants Co., Ltd.
Nippon Koei Co., Ltd.
CTI Engineering Co., Ltd.

Table 2.5.3 List of Long Term Plan

Project	Construction Period	Operation starting Year	Investment cost (mil.THB)
1) Sirat expressway – government center	2031-2036	2036	11,495
2) Western outer ring road elevated project, Section 2 (Bang yai-Bang pa in)	2032-2038	2038	36,339
3) Chalong rat – paholyothin expressway	2033-2038	2038	9,805
4) Chalong rat – klong song	2034-2040	2040	18,755
5) Udon ratthaya-western outer ring road	2035-2041	2041	22,322
6) Western outer ring road-nakornpathom	2036-2042	2042	35,590
7) Rattana thi bet- udon ratthaya- paholyothin expressway	2037-2043	2043	39,289
8) Klong song- paholyothin expressway	2038-2044	2044	14,684

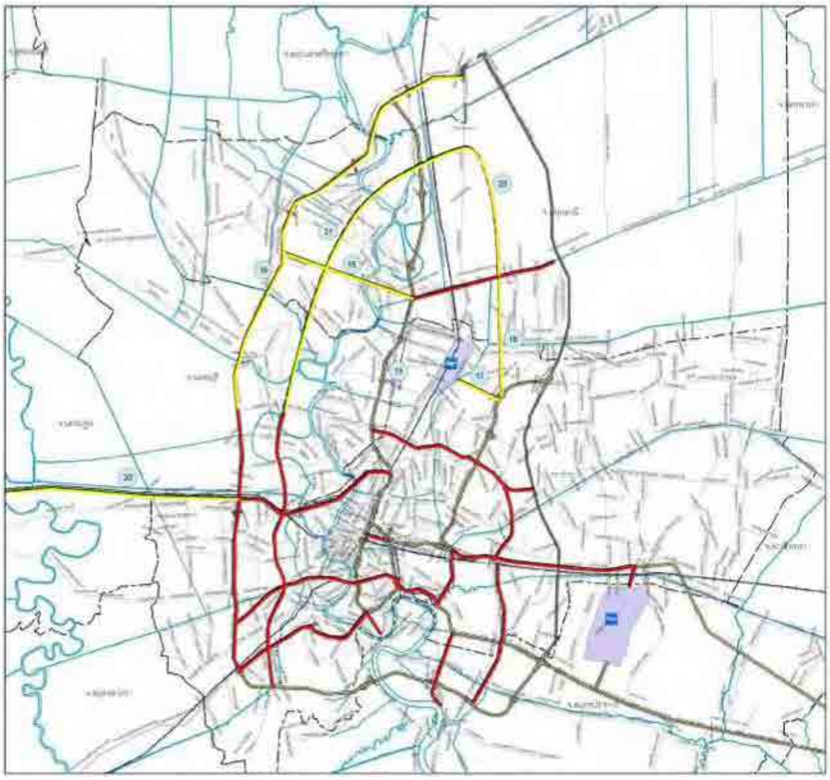


Figure 2.5.5 Long-Term Expressway Plan in BMA

(c) Intercity Expressway Plan

The Intercity Expressway Plan consists of 15 projects with the total length 1,973.5 km and investment cost of 334,606 million THB. These projects could be divided into 2 phases as follows.

- Middle term plan will be constructed during fiscal year 2021-2030, including 4 projects with 138.5 km in length and 43,793 million THB investment cost.

Table 2.5.4 List of Middle Term Plan of Intercity Express Plan

Project		Construction Period	Operation starting Year	Investment Cost (mil.THB)
1)	Udon rattaya – highway no.32	2021-2026	2026	1,824
2)	burapha withi-pattaya expressway	2022-2028	2028	18,843
3)	Outer eastern ring road – sraburi expressway	2023-2029	2029	19,808
4)	Udonrattaya-Highway no.1 expressway	2023-2028	2028	3,318

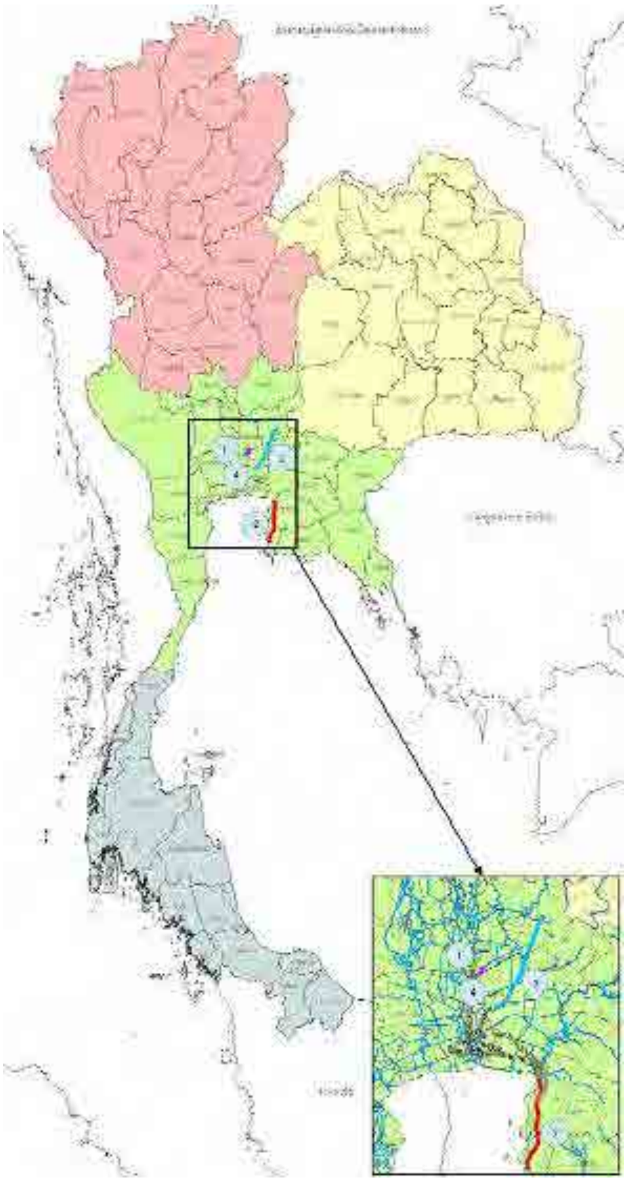


Figure 2.5.6 Middle-Term Intercity Expressway plan

- Projects in the Long Term Plan will be constructed during fiscal year 2031-2040, including 11 projects with 1,835 km in length and 290,813 million THB investment cost as shown in Table 2.5.5.

Table 2.5.5 List of Projects under the Long-Term Plan of Inter-City Expressway

Project	Construction Period	Operation starting Year	Investment Cost (mil.THB)
Sraburi-Nakornrachasima	2031-2037	2037	16,610
Chonburi-Srakawe-Nakornrachsima expressway	2032-2038	2038	29,007
Panthong-Pamok expressway	2033-2039	2039	21,864
Pamok-Bangkhuntien expressway	2034-2040	2040	22,360
Bang pa in –Pamok-Nakorn Sawan expressway	2035-2041	2041	22,865
Outer western ring road-Aranyaprathet expressway	2036-2042	2042	37,169
Nakornsawan-Phisanulok expressway	2037-2043	2043	15,488
Udonrattaya-Supanburi expressway	2038-2044	2044	6,975
Pattaya-Rayong-Chanthaburi	2039-2045	2045	21,634
Andaman port-port on east coast connection expressway	2039-2045	2045	23,153

Figure 2.5.7 Long-Term Intercity Expressway Plan

2.6 Institutional Setup for Water Resources Management

2.6.1 Water Governance in Thailand

Currently, there are 19 ministries under the Prime Minister, five Deputy Prime Ministers and the Office of Prime Minister in Thailand. Out of these, nine ministries at least have substantial engagement in water related issues in Thailand. Table 2.6.1 lists all Thai Government ministries and marks comparatively major water related ministries.

In addition to this administrative system, it is highlighted that Royal Initiatives by His Majesty, the King, takes key role on water resources development and flood management. For example, the Royal Irrigation Department (RID), the Department of Highway (DOH), the Bangkok Metropolitan Administration (BMA) and the State Railway of Thailand (SRT) collaboratively construct the so-called the King's dike, which protects Bangkok Metropolitan Area from the intrusion of flood water.

Table 2.6.1 Thai Government Organization and Water Issues

Portfolio	Overseeing water issues
Ministry of Interior	O
Ministry of Justice	
Ministry of Defense	O
Ministry of Finance	
Ministry of Foreign Affairs	
Ministry of Social Development and Human Security	
Ministry of Agriculture and Cooperatives	O
Ministry of Transportation and Communication	
Ministry of Natural Resources and Environment	O
Ministry of Information and Communication Technology	
Ministry of Energy	O
Ministry of Commerce	
Ministry of Labor	O
Ministry of Culture	
Ministry of Science and Technology	O
Ministry of Education	
Ministry of Public Health	O
Ministry of Industry	O
Ministry of Tourism and Sports	

Note: the "O" is subjectively given by the Consultant team for easy understanding.

2.6.2 National Boards and Committees

The principal organizations responsible for developing policies on water related issues are NESDB, NEB, NWRC and NDPMC. The composition of these organizations are given in Table 2.6.2.

National Economic and Social Development Board (NESDB)

- Established under the National Economic and Social Development Act, 1978.
- Mandated to prepare the 5-year National Economic and Social Development Plan.

National Environment Board (NEB)

- Established under the Enhancement and Conservation of National Environment Quality Act, 1992.
- Mandated to prepare environmental policies and plans.

National Water Resources Committee (NWRC)

- Established under the Office of the Prime Minister's Regulation on National Water Resources management, 1989. The current committee is appointed under a Prime Minister's Office Order (403/1997)
- Mandated to develop policies with national goals and policies on Integrated Water Resources Management.

National Disaster Prevention and Mitigation Committee (NDPMC)

- Established under the Disaster Prevention and Mitigation Act, 2007.
- Mandated to propose policy for formulation of the National Disaster Prevention and Mitigation Plan. NDPMC developed the National Disaster Prevention and Mitigation Plan BE.2553-2557 (2010-2014), which was approved by the Cabinet in January 2009.

Table 2.6.2 Membership of Boards and Committees

Official	NESDB	NEB	NWRC		NDPMC
			(RNWRM Article 6*)	PM Order 403 *	
Prime Minister	Chair	Chair	(Chair)		Chair
Deputy PM		Vice Chair		Chair	
Minister attached to Office of PM				Vice Chair	
Secretary-General of the Office of PM			(Secretary)	Secretary	
Secretary-General, State Council				✓	
Secretary-General, Civil Service Commission	✓				
Minister for Finance		✓			
Director General, Bureau of Budget	✓	✓			✓
Secretary-General, Bureau of Budget				✓	
Secretary-General, Board of Investment		✓			
Director General, Fiscal Policy Office	✓				
Governor, Bank of Thailand	✓				
Secretary-General, Office of NESDB	Secretary	✓			
Governor, Electricity Generating Authority of Thailand				✓	
Director, Office of NWRC			(Assistant Secretary)	Assistant Secretary	
Minister for Science Technology & Environment		Vice Chair			
Permanent Secretary, MOSTE		Secretary		✓	
Minister for Defense		✓			
Permanent Secretary, MOD					✓
Minister for Agriculture and Cooperatives		✓			
Permanent Secretary, MOAC				✓	✓
Director-General, RID				✓	
Minister for Transportation		✓			
Permanent Secretary, Transportation and Communication					✓
Director-General, Harbor Department				✓	
Minister for Interior		✓			1st Vice Chair
Permanent Secretary, MOI				✓	2nd Vice Chair
Director General, Department of Disaster Prevention and Mitigation					Secretary
Minister for Education		✓			
Minister for Public Health		✓			
Permanent Secretary, MPH				✓	✓
Minister for Industry		✓			
Permanent Secretary, MI				✓	
Director-General, Mineral Resources Department				✓	
Permanent Secretary for Social Development and Human Security					✓
Permanent Secretary, MNRE					✓
Permanent Secretary, Information and Communication Technology					✓
Commissioner-General of Royal Thai Police					✓
Supreme Commander					✓
Commandant of Royal Thai Army					✓
Commandant of Royal Thai Navy					✓
Commandant of Royal Thai Air Force					✓
Director General of National Security Council					✓
Experts	9	8	As seen fit	8	5

* While the NWRC was established under Article 6 of the Prime Minister's Regulation on National Water Resources Management, 1989 (RNWRM), the current committee is appointed under the Prime Minister's Office Order (403/1997). *(Note: Amended based on the WB report)*

(1) Strategic Committee for Water Resources Management and Single Command Authority

On 11 November 2011, triggered by the devastating floods, the Royal Thai Government established two strategic committees: the Strategic Committee for Water Resources Management (SCWRM) and the Strategic Committee for Reconstruction and Future Development (SCRFD). These are developing long-term strategies for the future water resource management system and economic recovery respectively.

The Strategic Committee for Water Resources Management (SCWRM) is chaired by the Deputy Prime Minister and Commerce Minister Kittiratt Na Ranong, and has been mandated to draw up plans to prevent future flooding. The Office of SCWRM is tasked with coordinating related plans, guidelines, measures, and budget allocations in an integrated manner. It is placed under the Secretariat of the Prime Minister. The Office of the National Economic and Social Development Board (NESDB) takes the role of Secretariat to the Committee. The member of the SCWRM is shown in the Table 2.6.3.

Table 2.6.3 Members of Strategic Formation Committee for Water Resource Management

No.	Name	Position
1.	Mr. Sumet Tantivejkul	Advisor
2.	Prime Minister or Deputy Prime Minister as assigned	Chairman
3.	Mr. Kitja Pholpasri	Committee Member
4.	Mr. Chukiat Subpaisarn	Committee Member
5.	Mr. Teera Wongsamuth	Committee Member
6.	Mr. Nipat Pukkanasut	Committee Member
7.	Mr. Pramote Maikrad	Committee Member
8.	Mr. Prodprasob Surassawadee	Committee Member
9.	Mr. Pitipong Pengboon Na Ayudha	Committee Member
10.	Mr. Royon Chitredon	Committee Member
11.	Mr. Ratchathin Sayamanon	Committee Member
12.	Mr. Srisuk Chandharangsu	Committee Member
13.	Mr. Sanit Aksornkaew	Committee Member
14.	Mr. Sombat Yumuang	Committee Member
15.	Mr. Samith Thammasaroj	Committee Member
16.	Mr. Ajaporn Jarujinda	Committee Member
17.	Mr. Ampon Kittiampon	Committee Member
18.	Secretary General of SCMWR	Committee Member and joint secretary
19.	Secretary General of NESDB	Committee Member and joint secretary
20.	Director General of Royal Irrigation Department	Committee Member and assistant secretary
21.	Director General of Department of Public Works and Town & Country Planning	Committee Member and assistant secretary
22.	Mr. Supoj Tovijakchikul	Committee Member and assistant secretary
23.	Mr. Seree Suparatit	Committee Member and assistant secretary
24.	Mr. Anon Sanitwong Na Ayudhaya	Committee Member and assistant secretary

Kimio Takeya, JICA Visiting Senior Advisor, was appointed as only foreign advisor for SCWRM in the 1st Committee Meeting on 22 November, and he has been a major participant in formulating Draft Master Plan of SCWRM, which is described in Chapter 4.

In the same Committee Meeting held on 7 December chaired by Prime Minister, Takeya explained the necessity of precise topographical measurement with Laser Profiler. The Committee permitted the implementation of aerial topographical survey by JICA.

Only two months after establishment of SCWRM, the Master Plan for Water Resources Management (M/P-WRM) was unveiled by this committee on 20 January 2012. The outline and detailed contents are described in this section and in Chapter 4.

In the end of February 2012, the Thai Cabinet responded to a proposal by the SCWRM that a single command authority be set up. The Prime Minister appointed two different levels of committees for water management, flood prevention and troubleshooting. In particular, National Water Resources and Flood Policy Committee will be given a big say on how the 350 billion Thai baht earmarked for the country's flood prevention and water management activities is spent (The Nation, Feb 2012).

The National Water Resources and Flood Policy Committee (NWRFPC) is assigned to have the authorities 1) to set the national policy for water resources management, flood prevention and troubleshooting; 2) to specify the systematic water and flood management for implementation of relevant government agencies, 3) to set guidelines and restructure water management organizations in coordination among the committees and government agencies relating to water management and to propose the Cabinet to promulgate or amend the water related laws or regulations, 4) to propose to the Cabinet the criteria for indemnity to flood victims, and 5) to take other relevant actions. The NWRFPC is chaired by the Prime Minister and two Deputy Prime Ministers are appointed as the vice chairpersons. It keeps six advisors and approximately forty members including eight Ministers.

Table 2.6.4 Members of National Water and Flood Policy Committee

No.	Name	Position
1	Mr. Sumet Tantivejkul,	Advisor
2	MRV. Disanadda Diskul,	Advisor
3	Mr. Dissathorn Watcharothai,	Advisor
4	Mr. Veerapong Ramangkoon,	Advisor
5	Mr. Pitipong Puengboon Na Ayudhaya,	Advisor
6	Mr. Kitja Phonphasi,	Advisor
7	Prime Minister,	Chairperson
8	Deputy Prime Minister (Mr. Yongyuth Wichaidit),	1st Vice Chairman
9	Deputy Prime Minister (Mr. Kittirat Na Ranong)	2nd Vice Chairman
10	Minister of the Prime Minister's Office (Mr. Niwatthamrong Boonsongpaisarn)	Member
11	Minister of Defense	Member
12	Minister of Finance	Member
13	Minister of Agriculture and Cooperatives	Member
14	Minister of Transport	Member
15	Minister of Natural Resources and Environment	Member
16	Minister of Information and Communication Technology	Member
17	Minister of Interior	Member
18	Permanent Secretary, the Office of the Prime Minister	Member
19	Permanent Secretary, Ministry of Social Development and Human Security	Member
20	Permanent Secretary, Ministry of Interior	Member
21	Secretary-General of the Prime Minister	Member
22	Secretary-General of the Cabinet	Member
23	Secretary-General, Office of State Council	Member
24	Secretary-General, Office of the National Economic and Social Development Board	Member
25	Secretary-General, Office of the Public Sector Development Commission	Member
26	Secretary-General, Office of the Royal Development Projects Board	Member
27	Director, Bureau of the Budget	Member
28	Supreme Commander	Member
29	Commander-in-Chief, Royal Thai Army	Member
30	Commander-in-Chief, Royal Thai Navy	Member
31	Commander-in-Chief, Royal Thai Air Force	Member
32	Director-General, National Police Bureau	Member
33	Director-General, Pollution Control Dept.	Member
34	Director-General, Marine Department	Member
35	Director-General, Royal Irrigation Dept.	Member
36	Director-General, Department of Marine and Coastal Resources	Member
37	Director-General, Department of Water Resources	Member
38	Director-General, Department of Groundwater Resources	Member
39	Director-General, Royal Forest Department	Member
40	Director-General, Department of Disaster Prevention and Mitigation	Member
41	Director-General, Department of Public Works and Town & Country Planning	Member
42	Director-General, Meteorological Dept.	Member
43	Director-General, Department of National Parks, Wildlife and Plant Conservation	Member
44	Director, National Disaster Warning Center	Member
45	Director, Hydro and Agro Informatics Institute	Member
46	Director, Geo-Informatics and Space Technology Development Agency, Prevention and Mitigation	Member
47	Governor, Metropolitan Waterworks Authority	Member
48	Governor, Provincial Water Works Authority	Member
49	Governor, Electricity Generating Authority of Thailand	Member
50	Governor, Bangkok Metropolitan Administration	Member
51	Secretary-General, Office of the National Water and Flood Policy (ONWFP)	Member and Secretary
52	Mr. Anon Sanitwong Na Ayudhaya	Member and Assistant Secretary

The Water Resources and Flood Management Committee (WRFMC) will operate under the National Water Resources and Flood Policy Committee (NWRFPC). It is mandated 1) to establish the operation plan and implement water and flood management according to the NWFPC policy; 2) to set the procedures for relevant government agencies to prevent and solve flood disasters appropriately; 3) to approve plans and projects proposed by the relevant government agencies and approve the budget for resources; 4) to direct, control, inspect and assess the outcomes of relevant government agencies; and 5) to take other relevant actions. The Minister of Science and Technology chairs this committee and the Minister of the Prime Minister's Office is the vice chairperson. Total eighteen members including three advisors and permanent secretaries of Ministry of Interior, Ministry of Transportation and Communication and Ministry of Agriculture and cooperatives constitute the Committee.

Table 2.6.5 Members of Water Resources and Flood Management Committee

No.	Name	Position
1	Mr. Kitja Phonphasi	Advisor
2	Mr. Pitipong Puengboon Na Ayudhaya	Advisor
3	Mr. Vira Wongsaengnark	Advisor
4	Minister of Science and Technology	Chairman
5	Minister of the Prime Minister's Office (Mr. Niwatthamrong Boonsongpaisarn)	Vice Chairman
6	Permanent Secretary, Ministry of Interior	Member
7	Permanent Secretary, Ministry of Transport	Member
8	Permanent Secretary, Ministry of Agriculture and Cooperatives	Member
9	Secretary-General, Office of State Council	Member
10	Director-General, Royal Irrigation Dept.	Member
11	Director-General, Department of Disaster Prevention and Mitigation	Member
12	Director-General, Department of Public Works and Town & Country Planning	Member
13	Chief of Staff, Royal Thai Army	Member
14	Governor, Bangkok Metropolitan Administration	Member
15	Mr. Royon Chitdon	Member
16	Mr. Ampon Kitti-ampon	Member
17	Secretary-General, Office of the National Water and Flood Policy (ONWFP)	Member and Secretary
18	Mr. Anon Sanitwong Na Ayudhaya	Member and Assistant Secretary

(2) Major Water-Related Agencies

(a) Ministry of Natural Resources and Environment (MNRE)

Established in 2002, the MNRE is younger than other water-related ministries, and its mission is to preserve, conserve, develop and rehabilitate natural resources and environment to ensure their sustainable use, with active participation and support of the public and all stakeholders. "Natural resources" includes surface and ground water, forestry, mineral resources. The Department of Water Resources and the Pollution Control Department are under this Ministry.

(b) Department of Water Resources (DWR)

The DWR is leading the promotion of Integrated Water Resources Management (IWRM) implementation. Twenty-five river basin committees (RBCs) have been organized by the DWR (refer to the section of "River Basin Committee"). DWR is mandated to set policies and plans on water resources protection and management. The DWR has drafted a new water resources law after extensive public consultation, which is pending approval by the Parliament.

(c) Pollution Control Department (PCD)

PCD has the mission to regulate, supervise, direct, coordinate, monitor and evaluate with respect to rehabilitation, protection and conservation of environmental quality. Major activities are 1) providing recommendations for establishment of standards relating to environmental quality; 2) developing environmental quality management plans; and 3) monitor environmental quality and prepare an annual report on the state of pollution.

(d) Royal Irrigation Department (RID)

RID is under the Ministry of Agriculture and Cooperatives (MOAC). It can be said that Ministry of Agriculture and Cooperatives (MOAC) is the main ministry with broad jurisdiction and control over the development and conservation of water-related activities such as irrigation, drainage, land reclamation, flood control, water transportation on irrigation waterways, and the conservation/storage of water and maintenance of the flow of river water. The above-mentioned responsibilities are carried out mainly by RID. Many of the Royal Initiatives of His Majesty are also undertaken by RID.

(e) Department of Disaster Prevention and Mitigation (DDPM)

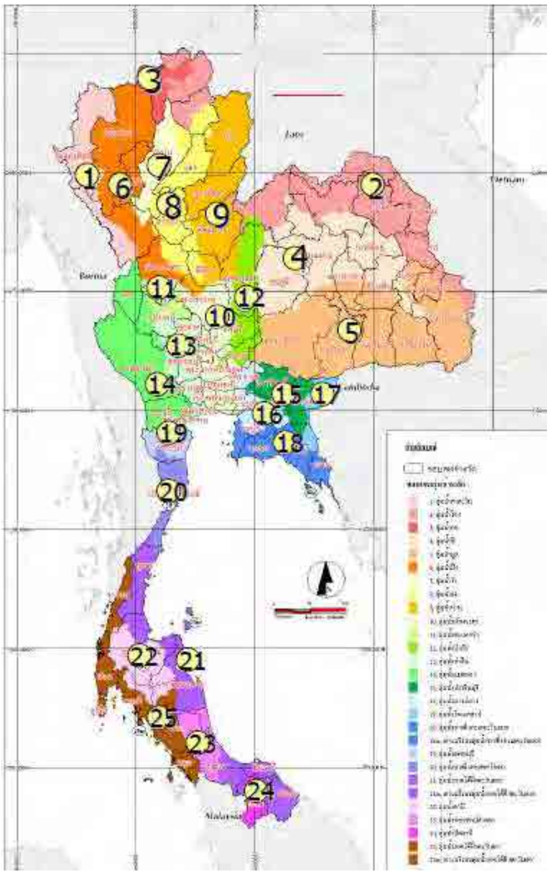
DDPM was established under the Ministry of Interior in 2002. In compliance with its mandate, DDPM prepared the draft National Disaster Prevention and Mitigation Plan for consideration in NDPMC, which was approved by the Cabinet in 2009.

(f) Electricity Generating Authority of Thailand (EGAT)

EGAT is a state enterprise under the Ministry of Energy, which is involved in the generation and transmission of electricity including hydropower plant operation by such facilities as the Bhumibol Dam and Sirikit Dam which have the largest reservoirs in Chao Phraya River basin. EGAT together with RID allocate water to various users based on the planned outflow.

(g) River Basin Committee (RBC)

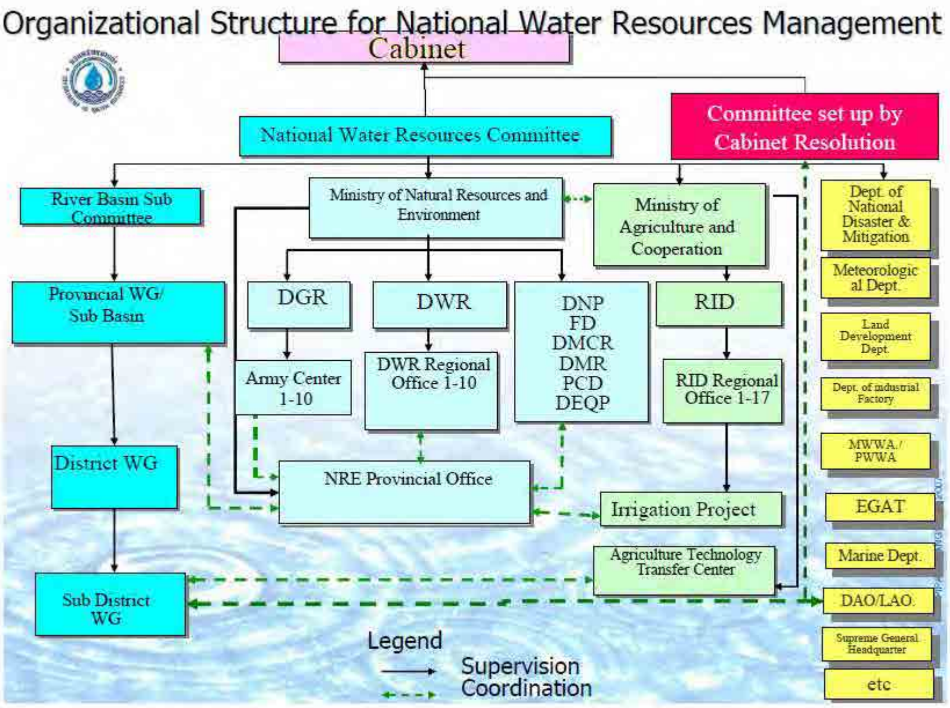
As the progress made by DWR, 25 River Basin Committees (RBCs) have been established in 2004 (see Figure 2.6.1). The establishment process had been started in the middle of the 1990s in Chao Phraya River basin with bottom up approaches by involving lots of stakeholders. As a result of this process, some of the RBCs decided that they take responsibilities of 1) information/data base; 2) Policy and planning; 3) regulation; 4) technical; 5) public relation and coordination; 6)conflict resolution; and 7) monitoring and evaluation. However, the contribution of each RBC on the above-mentioned activities is unclear. Figure 2.6.2 shows the current system of water resources management.



25 Basins	
1. Salawin	14. Mae Klong
2. Mae Khong	15. Prachin
3. Kok	16. Bangpakong
4. Chi	17. Tonle Sap
5. Mun	18. East Coast
6. Ping	19. Phechaburi
7. Wang	20. West Coast
8. Yom	21. South East Coast
9. Nan	22. Ta Pi
10. Chao Phraya	23. Songkhla Lake
11. Sakae Krang	24. Pattani
12. Pa Sak	25. South West Coast
13. Tha Chin	

Source: National Policy on Water Resources Restoration in Thailand Presentation in ARRN International Forum. Surapol. DWR

Figure 2.6.1 River Basin Committee (RBC) Coverage



Source: National Policy on Water Resources Restoration in Thailand. Presentation in ARRN International Forum. Surapol. DWR

Figure 2.6.2 Current Structure of Water Resources Management at the National Level

(3) Laws, Policies and Plans

(a) Water Related Laws

Table 2.6.6 shows the major water related laws and regulations and their main contents. In addition to the existing laws and regulations, the Water Resources Law has been drafted, but not approved yet.

Table 2.6.6 Major Laws and Regulations

Legislation	Year	Regulated Activities	Ministries in charge
Canal Conservation Act.	1902	Prohibits dumping or discharging of wastewater in canals	MOAC
Water Hyacinth Elimination	1913		
Private Irrigation Act	1939		
Royal Irrigation Act	1942	Prohibits dumping of garbage or discharging polluted water or chemicals into irrigation canals	MOAC
Fisheries Act	1947	Prohibits dumping or discharging of hazardous chemicals into water resources reserved for fishing	MOAC
Penal Code	1956	Prohibits adding harmful substances in water resources reserved for consumption	
Ditch Act	1962		
Metropolitan Water Supply Authority Act	1967		
Electricity Generating Authority of Thailand Act	1968	Establishes the EGAT to obtain and deliver electricity by utilizing water resources for power generation	
Land Allocation for Agricultural Purpose Act	1974		
Artesian Well Water Act	1977		
Provincial Water Supply Authority Act	1979		
Building Control Act	1979	Regulates discharges of water pollution from building	MOI
Water Supply Canal Conservation Act	1983		
Real Estate Expropriation Act	1987		
Enhancement and Conservation of National Environmental Quality Act	1992	Regulates specified point sources for wastewater discharges into public water resources, or the environment, based on effluent standards	MNRE
Factories Act	1992	Limits level of effluent discharged and restricts concentration levels of chemical and/or metal pollutants	MI
Navigation in Thai Waterways Act (Volume 14)	Amended in 1992	Prohibits dumping of any refuse including oil and chemicals into rivers, canals, lakes or waterways that may pollute the environment or disrupt navigation in Thai waterways	MOTC
Public Health Act	1992	Regulates nuisance activities related to water pollution such as odor, chemical fumes, wastewater discharge system of buildings, factories or animal feedlots that cause harmful health effects	MOPH
Cleanliness and Tidiness of the Country Act	1992	Prohibits dumping of refuse in waterways	LAOs

Source: Water Environment Partnership in Asia (WEPA) Website; http://www.wepa-db.net/policies/measures/currentsystem/thailand.htm, and List of Water Resources Laws, Department of Water Resources, MNRE

(b) Draft Water Resources Law

Reforming attempt of the water resources law was started in the beginning of 1990s since the necessity of establishing an apex body was recognized to be able to guide the operation of fragmented departments into the same direction. At the same time, the concept of water right was required to be clearly defined. The law was drafted in 1993 aiming to establish the Ministry of Water Resources and the National Water Resources Committee as the apex body, but not approved due to the ratification of the new Constitution in 1997 and other reasons.

In 2002, the Thai Government set up the Ministry of Natural Resources and Environment including the Department of Water Resources. Then, the DWR commissioned an expert team, which developed the draft of the revised Water Resources Law with respect to the participatory process. One of the important issues addressed in the law is the water right. It tries to introduce the "permit system" into Thailand and expected to improve the water use efficiency taking into consideration people in poverty. In institutional aspect, the law aims to establish the National Water Resources Committee and a River Basin Committee in every river basin. However, this water law is still under discussion in Thailand and has not materialized yet. Despite of the absence of this law, the National Water Resources Committee and 25 river basin committees have been established based on the order issued by the Office of the Prime Minister.

Box: Fourteen Disasters in M/P-NDPM

1) Flood and landslide
2) Tropical cyclone
3) Fire
4) Chemical and hazardous materials
5) Transport
6) Drought
7) Cold spell
8) Forest fire and haze
9) Earthquake and structural collapse
10) Tsunamis
11) Human epidemic
12) Plant disease and Pest
13) Animal and aquatic animal epidemics
14) Information technology threat

(c) National Disaster Prevention and Mitigation Plan BE.2553-2557 (2010-2014)

Pursuant to the Disaster Prevention and Mitigation Act BE2550 (2007), the Department of Disaster Prevention and Mitigation had formulated the National Disaster Prevention and Mitigation Master Plan (M/P-NDPM.) which was approved by the Cabinet in 2009 after deliberation by the National Disaster Prevention and Mitigation Committee. The M/P-NDPM aims to initiate any level of governmental and non-governmental agencies into the framework and guideline to undertake disaster management activities, and systematize the operating procedure and preparedness nationwide.

The strategy of disaster management is framed into four phases: 1) Disaster prevention and impact reduction; and 2) Preparedness (which are both in the pre-disaster stage; 3) Disaster emergency management is for the middle of disaster; and 4) Rehabilitation and reconstruction is distributed into the post disaster management. (Figure 2.6.3)

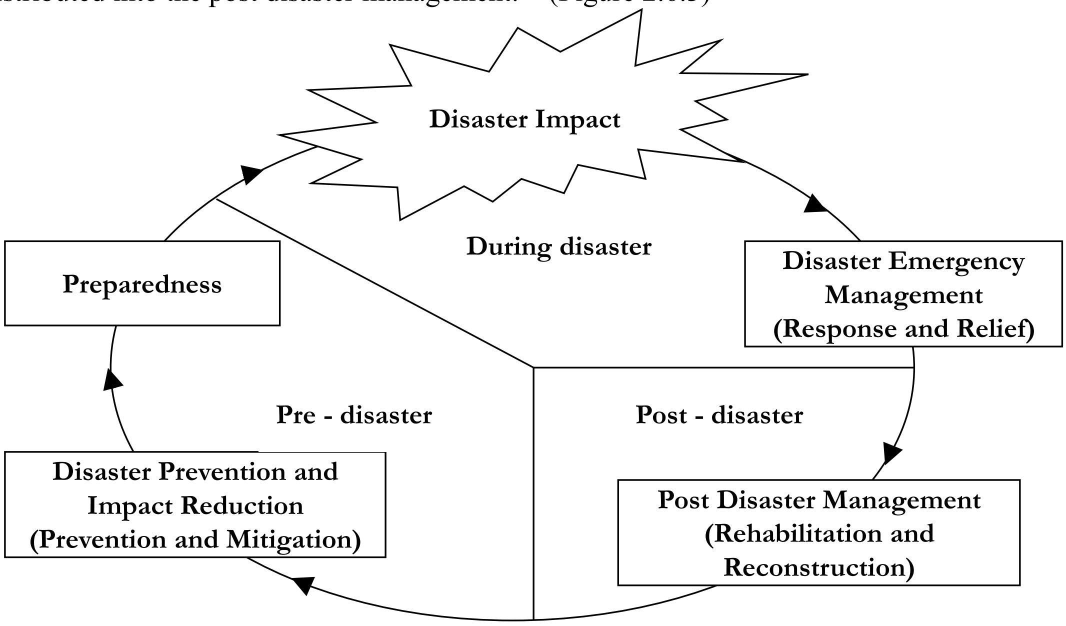


Figure 2.6.3 Disaster Management Cycle

It is stipulated in the M/P-NDPM that emergency operation centers in the respective administrative levels are to be established during a disaster. In the case of the 2011 flood, the Flood Relief Operation Center (FROC) superseded the Emergency Operation Center and coordinated the delivery of aid.

The FROC organization included all ministers, the Bangkok Metropolitan Administration (BMA), the armed forces, and government agencies involved in flood relief operations. It was directed by the Minister of Justice, and worked directly under the Prime Minister. The FROC administration consisted of 2 parties: (i) the operation team headed by the Minister of Science and Technology; and (ii) the planning and prevention team headed by the Minister of Transportation (ADB 2012[1]).

(d) Role of Provincial Government and Bangkok Metropolitan Administration

Figure 2.6.4 simply schematizes the Thai provincial government administration systems. The decentralization process in Thailand started in the 1990s, and still underway. Currently, the administration system in Thailand can be categorized into three: 1) central administration by the national government; 2) provincial administration by the provincial offices of the national government; 3) provincial administration by the municipalities. The Ministry of Interior dispatches governors to every province and district except the Governor of Bangkok Metropolitan Administration who is installed by direct election. It can be said that the current provincial government is not an autonomous body but an aggregation of national government provincial offices.

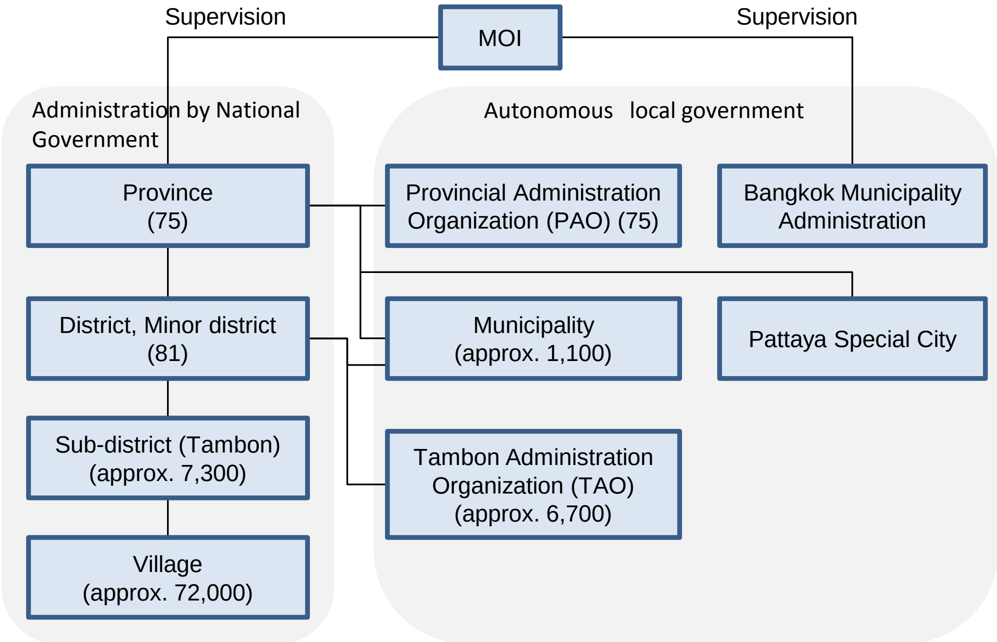


Figure 2.6.4 The Thai Provincial Government Administration System

With regard to disaster management, the DPMA clearly mentions that Provincial Governors as the provincial director shall be responsible for disaster prevention and mitigation in their own provinces, and the same holds for the Bangkok Governor and the provincial governors.

Similar to the formulation of the National Disaster Prevention and Mitigation Plan (NDPMP), the Disaster Prevention and Mitigation Act BE.2550 (2007) (DPMA) requires the provincial governors to formulate their own provincial disaster prevention and mitigation plans while the Bangkok Governor is to prepare the Bangkok Metropolitan Disaster Prevention and Mitigation Plan, keeping consistency with the NDPMP. The plans only address nonstructural type measures for preparedness, such as early warning system and required equipment, and also contain operation and cooperation plans when a disaster strikes.

[1] Rapid Flood Management Assessment (2nd Draft). ADB. January 2012

In accordance with the Royal Decree of Provincial and Integrated Provincial Cluster Administration BE.2552 (2008), the provincial government and provincial cluster are entitled to directly request budget from the national government. Prior to the receipt of budget allocation, the provincial governments are required to formulate several provincial plans; e.g., the Provincial Development Plan and the Provincial Annual Public Service Plan with budget proposals. The budget for implementing the disaster management needs to be incorporated in this process.

(e) Master Plan for Water Resources Management, January 2012

In response to the devastating flood disaster in 2011, the Prime Minister as Chairman of the Strategic Committee on Water Resources Management (SCWRM) unveiled the Master Plan for Water Resources Management (M/P-WRM) on 20 January 2012. The plan sets two different time scale goals. In short term, it aims to decrease the damage from possible floods in 2012. The goal of the long term is to improve the flood management system in an integrated and sustainable manner. The structure and contents are described in Chapter 4.

2.6.3 Financial Response

(1) Special Loan for People Damaged by Flood in 2011

A special loan for people who suffered from damage due to flood in 2011 was set up 26 January 2012 with "Emergency Decree on Financial Aids for Person Damaged by Flood of 2011." According to the Decree, persons entitled to get a loan in this set up are as follows:

- A natural person having domicile, dwelling place, work place, business place within the flood affected area; and
- An entrepreneur of small or medium enterprise within the flood affected area.

Special loan is arranged as follows:

- The Bank of Thailand (BOT) will make special lending to commercial banks with no interest. This lending shall not exceed 300 billion THB in total.
- Commercial banks will offer special loans to entitled persons, financing with the special lending by BOT, which is no more than 70% of the loan amount. The interest rate shall not exceed 3%.
- When the commercial bank receive the repayment from the borrower, the commercial bank shall repay it to BOT. The commercial bank shall repay the special lending within 5 years.

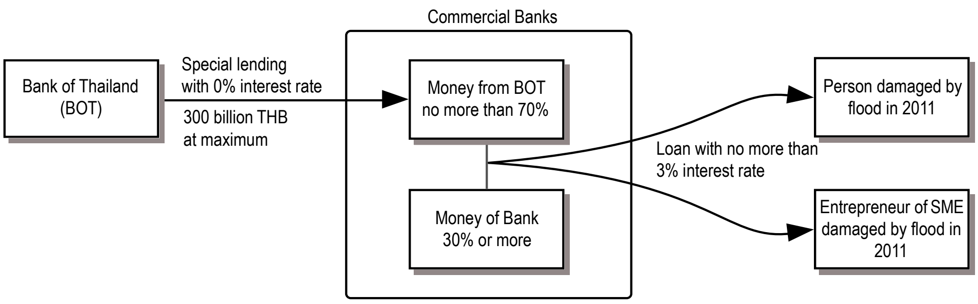


Figure 2.6.5 Special Loan for People Damaged by Flood in 2011

(2) Flood Insurance (Catastrophe Insurance Fund)

The Catastrophe Insurance Fund (hereinafter referred to as "Fund") was established under the "Emergency Decree on Establishment of Fund for Promotion of Catastrophe Insurance of 2012," which became public on 26 January 2012. The main objective of the Fund is to develop an insurance system backed by the Government to make compensation for the losses by large-scale disasters to promote incentive for foreign direct investments in Thailand since private insurance companies had been rejecting the payment of insurance money for the damages caused by a flood in the insurance contracts renewed after the flood in 2011, where a lot of enterprises were actually uninsured.

Thai Government allocated 50 billion THB to the Fund. The total risk coverage is expected to amount to 500 billion THB with the insurance and reinsurance of local and foreign insurance companies participating in the system. Among 50 billion THB allocated by the Government, 30 billion THB is to be used as the source of insurance payment for the damages by disaster, and 20 billion THB is to be used for the premium of reinsurance in the first fiscal year.

Insurance based on the Fund covers not only large-scale companies but also medium to small-scale companies as well as general residences. It is expected to work as a safety net for a wide range of disasters. The insurance has been started to sell through private insurance companies from March 2012. (See Figure 2.6.6).

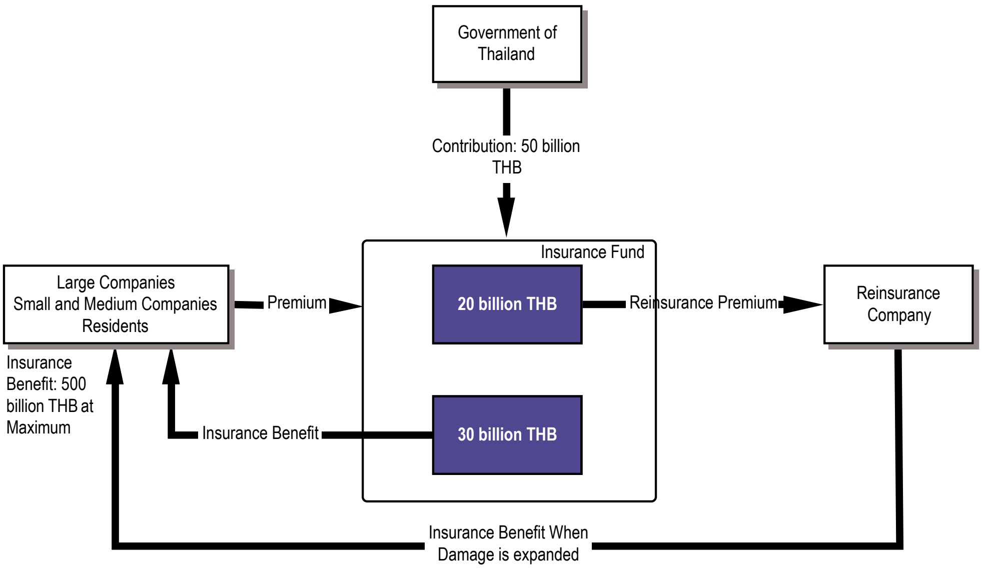


Figure 2.6.6 Structure of Catastrophe Fund

(3) Rice Cropping Insurance Project

The system of Rice Cropping Insurance started in 2009. The insurance project is managed by Bank for Agriculture and Agricultural Cooperatives (BAAC), which is under the control of the Government. The insurance project was modified in 2012 considering the flood in 2011 (See Table 2.6.7).

Table 2.6.7 Land Use Control Procedure

Items	2011	2012
Premium	129 THB/rai	129 THB/rai
Disaster Coverage	Flood, delayed rain, gale, cold weather, hail, fire	Flood, delayed rain, gale, cold weather, hail, fire, pest, pestilence
Insurance Money to Be Paid	2,006 THB/rai if disaster occurs after 61 days passing since cultivation, 606 THB/rai before 61 days passing since cultivation	555 THB/rai for pest, pestilence 1,111 THB/rai for other disasters No restriction of days passing since cultivation
Other	-	Additional 2,222 THB/rai will be paid by the Government if Department of Disaster Prevention and Mitigation announces it as disaster area.

Note: 1 rai = 0.16 ha =1,600 m² Source: http://news.voicetv.co.th/business/30792.html/

2.7 Flood Management after 1999 JICA Study

2.7.1 Related Studies after 1999 JICA Study

After 1999 JICA Study, no substantial measure has been implemented except for a loop-cut in the lowest section of Chao Phraya River. However, several studies have been conducted to realize flood management plans as shown in Table 2.7.1.

Table 2.7.1 Related Studies after the 1999 JICA Study

Category	No.	Title	Year	Done by	Key words
Flood Mitigation	F-1	Thailand Natural Resources Management project & Irrigation Management modernization component	2001	RID (Panya)	Western Bangkok flood diversion
	F-2	Hydrodynamic flow measurement in the Chao Phraya river	2004	TRF RDPB & RID	Relationship flood flow rate & tidal condition
	F-3	Project on Framework and Integrated Water Resource Management and Development Plan for the Chao Phraya river basin (Ta Pra-saong Dai project)	2004	CPB	National Strategy plan for the Greater Chao Phraya and King projects
	F-4	Lad Pho an Ingenious implement of Chao Phraya River	2006	KU/RID/ RDPB	New flood diversion concept (short cut) and King project
	F-5	Feasibility Study and IEE Study for eastern diversion route on the lower Chao Phraya by improvement of river sections and drainage system (from Chao Phraya to Bang Pakong river basin	2006	RID	Easter flood diversion
	F-6	Flood Mitigation Master Plan for Chao Phraya Delta	2006	RID(AIT)	Western flood diversion
	F-7	The Management and Development of Large-scale Agricultural Area in Mitigation of Medium to Large Floods in the Chao Phraya River Basin according to the Royal Initiative (Pilot project on the development of agricultural and flood plain area for flood released	2008	RID/Kasetsart /Chula	Monkey cheek concept, Flood management and King project
	F-8	Master Plan Study on Integrated Flood Mitigation Management in the Lower Chao Phraya River Basin (2011, by RID)	2008	RID	M/P of lowland flood management applying Monkey Cheek Concept

Category	No.	Title	Year	Done by	Key words
	F-9	Feasibility study on Integrated Flood Mitigation Management in the Lower Chao Phraya River Basin	2010	RID	concepts of effective flood mitigation in Thailand
	F-10	Flood Management in the Eastern on Chao Phraya river area under the Chao Phraya Barrier	2012	RID/Panya	F/S of Eastern Diversion Channel
	F-11	Water Crisis of Yom river basin master plan	2011	DWR	Flood mitigation, management at river basin level
Water Resources Management	WR-1	Integrated Plans for Water Resources Management in the Ping River Basin	2003	DWR	River basin management
	WR-2	Integrated Plans for Water Resources Management in the Pasak River Basin	2003	DWR	River basin management
	WR-3	Integrated Plans for Water Resources Management in the Wang River Basin	2006	DWR	River basin management
	WR-4	Integrated Plans for Water Resources Management in the Yom River Basin	2006	DWR	River basin management
	WR-5	Integrated Plans for Water Resources Management in the Nan River Basin	2006	DWR	River basin management
	WR-6	Integrated Plans for Water Resources Management in the Chao Phraya-Tachin River Basins	2008	DWR	River basin management
	WR-7	Integrated Plans for Water Resources Management in the Tachin River Basins	2008	DWR	River basin management
	WR-8	Integrated Plans for Water Resources Management in the Sakae-Krung River Basin	2008	DWR	River basin management
	WR-9	Water Resources Management Integration Plan for 25 River Basins	2008	DWR	Integrated river basins management in the Greater Chao Phraya
	WR-10	MP of Groundwater management & development	2006	DGR	Groundwater resources, Master Plan
	WR-11	The 10th National Economic and Social Development Plan	2009	NESDB	National economical and social plan for project development
	WR-12	The 11th National Economic and Social Development Plan	2011	NESDB	National economical and social plan for project development
Water Utilization	WU-1	Tele-metering and DSS in Chao Phraya RB	2010	DWR	Tools for monitoring, forecasting and Decision Support System (DSS)
	WU-2	Feasibility study, Conceptual Design and IEE of the Bung Boraphet wetland, Nakhon Sawan province	2008	DWR	Flood management by rehabilitation and conservation at project level
	WU-3	Installation of Early Warning system in Flash flood in the risky area of Greater Chao Phraya RB	2010	DWR	Tools for monitoring, forecasting and Decision Support System (DSS) in the flash flood risky area
	WU-4	Register of the wetland and national water resources	2010	DWR	List of the potential wetland and water resources for Flood management by rehabilitation and conservation concepts
	WU-5	Master Plan and data collection of flood protection and pumping systems in Bangkok Metropolis	2010	BMA	Bangkok Metropolis drainage system and its potential
	WU-6	Study on the alternatives of proposed Kaeng Sua Tein large scale reservoir and new alternatives	2010	RID	Main regulator of Yom river Basin
	WU-7	Construction of Kiew Kor Mar large scale reservoir, Lumpang province (Wung river basin)	2010	RID	main regulator of Wung river Basin
	WU-8	Construction of Kaew Noi Bum Ra-oung Dan large scale reservoir, Phitsanulok province (Nan river basin)	2011	RID	main regulator of Nan river Basin
	WU-9	Proposed Mae Khan large scale reservoir, Ping river basin	2009	RID	main regulator of Ping river Basin
	WU-10	Proposed Mae Wong large scale reservoir, Sakae Krung river basin	2009	RID	Main regulator of Sakae Krung river Basin
	WU-11	Proposed Nam Lee large scale reservoir, Nan river basin	2009	RID	main regulator of Nan river Basin
	WU-12	Proposed Ma-ouk Lek large scale reservoir, Nan river basin	2009	RID	main regulator of Nan river Basin
	WU-13	Statistical data on development of irrigation 2011key words: progress of development of water utilities	2011	RID	Working progress of water utilities

Among these studies, the studies much concerned with flood management are F-3, F-4, F-5, F-6, F-8, F-9 and F-11.

2.7.2 Observations on the Previous Studies

In principle, most of the previous studies mentioned in previous section (1) have a close relationship to the Master Plan by SCWRM in the following points:

(1) Overall Review on Previous Master Plan (1999 by JICA) by F-1 Study

After the JICA M/P Study in 1999, the Crown Property Bureau (CPB) conducted an overall review on the JICA M/P by "F-3: Project on Framework and Integrated Water Resource Management and Development Plan for the Chao Phraya River Basin 2004 by CPB." In this report, the direction of the realization of overall flood control project is shown in the following manner:

- For the realization of the flood control project in a combination of nonstructural and structural measures, a central agency or working group is recommended to conduct a feasibility study and work on design immediately.
- For the realization of these measures, they should be implemented by dividing the project components into three phases: short term (within 5 years), mid-term (within 15 years) and long-term (within 25 years).
- Regarding the diversion channel, immediate action for its realization is proposed. Otherwise, the realization of the diversion channel on the proposed route becomes very difficult due to rapid urbanization in the area on/around the route of the diversion channel.
- As for the retention areas, enhancement of the function of retention area in the Chao Phraya River basin is proposed. In this context, the other site for retention area except the proposed one in the JICA M/P is proposed to be arranged in the upper Nakhon Sawan Area.

(2) Historical Background of Western Diversion in the Chao Phraya Delta

In the M/P by SCWRM, a diversion channel or natural floodway at the western side in the Chao Phraya River is proposed to be provided. The studies on the diversion channel at the western side have been conducted historically as follows:

- F-1: Thailand Natural Resources Management Project & Irrigation Management Modernization Component (2001 by RID)
- F-6: Flood Mitigation Master Plan for Chao Phraya Delta (2006 by RID)

Output of these studies can be used in the following points:

- In these studies, the river conditions of Tha Chin River such as flow capacity, purpose of water utilization, and land use condition along the river are broadly introduced, and these information are basic ones to examine the alternative route of western diversion channel.
- Especially, socio-environmental condition including number of affected people is one of the significant issues to evaluate the possibility of the alternative route of the western diversion channel.
- Also, flood conditions along the Tha Chin River, which is an essential information to identify the flood behavior relating to estimation of the benefit for the flood control project, are introduced as well as rough cost for construction of the western diversion channel. The information can also be used to examine the alternative route of western diversion channel.

On the other hand, the following study items will not be applied for the M/P by SCWRM as well as this JICA Study in the following reasons:

- Through these studies, it has been clarified that the improvement of Tha Chin River is not suitable to make the river as the western diversion channel mainly due to land acquisition problem, so that the output of these studies will not be used as the appropriate diversion channel route.
- In these studies, there is no discussion on possibility of the natural floodway along the course of Tha Chin River. Therefore, the viability of the natural diversion channel needs to be newly examined.

(3) Historical Background of Eastern Diversion in the Chao Phraya Delta

Likewise, there are several studies to identify the possibility of the eastern diversion channel project as shown below:

- F-5: Feasibility Study and IEE Study for eastern diversion route on the Lower Chao Phraya by improvement of river sections and drainage system (from Chao Phraya to Bang Pakong river basin (2006 by RID))
- F-11: Flood Management in the Eastern on Chao Phraya river area under the Chao Phraya Barrier (2012 by RID)

The main difference between F-5 and F-11 is the objective stretch as the eastern diversion channel; namely, the former study covers only the stretch of the Rapiphat Channel from the point of Rama 6 gate in the Pasak River to the Gulf of Thailand, while the latter covers the whole stretch of Chai Nat – Pasak – Rapiphat Channel. Hence, the former study in which the F/S and IEE were finished has been expected to proceed to the D/D and implementation when the budget for the purpose becomes available under the Thai Government procedure. However, the former plan was not implemented and the latter study was newly conducted.

The output of these studies can be used in the following points:

- In these studies, the river conditions of Chai Nat - Pasak – Rapiphat channel such as flow capacity, purpose of water utilization, and land use condition along the channel are broadly introduced, and these information are very useful to examine the alternative route of the eastern diversion channel.
- Especially, socio-environmental condition including number of affected people is one of the significant issues to evaluate the possibility of the alternative route of the eastern diversion channel.
- Also, flood conditions along the Chai Nat – Pasak – Rapiphat channel, which is essential information to identify the flood behavior relating to estimation of the benefit for the flood control project, are introduced as well as rough cost for construction of eastern diversion channel. The information can also be used to examine the alternative route of the eastern diversion channel.

On the other hand, the following study items will not be applied for the M/P by SCWRM as well as this JICA Study in the following reasons:

- In these studies, there is no discussion on possibility of the natural floodway along the course of Chai Nat – Pasak – Rapiphat channel. Hence, the possibility of the natural diversion channel needs to be newly examined.
- As the design discharge for the eastern diversion channel, 1,000m^3/s has been applied for the study. This design discharge may not be based on the comparison among alternatives, so that it is necessary to examine that the flow capacity of 1,000m^3/s is reasonable as the design discharge for the diversion channel through comparison among other alternative measures.
- For the inundation analysis to evaluate the effectiveness of the diversion channel, the simulation model was developed using the existing topographic map. In this JICA Study,

precise topographic map, which will be newly developed by laser profiler, will be used for the inundation analysis and, therefore, it is necessary to newly formulate the flood inundation model as well using such precise topographic map.

(4) Historical Background of Retention Area

In the M/P by SCWRM, it is also proposed to provide retention area, which is regarded as one of most significant flood control measures in the Chao Phraya River basin. The study on the retention area, which is considered in two areas, up-stream of Nakhon Sawan and Chao Phraya Delta in accordance with the strategy set up through above (a) study by CPB, has been conducted historically in the following ones:

- F-7: The Management and Development of Large-scale Agricultural Area in Mitigation of Medium to Large Floods in the Chao Phraya River Basin according to the Royal Initiative (2008 by CPB/Kasetsart, Pilot project on the development of agricultural and flood plain area for flood released)
- F-8: Master Plan Study on Integrated Flood Mitigation Management in the Lower Chao Phraya River Basin (2009, by RID)
- F-9: Feasibility Study (FS) and IEE study for flood alleviation by using of lowland management for the lower zone areas such as Pamok – Puk Hai (C2) and Western Ang Thong (C8) in Ang Thong and Ayutthaya provinces) (2010 by RID)

Output of these studies can be reviewed in the following points:

- Through these studies, the effectiveness and limit of function of the retention areas as flood control measures were planned based on the designated area for about 1,800 km^2. The effectiveness and function of the retention areas are useful information for flood risk management.
- Also, several issues for utilization of agricultural land (including irrigation areas) in low-lying area as the retention area have been identified and examined.
- Especially, it was pointed out that public participation is one of the significant issues to be carefully examined for getting the cooperation of land owners and farmers of the proposed retention area.
- Detailed information on the land use conditions as agricultural area including methods of planting should be examined for reduction of flood disaster risks.
- In the F/S study (F-9), the necessary facilities including the cost to enhance the function of the retention area were introduced. This information is very useful to evaluate the project feasibility and will be used for this study.

The following study items shall be considered in the formulation of Master Plan:

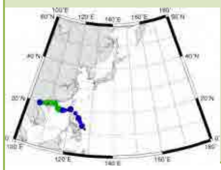
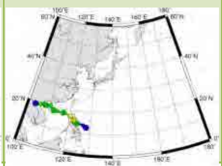
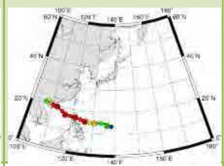
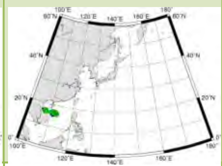
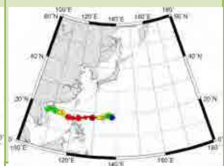
- Based on these studies, SCWRM has proposed in its M/P to expand the retention area from the above 1,800 km^2 to 3,200 km^2 to enhance the flood control function of the retention area.
- SCWRM also proposed in the M/P to introduce more concrete compensation system for the designated retention area through categorization into several types of areas for the compensation.
- The effectiveness of the retention areas shall be assessed by a flood inundation analysis model based on the MIKE11 and precise topographic digital data, which have been developed by the JICA Study of laser profiler survey.

CHAPTER 3 2011 YEAR FLOOD

3.1 Meteorology and Hydrology

3.1.1 Meteorology

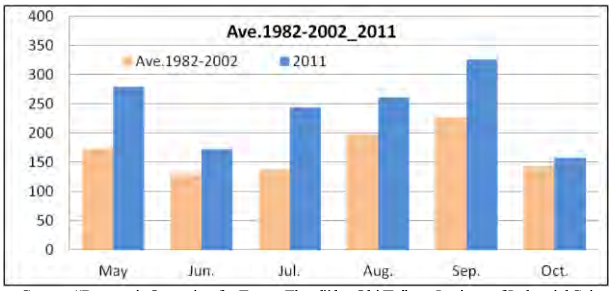
Four tropical storms, Haima (June), Nock-Ten (July), Haitang (September) and Nalgae (September-October), and Typhoon Nesat (September) hit Thailand one after another between June and October 2011, although only 1.5 tropical storms or typhoons hit Thailand on average annually in the past. These storms brought historical heavy downpours in the Chao Phraya River Basin. Courses of the storms are presented in Figure 3.1.1 together with their wind speeds and air pressures.

4: HAIMA	8: NOCK-TEN	17: NESAT	18: HAITANG	19: NALGAE
				
6/21 - 6/25	7/26 - 7/31	9/24 - 9/30	9/25 - 9/27	9/27 - 10/05
985 hPa	984 hPa	950 hPa	996 hPa	935 hPa
40 knots	50 knots	80 knots	35 knots	95 knots

Data Source: "Reservoir Operation for Future Flood" by Oki Taikan, Institute of Industrial Science, The University of Tokyo, Presentation Material for 1st Joint Seminar of Integrated Water Resources Management on January 14, 2012.

Figure 3.1.1 Course of Typhoons that hit Thailand in 2012

According to RID, the accumulated rainfall record in Thailand from January 1, 2011 to November 27, 2011 is 1,888.3 mm, or 365.9 mm (24%) more than the average of 1,522.4 mm. Figure 3.1.2 compares average monthly rainfalls in 24 years from 1982 to 2002 and those of 2011. The monthly rainfall of 2011 exceeded the averages consecutively from May to October. These heavy rainfalls resulted in large flood and extensive inundation.



Data Source: "Reservoir Operation for Future Flood" by Oki Taikan, Institute of Industrial Science, The University of Tokyo, Presentation Material for 1st Joint Seminar of Integrated Water Resources Management on January 14, 2012.

Figure 3.1.2 Basin Mean Monthly Rainfall of Chao Phraya River Basin

3.1.2 River Discharge

Figure 3.1.3 shows hydrograph of the past major floods. The record-high discharge is 5,451 m^3/s of 2006[2], followed by 4,820 m^3/s of 1995. 4,686 m^3/s of 2011 is the third largest.

The 2011 hydrograph forms a very gentle mountain. The discharge increases gradually. The period while the discharge exceeded the river flow capacity of 3,500 m^3/s is about 1.5 month. This long high floodwater weakened river dikes, and finally breached them at several locations, between Nakhon Sawan and Ayutthaya in particular as shown in Figure 3.2.1.

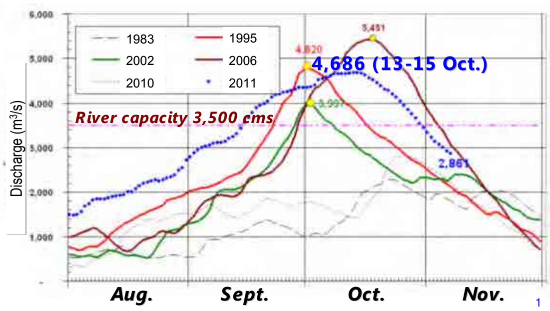


Figure 3.1.3 Hydrograph at Nakhon Sawan

[2] The result of examination on hydrological data, discharge in 2006 was converted with wrong rating curve. Record-high discharge is 1995yr

If the abundant rainfall volume of 2011 is considered, however, the 4,686 m^3/s at Nakhon Sawan seems too small. One reason is probably water storages by the two large dam reservoirs, Bhumibol and Sirikit. As much as 12 billion m^3 was stored by the two reservoirs from May to November 2011.

There are 4 large dams, Bhumibol, Sirikit, Parsak Chonlasit and Kwai Noi dams, located in the Chao Phraya River Basin of which effective storage capacity are greater than 500 million m^3. During the 2011 flood, Bhumibol Dam stored 7.5 billion m^3, Sirikit Dam 4.7 billion m^3, Pasak Chonlasit 0.8 billion m^3, and Kwai Noi Dam stored 0.7 billion m^3 from May to October. However, these four dam reservoirs became full by early October and they had to discharge high volumes of water into downstream.

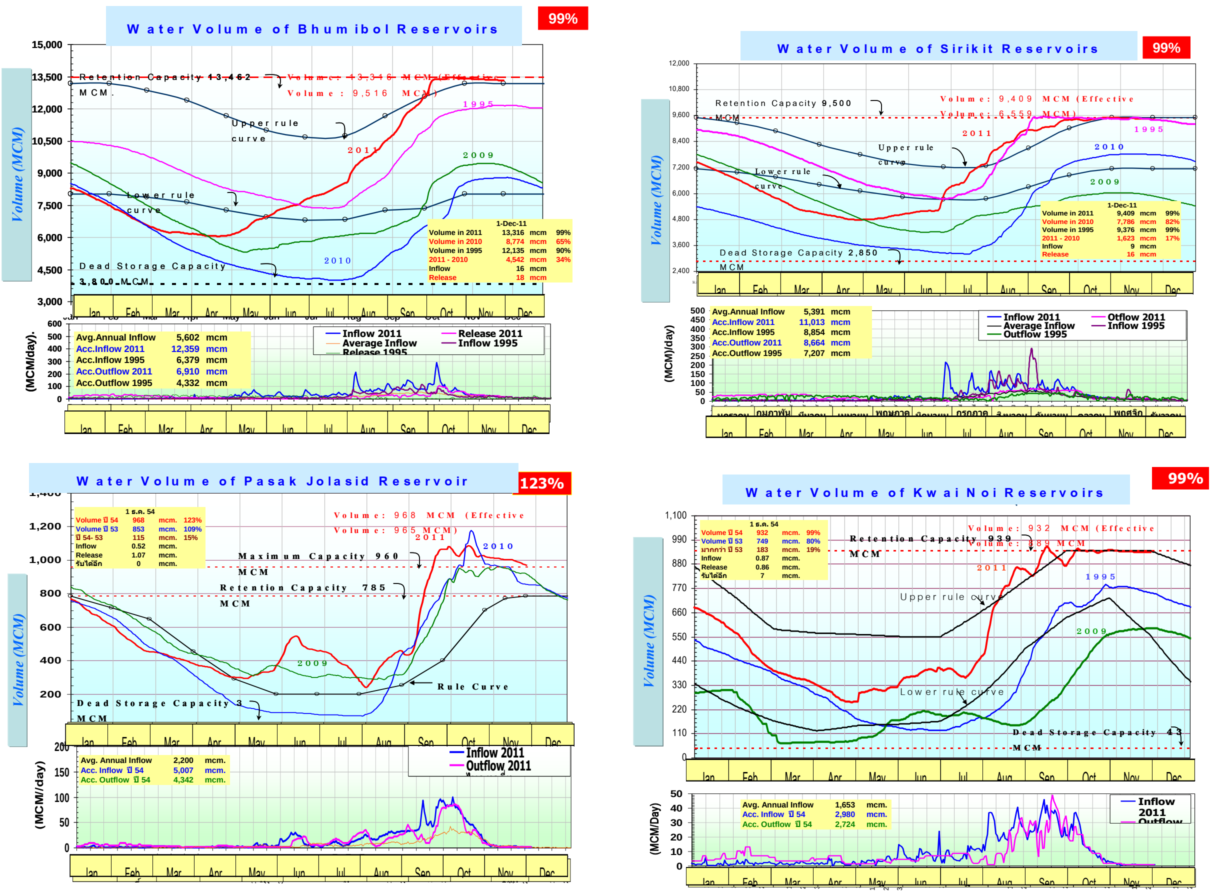


Figure 3.1.4 Operation Records of Four Major Dam Reservoirs

3.2 Dike Breach and Inundation

3.2.1 Dike Breach

During the 2011 flood, dike breaching took place on the main dikes of the Chao Phraya River as shown in Table 3.2.1 and Figure 3.2.1. These dike breachings occurred between September 13 and the beginning of October, 2011, while the water level at C.2 Nakhon Sawan reached the peak level on October 13, 2011. Therefore, all breaches took place in the rising stage.

According to the RID Manorom Operation and Maintenance Project Office which is responsible for the 31km-long upper dike, the dike was constructed in 1981 and 1982. The crown width was about 4 m and the dike height was too low to accommodate the 2011 flood discharge. The river water flowed over and eroded, and finally breached the dike at these locations. It took 3 to 34 days, depending upon the location, to stop the water spillage by sinking gabions. In 2012 the dike was improved with design dike crest level of 0.8m above the 2011 water level and dike crown width of 6m.

The dike of the Chainat-Ayutthaya river channel that is under the management of the RID Maharaj Operation and Maintenance Project Office was breached by overflow and erosion. It took 25 to 40 days to stop the spillage. According to the RID office, overflow was seen at many locations. The dike was generally breached 4 or 5 days after the overflow began. There were found many irrigation pipes at the breached sections. The office personnel suspect that these pipes, which had been put into the dike embankment by farmers to draw water from the canal to paddy fields between the dike and the Chao Phraya River, weakened the dike considerablly. The breached sections were eroded by water as deep as 12 to 16m from the original height.

Table 3.2.1 Dike Breach Sections in 2011 Flood

No.	Location	Side	Type	Location (upstream)	Location (downstream)	Length of broken dike/overflow	Date	Remarks
1	Chainat front dike_cross-dike	Left	Dike break	N15 16' 09.55" E100 05' 26.41"	N15 16' 09.19" E100 05' 27.00"	20	2011/9/22	
2	Chainat front dike_cross-dike	Left	Dike break	N15 16' 09.05" E100 05' 30.16"	N15 16' 09.18" E100 05' 32.86"	80	2011/9/22	
3	Local road	Left	Dike break	N15 16' 14.53" E100 05' 31.42"	N15 16' 13.55" E100 05' 34.98"	110	2011/9/22	
4	Chainat main dike along route No.1	Left	Dike break	N15 16'30.63" E100 05' 40.69"	N15 16' 27.62" E100 05' 40.32"	100	2011/9/22	
5	Chainat main dike along route No.1	Left	Dike break	N15 16' 20.05" E100 05' 38.26"	N15 16' 17.78" E100 05' 37.96"	70	2011/9/22	
6	Chainat main dike along route No.1	Left	Dike break	N15 16' 13.86" E100 05' 36.88"	N15 16' 13.41" E100 05' 36.75"	15	2011/9/22	
7	Chainat main dike along route No.1	Left	Dike break	N15 16' 08.13" E100 05' 35.27"	N15 16' 07.29" E100 05' 35.07"	30	2011/9/22	
8	Chainat main dike along route No.1, near hill	Left	Dike break	N15 13' 59.50" E100 06' 11.57"	Unknown	100	2011/9/22	length is estimated value
9	Upstream of 2km from Chao Phra Dam, Spillway	Left	Overflow	N15 10' 35.06" E100 09' 36.53"	Unknown	1,000	2011/9/18	Spillway established on the road, 17.0MSL(estimated)
10	Downstream of 2km from Chao Phra Dam	Left	Dike break	N15 10' 22.83" E100 11' 39.65"	N15 10' 26.30" E100 11' 45.13"	200	2011/9/22	
11	Downstream of 5km from Chao Phra Dam	Left	Dike break	N15 11' 13.41" E100 13' 01.43"	N15 11' 14.40" E100 12' 59.47"	65	2011/9/22	
12	Downstream of 5km from Chao Phra Dam	Left	Dike break	N15 11' 09.95" E100 13' 08.22"	N15 11' 11.46" E100 13' 05.37"	100	2011/9/22	
13	Downstream of Chao Phra Dam	Left	Overflow	Downstream of 1km from Chao Phra Dam	N15 06' 49.74" E100 16' 18.56"	14,000	Unknown	coordination of downside is unknown
14	Bang Chom Sri gate in Sing Buri region	Left	Dike break next to water gate	N15 03' 15.70" E100 19' 13.53"	N15 03' 17.22" E100 19 12.15"	60	2011/9/13	
15	Downstream of 1km from Bang Chom Sri gate in Sing Buri district	Left	Dike break	N15 02' 51.38" E100 19' 32.43"	N15 02' 49.77 E100 19' 33.28"	55	2011/9/14	
16	Downstream of 7km from Bang Chom Sri gate in In Buri district	Left	Dike break	N14 59' 31.04" E100 20' 36.01"	N14 59' 29.35" E100 20' 36.48"	55	2011/9/17	
17	Water Gate at the Tha Chin River (regulator)	right	Gate Open	N15 12' 57.81" E100 04' 21.70"				B=7m, 4 gates (estimated), $220m^3/s > 350m^3/s$
18	Phra Ngam Water Gate (Regulator)	right	Dike break next to water gate	N14 45' 33.04" E100 25' 49.87"	Unknown	50	2011/9/15	length is estimated value

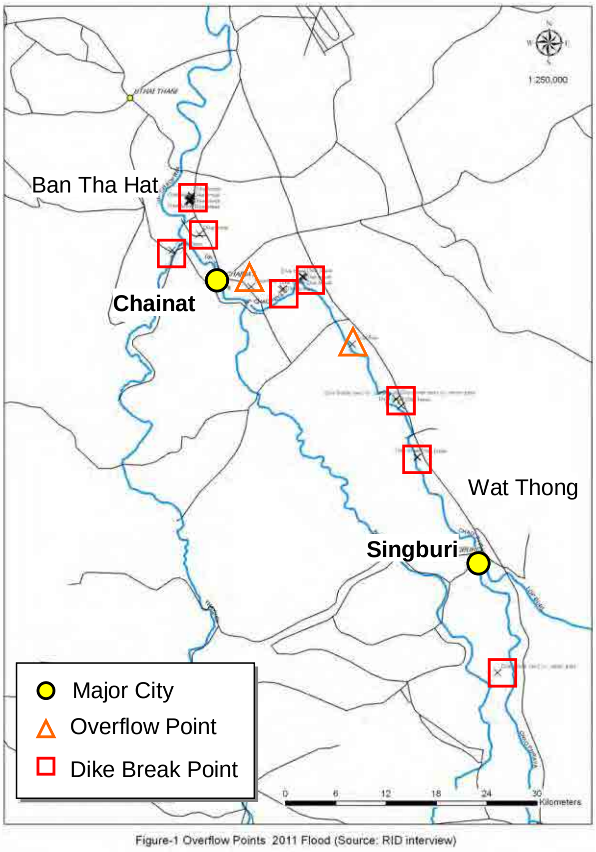


Figure 3.2.1 Locations of Dike Breaches

3.2.2 Inundation

Due to low flow capacity of the Chao Phraya River, abundant water spilled from the breached sections or over the river dikes and banks to flood plains. Figure 3.2.2 shows transition of the flood inundation areas.

Flood inundation occurred in the Nan and Yom River Basins as early as late July. The inundated water reached Nakhon Sawan in September. In the middle of September dike breachings and overflow began to take place in the delta area below Nakhon Sawan. The spilled water flowed down in both the eastern and western sides of the Chao Phraya River. In the middle of October the flood water swallowed 7 industrial estates in Ayutthaya and Pathum Thani provinces one after another. Finally it entered into a part of Bangkok by the beginning of November. In the lower areas the inundation continued until flood water was drained naturally or by pumps in December or later.

The total inundation area is estimated at approximately 28,000km^2. Table 3.2.2 compares inundation areas of past major floods, and it is easily understood how extensive the flood inundation of 2011 was. Accordingly the ext-inundation caused enormous flood damages as summarized in Table 3.2.3. 13 million people, which corresponds to 1 of 5 Thai people, were affected and 657 people were killed in the flood (as of December 1, 2011). Houses and infrastructures as well as agriculture areas were heavily damaged. In particular, as explained in the following subsection in detail, manufacuters incurred huge damages and losses.

Table 3.2.2 Inundation Areas of Past Floods

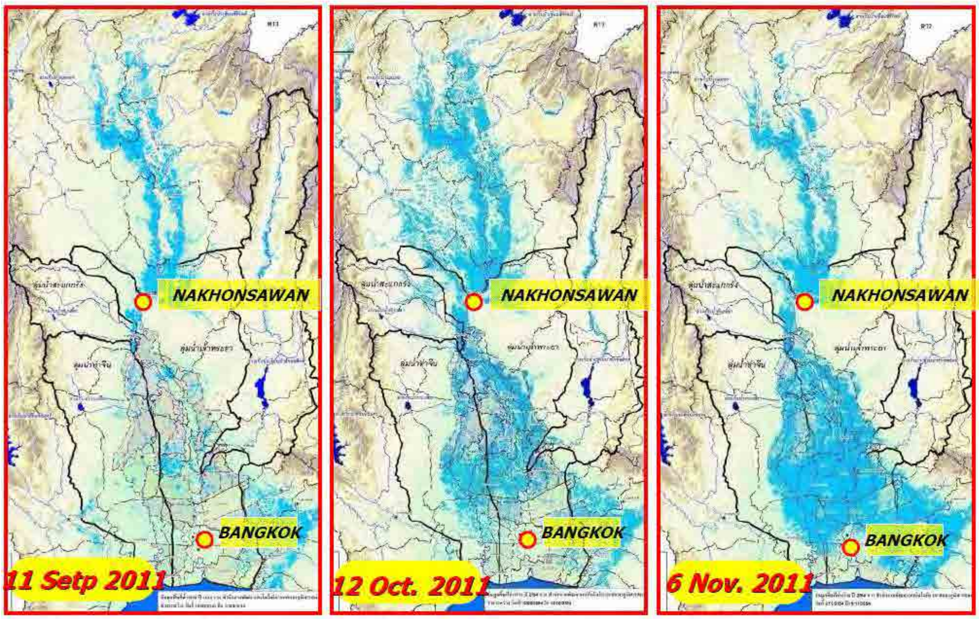
Year	Inundation Area (km^2)
1983	11,900*
1995	6,140*
1996	7,120*
2002	5,080*
2006	19,000*
2011	28,000

* Data Source of inundation area: "Integated Flood Mitigation management in the Lower Chao Phraya River Basin" Dr. Somkiat P. & Dr. Pornsak S., 2007

Table 3.2.3 Flood Damages

Items	Contents
Affected Areas	43,600 villages, 4,917 sub-districts, 684 districts of 65 provinces.
Affected Population	In total 13,425,869 people of 4,039,459 families are affected.
Damaged Houses	2,329 houses: wholly damaged. 96,833 houses: partly damaged.
Agriculture damage	1.8 million hectare cultivated area,
Damages of Infrastructures	13,961 roads, 982 weirs, 142 embankments, 724 bridges,
Damage of livestock	13.41 million livestock
Damages of fish/shrimp/shell ponds	over 37,107 ha
Death toll	657 deaths(in 44 provinces)

Flood Damages as of December 1, 2011
Date Source: DDPM



Data Source: GISDA

Figure 3.2.2 Flood Inundation Areas by 2011 Flood

From Figure 3.2.3 to Figure 3.2.8 show a flow direction of inundated water in 2011 and they clear the inundated water movement during flood season and help understanding where inundated water come from. The flow direction was obtained from the flood mark survey conducted by JST. Maximum inundation depth, times-series inundation depth and flow direction were collected by interview survey at approx. seven thousands (7,000) points in flood plain area.

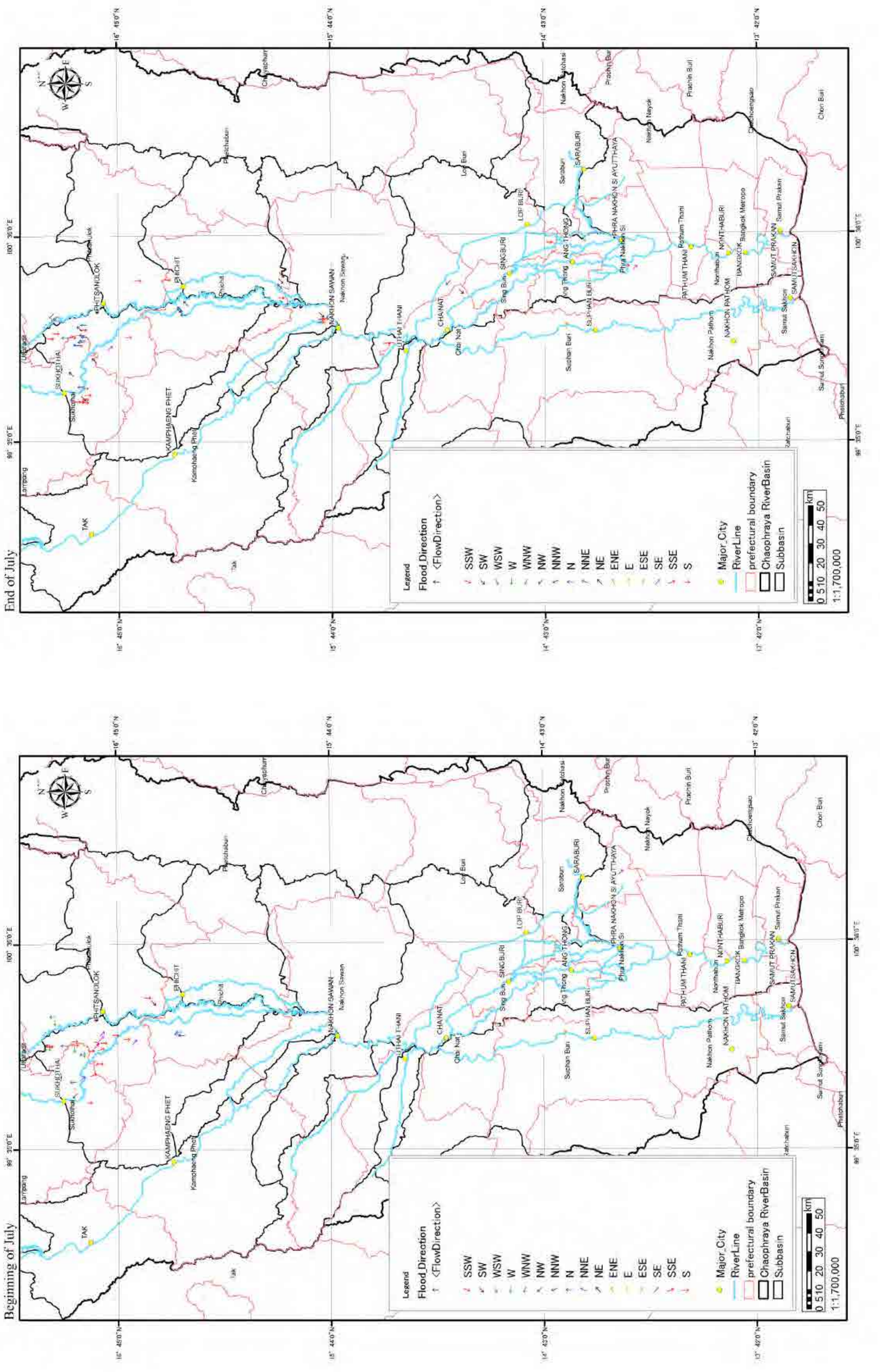


Figure 3.2.3 Flow Direction of Inundated Water in July 2011 (Result of Flood Mark Survey 2012)

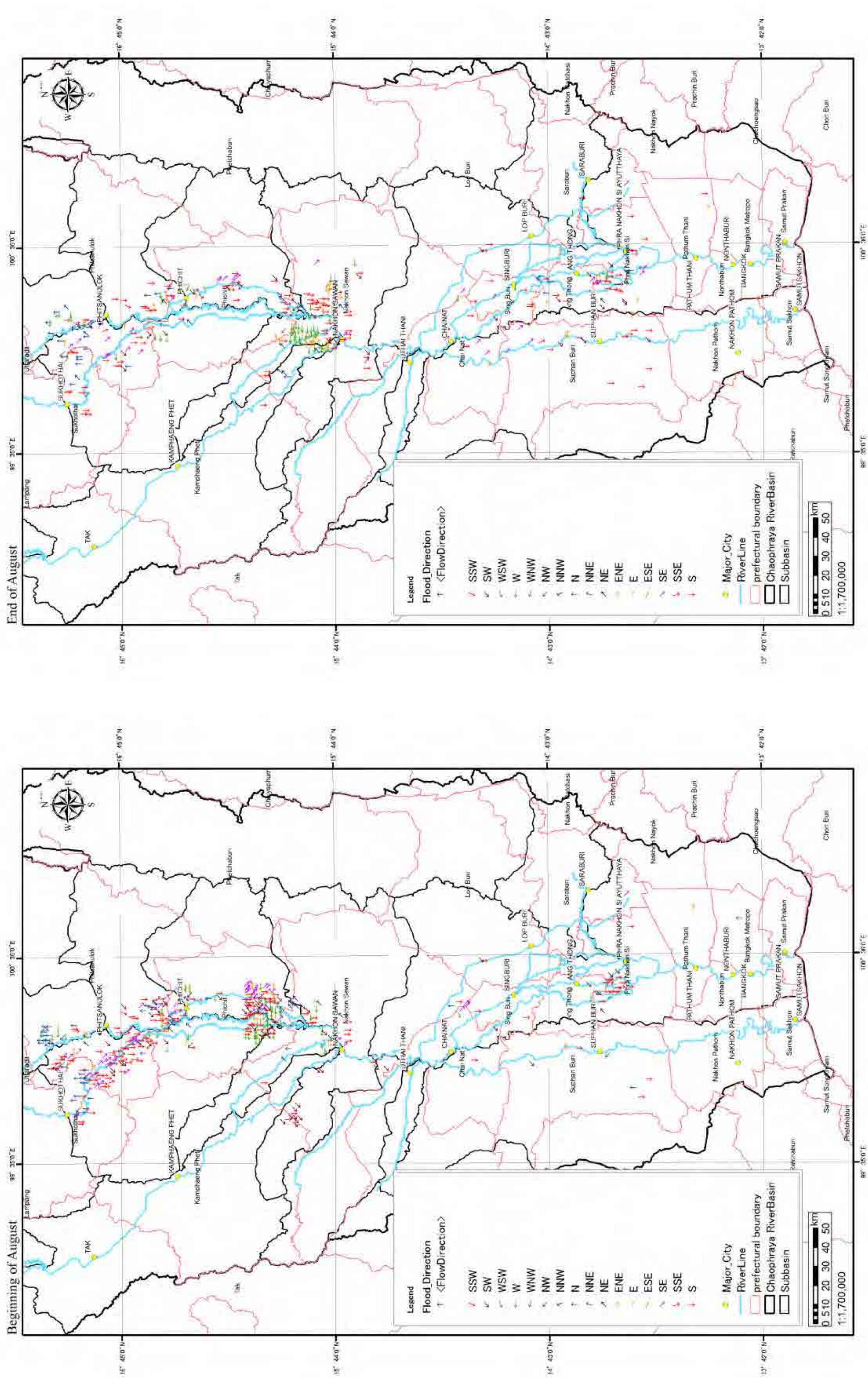


Figure 3.2.4 Flow Direction of Inundated Water in August 2011 (Result of Flood Mark Survey 2012)

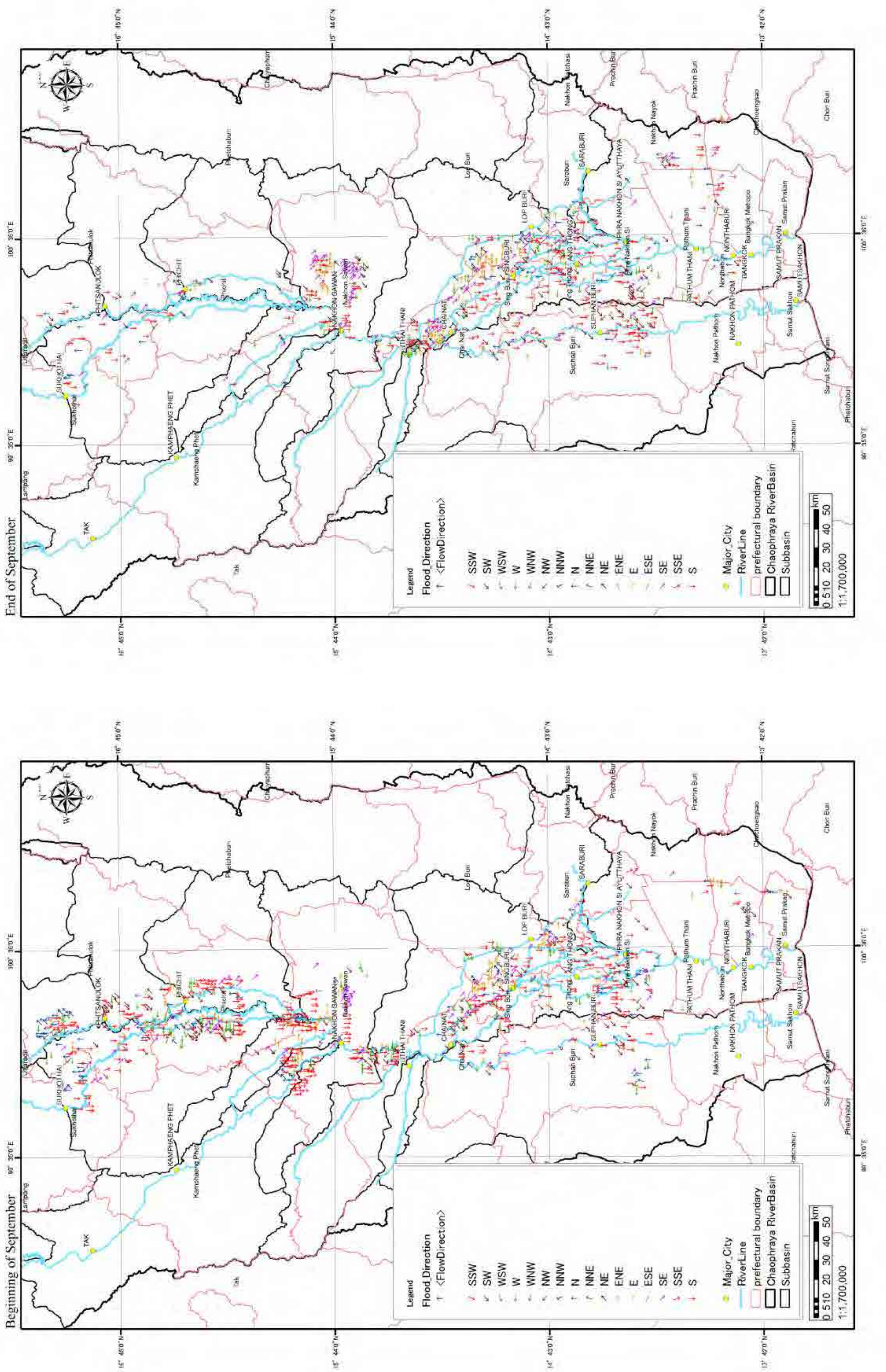
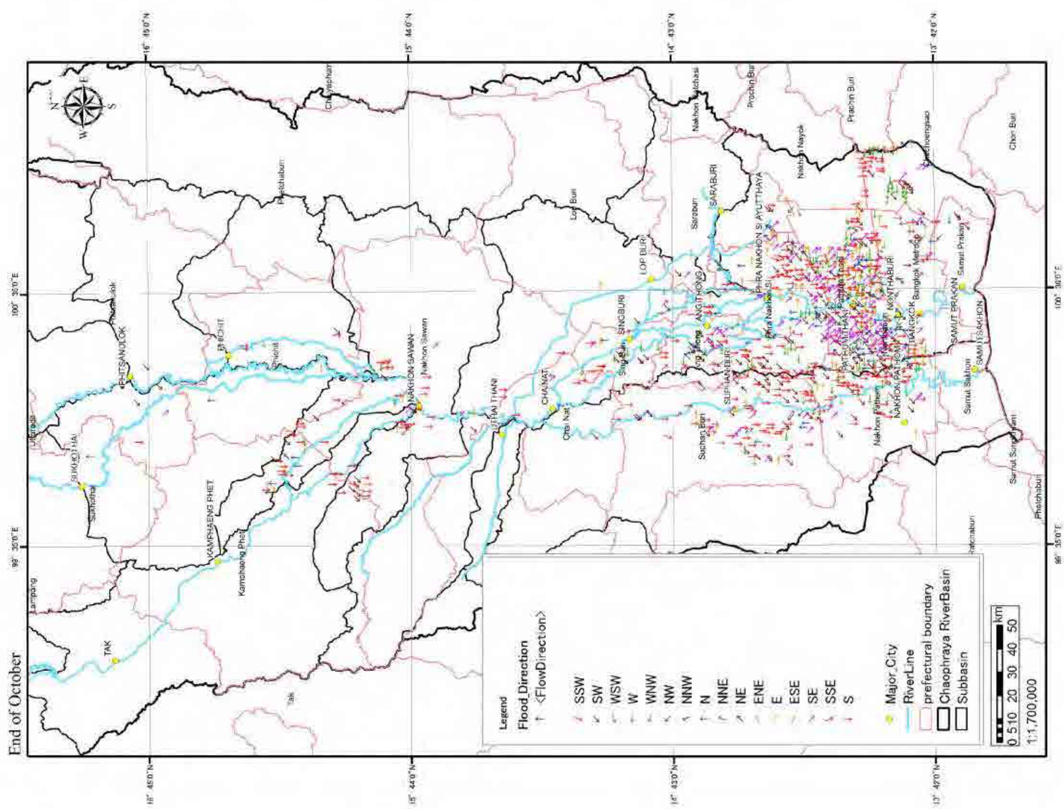


Figure 3.2.5 Flow Direction of Inundated Water in September 2011 (Result of Flood Mark Survey 2012)



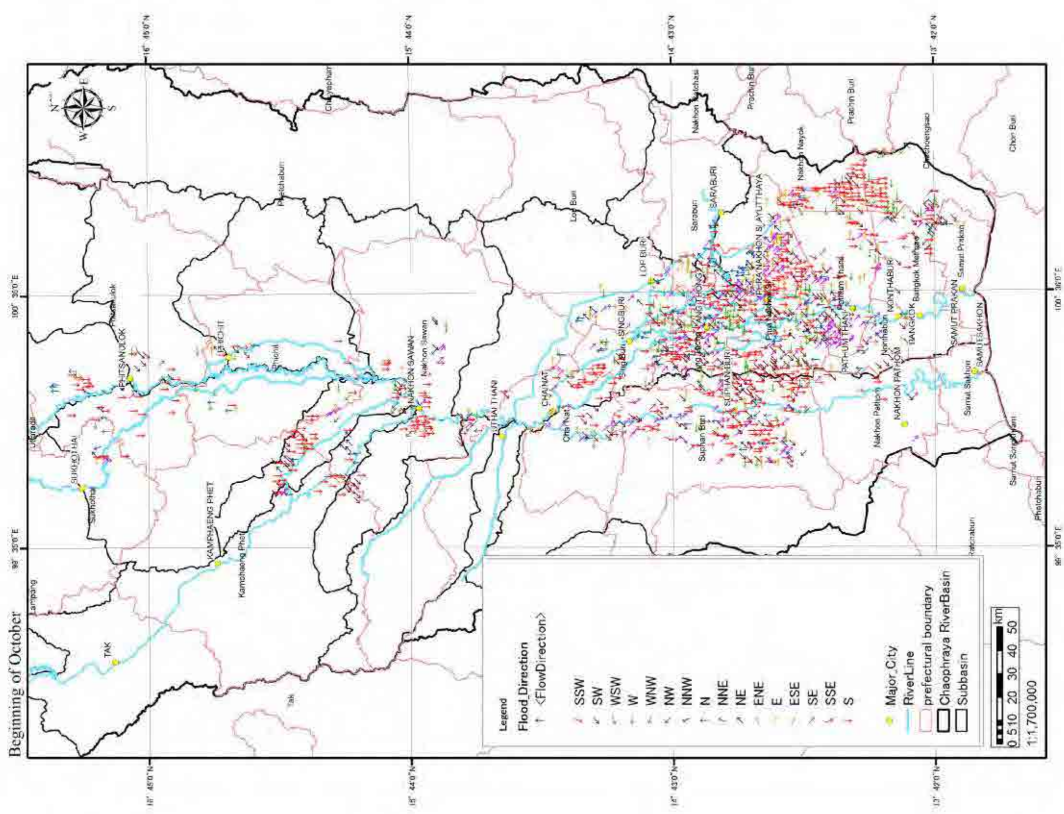


Figure 3.2.6 Flow Direction of Inundated Water in October 2011 (Result of Flood Mark Survey 2012)

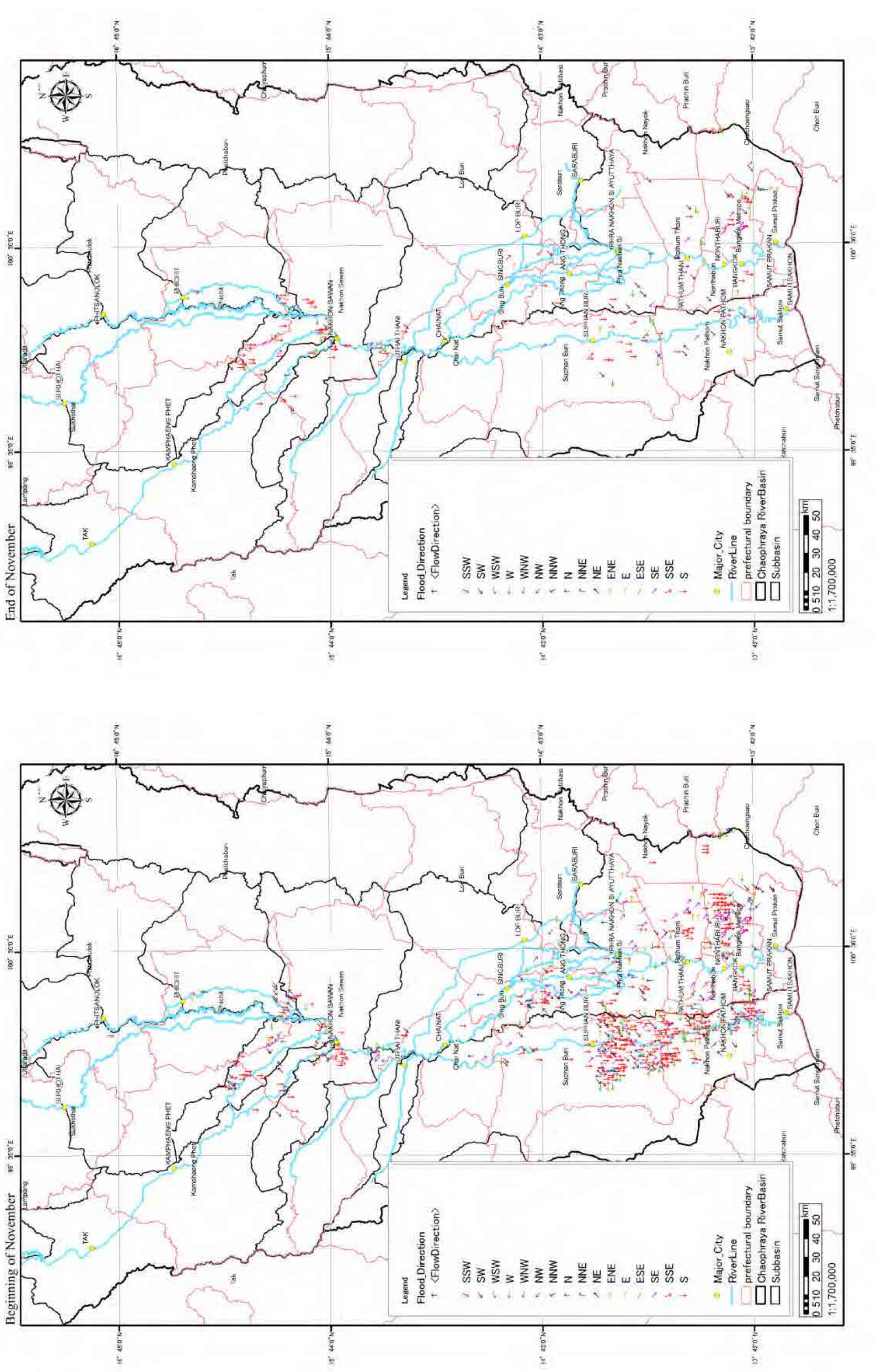
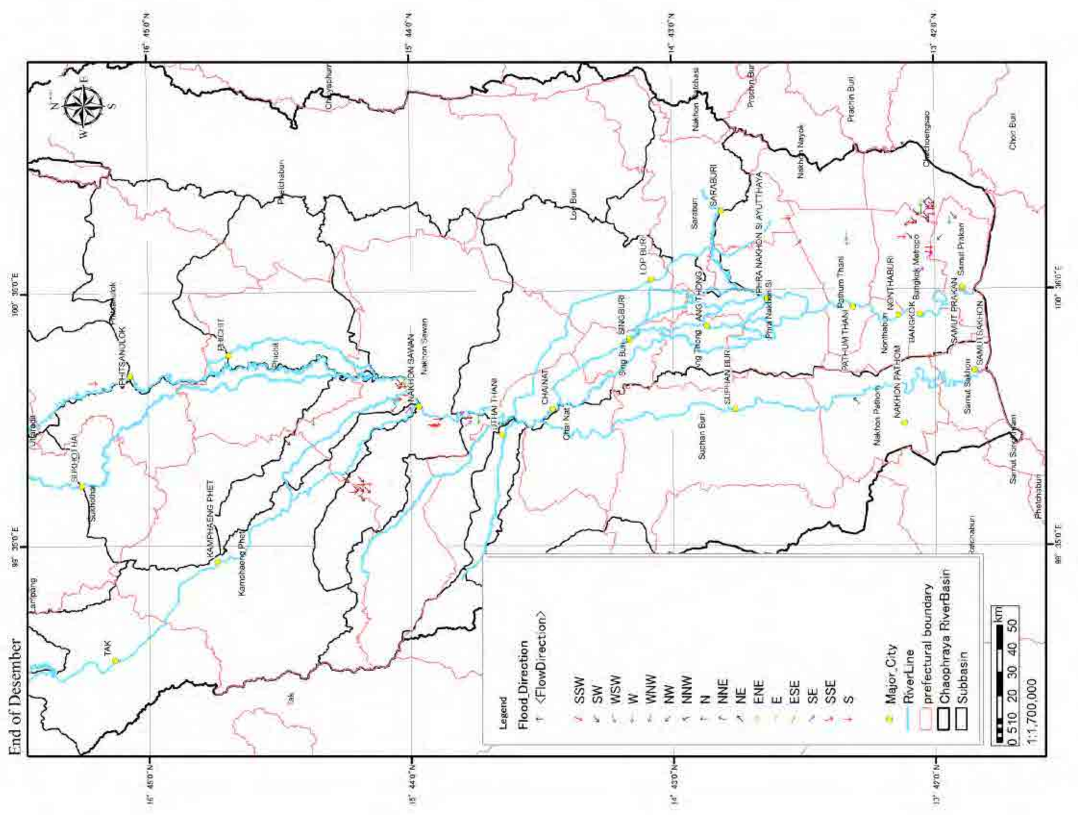


Figure 3.2.7 Flow Direction of Inundated Water in November 2011 (Result of Flood Mark Survey 2012)



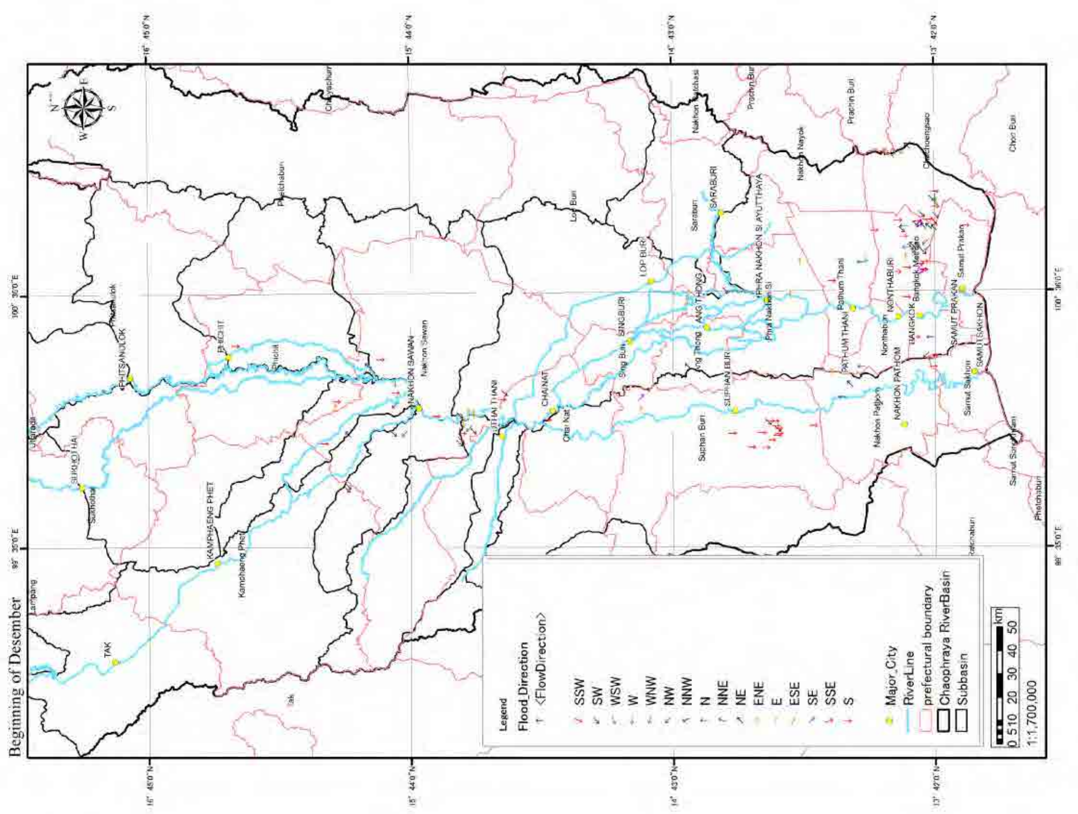


Figure 3.2.8 Flow Direction of Inundated Water in December 2011 (Result of Flood Mark Survey 2012)

3.3 Chronology of Flood Events

Major flood events including meteo-hydrological information, flood phenomena and flood responses from June to December 2011 are summarized in Table 3.3.1.

Floods took place as early as June in upper provinces such as Pichit, Nan, Tak, Payao, Prae and Sukhothai under influences of the tropical storm, Haima. Even between the beginning of August and the middle of September when there was neither typhoon nor tropical strom, it rained much more than usual. After that, a typhoon and two tropical storms hit and brought heavy rainfall to Thailand one after another through late October. Receiving these rainfalls, the flood water developed gradually, filling the dam reservoirs, overflowing the river banks, and breaching the river dikes. The river discharge at Nakhon Sawan reached its peak in the middle of October, and the river water level at Bangkok recorded the maximum level during the spring tide October 30. Flood water entered into Bangkok by the beginning of November mostly from the upper northern areas, not from the river. Bangkok became dry by the end of December, but five provinces, Ayutthaya, Pathum Thani, Nontaburi, Lopburi and Nakorn Pathom had to wait a few weeks more.

Table 3.3.1 Chronological Table of 2011 Flood

Period	Meteorology -Hydrology	Major Flood Phenomena	Major Flood Responses
1 - 10 June			
11 - 20 June			
21 - 30 June	Tropical Storm Haima	Flash floods in Pichit, Tak, Nan, Payao, Prae and Sukhothai Provinces	
1 - 10 July			
11 - 20 July			
21 - 31 July	Tropical Storm Nock-Ten	Floods in Prae, Nan, Pichit and Uttradit Provinces	
1 - 10 August		Floods in Chiang Mai, Lum Phun, Lum Pang, Sukhothai, Phitsanulok, Phetchaboon and Tak Provinces	
11 - 20 August			Establishment of Center for Emergency Management (Aug. 20)
21 - 31 August			Establishment of National Committee on Floods, Tropical Storm and Mudslide (Aug. 25)
1 - 10 September		Dike Breaches (3 locations in Chainat Province)	Establishment of Flood Crisis Prevention Center by DDPM (Sep. 2)
11 - 20 September		Dike Breaches (4 locations in Chainat and Singburi Provinces)	Establishment of 25 River basin National Joint-Committee (Sep.14)
21 - 30 September	Typhoon Nesat, Tropical Storm Haitang	Dike Breaches (4 locations in Chainat and Singburi Provinces) Bhumibol and Sirikit dams became full.	
1 - 10 October	Tropical Storm Nalgae	Flood water into 2 industrial estates in Ayutthaya Province	Preparation of evacuation areas for all provinces by NDWC (Oct. 7) Beginning of piling of sand bags for Bangkok (Oct. 7)Establishment of FROC to supersede Center for Emergency Management (Oct. 8)
11 - 20 October	Peak discharge at Nakhon Sawan (C.2)	Flood water into 5 industrial estates in Ayutthaya and Pathum Thani Provinces	Establishment of Relief Committee (Oct. 12) Announcement of evacuation to critical flood areas by NDWC (Oct. 15) Order by PM of Measures for Designated Disaster Areas (Oct. 20)
21 – 31 October	Peak Water Level of Chao Phraya R. in Bangkok	Flood water into Don Muang Airport (Oct. 25) Flood water into MWA canal (Oct. 26)	
1 - 10 November			Establishment of Flood Recovery and restoration Committee (Nov. 4) Establishment of Public Communication Committee (Nov. 4)
11 - 20 November			Establishment of SCWRM and SCRFD (Nov. 11)
21 - 30 November			Declaration of natural disaster mitigation and reliefs areas (Nov. 25)
1 - 10 December			
11 - 20 December			
21 - 31 December		Flood in Bangkok ended but Ayutthaya, Nakhon Pathom, Nonthaburi, Lopburi and Pathum Thani were still suffering.	

To cope with these flood phenomen, the Thai Government established on August 20, 2011 the Center for Emergency Management as a command organization of national level under the 2P2R (Preparedness, Prevention, Response and Recovery) policy. This center was consequently superseded by FROC (Flood Relief Operations Center) on October 8. In addition, the following seven committees were also established one after another. Five committees out of them from 1) to 5) are those which aimed to responded to actually evoluting flood problems. The rest, SCWRM and SCRFD, which was established on November 11, aimed toward the restoration and the future development after the flood. It is noted in particular that SCWRM proposed the Master Plan of which concrete contents are required to be proposed by this study.

1) 25 August : National Committee on Floods, Tropical Storm and Mudslide
2) 14 September : 25 River basin National Joint-Committee
3) 12 October : Relief Committee

4) 04 November : Flood Recovery and Restoration Committee (Nov. 4)
5) 04 November : Public Communication Committee (Nov. 4)
6) 11 November : Strategic Committee for Water Resources Management (SCWRM)
7) 11 November : Strategic Committee for Reconstruction and Future Development (SCRFD)

According to the Rapid Flood Management Assessment by ADB, however, it has been pointed out that these responses were rather proactive, that time and information necessary for decision-making was limitted due to many intermediate organizations along the information dissemnation chains, and that public awainess are declining due to modernization. As a result of the reconsideration on these flood responses in the 2011 flood, SCWRM proposed a single command authority for more unified flood management, which were created actually in February 2012 as two committees of National Water and Flood Policy Committee (NWFPC) and Water and flood Management Committee (WFMC).

3.4 Flood Damages and Loss

After the flood disaster, damages and losses were assessed by various agencies. The World Bank has conducted a Post Disaster Needs Assessment (PDNA) in collaboration with the Ministry of Finance and both national and international various agencies. This survey was conducted 7-25 November 2011 to estimate damages and losses incurred by the flood in 2011. A full assessment report was finalized on January 27 2012. There are also other damage assessments and preliminary cost estimations for rehabilitation projects compiled by the government of Thailand and Asian Development Bank (ADB) as well as Japan External Trade Organization (JETRO). These documents are also reviewed in the following subsections. It must be noted that the time and resources are so limited for all surveys that the figures need to be treated as indicative to show the situation at the time of the studies.

3.4.1 PDNA

Based on DALA (Damage and Losses Assessment) methodology, the total damages and losses incurred by the flood in 2011 was 1.43 trillion THB, out of which the damages of the physical assets amounts to 630.3 billion THB and associated losses are 799 billion THB respectively. According to DALA methodology, damage refers to direct impacts on physical assets, products, raw materials machinery and properties. Losses include reduced or lost production opportunities such as loss of income, reduced production efficiency, increasing expenditures over a period of time. Reduction in income due to cut of service delivery, increase in transport costs are also considered to be losses.

Table 3.4.1 Summary of Damages and Losses by Sector (THB millions)

Subsector	Disaster Effect			Ownership	
	Damage	Losses	Total	Public	Private
Infrastructure					
Water Resources Management	8,715	-	8,715	8,715	-
Transport	23,538	6,938	30,476	30,326	150
Telecommunication	1,290	2,558	3,848	1,597	2,251
Electricity	3,186	5,716	8,901	5,385	3,517
Water Supply and Sanitation	3,497	1,984	5,481	5,481	-
Productive					
Agriculture, Livestock and Fishery	5,666	34,715	40,381	-	40,381
Manufacturing	513,881	493,258	1,007,139	-	1,007,139
Tourism	5,134	89,673	94,808	403	94,405
Finance & Banking		115,276	115,276	74,076	41,200
Social					
Health	1,684	2,133	3,817	1,627	2,190
Social	-	-	-	-	-
Education	13,051	1,798	14,849	10,614	4,235
Housing	45,908	37,889	83,797	12,500	71,297
Cultural Heritage	4,429	3,076	7,505	3,041	4,463
Cross Cutting					
Environment	375	176	551	212	339
Total	630,354	795,191	1,425,544	141,477	1,284,066

Source: DALA estimates, NESDB and Ministry for Industry damages and losses in Thailand floods 2554 Rapid Assessment for RRR.01-18-2012
Note: Losses for each sector include higher expenditures due to floods

Manufacturing sector accounts for -hirds of the disaster effects. Industrial estates in Ayutthaya and Pathum Thani provinces are severely impacted. Water resources management sector counts only damages referring to the physical damages made to the dykes, levees and canals, while finance and banking sector count only losses without serious physical damages. The tourism sector also incurred heavy losses by losing tourists visits and canceling of attraction and events rather than damages made on physical assets.

3.4.2 Rapid Flood Management Assessment by ADB

Asian Development Bank conducted a rapid flood management assessment after the flood in 2011 and released a report in January 2012. The analysis in the report summarizes the impact of the flood, flooding mechanism, including rainfall records, reservoir operation and flood water diversion. The financial impact estimate is cited as 1.4 trillion THB from the assessment of the World Bank.

Table 3.4.2 Assessment by ADB of the Flood Impact by Sector

Sector	Impact
Agriculture	12.61 million ha farmland
Industry	9,859 manufacturing plants in 8 province 838 factories in 7 industrial parks
Historical Site	313 sites damaged (Ayutthaya counts for 130)
Education	3,088 schools
Waste Management in BMA	12,963 tons/day (146.62% of average trash: 8,500tons)

The ADB report analysis suggests that change of land use pattern, namely, filling up of wetlands and lack of town planning, increased the surface runoff and retarded flood water flow. Inappropriate planning and/or engineering designs of infrastructure without considering water flow patterns also contributed to complicate the flood management.

3.4.3 Industrial Parks and Estate Survey by JETRO

Japan External Trade Organization (JETRO) has conducted questionnaire surveys at the occasions of business seminars with Japanese companies. The focus of the survey by JETRO is to update the damage and impact situations of the Japanese companies and to offer information as to the current situation and the policies and measures taken by the Thai government in relation to the trade and investment so that Japanese companies can make timely business decisions. This helps the Government of Japan to extend policy assistance to both Thai and Japanese related parties to facilitate quick recovery of the manufacturing sector.

In terms of impacts of manufacturing and retail sectors for Ayutthaya and Pathum Thani provinces, JETRO estimates 208,611 million THB and PDNA estimates 196,436 million THB. The estimates are similar although surveys depend on the different samples.

Japanese companies answered to a questionnaire survey in November that they would like to resume manufacturing at the same factory in Thailand. No company wanted to move out of Thailand, however, if the situation in the future does not get improved business decisions which may have to be taken otherwise.

Table 3.4.3 Summary of Survey by JETRO

Industrial Estates	Date of start of inundation	Date of start of drainage	Date of drainage completed
Saha Rattana Nakorn	4 October, 2011	30 November, 2011	4 December, 2011
Rojana	9 October 2011	7 November 2011	28 November 2011
Hi-tech	13 October 2011	8 November 2011	25 November 2011
Banpa-in	14 October 2011	8 November 2011	17 November 2011
Factory Land	15 October 2011	Early November	16 November 2011
Nava Nakorn	17 October 2011	18 October 2011	8 December 2011
Bankadi	20 October 2011	25 November 2011	4 December 2011

Source: JETRO survey on 16 December 2011

3.4.4 Others

Even though the mainly damaged industrial areas are located in the past flood plain and have been most vulnerable to flood, the tenant companies were not informed at all about that. As a result, awareness of the risk was low and preparation for flood was insufficient as a whole.

Generally speaking, like in the United States, the premiums change in accordance with inundation depth so that users of the survice can recognize the risk in the sound market mechanism. However, the premiums there were not changed depending on the potential of risk at each area.

As a whole, a recoginitional capacity of the flood risk seems to have been low among the damaged companies.

CHAPTER 4 MASTER PLAN BY THAI GOVERNMENT

4.1 Introduction

On January 20, 2012 the Prime Minister of Thailand unveiled in a press conference a Master Plan for sustainable water resources management that has been prepared by SCWRM. The Master Plan comprised of two action plans: 1) Action Plan for Water Management for Urgency Period, and 2) Action Plan of Integrated and Sustainable Water Resources Management in Chao Phraya Floodplain, to ensure the continuity of the country's development even with future drought and flood. This chapter explains the outline of the Master Plan.

4.2 Outline of the Master Plan

4.2.1 Objectives

There are three objectives of the Master Plan as follows:

(1) To prevent and minimize losses and damages from medium- to large scale flood;

(2) To improve the capacity of flood prevention system and urgent flood management, and increase the capacity in warning system; and

(3) To build confidence and increase incomes of farmers, communities while managing water, land and forest in sustainable manner.

4.2.2 Action Plan for Water Management for Urgency Period

The action plan is to respond to possible floods in 2012. Its key principle is to reduce the loss and damage due to flood and minimize the economic and social impacts. There are six main work plans which are being implemented with THB 18,110 million budget for 2012 as shown in Table 4.2.1

Table 4.2.1 Action Plan of Water Management for the Urgency Period

Work Plan	Budget in 2012 (THB mil.)	Budget in 2013 (THB mil.)	Timeframe	Responsible Agencies
1. Work Plan for Management of Major Water Reservoirs and Formulation of the National Annual Water Management Plan • Improve the efficiency of the country's water management system and the main dams and increase capacity in annual flood prevention and mitigation by assigning RID to develop the National 2012 Major Water Reservoirs and Water Management Plan.	-	-	Progress to be reported to SCWRM by Jan. 2012	Main: RID Supports: EGAT, TMD, LAO, SCMATWS* and SCWRM
2. Work Plan for Restoration and Efficiency Improvement of Current and Planned Physical Structures • Renovation of dikes , dams, check dams and water drainage system for capacity increasing • Renovation of water drainage channels, digging canals, clearing canals and water drainage canals • Increasing capacity in water drainage and water runoff management • Strengthening dikes and carrying tasks recommended by King's Initiative	12,610.34	4,515.70	Projects finalized by January 2012s	Main: SCSTPM Supports: RID, HD, RRD, MD, MOI, BMA and SRT
3. Work Plan for Information Warehouse and Forecasting and Disaster Warning System • Formulation of a development plan for setting up of the national water information ware house • Formulation of development plan for improving water forecasting • Formulation of a development plan for upgrading the national disaster warning system	4,500	-	Completed in March 2012	Main: SCSTPM Supports: RID, HD, RRD, MD, MOI, BMA and SRT
4. Work Plan for Response to Specific Area • Restoration and redevelopment of critical areas such as communities, industrial estates, cultural heritage sites or the overall significant areas to be capable of flood prevention, mitigation and preparation for the impacts from flood.	1,000	-	Completed in March 2012	Main: MOI, MST, MNE, and MOD Supports: MI, BMA, LAO and communities in risk areas

Work Plan	Budget in 2012 (THB mil.)	Budget in 2013 (THB mil.)	Timeframe	Responsible Agencies
5. Work Plan for Assigning Water Retention areas Recovery Measures • Identify Monkey Cheek reservoirs in upper and lower Chao Phraya River Basin • Formulation of a plan for channeling water to monkey cheek reservoirs • Identify measures of compensation to affected people	-	-	Completed in March 2012	Main: MOA, Supports: MOI
6. Water Management Institutions • Arranging meeting between SCWRM and SCRFD to propose Work Plan for Revising Organization for Water Management • Setting up of Task Force Committee to monitor the progress of the action plan for the urgency period.	-		Completed in January 2012	Main: OCS, Supports: SCWRM, SCRFD, MOI, MOAC, MONRE, MOT and OSCWRM
Total	18,110.34	4515.70		

* SCMATWS: Sub-committee for Monitoring and Analyzing Trends of Water Situation of SCWRM
** SCSTPM: Subcommittee on Short-term Plan and Measures of SCWRM
Data Source: Master Plan on Water Resource Management, 2012, SCWRM

4.2.3 Action Plan of Integrated and Sustainable Water Resources Management in Chao Phraya Floodplain

This comprehensive long-term action plan has been prepared by the Sub-Committee for Long Term Planning and Sustainable Solutions under SCWRM. Eight work plans are proposed with a total budget of THB 300 billion. The work plans, which are also called "Backbone Projects," show national strategies for integrated and sustainable water resources management in the Chao Phraya River Basin. However, they still remain as framework plans without concrete contents such as work sites, work items and quantities, and implementation agency, time schedule, hydraulic effectiveness, cost and benefit, environmental and social considerations are yet to be studied.

(1) Principles

The long-term action plan is based on the following seven principles:

a) Flood is a natural phenomenon with benefits, such as to maintain the proper balance among water, land and human resources and to ensure sufficient supply of water for household and business consumption and ecological conservation;

b) Flood management means ensuring proper flow (through rivers and floodways) and providing sufficient storage (further develop "Monkey Cheek");

c) There is a need to regulate land use to ensure its consistency with the water management plan. – When flood occurs, the goal is to mitigate the impacts and damages. –This could also serve as an opportunity to increase income and improve social security for grassroots;

d) Drought prevention and ecological conservation are integral parts of flood strategy;

e) The strategy is based on the principles of "sufficiency economy" and "neo-agriculture";

f) There is a need to establish a "Single Command Authority" to ensure coherent and timely decision based on the central database and common interests; and

g) It is important to promote public awareness of people (both in the floodplain and other areas) to ensure their support and cooperation for flood management strategy.

(2) Work Plans and Project Components

Based on the above principles, the THB 300 billion action plan composed of eight work plans was proposed as shown in Table 4.2.2.

Table 4.2.2 Action Plan of integrated and Sustainable Water Resources and Flood Management for Chao Phraya River Basin

Work Plan	Budget (THB million)	Timeframe	Responsible Agencies
1. Work Plan for Restoration and Conservation of Forest and Ecosystem <Project Examples> • Soil improvement and conservation in the upper basin area by reforestation of forest areas in the length of river basin in Ping, Wang, Yom, Nan, Sakae Kurang, Tha-Chin and Pasak • Reservoir Construction in Yom, Sakae Krung, Nan and Pasak River Basin	60,000	2012 onwards	MNRE, MOAC, RID
2. Work Plan for Management of Major Water Reservoirs and Formulation of Water Management <Project Examples> • Formulation of water management plan in major reservoirs and various scenarios, as well as dissemination of the related information to the public	-	2012 onwards	RID and EGAT
3. Work Plan for Restoration and Efficiency Improvement of Current and Planned Physical Structures <Project Examples> • Flood diversion channel construction and improvement of water dike, reservoir, water drainage and water gateway in order to deviate water from Pasak and Chao Phraya Rivers to Bangkok Gulf • Land use planning and land using according to the plan as well as the setting up of area protection system • Water quality and levee improvement in the major river system	177,000	2012 onwards	MOAC, MNRE, MOT and OPM
4. Work Plan for Information Warehouse and Forecasting and Disaster Warning System <Project Examples> • Formulation of the database system, forecasting system, and warning system as well as setting up of the institution rule and regulation providing and enhancing the participation of all stakeholders	3,000	2012 onwards	OPM
5. Work Plan for Response to Specific Areas <Project Examples> • Development of flood protection system in important areas • Formulation of negotiation process with flood victims/communities • Setting up the system of instrument warehouse • Analyzing the impact of water prevention system implemented by private sector • Preparation of the transportation during flood • Improvement of related municipal laws and codes • Formulation of a plan of assistance and recovery of flood victims • Setting up of infrastructure standards for building up the capacity in flood prevention and protection	-	2012 onwards	MOI, and MOT
6. Work Plan for Selecting Water Retention areas Recovery Measures <Project Examples> • Improving/adapting irrigated agricultural areas into retention areas (Monkey Cheek) comprising of irrigated agricultural areas in Phisanulok, Ramsar Site and Greater Chao Phraya Project.	60,000	2012 onwards	MOAC, MNRE and MOI
7. Work Plan for Improving Water Management Institutions <Project Examples> • Setting up of the integrated water management organizations as a permanent single command entity	-	2012 onwards	OPM and related agencies
8. Work Plan for Creating Understanding, Acceptance, and Participation in Large Scale Flood Management from all Stakeholders <Project Examples> • Dissemination of public's implementation on flood/water management through various media as well as to create people participation on water management	-	2012 onwards	OPM and related agencies
Total	300,000		

Data source: Master Plan on Water Resource Management, 2012, SCWRM

4.3 Towards Implementation of Water Resources Management Measures

The single command authority for water resources and flood management consisting of two levels of committees (NWRFPC and WRFMC) was established at the end of February 2012, and the role of SCWRM was over. The NWRFPC and WRFMC have taken responsibilities to implement the Master Plan formulated by the SCWRM. The Master Plan was composed of both urgent and long term work plans. In July the WRFMC announced an international tender for a Conceptual Plan for the Design of Infrastructure for Sustainable Water Resources and Flood Management composed of eight projects.

CHAPTER 5 BASIC ANALYSIS CONDUCTED BY IMPAC-T AND ICHARM

5.1 General

As explained in Chapter 1, two members of the Japanese Advisory Committee, IMPAC-T (University of Tokyo) and ICHARM, had conducted preliminary studies in an early stage between January and April 2012. IMPAC-T (University of Tokyo) conducted the runoff analysis for the upper Chao Phraya River Basin, of which outputs were used as input data for a flood simulation model that had been developed by ICHARM. The runoff analysis and simulation models were further used to roughly examine the effectiveness of several measures (modification of dam reservoir operation, retarding basins (monkey cheek), floodway or flood diversion channels, etc.) proposed by SCWRM.

The study results were presented to the agencies concerned at a meeting on April 26, 2012. Although the studies were briefly made, the results show a certain effectiveness of the measures in a quantitative manner, and some suggestions were given for the Consultant's Team to follow in the succeeding study stages.

5.2 Hydrological Analysis by IMPAC-T TEAM

5.2.1 Objective

There are two objectives of the IMPAC-T Team hydrological analysis as follows;

- To develop a model to conduct the hydrological analysis of the upper basin of Nakhon Sawan in the Upper Chao Phraya River Basin; and
- To analyze the effectiveness of reservoir operations for the short-term and long-term flood protection of the Bhumibol and Sirikit dams by applying various rule curves in the developed model.

5.2.2 Outline of Study Process and Output

(1) Data Development

To develop the hydrological models such as the HO8 and SiBUC models, the IMPAC-T Team collected input data including meteorological and geographical data from RID and TMD. The developed model was used to conduct the long term analysis of river discharge, reservoir storage and reservoir release, excluding the analysis of inundated area. To execute the HO8 and SiBUC models, seven (7) meteorological variables were indispensable which data must be collected at daily interval. These seven (7) variables were air temperature, humidity, air pressure, wind speed, shortwave radiation, long wave radiation and precipitation. For the model development, all collected data were gridded into 5 min longitude/latitude which is equivalent to an area of approximately 9km × 9km.

(2) Model Preparation and Validation at Nakhon Sawan

Initially, two hydrological models, the HO8 and SiBUC models were considered for this study. Finally, the HO8 model was chosen for this study for the following reasons: (i) The HO8 is capable of simulating both natural water cycle and human water activities on a daily basis; (ii) The model is flexible for setting of space and time (resolution and domain); and (iii) It is an open source software.

(3) Modeling Reservoir Operations

In reality, reservoir operations are very complex; however, an idealized simple simulation can offer basic information for the initial river management planning. For this study, IMPAC-T Team focused on simulating various operation scenarios only at the Bhumibol and Sirikit reservoirs. Several rule curves were formulated.

Firstly, the developed model was used to evaluate all rule curves by simulating the monthly runoff at Nakhon Sawan. The simulation results showed that there was a great agreement in the monthly runoff values between the observed data and the HO8 model simulated values. Therefore, the model validation indicated that the IMPAC-T Team succeeded in developing the hydrological model for reservoir operation.

Secondly, new 2012 rules were applied to the model to evaluate the effectiveness of various rule curves. The simulation results indicate that the operation scenario which extended until July could further reduce the flow peak at Nakhon Sawan.

Thirdly, based on the long term reservoir simulation, it is also concluded that the new 2012 rule curve could disperse the discharge and reduce the peak; therefore, the rule is effective for flood protection in the basin under study. However, if a rule curve which does not optimize the reservoir operation is applied, the simulation results would indicate that there is always a trade-off between flood risk and drought risk. An effective rule curve must be formulated to reduce such risks by optimizing the reservoir operation.

Finally, this study emphasized the importance of data quality and quantity of ground observation. With the limited amount of available data, the outcome of the developed HO8 model could be restricted in comparison with the simulation results of full data set.

5.2.3 Suggestions

To improve the developed model, additional data must be collected from RID and TMD. The data which need to be collected consist of the meteorological observation data including the previously mentioned six variables (air temperature, humidity, wind speed, air pressure, shortwave radiation and longwave radiation) on a daily basis from as many stations as possible including 2010-2011.

5.3 Rainfall-Runoff-Inundation Analysis for the Evaluation of Floodways by ICHARM

5.3.1 Objective

There are three objectives of the ICHARM Rainfall-Runoff inundation analysis for the evaluation of floodways as follows:

- To simulate the 2011 flood at the lower part of the Chao Phraya River Basin;
- To evaluate the master plan proposal, particularly, the floodway plan; and
- To evaluate the effects of the proposed floodways in terms of water level, discharge and inundation through a rainfall-runoff-inundation analysis.

5.3.2 Outline of Study Procedure and Output

(1) Simulation Conditions

ICHARM developed the Rainfall-Runoff Inundation (RRI) Model with satellite-based topographic and rainfall information to simulate river discharges and inundation in the lower part of the Chao Phraya River Basin. The total area for this study is 41,000 km². One of the features of the RRI Model is that it can simulate inundation and river running interactively. The model simulates flow parameters including water level and discharge in rivers by solving one-dimensional diffusion in river and two-dimensional diffusion on slope along with vertical infiltration, and subsurface and surface flow.

The calculation period to simulate and understand the 2011 flood was July 1, 2011 to November 30, 2011. The simulation area was gridded with mesh size of 30 sec which is equivalent to an area approximately 0.9km × 0.9km. The model was developed with satellite based topographic data and the 1999 surveyed river cross sections. The ground observed rainfall data was obtained from the National Climate Data Center (http://www.ncdc.noaa.gov/oa/ncdc.html). The observed time-series discharge at Nakhon Sawan and the Pasak Dam were set as boundary condition, whereas evapotranspiration was set for 5mm/day.

(2) Model Validation and Simulation Results

Firstly, the model was validated for the 2011 flooding conditions. The RRI model results were compared with the satellite based inundation estimate which concluded that the inundation pattern of the model relatively resembled the satellite data. Then, the simulated flow parameters including water depth and discharge in and along the rivers were compared with the observed data at Chainat, Ayutthaya and Bang Sai. The model faced some difficulty in predicting water levels, especially at Chainat, where the RRI model underestimated water level by 3 m at peak in September 2011. On the other hand, the discharge simulation gave a relatively good result indicating that the estimated inundation volume was very reliable.

The simulation setting followed the proposed master plan by the Thai Government, including three diversion channels: (i) the West Diversion Channel with the conveyance capacity of 1,000 m^3/s; (ii) the East diversion channel with the conveyance capacity of 1,000m^3/s; and (iii) the Outer Ring Road Diversion Channel with the conveyance capacity of 500m^3/s. It was assumed that the diverted water directly poured into the sea without causing inundation.

For this study, four different flow calculation scenarios were simulated: (i) 2011 flow route [2011 Calc.]; (ii) 2011 flow route with floodways [With Floodway]; (iii) 2011 flow route with floodways and embankment[With Floodway and Embankment]; and (iv) 2011 flow route with only embankment (no floodways)[With Embankment].

From the simulation results, inundation volume was calculated for each calculation scenario. It was determined that the inundation volume at the upstream area of Ayutthaya can be reduced by the floodways from 4.1 billion m^3 to 1.2 billion m^3. In other words, even after the construction of floodways, there are still possibilities of inundation which need to be controlled by other measures. Currently, RID is proposing to secure lands for Monkey Cheek or retention ponds with the storage capacity of 1.9 billion m^3. Therefore, the 2011 flood can be successfully managed by the combination of floodways and Monkey Cheek (or retention ponds).

Many factories and important facilities are located in the area, which were also severely impacted by the 2011 flood. For the area, the averaged inundation depth reduced from 0.8m to 0.3m by the floodways can be further reduced to 0.2m by the floodways and embankment scenario. In other words, the inundation volume in the area calculated from the simulated inundation depth at the southeastern part of Ayutthaya can be reduced from 1.5 billion m^3 to 0.5 billion m^3 by the construction of three floodways.

As for the "With Embankment" route scenario when the embankment is constructed before or without the floodways, it was determined that the inundation volume in the area would decrease by 1.00 billion m^3 while the average inundation depth would also decrease by 0.56m. However, in other areas, the inundation volumes and averaged inundation depths would slightly increase and the water level at Ayutthaya and Bang Sai would increase by 0.2 m and 0.3 m, respectively.

Finally, the study indicated the importance of local rainfall generating inland flooding. Otherwise, the total inundation volume would become half when factoring out the local rainfall amount over the area.

5.3.3 Conclusion and Suggestions

In this study, the RRI model was developed to simulate the 2011 flood at the lower part of the Chao Phraya River Basin. The model accuracy was found to be within the acceptable range for this type of study except the water level results at Chainat. Further analysis was conducted by utilizing the developed RRI model to evaluate the effects of the proposed floodways and embankment including four flow route scenarios. The analysis concluded that any combination of floodways and embankment could successfully reduce the inundation condition such as inundation volume, inundation area and depth.

The simulation was conducted with satellite-based topographic data to understand the general characteristics of the effects of the proposed plan. Therefore, for the future work, it is suggested to conduct the detailed analysis by replacing the satellite-based topographic data with Laser Profiler (LP) topographic data when the data is available in 2012.

CHAPTER 6 BASIC STUDY AND ANALYSIS

6.1 Questionnaire Survey on Flood Inundation and Damage

6.1.1 Introduction

(1) Objectives of the Survey

The objectives of the survey are: i) To identify the actions taken by the residents and communities before and during the 2011 Flood; and 2) To collect data and information on the damages and losses as well as the assets damageable by flood. (As for the contents of the Questionnaire, refer to Annex-).

(2) Survey Items

The items shown in Table 6.1.1 were included in the survey.

Table 6.1.1 Survey Items on Flood Inundation and Damage

Items	Sub-items	Detailed	Remarks
Respondent	Respondent's Background	- Civil Status - Educational Attainment - Number of Families Staying in the Current Residence - Condition of Residence*	* Building Type, Number of Stories, Total Floor Area, Ground Floor Elevation, Length of Residence
	Business Type	- Number of Workers - Position of Respondent in the Establishment - Condition of Building** - Length of Business Operation	** Building Type, Number of Stories, Total Floor Area, Ground Floor Elevation
Flooding Conditions in the 2011 Flood	Source of Flood		
	Duration and Depth of Flood	-	
	Continuation of Flood		
Flood Warning and Response Operation	- Flood Information/Warning		
	Source of Information/Warning		
	Needed Information		
	Evacuation during Flood	-	
	Reasons of No Evacuation		
	Timing of Evacuation		
	Place to Evacuate		
	Assistance to Evacuation		
	Type of Transportation for Evacuation	-	
Flood Damage in the 2011 Flood (Farmers and Residents)	Type of Damage	- Injury or Death by Flood - Damage on Farm Products - Damage on Livestock/Poultry - Damage on Agricultural Machinery - Damage on Houses/Buildings - Damage over Fixture/Furniture - Damage over Equipment - Damage over Outdoor Facilities - Damage Ratio after Cleaning/Washing	
	Flood Loss	- Diseases Acquired - Days without Electricity & Water Supply Services - Compensation and Expenses for Electricity and Water Supply - Persons and Days not available for Job and School	

Items	Sub-items	Detailed	Remarks
Flood Damage (Establishment) in the 2011 Flood	Type of Damage	- Injury or Death by Flood - Damage on Fixed Assets - Damage on Inventory Assets - Damage on Buildings - Damage on Equipment/Facilities - Damage on Outdoor Facilities - Recovery Ratio after Cleaning/Washing	
	Flood Loss	- Days without Electricity & Water Supply Services - Compensation and Spending for Electricity & Water Supply - Days without Operation and Requires for Full Operation	
Media Availability during the 2011 Flood	Most Useful & Reliable Media for the Information on Flood Situation	-	
	Internet Access	- How to connect to the internet during flood - Location of Internet Access - Frequency of Using the Internet	
	Most Useful Information Acquired during Flood		
	Most wanted information (but could not be acquired		

(3) Survey Period and Number of Samples

The survey was conducted from August 20 to October 23, 2012. The survey teams collected 1,200 samples using the questionnaire form during interviews. On average, approximately 18 samples were collected daily for 65 days.

(4) Survey Area

The survey area covered five (5) provinces in the Upper Chao Phraya River Basin (Kampaeng Phet, Nakhon Sawan, Phichit, Phitsanu Lok and Sukhothai) and 18 provinces in the downstream.

Major respondents were from residences (1,048 or 87.3%) aside from the 127 data (10.6%) from establishments. Others included schools, hospitals, government offices and temples.

Of the data from residences, 277 samples were obtained in the upstream while 771 were from the downstream, which is 2.8 times more than the figure in the upstream.

For the establishment, 39 samples were from the upper and 88 from the downstream, respectively. Regional balance of data acquired almost coincide with the survey plan (refer to Figure 6.1.1).

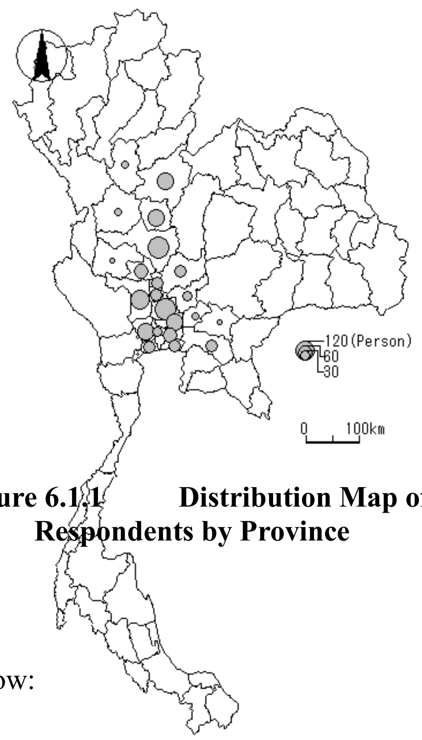


Figure 6.1.1 Distribution Map of Respondents by Province

6.1.2 Results of Questionnaire Survey

The results of the questionnaire survey are as summarized below:

(1) Flood Conditions

The 2011 Flood conditions including source and depth/duration were retrieved from the accomplished questionnaires as follows:

Figure A.1.(1) Distribution Map of Respondents by Province

- Source: Rivers (30%) were the main source of the flood, followed by the canals (28%); however, 13% (134/1,040) of the respondents answered that the water emanates from both canal and road, as shown in Figure 6.1.2.
- Depth/Duration: The average maximum depth from 858 samples was 0.93m (Standard Deviation, SD ± 0.74), ranging from 0.05 to 5m. The most frequent depth was 1.0 m (18%), followed by 0.5m (15%), 0.2m (14%), etc. Inundation above floor level lasted 51 days on average, ranging from 1 to 210 days. Sixty (60) days were the most frequent in duration.

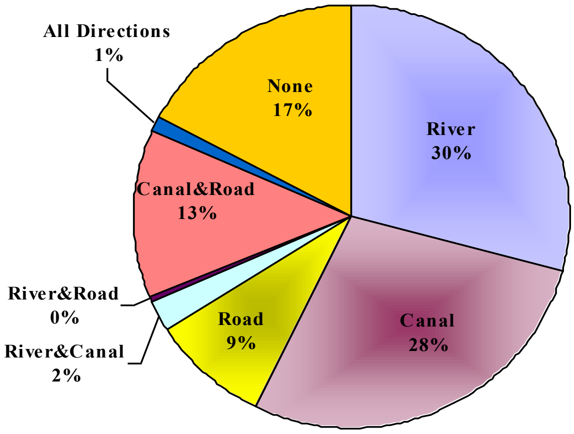
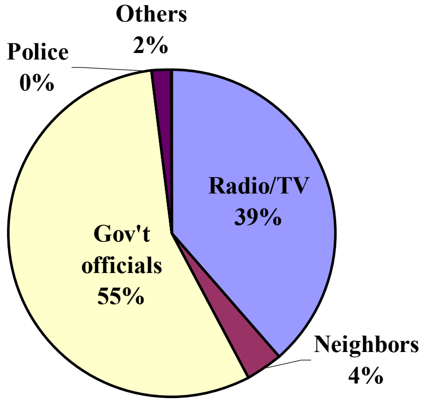


Figure 6.1.2 Proportion of Source of 2011 Flood

(2) Flood Warning and Response Operation

Fifty-nine percent (59%) of respondents received flood information and/or warning from some sources. Distribution of source is shown in Figure 6.1.3, indicating 55% of receivers got information from government officials concerned. Mass media such as radio/TV also contributed to the flood information but the proportion was less than that from the government sources. Details information on flood condition and estimated inundation area were required during the flood as shown in Figure 6.1.4.



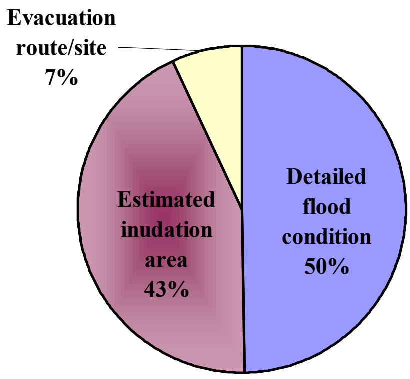


Figure 6.1.3 Source of Info/Warning (%) **Figure 6.1.4 Needed Information (%)**

Regarding the evacuation, 82% of the respondents did not evacuate during the 2011 Flood. The reasons were people's unawareness of the critical condition of the flood (76%), followed by no advice and nowhere to evacuate. Most people who evacuated took refuge in higher places (68%) and temples (8%), by car or on foot.

(3) Flood Damage

(a) Damage to Farmers and Residents

The most damaged was agricultural machinery, which occupy one-third of all damages, followed by houses/buildings; human life, furniture/fixtures, etc. (refer to Figure 6.1.5). As for human life, it seems that damage is related to daily life activities, not to injury or death. Damage to agricultural products like crops or livestock was minor. Table 6.1.2 present a summary of the damage to agricultural machinery, houses/buildings, furniture/fixtures, equipment and outdoor facilities, respectively.

Table 6.1.2 Damage to Property (Farmers/Residents)

Belongings	Avg. Damage (Range: %)
Agri. Machinery	53 (20-100)
Houses/Buildings	39 (5-100)
Furniture/Fixtures	54 (2-100)
Equipment	32 (1-100)
Outdoor Facilities	16 (10-50)

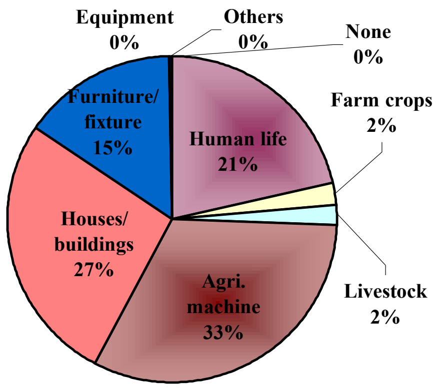


Figure 6.1.5 Damage to Property (Establishment)

(b) Damage to Establishments

The most damaged was inventory assets, occupying 22% of all damages, followed by facility/equipment, buildings, etc. Approximately one-third (29%) of the respondents did not receive any damage (refer to Figure 6.1.6). As for others, most answers were vehicles. Table 6.1.3 presents the summary of damage on fixed and inventory assets, buildings, equipment/facilities and outdoor facilities, respectively.

Table 6.1.3 Damage to Assets (Establishment)

Belongings	Avg. Damage % (Range %)
Fixed Assets	8.6 (0.1-1)
Inventory Assets	100 (0.05-100)
Buildings	3.2 (0.02-4)
Equipment/Facilities	9.9 (0.01-5)
Outdoor Facilities	4.6 (0.001-2.5)

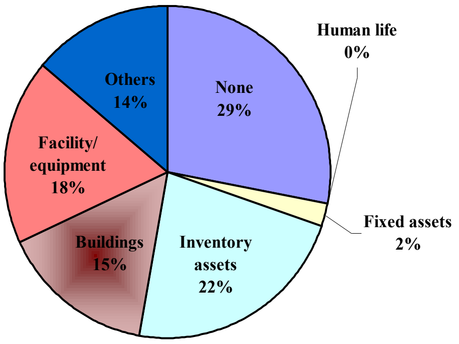


Figure 6.1.6 Types of Damage (Establishment)

(4) Media Availability

Interviewees felt the TV is the most reliable media when acquiring information on flood situation, followed by meetings, radio and newspaper. The percentage of mass media (TV, radio and newspaper) marked 86%, indicating that inhabitants place considerable trust on these media. Regarding the web usability like the Internet and tweet, the answer occupied only 1.5% of all media as shown in Figure 6.1.7.

As regards useful information acquired during floods, as shown in Figure 6.1.8, over 60% of the respondents evaluated the information from radio/TV as the most useful during the 2011 Flood followed by information from government offices concerned. Not one of the respondents mentioned any information from the police authorities.

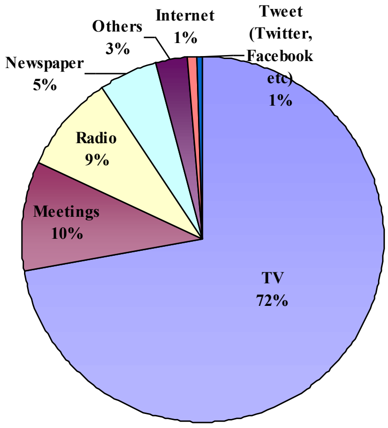


Figure 6.1.7 Useful/Reliable Media for the Information Dissemination of Flooding Situation

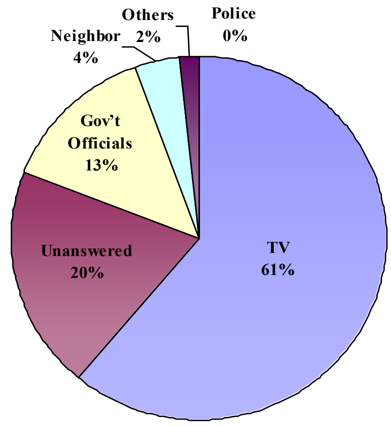


Figure 6.1.8 Useful Media of Information during Floods

6.1.3 Analysis

Analysis was made focusing on the evacuation activity and damage to households based on the flooding conditions.

(1) Estimation of Evacuation Curve

The survey results reveal that only 18% of the respondents had evacuated during the flood. Most of the non-evacuees claimed they did not feel that the flood situation was critical. To understand the relationship between flooding condition and evacuation action, the estimation of evacuation curves was examined based on the results of the survey.

The curves show the relationships between rate of evacuation and flooding parameters while the rate indicates the percentage of evacuated respondents at each level of a parameter. The durations of flood above floor level (days) and maximum flood depths above floor level (m) have been selected as parameters respectively.

The relationships are shown in Figure 6.1.9 and Figure 6.1.10 respectively. Both curves have statistically good and positive correlations. In Figure 6.1.9, for instance, 8.8% of the respondents (residents) would have evacuated if the flood above floor level lasted for 60 days. As for Figure 6.1.10, 8.8% of the respondents would have started evacuation if the maximum depth above floor level was 1.21 m high. In accordance with the estimation, it is necessary to have 2.70 m depth of inundation above floor level before 18% of the inhabitants think of evacuation.

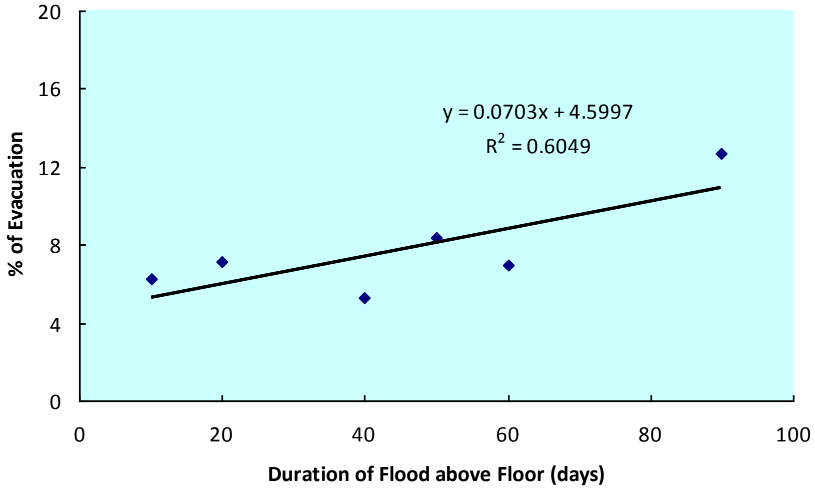


Figure 6.1.9 Relationship between Rate of Evacuation and Duration of Flood

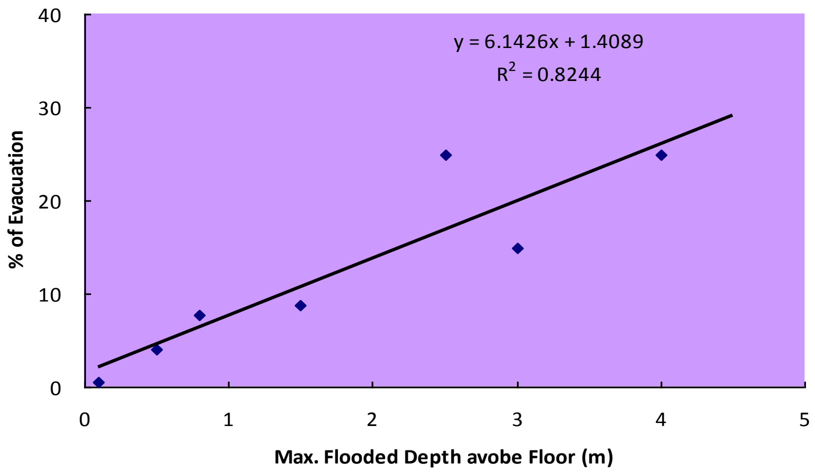


Figure 6.1.10 Relationship between Rate of Evacuation and Flood Depth

(2) Effect of Warning/Information on Evacuation

As mentioned above, 82% of the respondents did not evacuate during the 2011 Flood, and the main reason was unawareness that the flood would be critical (approx. three-fourths (76%) of respondents). Nevertheless, some warning/information has helped the inhabitants to notice the flooding condition and induce evacuation. To evaluate the effectiveness of information dissemination, a cross-table analysis was conducted to know which warning/information was statistically effective to initiate actions for evacuation.

Figure 6.1.11 shows whether or not the warning/information provision affected people's evacuation action, and the relationship was statistically examined with the chi-square test. The results indicate that evacuation was significantly chosen ($P<0.05$), but it was unclear which information was more effective to induce evacuation.

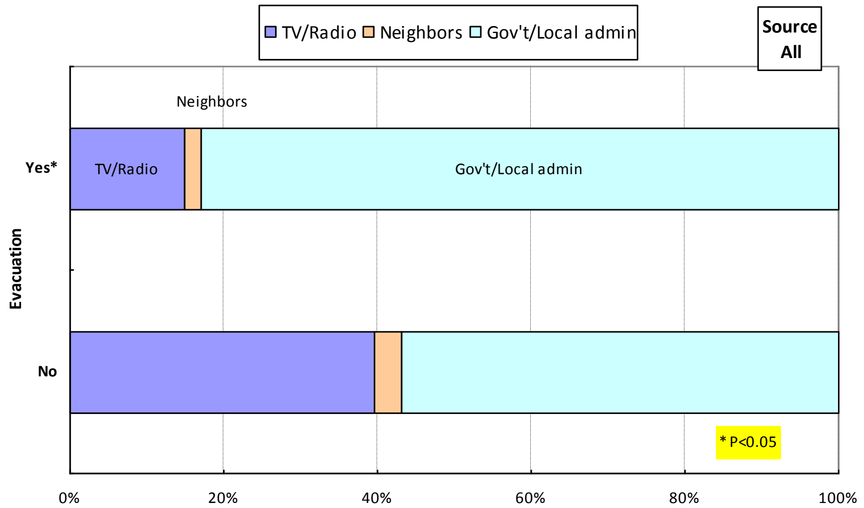


Figure 6.1.11 Cross-Table Analysis
(Between Source of Warning/Information and Evacuation Action)

To determine the effectiveness, evacuation actions were tested individually with the source (Radio/TV and Government/Local administration) as shown in Figure 6.1.12 and Figure 6.1.13, respectively. The effect of Radio/TV was statistically significant for people's evacuation action, but the information provided seemed to act inversely. On the other hand, the warning/information from the government or local administration could act positively on evacuation, according to Figure 6.1.13.

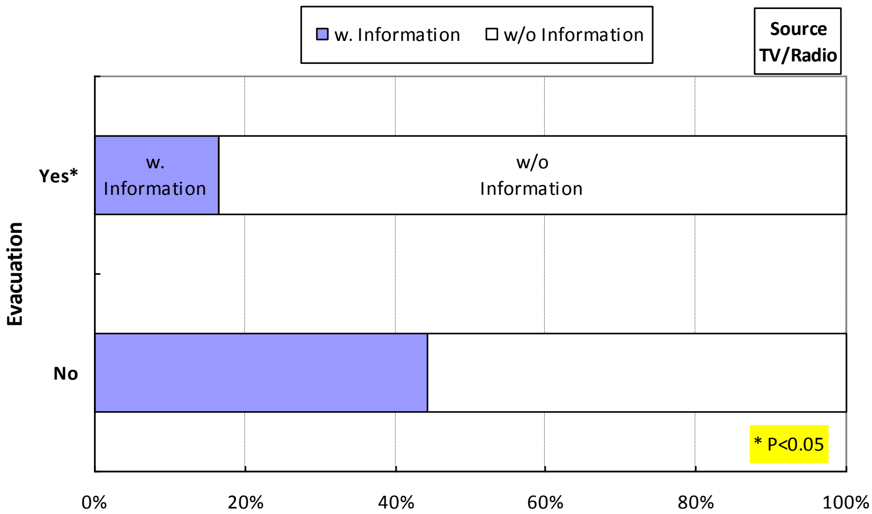


Figure 6.1.12 Cross-Table Analysis
(Between TV/Radio Information and Evacuation Action)

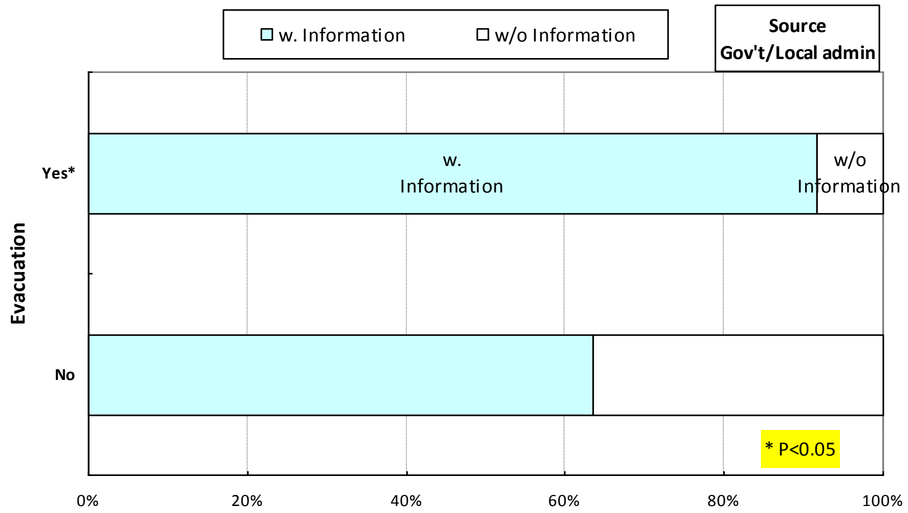


Figure 6.1.13 Cross-Table Analysis
(Between Government/Local Administration Information and Evacuation Action)

(3) Damage to Households by the 2011 Flood

Using the damage rate of properties per household, some trial calculations have been made to find the appropriate relationship with maximum depth or inundation days. However, no reliable correlation among them was found. The possible reason is that most answers regarding the amount of damage may not have been correct because the respondents did not remember or might have overestimated the damage after long times of flooding.

One factor that affects household economy is work suspension. If a worker of a household could not go to work due to the continuous flooding, the degree of inhibition (days, workers) might adversely affect the household income or livelihood.

Figure 6.1.14 shows the relation between duration of flood above floor (days) and the complex factor of work suspension, such as the product of suspended days and number of affected workers. The correlation is not high from the statistical viewpoint ($R^2 = 0.368$), mainly because of data being spread at 90 days of duration.

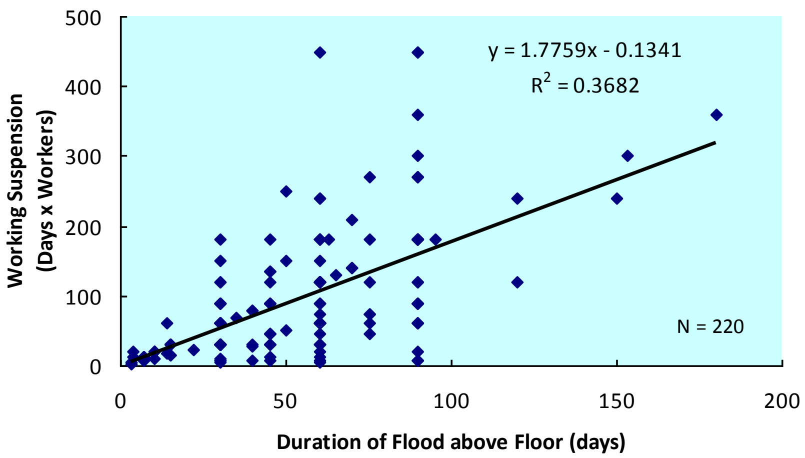


Figure 6.1.14 Relation between Work Suspension and Flood Duration (Days & Workers)

Next, trials to divide the factors of work suspension into each one were examined to see if individual factors were influenced. Figure 6.1.15 presents the relation of work suspended days with the duration of flooding. It is obvious that work suspended days had a statistically reliable correlation with the duration of flooding, but little relation with the number of workers suspended ($R^2 = 0.005$). Followed by the linear regression obtained in Figure 6.1.15, workers had to stop working for about 80 days and lose approx. 40,000 Baht as income opportunity when inundation lasted for 90 days (see the example in Table 6.1.4).

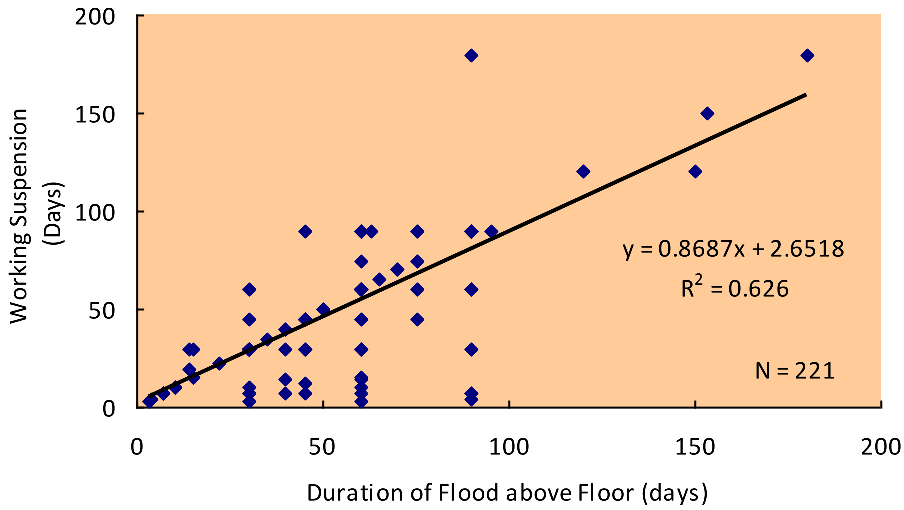


Figure 6.1.15 Relation between Work Suspension and Flood Duration (Work Suspension Days)

Table 6.1.4 Estimation of Income Loss due to Flood Duration

	Days of Inundation				
	10	30	60	90	120
Work Suspended Days	11.3	28.7	54.8	80.8	106.9
Estimated Income Loss (Baht)	5,609	14,247	27,203	40,109	53,065

Note: Average daily wage is assumed at 496.4 Baht in the industrial sector (Thai NSO, 2011)

6.1.4 Evaluation

The findings and evaluation on the survey are summarized as follows:

- No obvious relationship between damage by flood and flooding condition was found, mainly because answers on the amount of damage seem unreliable or unclear after more than half a year.
- However, the analysis show that flood duration has an impact on the income (no work days) of employees.
- Warning/information from government agencies played a significant role in evacuation. In such disaster cases, the government or local authorities should take more initiative in the evacuation.
- Public media like TV and radio were the main sources of information on the flooding situation and the government also contributed to the dissemination of information. However, a combined system of warning would be a more reliable and effective media of information dissemination.

6.2 Flood Impact Survey

6.2.1 Introduction

(1) Objectives of the Survey

The objectives of the Flood Impact Survey are: (i) To obtain data/information on damages and losses in the manufacturing sector from the ten (seven plus three) industrial estates located in the flooding area of the 2011 Flood; and (ii) To contribute to the drawing of a comprehensive master plan of flood management considering the important factors obtained from the survey.

(2) Survey Items

The items in Table 6.2.1 are included.

Table 6.2.1 Survey Items of the Flood Impact Survey

Items	Sub-items	Detailed	Remarks
General	Respondent's Background	- Company Profile* - Manufacturing of Company - Production and Assets**	* Company Name, Address, Status of Respondent ** Amount of Monthly Production, Fixed & Inventory Assets
Flooding Condition of 2011 Flood	Flood Experience		
	Flood Damage	-Maximum Inundation Depth/Duration -Estimated Damage (Properties, Workers)	
	Production (Operation)	-Magnitude of Production (Operation) Reduced -Duration of Production (Operation) Stopped	
	Insurance	-Coverage of Insurance	
Flood Prevention Works	Knowledge about Flood Condition		
	Existing Flood Prevention Works	-Works for own factory	
	Plans of Flood Prevention Works		
	Business Continuity Plan (BCP)		
	Existing Flood Works	-Works for the Industrial Estate	
	Future Plan of Prevention Works		
Information and Warning	Information on Flood	-Source of Information Received -Contents of Information	
	Information Network	-Media or Network Used	
	Plans of Flood Information / Warning Dissemination	-Media or Network to be Planned	
Response Action and Operation	Actions Taken before Flood		
	Actions Taken during Flood		
	Actions Taken Immediately after Flood	-Cost Consumed -Employees' Treatment	
Expectations with the Thai Government	Flood Prevention/Mitigation Works	-Expectation from the Thai Government -Recognition of the Planned Master Plan	
	Flood Information Dissemination	-Satisfaction with Flood Information Dissemination	
	Flood Warning System	-Satisfaction with Flood Warning System	
	Flood Response Operation	-Satisfaction with Assistance /Relief Operation	
	Recovery & Rehabilitation	-Satisfaction with Assistance for Recovery / Rehabilitation	
Business Plan	Current Condition of Operation		
	Future Plan of Operation		

(3) Survey Period, Number of Samples and Survey Area

The survey began on August 20, 2012 and ended on October 24, 2012. The survey teams collected 923 samples using the questionnaire form in an interview. The target factories were selected in ten (10) industrial estates which include the seven (7) damaged industrial estates along the Lower Chao Phraya River. Among the factories, answers were obtained from 923 of the 1,261 factories because 130 factories rejected answering and 208 had closed or moved to other locations. Considering the closed/moved factories, recover rate was 88% (923/ (1,261-208)). Result of questionnaire collection and distribution map of the surveyed industrial estates are shown in Table 6.2.2 and Figure 6.2.1, respectively.

Table 6.2.2 Result of Questionnaire Collection from Ten Industrial Estates

	Industrial Estate	Surveyed	Rejected	Closed/Moved	Total
1	Saha Rattana Nakorn	26	0	17	43
2	Rojana	163	0	37	200
3	Hi-tech	85	17	19	121
4	Factory land	60	0	25	85
5	Bang Pa-in	75	4	24	103
6	Navanakorn	175	3	40	218
7	Bangkadi	33	0	12	45
8	Bangchan	58	0	21	79
9	Ladkrabang	126	23	10	159
10	Bangpoo	122	83	3	208
Total		923	130	208	1,261

Figure 6.2.1 Distribution Map of Ten Surveyed Industrial Estates

(4) Outline of Surveyed Company Profile

Among the factories surveyed, manufacturing electric/electronic machinery was the majority, occupying 16% of the whole, followed by chemical and general machinery. Statistics regarding factory facts are as follows (average): 310 employees, 18,300 m^2 of area, THB224M of monthly production, THB600M and 204M of fixed and inventory assets, respectively.

6.2.2 Flood Damage

Average inundation depth was 2.2m, minimum (0.6m) observed in Factory Land and maximum (4.9m) in Hi-Tech. Most frequent depth (mode) was 2.5m. For inundation duration, 57 days was on average, from 3 to 120 days. The mode was 60 days. Statistics on damages in the seven flooded industrial estates are summarized as follows (average):

- Facilities/Equipment: 99% of factories had some damage on their fixed assets with THB441M per factory.
- Inventory Assets: Damage for 97% of factories was reported with THB137M per factory.
- Worker: One factory in Navanakorn reported injury and death of one (1) worker.
- Production: Average percentage of production reduction was 82%, which was well compatible with the average values of each industrial estate. Average inundation duration days were 135 days, ranging 2 to 300 days. The difference in Navanakorn was widest.

6.2.3 Flood Prevention Works

(1) Preparation

About 67% of the responding factories recognized that their industrial estates locate in a flood-prone area, while 59% are in the flooded estates. Expectation for flood protection measures to industrial estates was pessimistic among the flooded in general (43% with no expectation).

Three-fourths (75%) of the inundated factories had a plan to strengthen their self-protection measures. For the measures, factories put the priority on sand bags, followed by diking, lifting up stuffs (machines/equipment), drainage pump, etc., in accordance with Figure 6.2.2.

Ninety percent (90%) of the inundated factories recognized that their industrial estates had a plan to strengthen the prevention measures. As for the measures, factories put the priority on sheet piles (78% in the flooded and 53% in non-flooded), followed by secondary walls/shutters, diking, etc.

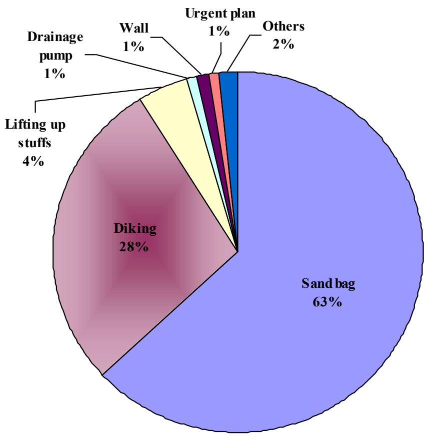


Figure 6.2.2 Flood Prevention Measures (Inundated Industrial Estates)

(2) Business Continuity Plan (BCP)

Approximately one-third (32%) of the factories prepared a BCP, while 38% of the flooded did. Most factories with a BCP created it in 2012, probably after the 2011 Flood. All factories had included an action plan for flood disasters into their own BCP.

Requests to the Thai Government for mitigation and recovery against flood disaster that are not covered by the BCP are:

- Mitigation: More than half of the factories (66%) required the assistance on finance including tax refund, income compensation, and tax reduction. On the other hand, 18% of the inundated factories hoped nothing (None).
- Recovery: Subsidy by the Government and budget support were listed on the priority. However, 32% of the inundated factories did not require anything, showing the value seems higher than that for mitigation (18%).

(3) Information and Warning

Half of the factories got the information from the media like TV/radio/newspaper when obtaining information or alert/warning on the flood in 2011. Industrial estate offices also contributed to the information dissemination (34%). Most provided information was regarding flood condition (79% for the inundated estates and 67% for the non-inundated), followed by advice for the next action, evacuation alert.

All the industrial estates provided information network on flood, and then were evaluated as sufficient information network providers by factories. Regarding the type of media, executive telephone line were the most (41%), followed by the internet, paper circulation, etc.

Most factories (88%) recognized that their industrial estates had plans of information network for future floods. As for the type of planning items for the information network, the internet was ranked at the top (54% among all estates), and about one-third of the factories knew or held exclusive telephone lines. E-mail system and propaganda were also included.

(4) Response Action and Operation

Actions taken by factories were naturally different at each stage like before and during the flood. Before the flood, almost half of the inundated factories prepared a measure and about 40% of the factories collected information and asked for assistance (refer to Figure 6.2.3). During floods, evacuation was taken by 87% of the inundated factories and 68% of the whole. However, conducting preventive measures was not high, according to Figure 6.2.4.

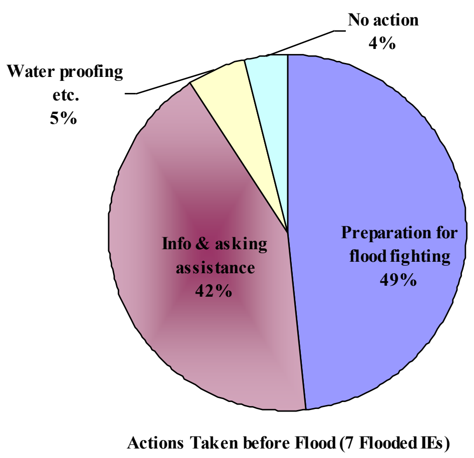


Figure 6.2.3 Actions Taken before Flood

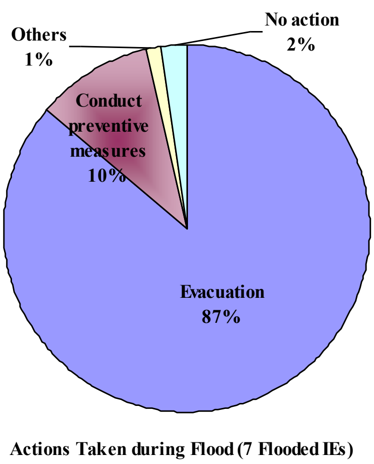


Figure 6.2.4 Actions Taken during Flood

(5) Expectations from the Thai Government

(a) Flood Prevention and Mitigation Works

Eighty-five percent (85%) of the inundated factories did not expect any flood prevention/mitigation works for the Chao Phraya River from the Thai Government. On the other hand, 95% of the inundated industrial estates expressed their expectation for these works. The Master Plan by the Government was recognized by 91% of the inundated factories.

(b) Flood Information Dissemination

Most of the inundated factories (95%) were not satisfied with the flood information dissemination done by the Thai Government. To erase the dissatisfaction, 60% of the factories suggested that the content of information itself should be improved or reconsidered. Approximately 20% of the factories suggested an improvement on the way of dissemination.

(c) Flood Warning System

Like the results obtained from the questions above, 93% of the inundated factories were not satisfied with the flood warning system for the 2011 Flood. For improvement suggestions, 54% of the inundated (45% of the whole) pointed out earlier and time-serial warning, followed by detailed information based on analysis, and establishment of the unified organization for flood warning.

(d) Recovery and Rehabilitation

The rate of dissatisfaction was the same as that of flood response operation; namely, 96% of the inundated factories were not satisfied with the assistance for recovery and rehabilitation from the Thai Government. Two-thirds of the respondents (66%) requested financial assistance (tax exemption, soft loan, etc.) from the Government as an early recovery/rehabilitation measure.

(6) Business Plan

In comparison with the condition of factory operation before the 2011 Flood, half of the factories responded “reduced,” but 40% confessed “unchanged.” Among the seven inundated industrial estates, over 80% of the factories in Rojana answered unchanged. However, all factories in Factory Land responded “reduced.”

In the future plan, half of the factories have a will to maintain the scale of their business plan, 30% to expand but about 20% to shrink. Over 40% of inundated factories in Bang Pa-in and Navanakorn plan to expand their business, while approx. 50% of factories worried about the scale-down of business.

6.2.4 Analysis

Analysis was made focusing on the damage and expectations from the Government or industrial estates.

(1) Relationship of Damage Rate with Flood Conditions (Depth, Duration)

To understand the extent of damage inflicted by the 2011 Flood on the assets of a factory, the relationship between the damage rate of assets and flooding conditions like flood depth (above floor) and flood duration after data aggregation has to be analyzed. Figure 6.2.5 and Figure 6.2.6 show the relationship regarding the inundation depth above floor level. For the fixed assets, no damage was reported below the 0.5m depth, but the weighted average rate of damage had the tendency of decreasing until the 3m depth, and then turned rising over 3m. The same trend was seen in the relation with inventory assets. This result suggests that factories could take measures to move movable assets (machinery, materials, etc.) upstairs or somewhere under the 3m depth.

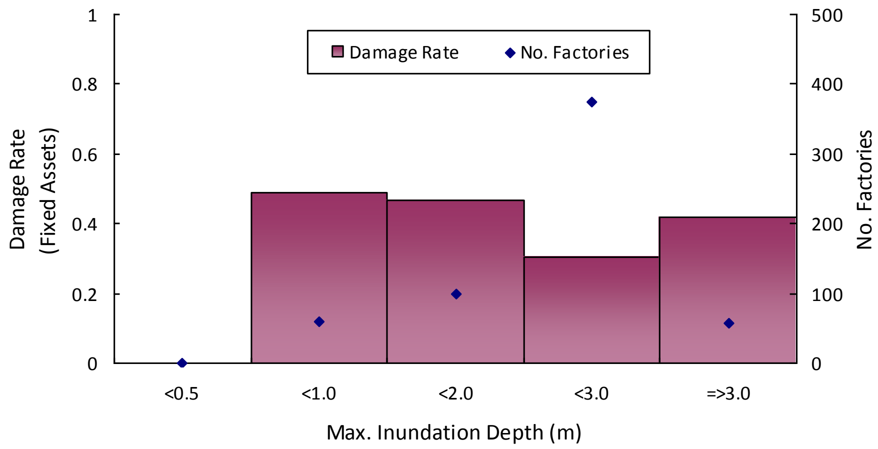


Figure 6.2.5 Relationship between Inundation Depth and Damage Rate (Fixed Assets)

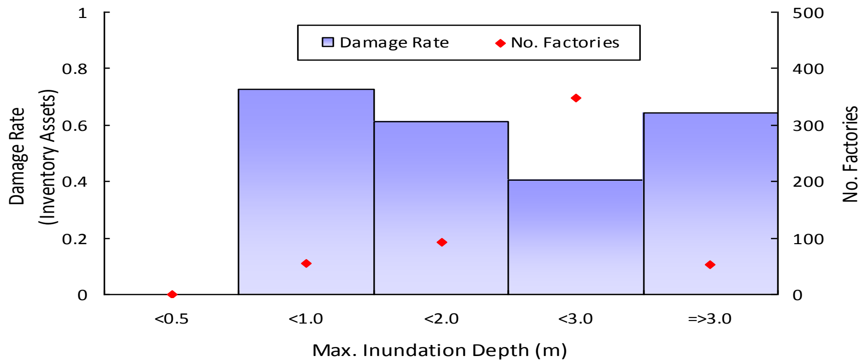


Figure 6.2.6 Relationship between Inundation Depth and Damage Rate (Inventory Assets)

Relations with inundation duration showed a different trend from those with inundation depth. The damage rate on fixed assets increased along the duration until 60 days, turning a decrease after the peak in Figure 6.2.7. However, for the inventory assets, the rate seemed to increase as the duration lasted. Taking account of the results, 30-60 days of duration could be a critical point whether the damage got worse or mitigated as shown in Figure 6.2.7.

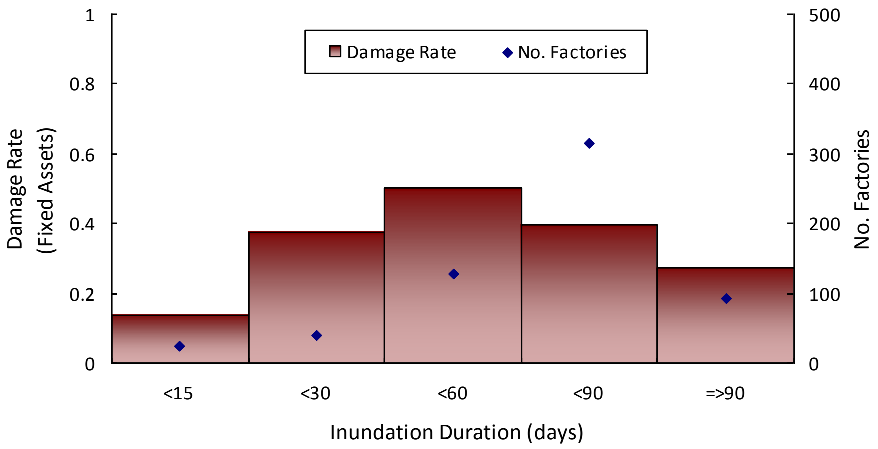


Figure 6.2.7 Relationship between Inundation Duration and Damage Rate (Fixed Assets)

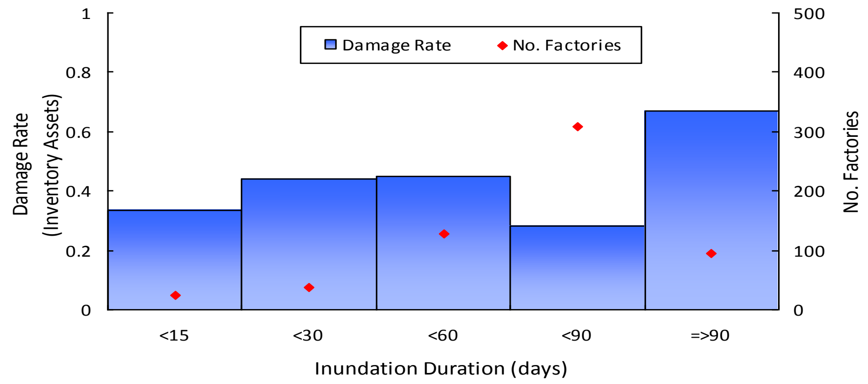


Figure 6.2.8 Relationship between Inundation Duration and Damage Rate (Inventory Assets)

6.3 Flood Response Operation Survey

6.3.1 Introduction

(1) Objectives

The objectives of this Survey are: (i) To identify the present operation mechanism and its problems to effect flood mitigation; (ii) To study on the new operation mechanism effective for flood mitigation; and (iii) To prepare the flood information network required for the effective operation mechanism.

(2) Scope of Work

The major scopes of work are: (i) Collection of data/information in the operation manuals/guidelines and records of operation of hydraulic structures and facilities such as dams, regulators, pumping stations, etc.; (ii) Conduct of interview with persons-in-charge of operation of hydraulic structures, particularly during the 2011 Flood; and (iii) Conduct of analysis of hydraulic conditions during the 2011 Flood, as well as the structures for compiling the problems and issues on operation and the recommendations on the information system for effective operation.

6.3.2 Summary of Survey

(1) Structures for Operation

The survey has been undertaken for 8 existing dams, 44 regulators, 12 pumping stations and 7 drainage tunnels (refer to Table 6.3.2, Table 6.3.3 and Figure 6.3.2 for the schematic diagram). Other than the two huge dams, Bhumibol and Sirikit, all structures are under the administration of RID[1]. Under BMA there is the drainage system composed of pumping stations, regulators, underground tunnels, etc.

(2) Current Operation Mechanism and Its Problems

The C.2 Stream Station (Nakhon Sawan) is practically used to monitor flood conditions and to conduct flood operation in the Lower Chao Phraya River Basin. Once the flow at the C.2 Stream Station reaches 2,000m^3/s, RID disseminates flood information to the public through the internet and notifies the Provincial DDPM about the flood condition along the Chao Phraya River. The Provincial DDPM shall then issue the announcement to the people living in low-lying areas and along the river banks to make them aware and be prepared for the impending disaster.

Dams

All hydraulic structures in the Chao Phraya River have been constructed mainly for irrigation and water supply. Dams/reservoirs work to store water during the rainy season and to supply water to the paddies in the dry season. Two huge dams, Bhumibol and Sirikit, are under the administration of EGAT, while their operations are actually conducted by the committee composed of EGAT, RID, etc. Due to the scale of the reservoirs of Bhumibol and Sirikit, they actually have a function of flood regulation. On the other hand, other dams/reservoirs must have minimal functions of flood regulation owing to their reservoir capacities.

Regulators

The regulators work to effectively supply/distribute the water within the receiving water volume from the upstream. The design discharge of a regulator is decided on the basis of irrigation area to be served. The regulator is hydraulically designed not only to accommodate the maximum irrigation requirement of the area to be served, but also to regulate the flood discharge of the Chao Phraya River.

Pumping Stations

Generally, the rice paddies situate in the low-lying area which is lower than the water level of the rivers and canals which supply the irrigation water. Therefore, the pumping station is constructed to drain the excess water stored in the rice paddy to the canals, and further operated to drain water from canals to main rivers during rainy season where water levels in the main rivers are higher than those in the canals.

(3) Operation in 2011 Flood

During the 2011 Flood, RID in corporation with RIO 12 (Regional Irrigation Office 12: responsible for the area on the right bank of Chao Phraya River) and RIO 10 (responsible for area on the left bank of Chao Phraya River) followed up and evaluated the situation throughout 24 hours. The operation itself was undertaken by the RID Project Office (O&M Office) for dams, regulators

[1] This Flood Response Operation Survey was undertaken and its final report was submitted by TEAM Consulting and Engineering and Management Co., Ltd. on November 30, 2012.
Drainage pumping stations under the administration of BMA are required to collect on their major features and operation records in the 2011 Flood. They will be compiled in the Final Report.

and pumping stations. The Project Office usually communicated to RIO and received the instruction from RIO.

RID attempted to reduce flow at the Chao Phraya Dam by diverting water to rivers/canals on both banks of the river, taking into account efficiency of the dam and the capacity of the river downstream of the dam in order to prevent river overflow. However this arrangement could not be done as planned because of inadequate capacities of river and canals and conflicts of people who are affected, etc. Generally, it is concluded that actual flood discharge and volume in the 2011 Flood exceeded the design discharge of each hydraulic structure, particularly the regulator.

In the actual operation during the 2011 Flood, the Project Office received the official information and instructions from RIO. RIO obtained the information from either the RID Central Office or other information sources, while the regulators in the Tha Chin River were operated following the instructions of RIO 12 where the orders are directed by the Flood Relief Operation Center (FROC). It is reported that there were no major issues in the official information transmission through the interview survey. However, some of the respondents of interview reported that the flood information/instruction requiring for operation of their structures were quite limited.

(4) Flood Protection and Drainage System under BMA

The drainage system of Bangkok is as summarized in Table 6.3.1.

Table 6.3.1 Hydraulic Structures in the Chao Phraya River under the Survey

Structures	Phra Nakhon Area	Thonburi Area	Total
Pumping Station	105	53	158
Regulator	105	109	214
Detention Pond	11	0	11
Dike	11	0	11
Drainage Tunnel	1	0	1
Road Culvert	6	2	8
Pumping House	1	0	1
Inlet Structure	4	0	4
Pumping System	1	0	1
Total	245	164	409

The flood protection system of Bangkok is provided with the water level of Chao Phraya River up to 2.50 m MSL, while the drainage system inside the polders is to cope with 60 mm/hr of the rainfall intensity with 285 regulators and 158 pumping stations in which the total discharge capacity is estimated to be 1,638.06 m^3/s.

Further, 7 underground tunnels were constructed to enhance drainage efficiency with 19 km of the total length and 155.5 m^3/s of the total drainage capacity. There is also a plan to construct additional 3 tunnels with 29 km of the total length and 180 m^3/s of the total drainage capacity.

(5) Flood Management and Operation Mechanism

The decision to receive flood water through a regulator into a project area was dependent on the decision at the project level. In case the project could not receive flood water, a report would be made and sent to RIO for approval. The flow chart of RID water management and operation is shown in Figure 6.3.1.

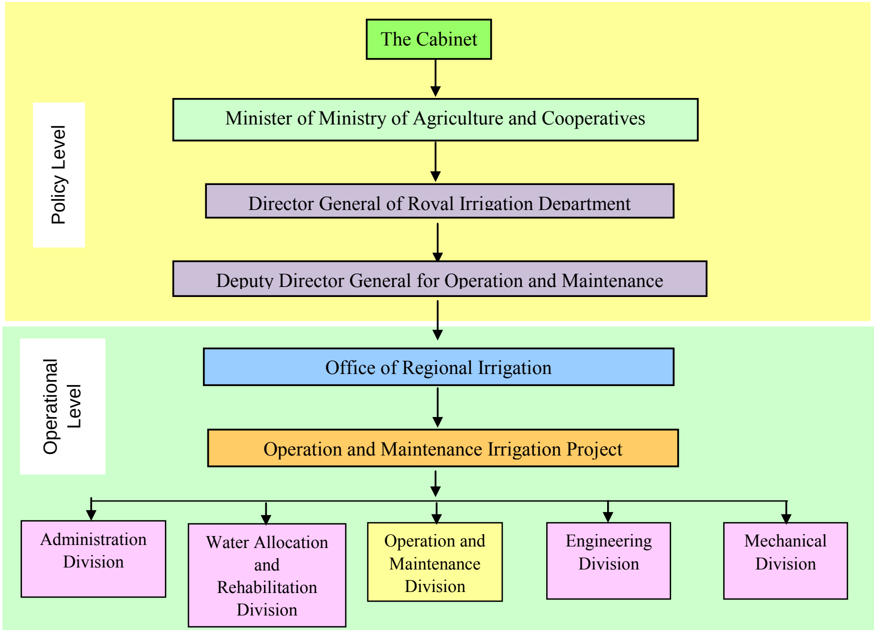


Figure 6.3.1 RID Water Management Organization

(6) Flood Information Dissemination

Orders and/or instructions for operation are transmitted down the line of authority from RID through RIO to O&M Irrigation Project via official letter, telephone, fax, or walkie-talkie. Information regarding operations of the concerned structures and the flood situation announced by RID are distributed through the line of authority as well. On the other hand, information, news, notification and announcement prepared by the respective government offices are disseminated to the concerned stakeholders and the public through different channels of communication such as telephone, facsimile, and radio.

6.3.3 Conclusion and Recommendation

(1) Conclusion

Flood preparation and information transmission/receipt for the operation of hydraulic structures were undertaken properly during the 2011 Flood, while the flood itself was an extraordinary event that was hardly controlled and mostly beyond the design capacities of all existing structures in the Chao Phraya River Basin. On the other hand, more effective coordination and cooperation among the agencies are required.

(2) Recommendation

Some recommendations were made through the Survey mostly on the information system for the effective structure operation as follows:

- Information on incoming inflow can be obtained from real-time data of telemetry stations.
- Telemetering and warning systems are required to obtain information of side flows at many locations based on the detailed hydrological analysis.
- Information obtained from telemetering system must be accessible directly in real-time from any project site concerned in order to use for assessing the flood situation as well as for water management.
- Update of information on present conditions of rivers/canals and structures are required, e.g., cross-sections, rating curves, gate flow equations, etc.
- Cooperation from local people is highly required for effective operational situation.

6.3.4 Analysis and Evaluation

Flood response operation in the Chao Phraya River Basin is analyzed and evaluated in line with the objectives of this Survey.

(1) Existing Operation Mechanism for Flood Mitigation

All hydraulic structures such as dams, regulators and pumping stations have been designed and constructed for irrigation water supply and drainage, while the drainage functions are allocated to prevent the flood damages in the irrigation areas, and two huge dams, Bhumibol and Sirikit may function to reduce the flood flows to the downstream owing to their scales.

The drainage system for Bangkok has been provided against the storm rainfall of less than 60 mm/hr and still developed to cope with the urban expansion.

Therefore, the flood response operation during the 2011 Flood, of which scale is estimated at more than 100-year return period, was very limited to mitigate the flood damage. The flood discharge and volume were far more than the designs of structures. Correspondingly, the guidelines and manuals of operation were not prepared.

Information system and network for operation functioned effectively even if the system had been provided for irrigation and drainage.

(2) New Operation Mechanism

Through the 2011 Flood, there have been identified and recognized three actions to be taken for preparation for the recurrence of big floods like the 2011 Flood, as follows:

(a) Upgrade of Structures

Through the detail hydrologic and hydraulic analyses, the existing structures shall be upgraded and/or replaced to make them effective for flood mitigation as well as maintain the original functions of irrigation water supply and drainage.

(b) Institutional Reform or Coordination

Most of the structures are under the management of RID and it’s regional and project offices, except Bhumibol and Sirikit dams and the Bangkok drainage system.

The integrated operation of all structures requires close institutional coordination or establishment of a unified organization for extreme flood events.

(c) Effective Information System

While upgrading the existing information system together with additional networking among the offices concerned, an effective information system including real-time meteorological-hydrological observation stations covering the whole river basin is indispensable for the integrated flood response operation.

(3) Flood Information Network for Effective Operation

Particularly, the flood information network is indispensable to provide for effective operation. The vast river basin area of Chao Phraya and numbers of hydraulic structures in the river basin need one comprehensive information network in order to grasp hydrologic and hydraulic conditions at every structure site for effective operation. Together with the meteorological conditions for estimating runoff discharges and the tidal gauges along the Gulf of Thailand for obtaining the hydraulic conditions in the estuaries of the Chao Phraya River and other neighbouring rivers/canals merging to the Gulf, the hydrological and hydraulic observation stations will detail the flood conditions basin-widely.

Table 6.3.2 Hydraulic Structures in the Chao Phraya River under the Survey (1/2)

Structures	Water Course	Name of Structure	Administration
Dam			
	Ping	1. Bhumibol Dam	EGAT
	Nan	2. Sirikit Dam	EGAT
	Kwae Noi (Nan)	3. Kwae Noi Dam	RID
	Wang	4. Kio Lom Dam	RID
	Wang	5. Kio Kho Ma Dam	RID
	Pasak	6. Pasak Dam	RID
	Sakae Krang	7. Tap Salao Dam	RID
	Tha Chin	8. Kra Siao Dam	RID
Regulator/ Weir			
	Yom	9. Mae Yom Weir	RID
	Nan	10. Phitsanulok Diversion Weir	RID
	Thap Salao	11. Thap Salao Diversion Weir	RID
	Yom to Nan	12. Control Regulator - DR. 15.8 (West)	RID
	Yom to Nan	13. Control Regulator No.1 - DR. 15.8 (East)	RID
	Yom to Nan	14. Control Regulator No.2 – DR. 2.8	RID
	Chao Phraya	15. Chao Phraya Dam	RID
	Suphan	16. Phonlatep Head Regulator	RID
		17. Ban Thabot Regulator	RID
		18. Sam Chuk Regulator	RID
		19. Pho Phraya Regulator	RID
	Noi	20. Borommathat Head Regulator	RID
		21. Channasut Regulator	RID
		22. Yang Mani Regulator	RID
		23. Phak Hai Rgulator	RID
	Noi - Suphan	24. Ladchand Regulator	RID
	Chainat - Pasak	25. Manorom Head Regulator	RID
		26. Chongkae Regulator	RID
		27. Khok Krathiam Regulator	RID
		28. Reong Rand Regulator	RID
	Chainat - Ayutthaya	29. Maharat Head Regulator	RID
	Makamthao-Uthong	30. Makamthao-Uthong Head Regulator	RID
	Pasak	31. Rama VI Barrage	RID
	Yom River	32. Ban Hat Saphan Chan Regulator	RID
	Chainat - Pasak	33. Bang Chom Sri Regulator	RID
	CPR – Lopburi River	34. Lopburi Head Regulator	RID
	Lopburi River	35. Lopburi Check Regulator	RID
		36. Lopburi Tail Regulator	RID
	CPR - Bang Kaew Canal - Lopburi River	37. Bang Kaeo Regulator	RID
	East side of Chao Phraya River		
	Rang Sit Canal	38. Chulalongkon Regulator	RID
	Rapeephat Canal	39. Phra Narai Regulator	RID
		40. Phra Mahin Regulator	RID
		41. Phra Ekathotsarot Regulator	RID
		42. Phra Sri Sin Regulator	RID
		43. Phra Sri Saowaphak Regulator	RID
	West side of Chao Phraya River (Linking between Chao Phraya – Tha Chin River)		
	Chao Chet - Bang Yi Hon Canal	44. Chao Chet Regulator	RID
		45. Banh Yi Hon Regulator	RID
	Phraya Ban Lue Canal	46. Singhanat Regulator	RID
		47. Phraya Ban Lue Regulator	RID
	Phra Phimon Canal	48. Bang Bua Thong Regulator	RID
		49. Phra Phimon Regulator	RID
	Yong - Bang Yai Canal	50. Yong Regulator	RID
	Maha Sawat Canal	51. Chimphli Regulator	RID
		52. Maha Sawat Regulator	RID

Table 6.3.3 Hydraulic Structures in the Chao Phraya River under the Survey (2/2)

Structures	Water Course	Name of Structure	Administration
RID-Pumping Stations			
	Tha Chin River and Chao Phraya River	1. Pathum Thani Project	RID
		2. Nonthaburi Project	RID
		3. Samut Prakan Project	RID
		4. Samut Sakhon Project	RID
		5. Northern Rangsit Project	RID
		6. Southern Rangsit Project	RID
		7. Phra-ong Chaiyanuchit Project	RID
		8. Chonhan Phichit Project	RID
		9. Chaochet-Bang Yihon Project	RID
		10. Phraya Banlue Project	RID
		11. Phra Phimon Project	RID
		12. Phasi Charoen Project	RID
BMA-Drainage Tunnels			
	Chao Phraya River	1. Sukhumvit 26 Drainage Tunnel	BMA
		2. Prem Prachakorn Diversion System	BMA
		3. Drainage System of Phayathai	BMA
		4. Sukhumvit 36 Drainage Tunnel	BMA
		5. Sukhumvit 42 Drainage Tunnel	BMA
		6. Drainage Tunnel from Makkasan Pond to Chao Phraya River	BMA
		7. Rama IX Drainage Tunnel	BMA

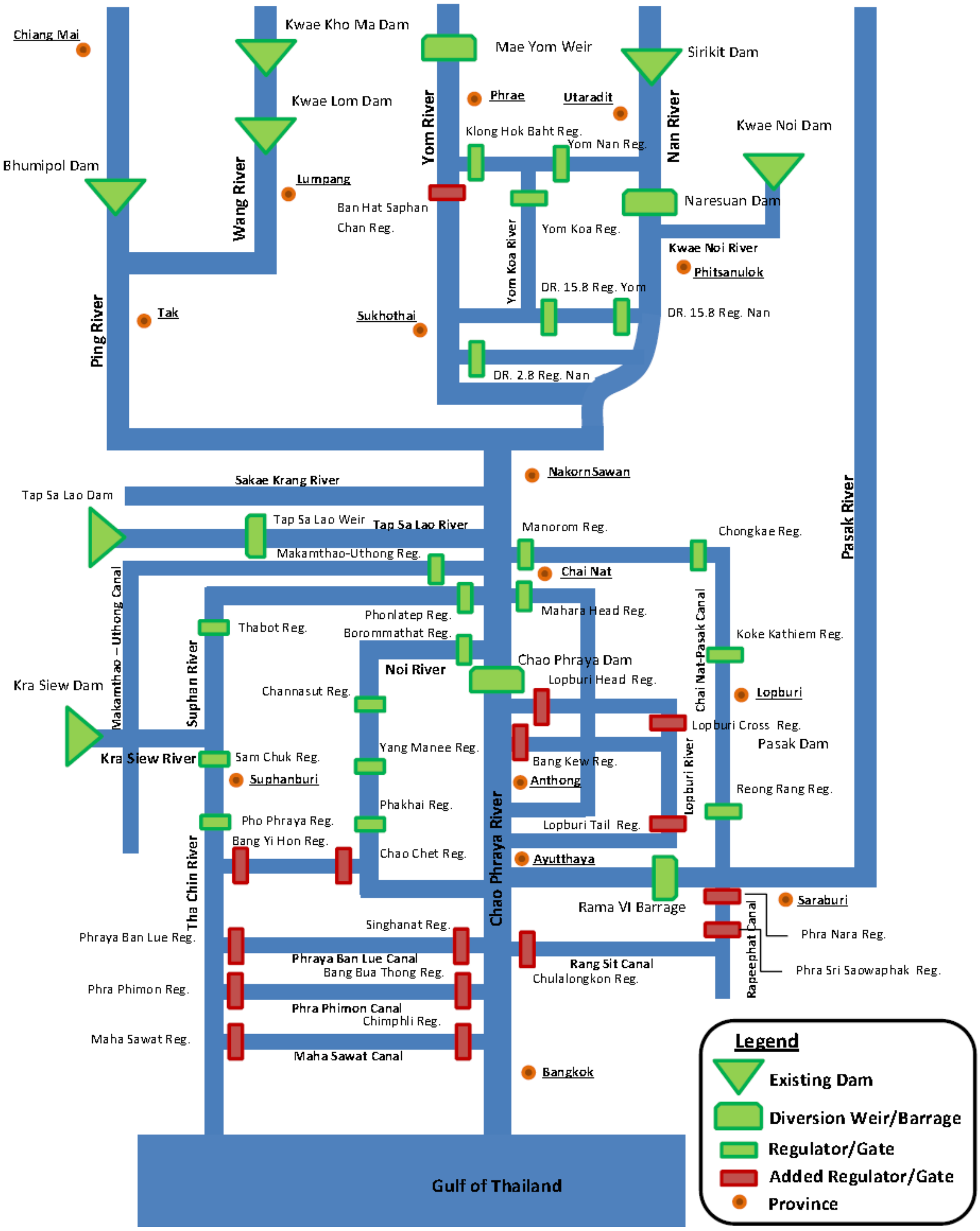


Figure 6.3.2 Schematic Diagram of Hydraulic Structures in the Chao Phraya River Basin

6.4 GIS Database

In the field of flood disaster, a large quantity of data/information is handled to understand the damaged conditions, to analyze some simulation and to make plans for the protection against next disasters. Therefore, a lot of data/information was collected from the various organizations concerned in the project. In terms of data management, the preparation of the database structure and information of data source, such as metadata are required to share the GIS database effectively among the related organizations.

In this session, the outline of GIS database which was generated in the project is introduced.

6.4.1 Basic Information

The basic information of constrructed GIS database is described in detail below.

(1) Data Type

Basically, there are three (3) kinds of data type in the GIS database.

1) Vector data (point, line and polygon)

2) Raster data (satellite image, DEM and scanned topographic map)

3) Tabular data (observation data)

(2) Data Format

Following data format for each data type was applied.

1) Vector data : ArcGIS Shape file format

2) Raster data : GeoTIFF format and JPEG format

3) Tabular data : MS Excel format

(3) Coordinate System

Following information was used for the coordinate system of GIS and remote sensing data.

1) Projected Coordinate System

- Projection: UTM(Universal Transverse Mercator) in Zone 47
- Origin of Meridian: 99° East of Greenwich
- Origin of Latitude: Equator
- Scale factor: 0.9996
- False easting: 500,000m
- False northing: 0m
- Unit of measurement: Meter
- Datum: WGS84

2) Geographic Coordinate System

- Latitude / Longitude Coordinate System
- Datum is WGS84enwich

6.4.2 Layer Structure

To manage the collected and created GIS data effectively for the Chao Phraya River Basin, the GIS database is being constructed based on the data dictionary of the RID (Royal Irrigation Department) in the currently ongoing project. The GIS data structure is listed below. There are 25 categories, such as Administrative Boundary, Population, Basin Boundary, Flooded Area, Transport, Water Body, Land Use, Topography, Hydrology, Irrigation, Industry, Satellite Imagery, Floodway, Retention Area and so on in the database, and some categories consist of a number of files. Finally, this GIS database shall be described in detail as a GIS Data Dictionary which is developed by RID

Administrative	Geology
Basin	Irrigation_Structure
Culture	Land_Use
Dam	Population
DEM	RID
Factory	Satellite
Flood_Analysis	Station
Flood_Area	Topographic
Flood_Structure	Transport
Forest	Water_Body

Figure 6.4.1 Constructed Layer Structure

6.4.3 Constructed GIS Database

In the project, many kinds of GIS data were collected from imvolved organizatrions and rearranged for the project purposes. The examples created using the constructed GIS data are shown below. In addition, the list of constructed GIS data is shown.

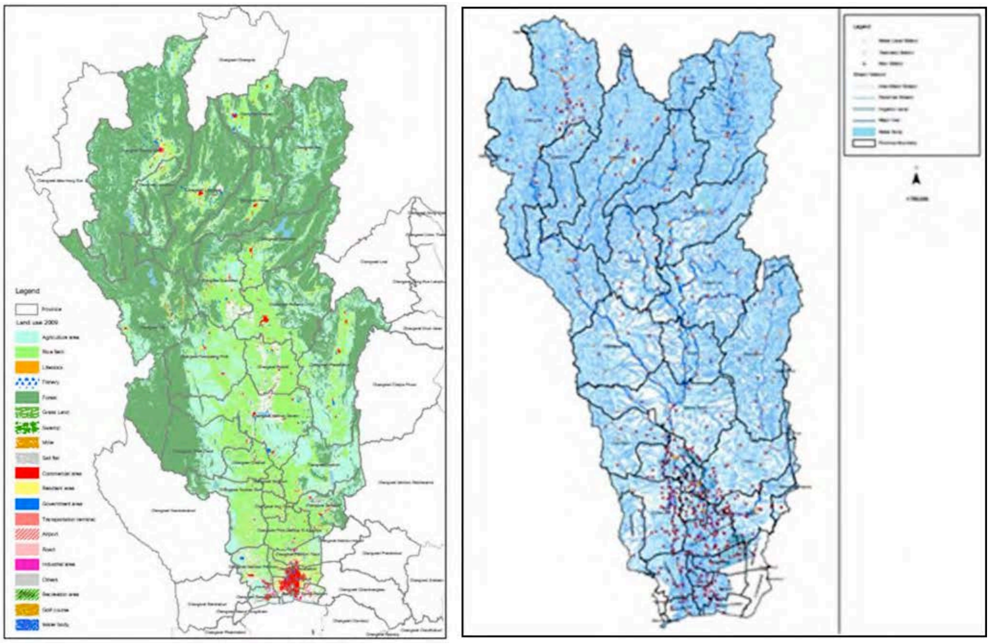


Figure 6.4.2 Thematic Maps created by Constructed GIS Data (Land Use, Station)

Table 6.4.1 The List of Constructed GIS Data

1. GIS Data (Vector Data)

Class	Leyer name	Data Format	From Where	Description
Admininistrative	Amp_pt_CPRB	Shape file (Point)	RID	Location of Apmphoe
	Amphoe_CPRB	Shape file (Polygon)	RID	Amphoe Boundary
	District_BMA	Shape file (Polygon)	BMA	Boundary of district of BMA
	Subdistrict_BMA	Shape file (Polygon)	BMA	Boundary of subdistrict of BMA
	Municipa_CPRB	Shape file (Polygon)	RID	Boundary of municipality
	Prov_pt_CPRB	Shape file (Point)	RID	Location of Provincial office
	Province_CPRB	Shape file (Polygon)	RID	Boundary of province
	Tambon_CPRB	Shape file (Polygon)	RID	Boundary of Tambon
	Village_CPRB	Shape file (Polygon)	RID	Location of Village
Basin	Basin_CPRB	Shape file (Polygon)	RID	River Basin Boundary
	Boundary_CPRB	Shape file (Polygon)	RID	Chao Praya River Basin Boundary
	Subbasin_CPRB	Shape file (Polygon)	RID	Sub Basin boundary
Culture	BMA office	Shape file (Point)	RID	Location of BMA District office
	Educate_BMA	Shape file (Point)	BMA	Location of School, University and Collage
	Hos_b_BMA	Shape file (Point)	BMA	Location of Big Hospital in BMA
	Hospital_BMA	Shape file (Point)	BMA	Location of hospital in BMA
	Landmark_BMA	Shape file (Point)	BMA	Location of landmark in BMA
	Landmark_CPRB_MOT	Shape file (Point)	MOT	Location of landmark in CPRB
	Police area_MOT	Shape file (Polygon)	MOT	Boundary of police station reponsible area
	School_BMA	Shape file (Point)	BMA	Location of school in BMA
Dam	Checkdam_CPRB	Shape file (Point)	RID	Location of Check dam in CPRB
	Dam_CPRB	Shape file (Point)	RID	Location of dam in CPRB
	Existing_Dam_CPRB	Shape file (Point)	RID	Location of Existing dam in CPRB
	Proposed_bigdam	Shape file (Point)	RID	Location of proposed big dam
	Proposed_Dam_CPRB	Shape file (Point)	RID	Location of proposed dam in CPRB
Flood_Area	Flood Potential Area	Shape file (Polygon)	GISTDA	Flood risk area
	Flood_08_2011_CPRB	Shape file (Polygon)	GISTDA	Flooded area in Aug 2011
	Flood_09_2011_CPRB	Shape file (Polygon)	GISTDA	Flooded area in Sep 2011
	Flood_10_2011_CPRB	Shape file (Polygon)	GISTDA	Flooded area in Oct 2011
	Flood_11_2011_CPRB	Shape file (Polygon)	GISTDA	Flooded area in Nov 2011
	Flood_12_2011_CPRB	Shape file (Polygon)	GISTDA	Flooded area in Dec 2011
	Flood_Grid_CPRB	Shape file (Polygon)	Study Team	Grid plan 2x2 sq.km for surveying
	Flood2005_CPRB	Shape file (Polygon)	GISTDA	Flooded area 2005
	Flood2006_CPRB	Shape file (Polygon)	GISTDA	Flooded area 2006
	Flood2007_CPRB	Shape file (Polygon)	GISTDA	Flooded area 2007
	Flood2008_CPRB	Shape file (Polygon)	GISTDA	Flooded area 2008
	Flood2009_CPRB	Shape file (Polygon)	GISTDA	Flooded area 2009
	Flood20010_CPRB	Shape file (Polygon)	GISTDA	Flooded area 2010
	Flood20011_CPRB	Shape file (Polygon)	GISTDA	Flooded area 2011
	Floodmark_CPRB	Shape file (Point)	Study Team	Location of flood depth serveying point
Flood_Structure	(Dyke) KingDike	Shape file (Polygon)	RTSD	Boundary of king dike
	(Dyke) ProtectionArea	Shape file (Polygon)	Study Team	Boundary of protection area
	(Floodway) Floodway_longterm	Shape file (Line)	Study Team	Alignment of flood way
	(Retention Area) RetentionArea_2012	Shape file (Polygon)	Study Team	Boundary of retention area
	(Retention Area) RetentionArea_Masterplan	Shape file (Polygon)	Study Team	Boundary of retention area from RID's master plan
	(Retention Area) RetentionArea_Study	Shape file (Polygon)	Study Team	Boundary of retention area from study team
	(Retention Area) RetentionArea_TOR	Shape file (Polygon)	Study Team	Boundary of retention area from TOR
Forest	Forest2004_CPRB	Shape file (Polygon)	Forest Dep.	Forest area 2004
	Forest2008_CPRB	Shape file (Polygon)	Forest Dep.	Forest area 2008
Geology	Geol_str_CPRB	Shape file (Polygon)	DMR	Geology structure
	Geology_CPRB	Shape file (Polygon)	DMR	Geology
Irrigation_Structure	Canal	Shape (Line)	RID	Location of canal
	Pump_station	Shape (Point)	RID	Location of pump station
	Regulator	Shape Point)	RID	Location of regulator
Land_Use	Land use 2002_CPRB	Shape file (Polygon)	LDD	Land use 2002 in CPRB
	Land use 2009_CPRB	Shape file (Polygon)	LDD	Land use 2009 in CPRB
Population	POP_CPRB	Shape file (Polygon)	DOPA	Population in Tambon level year 2011 in CPRB
RID	Hydro_center_CPRB	Shape file (Point)	RID	Location of water manangement and hydrology office
	Hydro_region_CPRB	Shape file (Polygon)	RID	Responsible area of water management and hydrology department regional office
	Irrigation office_CPRB	Shape file (Point)	RID	Location of RID regional office
	Irrigation_Project_area_CPRB	Shape file (Polygon)	RID	Responsible area of RID project office
	Prov_RID_CPRB	Shape file (Point)	RID	Location of RID provincial office office
	RID_CPRB	Shape file (Polygon)	RID	Responsible area of RID regional office
Station	Bouy_Station	Shape file (Point)	GISTDA	Location of Bouy station
	Coastal_Radar_Station	Shape file (Point)	GISTDA	Location of coastal radar station
	Coastal_Water_level_Station	Shape file (Point)	GISTDA	Location of coastal water level station
	Level_staion_CPRB	Shape file (Point)	RID	Location of water level station in CPRB
	Rain_station_CPRB	Shape file (Point)	RID	Location of rain station in CPRB
	Station_location	Shape file (Point)	RID	Location of Observation station
	Telestaion_CPRB	Shape file (Point)	RID	Location of telemetering station in CPRB
	Telemetry_Station_DWR	Shape file (Point)	DWR	Location of telemetering station in CPRB from DWR
	TMD_Station_CPRB	Shape file (Point)	TMD	Location of TMD station
	Weather_Station_CPRB	Shape file (Point)	RID	Location of weather station
Topographic	Contour_CPRB	Shape file (Line)	RID	Contour line
	Spot height_CPRB	Shape file (Point)	RID	Spot height
	(Topographic Map) Index50000	Shape file (Polygon)	RID	Legend of topograpic map
	(Map50000)	Raster (jpg file)	RID	Topographic map
Transport	BTS_MOT	Shape file (Line)	RID	Alignment of BTS and MRT line
	Mainroad_BMA	Shape file (Line)	RID	Main road in BMA
	Road_MOT_CPRB	Shape file (Line)	MOT	Road network in CPRB from MOT
	Road_RID_CPRB	Shape file (Line)	RID	Road network in CPRB from RID
	Rail_MOT_CPRB	Shape file (Line)	MOT	Rail track alignment in CPRB
	Station_MOT_CPRB	Shape file (Line)	MOT	Train station in CPRB
Water_Body	Main River_CPRB	Shape file (Line)	RID	Main river in CPRB
	Stream_CPRB	Shape file (Line)	RID	Stream in CPRB
	Water body_CPRB	Shape file (Polygon)	RID	Water body in CPRB

2. Image Data (Raster Data)				
DEM	GDEM_CPRB	GRID file	ASTER	Digital Elevation Data with 30m resolution in Chao Phraya River Basin
	SRTM_CPRB	GRID file	NASA	Digital Elevation Data with 90m resolution in Chao Phraya River Basin
Satellite	L5_129048_19960116	ERDAS Imagine	USGS	LANDSAT-5 observed in 1996
	L5_129049_19960116			LANDSAT-5 observed in 1996
	L5_129050_19960523			LANDSAT-5 observed in 1996
	L5_129051_19960523			LANDSAT-5 observed in 1996
	L5_130048_19960123			LANDSAT-5 observed in 1996
	L5_130049_19960123			LANDSAT-5 observed in 1996
	L5_130050_19960208			LANDSAT-5 observed in 1996
	L5_129048_20110415			LANDSAT-5 observed in 2011
	L5_129049_20110415			LANDSAT-5 observed in 2011
	L5_129050_20110415			LANDSAT-5 observed in 2011
	L5_129051_20110415			LANDSAT-5 observed in 2011
	L5_130048_20091212			LANDSAT-5 observed in 2009
	L5_130049_20091212			LANDSAT-5 observed in 2009
	L5_130050_20091212			LANDSAT-5 observed in 2009
Topographic	(Map sheet No.)	JPEG Image	RID	Scanned topographic maps at the scale of 1: 50,000
3. Tabular Data				
Factory	Factory data 2012	Exel	MOI	Factory data in 2012 from MOI

6.4.4 Data Dictionary

Basically, GIS Data itself, has attribute information, such as name, type, coordinate and so on, The information will be very useful for users to understand the data quality. Therefore, the data dictionary was prepared in the project, and it is attached as a supporting report.

6.4.5 Metadata

A metadata is extremely important information to handle the GIS data in terms of the data quality. If the GIS data has metadata, it is easy for users to understand the data quality and its source, for instance, who created the data, which is the responsible party for the data, what is the source data to generate the data, which area is covered, etc.

According to the ISO19115 (Geographic Information – Metadata), there are more than 400 elements for metadata. However, it would be take much time to prepare all metadata elements. On the other hand, a core metadata is about 40 elements with basic information. This core metadata is covering the minimum required information, such as data quality, data responsibility, reference system, identification, extent, etc. Therefore, the core metadata was prepared using Metadata Editor in Arc Catalog for the constructed GIS data in the project. The core metadata structure is shown below.

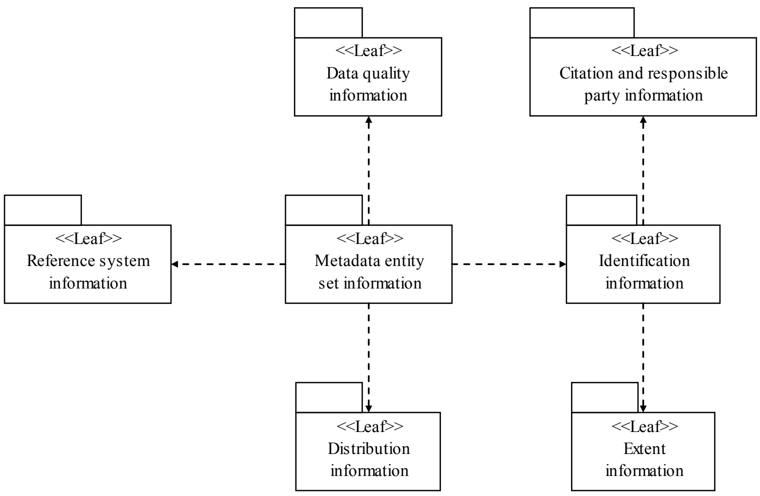


Figure 6.4.3 Core Metadata Structure

CHAPTER 7 HYDROLOGICAL STUDY

7.1 Observation Stations

To have a better understanding on the hydrological characteristics of the study area, field measured data, including water level, tidal level, discharge, and rainfall data needs to be collected and analyzed. In Thailand, there are several governmental agencies that are responsible for data collection and installation and operation of observation stations. In this section, general information on observation stations are summarized for each parameter including water level, tidal data and rain data.

7.1.1 Water Level and Discharge Measurements

Water level and discharge in the study area are observed mainly by two agencies, the Royal Irrigation Department (RID) and the Department of Water Resources (DWR). The total number of water level (discharge) stations in the Cho Phraya River Basin is 417, and among them 306 are RID stations and 111 are DWR stations. Water level stations are classified into two, gauging station with staff gauge measurement and telemetry station with automatic meter reading.

At each station, discharge measurements are taken for validating and updating the existing rating curve. DWR employ the current meter measurement, using cup type current meter and propeller type current meter, depending on the size of the surveyed river. RID also uses current meter as a base measurement method, and new technologies Acoustic Doppler Current Meter such as River Surveyor M9 and H-ADCP. These equipment are beneficial for the observation of hydraulic characteristics in detail at stations where the observation data is important for structure operation or the observed flow condition is unique, including adverse flow due to the tidal effect.

Generally, data validation and checking are conducted by “Staff Experience Check” before the data utilization, including publishing at Website or preparation of Yearbook.

7.1.2 Tidal Data Measurement

Tidal data is observed mainly by four agencies, the Royal Thai Navy (RTN), the Marine Department (MD), and the Port Authority of Thailand (PAT). In the Chao Phraya River Basin and the Gulf of Thailand, there are a total of 24 stations with two measurement methods, digital measurement and graphical measurement. RTN have 9 stations, one digital station and 8 graphical station, whereas MD and PAT stations are only graphical, 8 and 7 stations, respectively.

Although the timing varies from agency to agency, the data sheet is collected from the station once a month and submitted to the main office of each agency for further analysis. Typically an assigned officer reads the record and prepares a table of hourly record which is checked by “Staff Experience Check.” The collected data are used for various ways, RTN predicts the tidal level based on the observed data and publishes the data in digital form (CD-ROM) and hard copy (book), MD and PAT utilize the data for transportation or dredging projects.

7.1.3 Rainfall Measurement

Rainfall data is observed mainly by three agencies, Thai Meteorology Department (TMD), RID and DWR. The total number of rainfall stations installed in the Chao Phraya River Basin is 1,334. Among all stations, the number of stations of TMD, RID and DWR are 487, 494, 353 respectively. Station types include telemetry, manual and early warning stations. These stations spread over a wide area within the Cho Phraya Basin. RID stations concentrate covering the Lower Chao Phraya Basin around the Bangkok area, and DWR stations cover the upper Chao Phraya Basin. On the other hand, TMD stations are well distributed covering the enter river basin.

TMD publishes the observed data made available for the public to purchase and utilize for various purposes. The data include parameters such as rainfall, temperature, pressure, relative humidity, wind (speed and direction), evaporation and sunshine. Other agencies data are used to prepare the Yearbook or used for only internally, such as generating and conducting simulation.

7.2 Hydrological Analysis for Determination of Target Design Floods

7.2.1 Introduction

In order to determine one of the most important conditions for the Master Plan, Target Design Floods, a variety of hydrological analyses were conducted in accordance with the following flow:

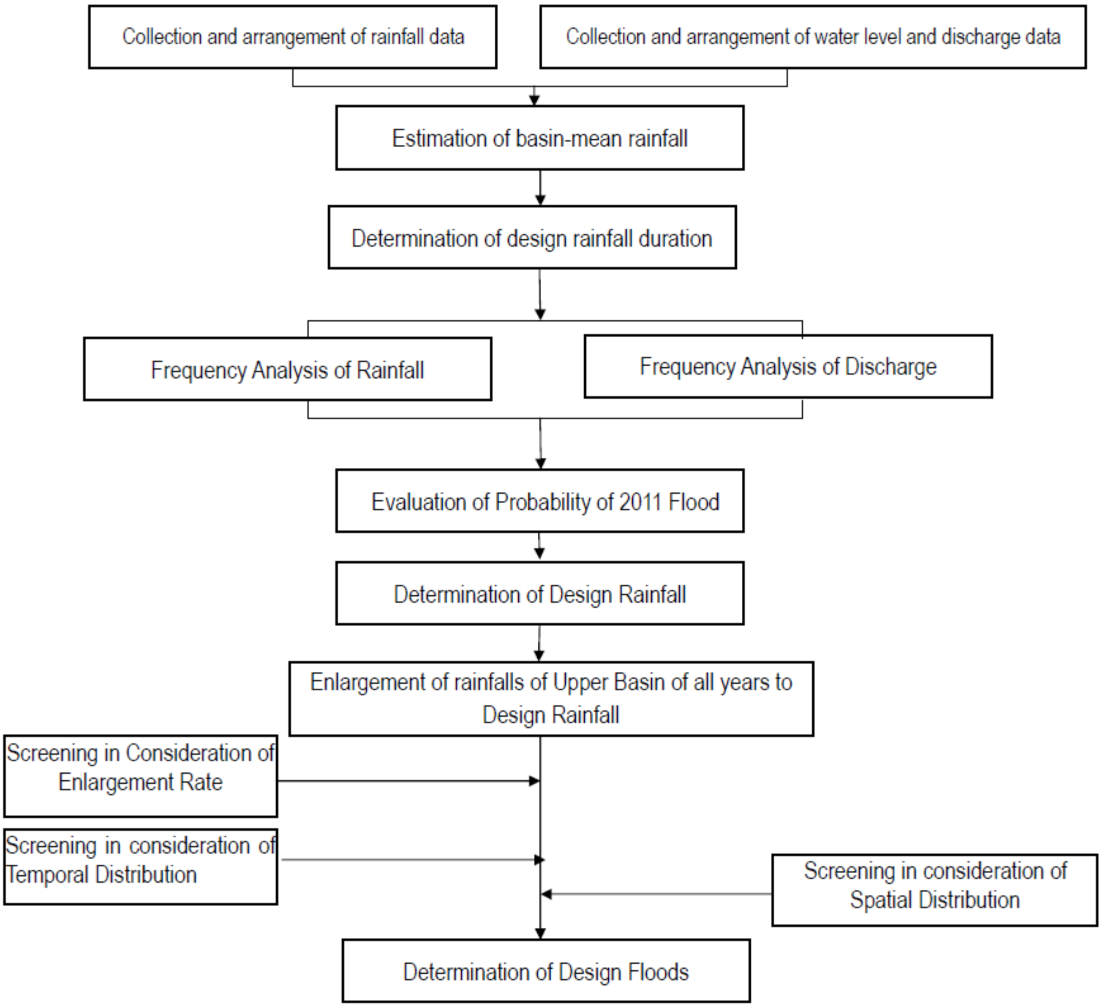


Figure 7.2.1 Flow of Determination of Target Design Floods

7.2.2 Rainfall Stations for Rainfall Analysis

(1) Data Collection

Rainfall data are collected from RID, TMD and DWR, etc., and arranged as presented in Table 7.2.1. The data collection was conducted in two stages. In the first stage before June 8, 2011 rainfall data of 241 stations were collected from the RID Data Center and TMD. However, the collected data are concentrated in the downstream area of the Chao Phraya River Basin and there are less data in the middle and upstream areas. Therefore, rainfall data are additionally collected again from RID Hydro Centers, TMD, DWR, etc., to improve the data density especially in the middle and upstream areas.

CTI Engineering International Co., Ltd.
Oriental Consultants Co., Ltd.
Nippon Koei Co., Ltd.
CTI Engineering Co., Ltd.

Table 7.2.1 Collected Rainfall Data

Data Set No.	Data Source	No. of Stations	Remarks
1	RID(RID data center)	195	-
2	TMD	46	-
3	RID&TMD (Hydrology)	292	・ Data period is as short as 4 years from 2009 to 2012.
4	RID&TMD (Website of RID Hydro-1)	145	・ There are many data errors (data year, code number, data format). ・ Many same data as Data Set 1 and 2are included.
5	RID&TMD (Hydro center 1)	185	・ Most of the data are for the stations upstream of Nakhon Sawan. ・ There are many data errors (data year, code number, data format). ・ Many same data as Data Set 1 and 2are included.
6	RID (Hydro Center 5)	16	・ There are many data errors (data year, code number, data format). ・ Many same data as Data Set 1 and 2are included.
7	DWR	35	・ Although the number of stations is 35, only those of 28 stations can be used because the others include long-term data lacking.
8	HAII	-	・ Data period is as short as 5 years from 2008 to 2012.

: Collected after June 8, 2012

(2) Setup of Alternative Combination of Rainfall Stations

It is very important to fix rainfall stations that are used for calculation of basin mean rainfall in consideration of spatial distribution of stations, data lacking situations and data periods. The relationship between basin mean rainfall and selected rainfall stations for the basin mean rainfall calculation is studied for the following four cases, focusing on the station density:

Case 1: TMD 46 Stations (TMD46)
Case 2: TMD46 + RID 195 Stations (TMD+RID)
Case 3: TMD46 + RID 195 + Additional 169 Stations (TMD+RID+169)
Case 4: All 505 Stations (Full)

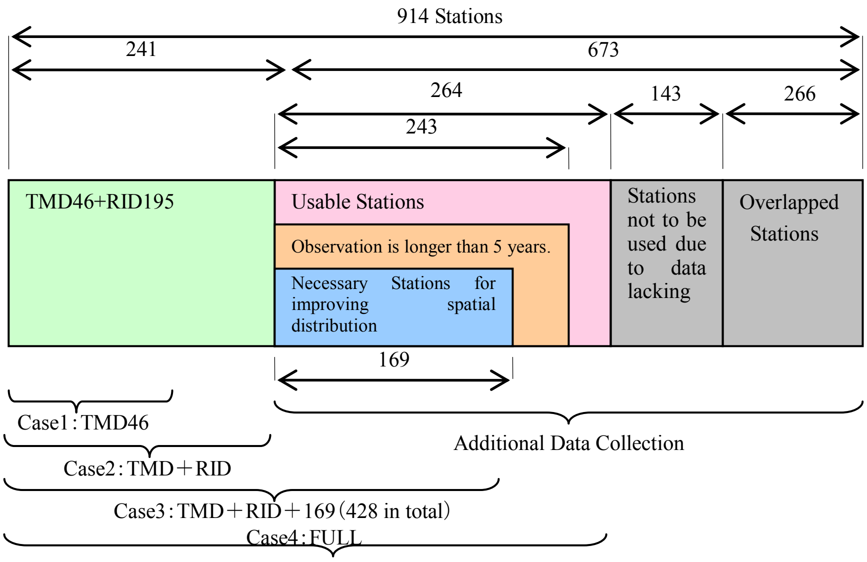


Figure 7.2.2 Number of Selected Stations for Four Cases

(3) Basin Mean Rainfalls of 4 Cases

Basin mean rainfalls of the 4 cases are compared in Table 7.2.2 and Table 7.2.3. The basin mean rainfall is the 6-month rainfall that seems to be more correlative to the flood phenomena of the Chao Phraya River Basin. Recent three flood years, 1995, 2006 and 2011 are selected for the comparison.

According to the tables, for the three cases 2 to 4 the differences of the basin mean rainfalls are about 3% or less. Especially, the differences between Cases 3 and 4 are very small, maximum ±0.7%. Similar tendency is observed for basin mean rainfalls of sub-basins.

Table 7.2.2 Basin Mean 6-Month Rainfalls of Upper Basin Upstream of Nakhon Sawan

Unit: mm

Division	Case1 (TMD46)	Case2 (TMD+RID)	Case3 (TMD+RID+ addition of 136)	Case4 (FULL)
1995 Flood	1,196 (-3.6%)	1,240 (-0.1%)	1,243 (0.2%)	1,241
2006 Flood	1,398 (0.9%)	1,344 (-2.9%)	1,375 (-0.7%)	1,385
2011 Flood	1,533 (3.6%)	1,474 (-0.3%)	1,483 (0.3%)	1,479

Note: Values in % are differences from Case 4.

Table 7.2.3 Basin Mean 6-Month Rainfalls of Entire Chao Phraya Basin

Unit: mm

Division	Case1 (TMD46)	Case2 (TMD+RID)	Case3 (TMD+RID+ addition of 136)	Case4 (FULL)
1995 Flood	1,171 (-3.5%)	1,211 (-0.2%)	1,216 (0.2%)	1,214
2006 Flood	1,312 (3.2%)	1,251 (-1.6%)	1,266 (-0.5%)	1,271
2011 Flood	1,437 (3.6%)	1,386 (-0.1%)	1,390 (0.3%)	1,387

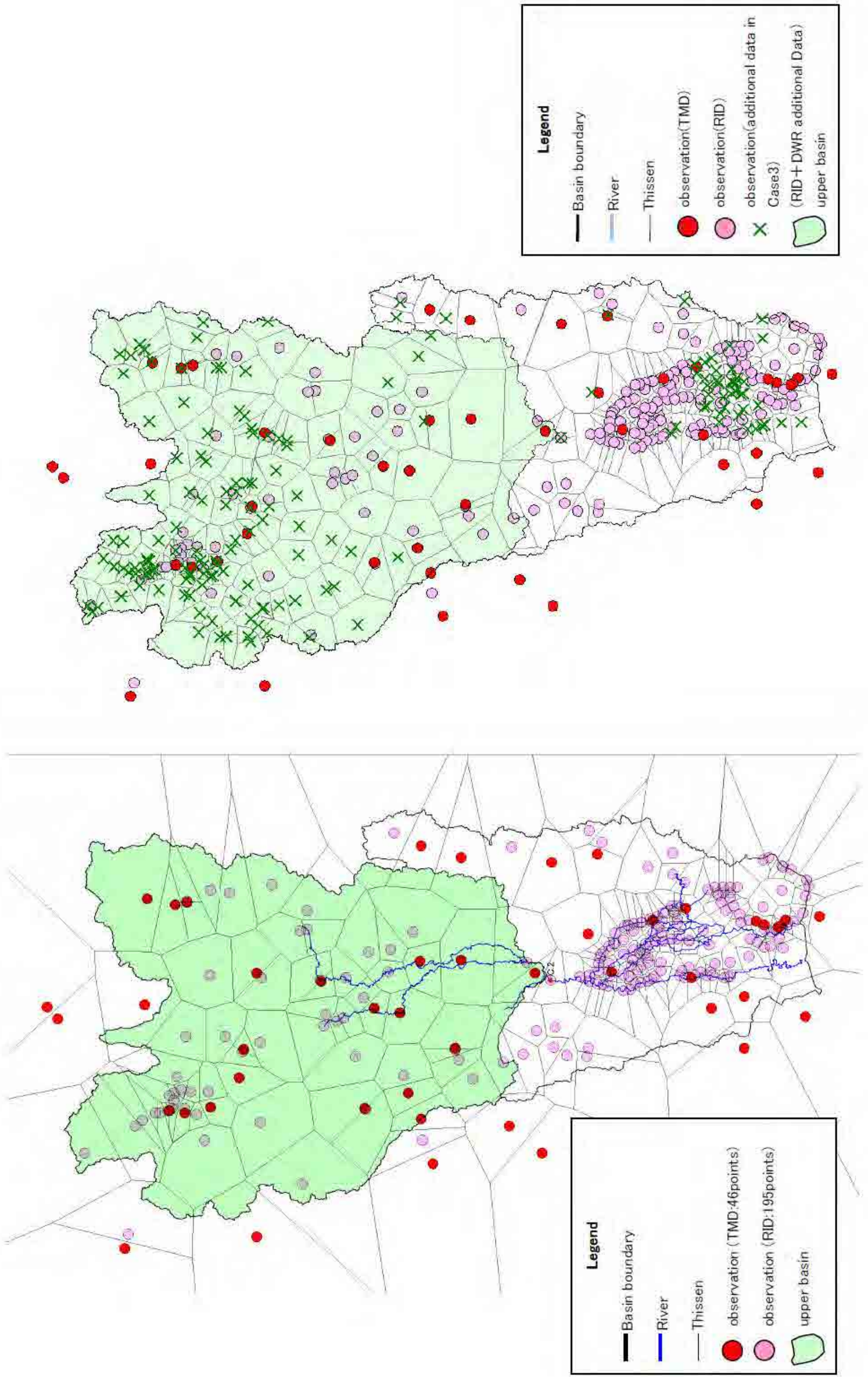
Note: Values in % are differences from Case 4.

(4) Determination of Rainfall Stations for Rainfall Analysis

Based on the above examinations, Case 3 (TMD+RID+169) is adopted as the combination of rainfall stations for the rainfall analysis in the next section from the following reasons:

- Differences among Case 2 (TMD+RID), Case 3 (TMD+RID+169) and Case 4 (Full) are small. Especially that between Case 3 (TMD+RID+169) and Case 4 (Full) is very small even for the basin mean rainfalls of the sub-basins.
- The maximum Thiessen polygon areas of Case 3 and Case 4 are at the same level. The both cases have higher station density than Case 2.
- Therefore, Case 3, to which usable stations were properly added to improve low station-density areas of Case 2, is recommendable.

Thiessen polygon divisions for Cases 2 and 3 are presented in Figure 7.2.3.



a) Case 2 (TMD+RID)

b) Case 3(TMD+RID+169)

Figure 7.2.3 Location of Rainfall Stations and Thiessen Polygons

7.2.3 Rainfall Analysis

(1) Setup of Design Rainfall Duration

Rainfall duration is one of the basic conditions for the planning of the Master Plan. Although the flood phenomena are influenced by a variety of factors of the vast river basin, an examination is made to determine the most influential rainfall duration on the flood phenomena of the Chao Phraya River Basin in this subsection.

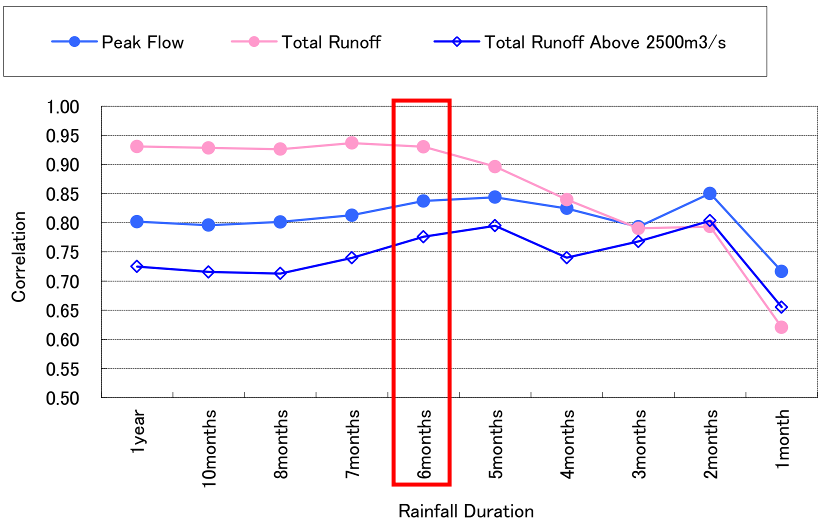
For this purpose, a regression analysis was made between basin mean rainfalls of different durations of the Upper River Basin upstream of Nakhon Sawan, the annual maximum discharges and the annual total discharge volumes and the annual total discharge volumes exceeding certain discharges (flow capacities of river channels) at C.2 Nakhon Sawan. Results are presented in Figure 7.2.4.

From the results the following can be said:

- Regarding the correlation between rainfalls of different durations and peak discharges, 2-month and 6-month rainfalls have higher correlation coefficients.
- 6-month or longer rainfall have higher correlation coefficients with the total runoff discharge volume.
- 2, 3, 5 and 6-month rainfalls have higher correlation coefficients with the discharge volumes exceeding the flow capacities.

Based on the above results, it is proposed to adopt 6 months as the design rainfall duration for the Chao Phraya River Basin from the following reasons:

- Since the flood of the Chao Phraya River Basin is characterized by its long-time flood phenomenon extending a few months, discharge volume seems to be more important than peak discharges.
- The first and second largest flood volume floods, the 2011 and 2006 floods have also the first and second largest 6-month rainfalls. It is deemed that the 6-month rainfalls reflect the flood scale very well.



Note: The flow capacity at C.2 Nakhon Sawan was evaluated to be 2500 m^3/s by JICA 1999 Study

Figure 7.2.4 Correlation Coefficients between Rainfall of Different Durations and Discharges

Regarding how to decide the 6-month rainfall period, the 6-month duration (183 days) is determined so that the 6-rainfall could be the maximum in the year as usually practiced when extracting extreme rainfall data for frequency analysis.

(2) Frequency Analysis

To assess the scale of the 2011 flood in terms of return period, frequency analysis of rainfall was conducted. Conditions of the analysis are as summarized in Table 7.2.4, and applied probability distribution models are listed in Table 7.2.5.

Table 7.2.4 Conditions of Frequency Analysis of Rainfall

Items	Description
Rainfall Data	Case3（TMD＋RID＋169）
Data Years	1961 to 2011（51years）
Number of Rainfall Station	428 stations at the maximum（different year to year）
Estimation of Basin Mean Rainfall	Thiessen Method
Thiessen Polygon Pattern	Annually fixed in principle.（However, if there are lacking rainfall data in three months from January to March, another Thiessen polygon pattern is created excluding the lacking stations.

Table 7.2.5 Probability Distribution Model

NO	Probability Distribution Model	
1.	Exp	Exponential Distribution
2.	Gumbel	Gumbel Distribution
3.	SqrtEt	Square-root Exponential Type Maximum Distribution
4.	Gev	Extreme Value Distribution
5.	LP3Rs	Peason Type III Distribution (Real Space)
6.	LogP3	Peason Type III Distribution (Logarithmic Space)
7.	Iwai	Iwai Method
8.	IshiTaka	Ishihara･Tahase Method
9.	LN3Q	Log-normal Distribution (Quantile Method)
10.	LN3PM	Log-normal Distribution 3 (Slade II)
11.	LN2LM	Log-normal Distribution 2 (Slade I, L-moment method)
12.	LN2PM	Log-normal Distribution 2 (Slade I, Product moment method)

Results of the frequency analysis for the Upper Basin upstream of Nakhon Sawan and the entire Chao Phraya River Basin are presented in Figure 7.2.5 and Figure 7.2.6.

Based on the above results, the return period of the 2011 Flood is estimated as summarized in Table 7.2.6. Namely, the return period of the 6-month rainfall of the Upper Basin in 2011 is estimated at about 50 to 350 years if those of models of which SLSCs (Standard Least Square Criterion) are equal to or less than 0.04 are applied. If LN2PM (Log-normal Distribution 2 (Slade I, Product Moment Method) that gives the smallest SLSC of 0.028 is applied, the return period is evaluated at 141 years. For the Entire Chao Phraya River Basin, the return period is estimated at about 90 to 210 years if models of SLSCs ≤ 0.04 are applied. If LN2PM that gives the smallest SLSC is applied, the return period is evaluated at 100 years.

Table 7.2.6 Evaluation of Scale of 2011 Flood

Rainfall Duration	Upper Basin upstream of Nakhon Sawan			Entire Chao Phraya River Basin		
	Range of probability	Minimum SLSC		Range of probability	Minimum SLSC	
	SLSC ≤ 0.04	Probability	Model	SLSC ≤ 0.04	Probability	Model
6 months	1/53 to 1/345	1/141	LN2PM	1/90 to 1/207	1/100	LN2PM

The probable rainfall (6-month rainfall) in upper area from Nakhon Sawan (C.2) and whole basin is shown in the following table.

Table 7.2.7 Probable Rainfall in Chao Phraya River Basin

Return Period	Rainfall (mm/6month)	
	Upper Nakhon Sawan (C.2)	Whole Basin
	Area: 105,000km^2	Area:163,000km^2
2	1,087	1,054
3	1,148	1,109
5	1,209	1,165
10	1,278	1,227
20	1,339	1,282
30	1,371	1,311
50	1,410	1,346
80	1,444	1,376
100	1,459	1,390
120	1,472	1,401
140	1,482	1,411
150	1,487	1,415
160	1,491	1,419
180	1,499	1,426
200	1,506	1,432

*Rainfall Duration: 6 month, equal to 183days
Probability density function: LN2PM

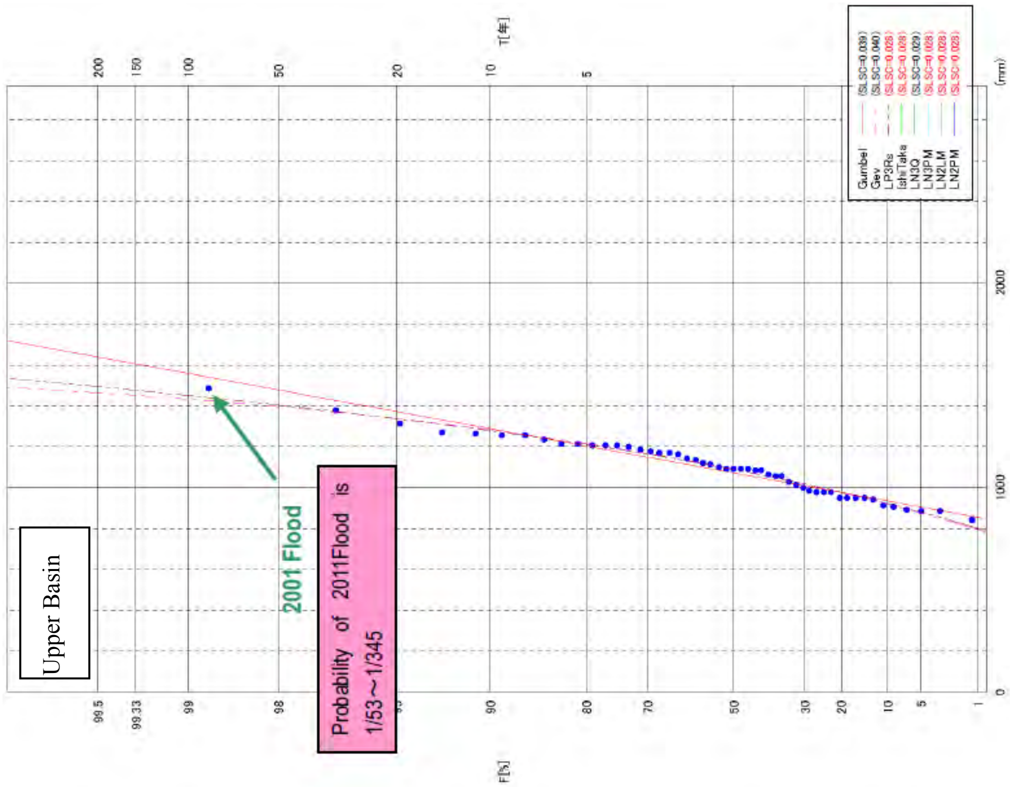


Figure 7.2.5 Probability Distribution on Gumbel Probability Paper (Upper Basin, 6-Month rainfall)

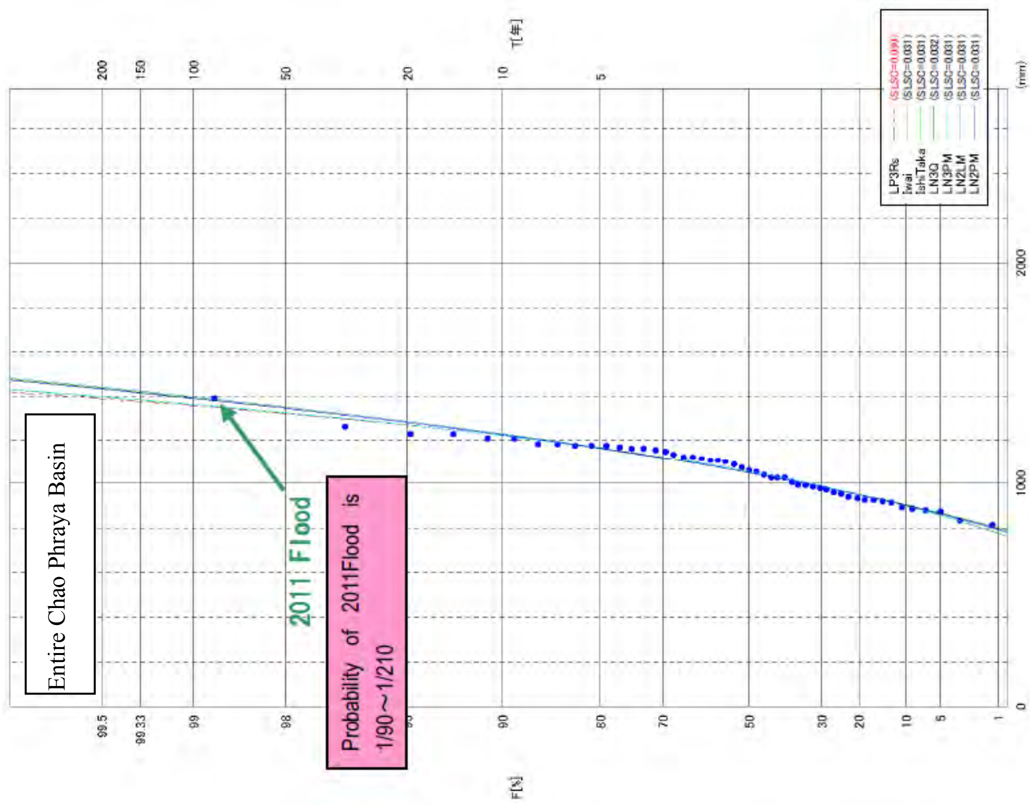


Figure 7.2.6 Probability Distribution Gumbel Probability Paper (Entire Chao Phraya Basin, 6-Month rainfall)

7.2.4 Frequency Analysis of Discharge

The scale of rainfall of the 2011 Flood was evaluated in the preceding section. In this section the scale of river discharge of the 2011 Flood is evaluated.

(1) C.2 Nakhon Sawan Discharge

Nakhon Sawan is one of the most important control points in terms of flood mitigation for the Chao Phraya River Basin. The location divides the river basin into the Upper Basin composed of three major tributaries, Nan, Yom and Ping and the Lower Delta Area where economical properties are concentrated. Therefore, discharge of C.2 Station at Nakhon Sawan is subject to the evaluation.

(2) Removal of Influences of Two Gigantic Dam Reservoirs

To correctly evaluate the discharge at Nakhon Sawan, influences of dam reservoirs should be removed from the observed data. There are many dam reservoirs in the Chao Phraya River Basin. Among them only two gigantic dams, Bhumibol and Sirikit, which started their operation in 1964 and 1974 respectively, significantly affect the discharge at Nakhon Sawan. Therefore, the observed discharge is modified by removing the influences of the two dam reservoirs.

The observed discharge data at C.2, Nakhon Sawan, after Bhumibol Dam started its operation in 1964 is modified under the conditions if the two gigantic dam reservoirs had not been existent. The methodology is explained as follows:

1. By using a MIKE11 Flood Routing model, discharges at Nakhon Sawan with and without the dam(s) are estimated respectively.
2. The flood regulation discharge at Nakhon Sawan is estimated by subtracting the discharge with the dam(s) from the discharge without the dam(s).
3. The regulation discharge is added to the observed discharge at C.2 (Nakhon Sawan). The obtained discharge in this way can be regarded as the discharge after influences of the dams were removed.

(3) Three Kinds of Discharge Data

A dataset of modified 56-year discharge data without dams at C.2 (Nakhon Sawan) are prepared by the calculation explained above. From this dataset, three kinds of discharge data that are subject to the frequency analysis are further prepared:

1. Maximum Discharge
2. Annual Total Runoff Volume
3. Runoff Volume exceeding Flow Capacity of 2,500m^3/s

(4) Frequency Analysis

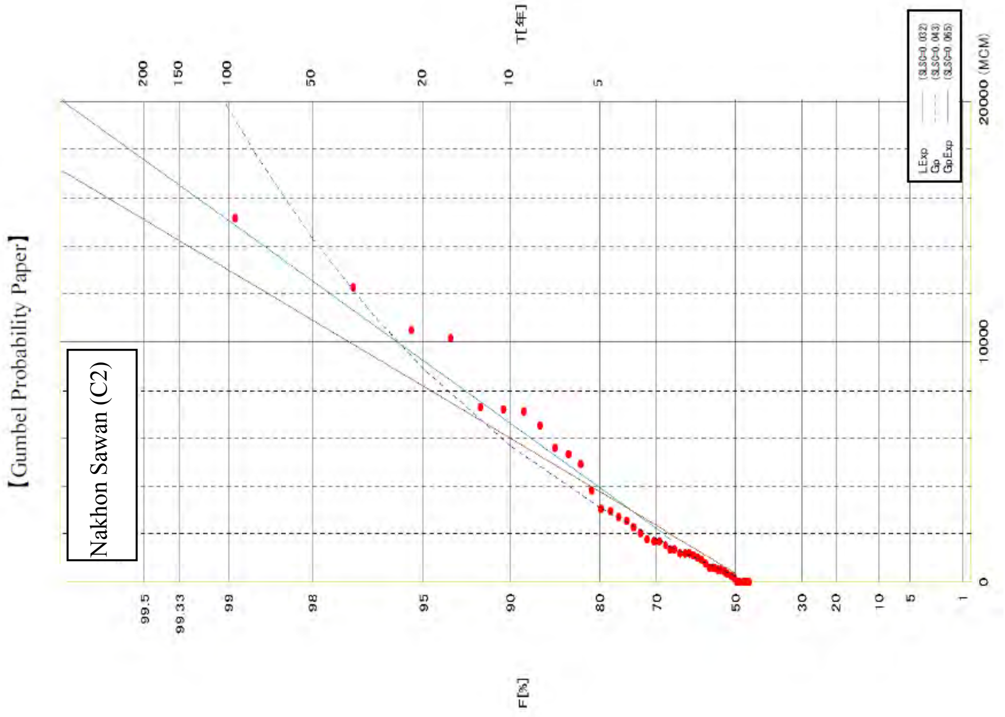
Frequency analysis was conducted for the three kinds of discharge data at Nakhon Sawan. Regarding the runoff volume exceeding the flow capacity of 2,500m^3/s, it is partial duration series data. Therefore, another frequency analysis method (partial duration series probability analysis method) was applied as shown in Figure 7.2.7.

Based on these results, the scale of the 2011 flood discharge is also evaluated as shown in Table 7.2.8, namely:

- The maximum peak discharge of 2011 is estimated at about 30 to 120 years of return period.
- The annual total runoff volume of 2011 is estimated at about 100 to 210 years of return period.
- The runoff volume exceeding the existing flow capacity of 2011, which might be regarded as inundation volume, is estimated at about 100 years of return period.

Table 7.2.8 Evaluation of Used Discharge Data for Frequency Analysis

Item	Value of 2011	Probability by Evaluation Criteria		
		Range of Probability (SLSC≤0.04)	Selected Frequency Function	Probability
Maximum Peak Discharge (m^3/s)	6,857	1/32 to 1/122	Gev	1/70
Total Runoff Volume (MCM)	55,570	1/102 to 1/207	Iwai	1/127
Runoff Volume Exceeding Flow Capacity (MCM)	15,154	1/102	Lexp	1/102



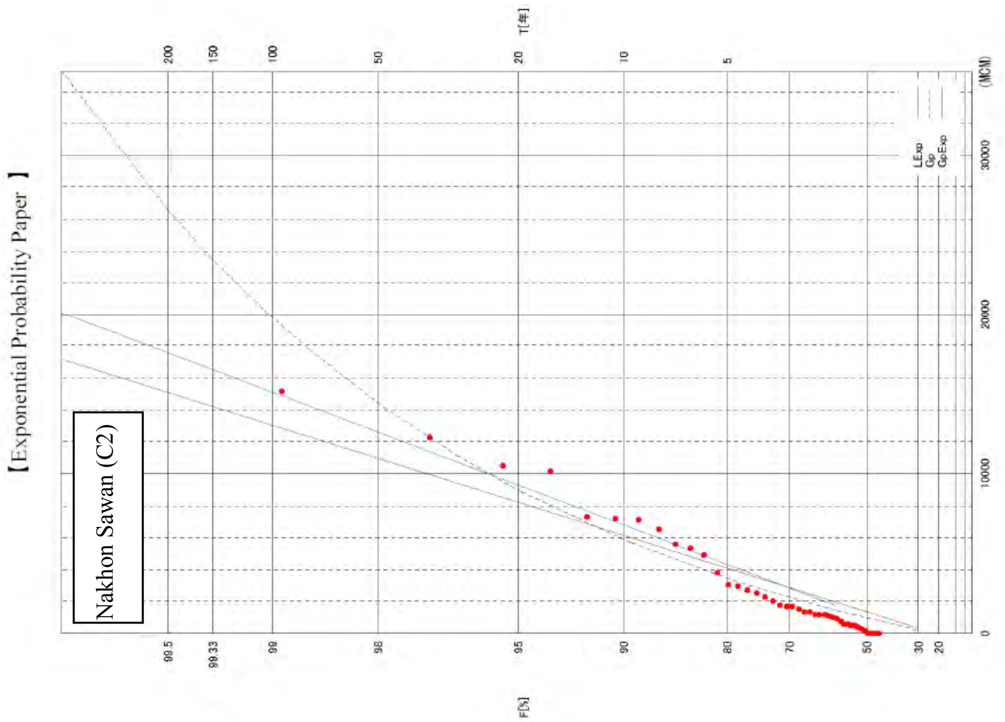


Figure 7.2.7 Frequency Analysis Results of Discharge without Dams at Nakhon Sawan (Total Volume Exceeding Flow Capacity of 2,500 m^3/s)

7.2.5 Determination of Target Design Floods

(1) Evaluation of Scale of 2011 Flood

Based on the results of the preceding sections, the scale of the 2011 flood is concluded as follows:

- Based on the scale of 1,390 mm, the basin mean 6-month rainfall of the whole basin is evaluated at 90 to 210 years of return period depending on the probability model, while it is 100 years of return period according to results with a probability model that gives the minimum SLSC and suitability of the plotting position of rainfall samples.
- The scale of the runoff volume exceeding 2,500 m^3/s at Nakhon Sawan, which might be regarded as inundation volume, is evaluated at about 100 years of return period.

(2) External Force for Planning of Flood Mitigation Measures

There are generally two ways to assume an external force for planning of flood mitigation measures. The first way is to directly use observed water levels or river discharges as generally practiced in Thailand. This is much easier, but water levels and discharges will be influenced by future development of the river basin including construction of structural measures and change of land use as well as climate change. Another way is to go back to rainfall data that are not influenced by the ground condition of the river basin. Water levels and discharges that will be fundamental parameters for planning of flood mitigation measures are estimated according to the ground condition through flood simulation. Impact of climate change will be also able to be easily incorporated to rainfall. This second way seems to be more suitable for the Chao Phraya River Basin.

In conclusion, it is proposed to determine the 2011 Flood (1,390 mm/6months for the whole river basin) as the design external force for this Study from the following reasons:

- RID practically adopts 100 years of return period for structural measures for the Chao Phraya River Basin
- The Thai Government also considers flood mitigation measures to cope with floods equivalent to the 2011 Flood, at least.
- The rainfall and the runoff discharge volume of the 2011 Flood are evaluated at around 100 years of return period.

However, to evaluate the countermeasures prepared in the study, the flood analysis with other rainfall patterns shall be conducted.

(3) Evaluation of Scale of 2011 Flood

The design external force is proposed to be the actual rainfall in 2011 as explained in the preceding subsection. Considering possibility of spatial and temporal distribution of rainfall pattern other than that of 2011, it is desirable to check if proposed measures can be still effective against the other rainfall patterns as shown in Figure 7.2.8. Since the scale of rainfall of the other years is less than 100 years of return period, these rainfalls are enlarged to the same value as the 2011 Flood.

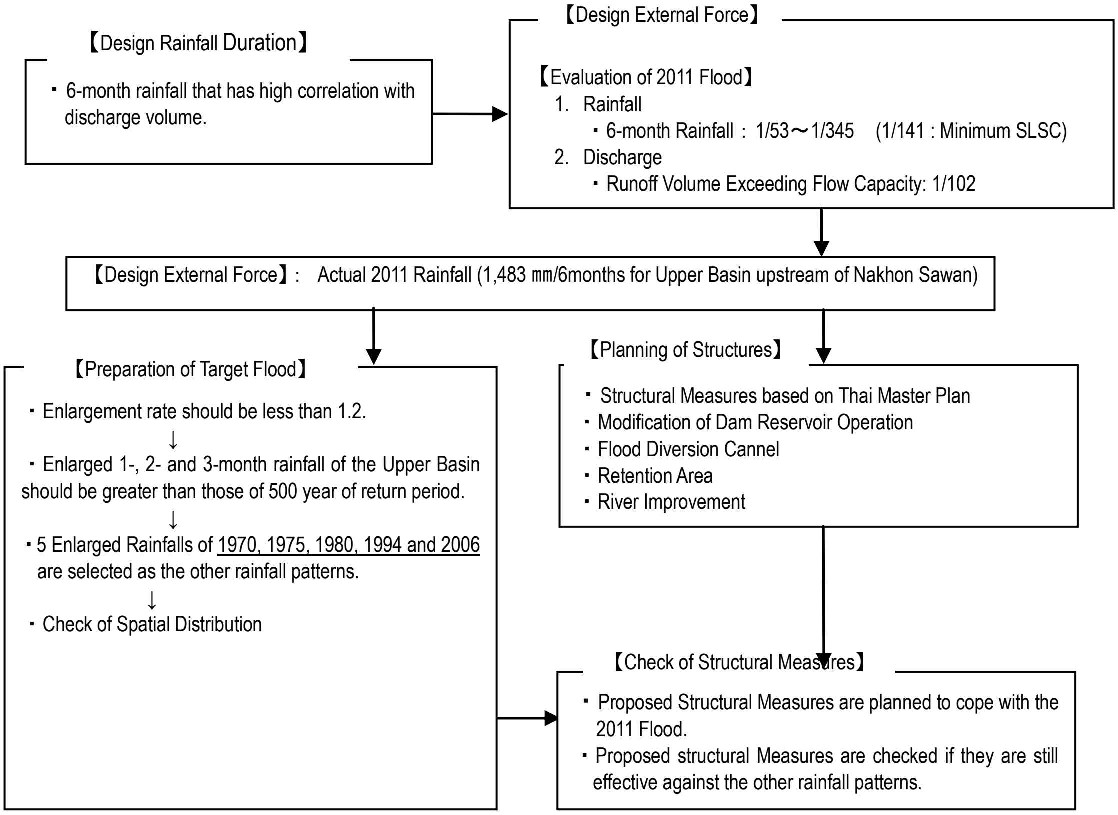


Figure 7.2.8 Flow of Planning of Structural Measures

(4) Rainfall Patterns

Rainfalls of the years other than 2011 are enlarged to the same quantity as the design external force. If small rainfalls are enlarged to the 2011 level, the enlarged rainfalls might produce abnormally large river discharges or abnormal shapes of hydrographs when they are used for flood simulation. To avoid this, the enlargement rates should be small and limited to less than a certain value.

Figure 7.2.9 shows a histogram of enlargement rates of 6-month rainfalls of the Upper Basin of the years from 1961 to 2011 (51 years in total) to the actual 6-month rainfall of 2011. According to this figure, the number of years of which enlargement rates are 1.1 or less is 2, and the number of years of which enlargement rates are 1.2 or less is 7. Since 7 rainfall patterns seem sufficient for checking effectiveness of structural measures, the enlargement rates of 1.2 or less are adopted.

From the above discussions, in addition to the 2011 Flood, rainfalls of six years; 1970, 1975, 1980, 1994, 1995 and 2006, are selected as the rainfall patterns to be evaluated, as shown in Table 7.2.9.

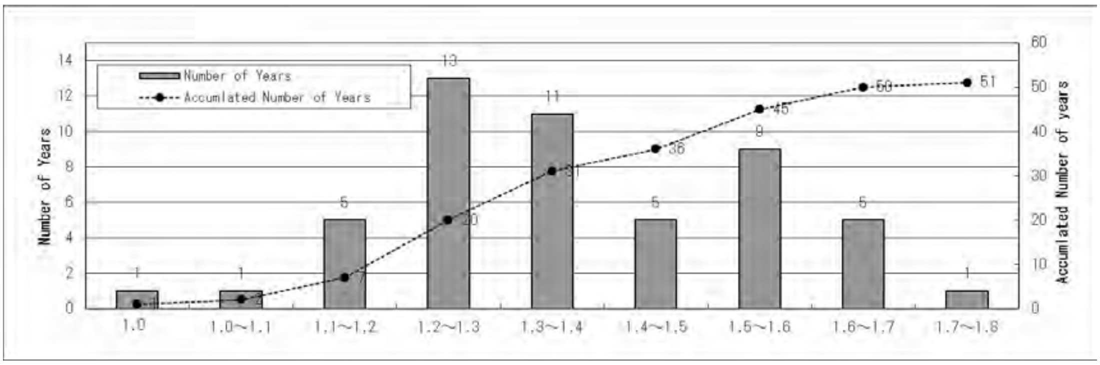


Figure 7.2.9 Histogram of Enlargement Rates to Actual 2011 Rainfall (1961 to 2011)

Table 7.2.9 Enlargement Rates to Actual 2011 Rainfall

	6-month Rainfall of Upper Basin 1,483mm				1-month rainfall		2-month rainfall		3-month rainfall	
year		1,483								
	Actual	Enlargement	Judgement	Ranking	Actual	Enlarged	Actual	Enlarged	Actual	Enlarged
	(mm)	Rate			(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
1961	1,208	1.228	Larger than 1.2	11	342	419	571	701	724	889
1962	1,117	1.328	Larger than 1.2	22	325	431	546	725	731	970
1963	1,235	1.201	Larger than 1.2	8	312	375	537	645	771	927
1964	1,163	1.275	Larger than 1.2	19	313	399	519	662	658	839
1965	979	1.515	Larger than 1.2	38	304	460	464	703	598	905
1966	1,065	1.393	Larger than 1.2	31	279	388	474	660	562	783
1967	974	1.522	Larger than 1.2	40	329	501	507	771	616	937
1968	911	1.628	Larger than 1.2	46	209	341	362	589	506	825
1969	1,055	1.406	Larger than 1.2	33	300	422	503	708	652	917
1970	1,266	1.172	○	4	335	393	578	677	733	858
1971	1,144	1.296	Larger than 1.2	20	305	396	511	662	692	897
1972	888	1.669	Larger than 1.2	48	234	391	414	691	555	927
1973	1,207	1.229	Larger than 1.2	12	322	396	577	710	754	927
1974	1,058	1.402	Larger than 1.2	32	273	383	504	706	660	925
1975	1,254	1.183	○	7	340	403	562	664	766	907
1976	1,174	1.263	Larger than 1.2	16	286	361	560	708	726	917
1977	948	1.565	Larger than 1.2	42	321	502	496	775	638	999
1978	1,214	1.222	Larger than 1.2	10	298	364	531	648	784	958
1979	949	1.563	Larger than 1.2	41	271	424	386	603	537	840
1980	1,255	1.181	○	6	326	385	573	677	739	873
1981	1,083	1.369	Larger than 1.2	30	276	377	453	620	681	932
1982	938	1.580	Larger than 1.2	45	292	461	466	737	555	877
1983	1,099	1.349	Larger than 1.2	24	245	330	491	662	675	911
1984	1,015	1.462	Larger than 1.2	35	236	346	401	586	547	800
1985	1,093	1.357	Larger than 1.2	26	245	333	450	610	604	820
1986	1,001	1.481	Larger than 1.2	36	251	373	412	610	531	786
1987	975	1.520	Larger than 1.2	39	316	480	532	809	626	951
1988	1,166	1.272	Larger than 1.2	17	255	324	450	572	625	795
1989	1,024	1.448	Larger than 1.2	34	268	388	401	581	531	770
1990	983	1.508	Larger than 1.2	37	273	411	391	589	510	768
1991	906	1.637	Larger than 1.2	47	275	450	436	714	563	921
1992	947	1.566	Larger than 1.2	44	274	429	467	732	668	1,046
1993	842	1.761	Larger than 1.2	51	274	482	411	723	526	927
1994	1,313	1.130	○	3	341	385	572	646	736	831
1995	1,262	1.175	○	5	358	420	655	770	838	985
1996	1,166	1.272	Larger than 1.2	18	302	384	550	700	696	885
1997	884	1.678	Larger than 1.2	50	251	421	470	788	666	1,118
1998	884	1.678	Larger than 1.2	49	246	413	403	676	601	1,008
1999	1,196	1.240	Larger than 1.2	14	272	337	469	582	647	802
2000	1,093	1.357	Larger than 1.2	25	266	361	421	571	559	759
2001	1,185	1.252	Larger than 1.2	15	313	392	478	598	631	790
2002	1,201	1.235	Larger than 1.2	13	402	496	605	747	728	899
2003	947	1.566	Larger than 1.2	43	266	417	450	705	621	973
2004	1,091	1.360	Larger than 1.2	27	271	369	486	661	624	849
2005	1,085	1.366	Larger than 1.2	29	347	474	525	717	702	959
2006	1,375	1.079	○	2	353	381	621	670	792	855
2007	1,214	1.221	Larger than 1.2	9	305	373	495	604	641	783
2008	1,114	1.331	Larger than 1.2	23	259	344	463	616	628	836
2009	1,090	1.361	Larger than 1.2	28	260	354	441	600	576	784
2010	1,135	1.306	Larger than 1.2	21	341	445	600	784	771	1,007
2011	1,483	1.000	○	1	332	332	629	629	857	857

※1-, 2- and 3-month rainfalls are maximum rainfalls within the period of the maximum 6-month rainfall.

CHAPTER 8 FLOOD MODEL DEVELOPMENT AND ANALYSIS

8.1 Outline

To analyze a flood situation and establish effective countermeasures, hydrological and hydraulic analysis model are developed. The model consists of three hydrological/hydraulic models; namely, the runoff model, the river network model (flood routing model) and the inundation model. The procedure for building the flood analysis model and parameter fitting for reproducing flood situations is shown in Figure 8.1.1.

1. Runoff Model (NAM Module)

- Setup sub-catchment area based on river/canal network
- Calculation of design rainfall
- Estimation of evaporation loss
- Runoff analysis in inland flooding area

↓

2. River Network Model (MIKE11)

- Collection of cross section data
- Set up initial roughness coefficient
- Modeling major regulators such as weirs, gates and barrages
- Set-up of boundary condition

↓

3. Inundation Model (MIKE 21)

- Building floodplain model with digital elevation model (LiDAR)
- Set up of roughness coefficient of floodplain considering the land use situation

↓

4. Re-producing Calculation (MIKE-FLOOD)

- Building of flood analysis model
- Selection of target floods and collecting hydrological information such as observed discharge/water level, tidal level and recorded flood inundation.
- Selection of validation point (at hydrological stations)
- To execute the flood analysis, modifying related parameters including boundary condition, roughness coefficient and so on, if any

Figure 8.1.1 Procedure of Hydrological and Hydraulic Model Building

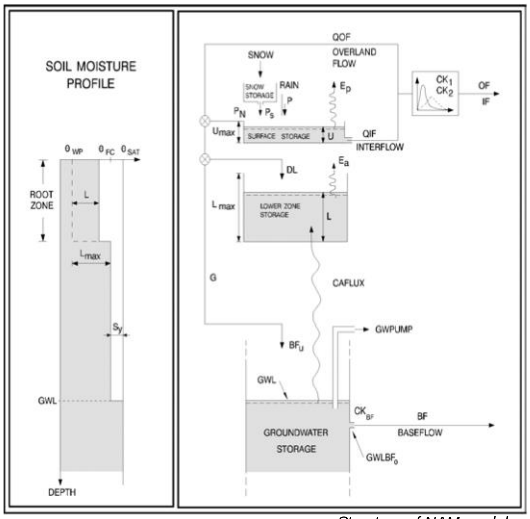
8.2 Runoff Model

8.2.1 Outline

To calculate runoff from each river basin, NAM (Nedbor-Afstromnings-Model) released by DHI[2] shall be employed. NAM is a kind of tank model and lumped runoff model developed by the Technical University of Denmark. It has four tanks describing runoff phenomenon including surface runoff, intermediate runoff and groundwater, and is used for both short-term and long-term runoff analysis. The outline of NAM and its parameters is as shown in Figure 8.2.1.

Run-off Analysis

NAM: *A lumped, conceptual rainfall-runoff model, simulating the overland-, inter-flow, and base-flow components as a function of the moisture contents in four storages.*



Structure of NAM model

Run-off parameters

Surface and root zone parameters	
U_{max}	Maximum water content in surface storage
L_{max}	Maximum water content in root zone storage
CQOF	Overland flow runoff coefficient
CKIF	Time constant for interflow
CK_{12}	Time constant for routing interflow and overland flow
TOF	Root zone threshold value for overland flow
TIF	Root zone threshold value for interflow
Groundwater parameters	
CK_{BF}	Baseflow time constant
TG	Root zone threshold value for groundwater recharge
CQ_{LOW}	Recharge to lower groundwater storage
CK_{LOW}	Time constant for routing lower baseflow
C_{area}	Ratio of groundwater catchment to topographical catchment area
GWL_{BF0}	Maximum groundwater depth causing baseflow
S_y	Specific yield
GWL_{FL1}	Groundwater depth for unit capillary flux

Figure 8.2.1 Outline of NAM and Model Parameters

8.2.2 Building Runoff Model

(1) Catchment Area

The Chao Phraya River System consists of eight major tributaries as shown in Table 8.2.1. In the study, the basin shall be divided into 27 sub catchment areas for runoff analysis as shown in Figure 8.2.2, considering major tributaries, canals, topographic features, dam catchment areas and flood control points (at hydrological station, for example C.2, Nakhon Sawan).

2 DHI Water & Environment, Denmark: http://www.dhigroup.com/

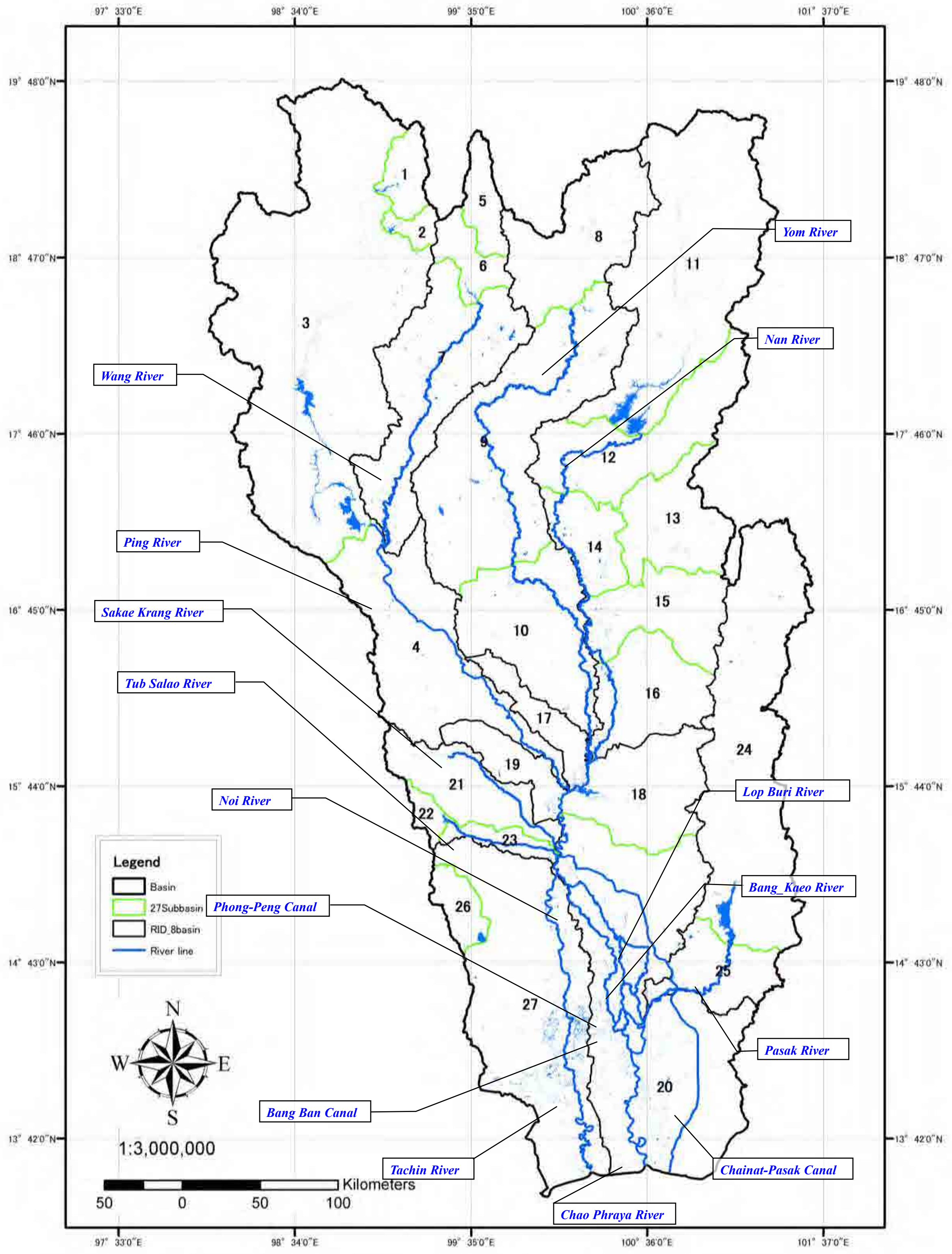


Figure 8.2.2 Sub catchment Areas in the Chao Phraya River System

Table 8.2.1 Subcatchment Area in the Chao Phraya River System

No.	Sub catchment Area	Area (km^2)*	Major River Basin
1	Ping Ngad	1,280	Ping
2	Ping Kwang	570	
3	Ping Bhumipl	24,310	
4	Ping D	8,380	
5	Wang Kew Kho Ma	1,350	Wang
6	Wang Kew Lom	1,420	
7	Wang D	8,020	
8	Yom U	5,580	Yom
9	Yom M	12,120	
10	Yom D	6,350	
11	Nan U	13,130	Nan
12	Nan M1	5,660	
13	Nan Kwae Noi	3,790	
14	Nan M2	2,310	
15	Nan M3	3,960	
16	Nan M4	4,100	
17	Nan D	1,720	
18	Chao Phraya U1	4,790	Chao Phraya
19	Chao Phraya U2	1,890	
20	Chao Phraya D	17,190	
21	Sakae Krang	3,480	Sakae Krang
22	Tab Salao Dam	540	
23	Tab Salao D	880	
24	Pasak Dam	12,840	Pasak
25	Pasak D	2,790	
26	Thachin KraSiew	1,190	Ta Chin
27	Tha Chin	13,000	
Total Area		162,640	

*Shape data of river basin (UTM Zone47) provided by RID. Catchment area is estimated with ArcGIS.

(2) Dam Catchment Areas

To establish the high-precision runoff model, large-size dams that have wide catchment areas shall be modeled, because dams could impound runoff from each river basin and control flow regime of downstream of dams. The dams built in the runoff model are tabulated in Table 8.2.2 and their locations are as shown in Figure 8.2.3.

Table 8.2.2 List of Dams Built in the Runoff Model

No.	Name	River	River Basin	Catchment Area(km^2)	Storage Volume (MCM)	
					Maximum	Retention
1	Mae Ngad Somboon Chol	Ping	Ping_Ngad	1,283	325	265
2	Mae Kwang Udom Thara	Ping	Ping_Kwang	566	263	263
3	Bhumibol	Ping	Ping_Bhumibol	24,305	13,462	13,462
4	Kiew Ko Ma	Wang	Wang_Kiew_Ko_Ma	1,354	209	170
5	Kiew Lom	Wang	Wang_Kiew_Lom	1,422	106	106
6	Sirikit	Nan	Nan_U	13,131	10,640	9,510
7	Kwae Noi Bumrung Dan	Nan	Nan_Kwae_Noi	3,793	1,080	939
8	Pasak Chollasith	Pasak	Pasak_Dam	12,835	960	785
9	Tab Salao	Sakae krang	Tab_Salao_Dam	543	198	160
10	Kra Siew	Tha chin	Thachin_Kra_Siew	1,193	363	240

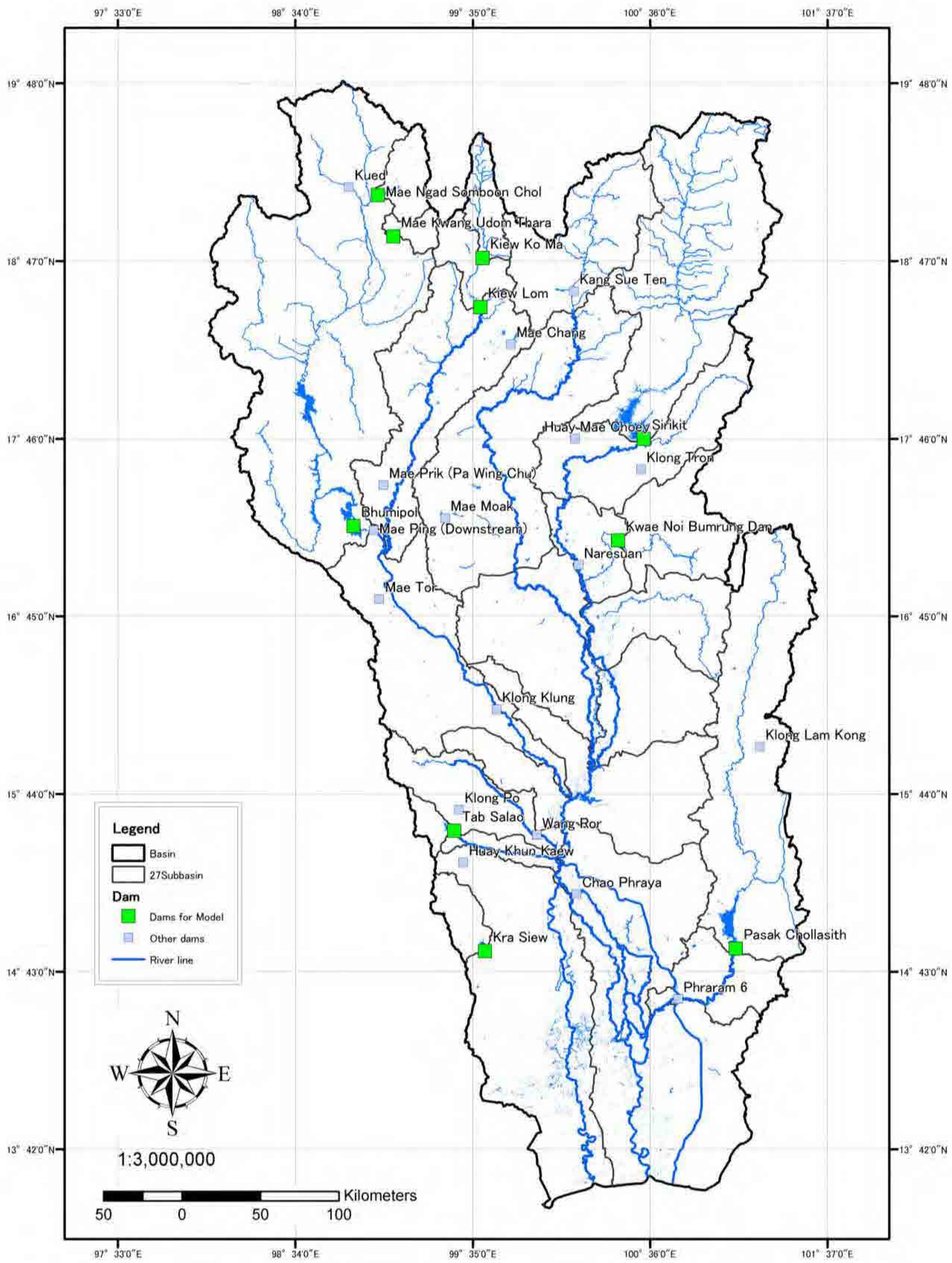


Figure 8.2.3 Location Map of Existing Dams for the Runoff Model

8.2.3 Input Data for the Runoff Model

(1) Rainfall

The observed daily rainfall data maintained by RID (Royal Irrigation Department) and TMD (Thailand Meteorological Department) shall be employed for the runoff analysis. As an input data, average rainfall of watershed calculated with the Thiessen Method shall be given to each sub catchment area.

In lowland areas dominated by inland flooding, observed rainfall depth is given directly to the inundation model (two-dimensional model) instead of the runoff calculation with NAM, since it is assumed that rainfall in the lowland will not flow into the rivers/canals due to flat topography (land slope) and thus accumulate before eventually draining through the drainage/irrigation canals. Based on the topography, ground elevation, irrigation canals and actual inundated area in recent years, the inland flooding area is determined to be 11,590km^2 as shown in Figure 8.2.7. In case of evaluation of effectiveness of the flood countermeasures proposed in this project, observed rainfall is not given to the inundation model. The flood countermeasures aim to deal with overflow flooding mainly and if inland flooding is counted on evaluating them, the effectiveness of the countermeasures might be blind. Inland flooding should be dealt with countermeasures against inland flooding such as improvement of drainage canals and installation of pump stations etc.

(2) Evaporation

As an input data of daily evaporation, the averaged 80% of pan evaporation amount at TMD synoptic station (refer to Figure 8.2.5) calculated by the Thiessen Method shall be given to each sub catchment area. Regarding daily evaporation, the evaporation measured by pan (pan evaporation) at the TMD synoptic stations is employed. Since pan evaporation is defined as the maximum potential of evaporation, it should be converted into actual evaporation by assuming an evaporation coefficient (= actual evaporation / potential evaporation). The assumed evaporation coefficient is calculated according to the Equation (1) at Sirikit Dam, Bhumibol Dam and C.2 (Nakhon Sawan), respectively, from observed daily rainfall, dam inflow, river discharge and evaporation data that are available from 1980 to 2011. Since long-term outflow from the catchment area, as long as 30 years, is estimated, the amount of groundwater and infiltration in a catchment shall be contained in discharge [Q in Equation (1)].

Calculated evaporation coefficients are 0.82 at Sirikit Dam, 0.75 at Bhumibol Dam, 0.84 at C.2, respectively. Therefore, 0.80, averaged by the values at the three points, is employed as the evaporation coefficient of the whole basin.

C (evaporation coefficient) = actual evaporation / potential evaporation (pan evaporation)

$$= \frac{\sum R - \sum Q}{\sum evap} \qquad (1)$$

Where, Q: discharge, R: rainfall, evap: evaporation

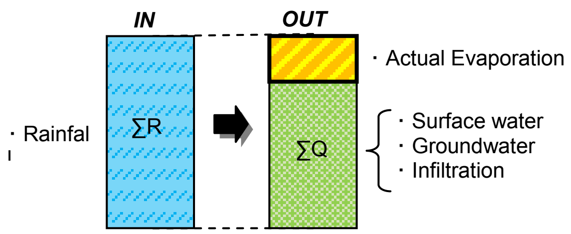


Figure 8.2.4 Water Balance in Catchment Area

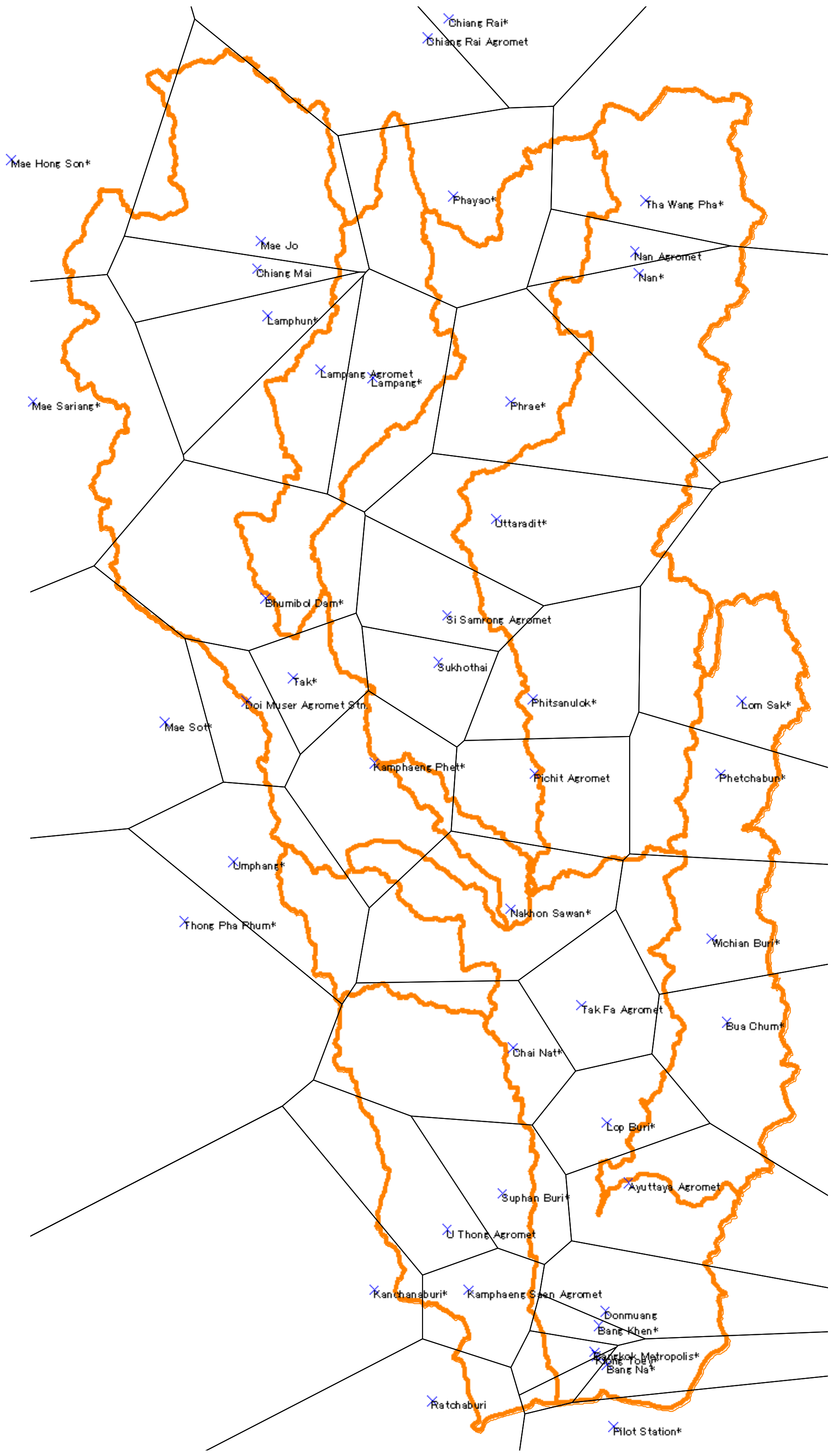


Figure 8.2.5 Location of TMD Station (46 Stations) and Cover area (with Thiessen Method)

Table 8.2.3 Assumed Evaporation Coefficient at Sirikit Dam, Bhumibol Dam and C.2

STN_CODE		Sirikit Dam	Bhumibol Dam	C.2
RIVER		Ping	Nan	Chao Phraya
SUB-BASIN		-	-	Chao Phraya
1.Catchment Area	(km^2)	13,131	24,305	58,205
2.Peak Discharge (record high)	(m^3/s)	4,303	3,605	5,451
3. Total Rainfall*[1]	(mm)	39,856	33,231	36,409
4. Evaporation*[1]	(mm)	32,864	35,211	36,636
5. Total Rainfall: ΣR	(MCM)	523,349	807,679	2,119,186
6. Total Evaporation: Σ_{evap}	(MCM)	431,537	855,803	2,132,398
7. Total Runoff : ΣQ	(MCM)	171,204	167,220	327,021
8. Evaporation Coefficient (5 - 7) / 6	-	0.82	0.75	0.84

*1 Total value from April to December 1980-2011; however, values in 1983 are not included because observed data is not available for over 60 days.

Table 8.2.4 Calculation of Average Rainfall and Evaporation

Items	Stations	Calculation Method
Average Daily Rainfall	TMD and RID; Total: 410 stations	Average rainfall of watershed is calculated with the Thiessen Method.
Average Daily Evaporation	TMD 46 stations	Actual evaporation is defined as 80% of pan evaporation. Average evaporation of watershed is calculated with the Thiessen Method.

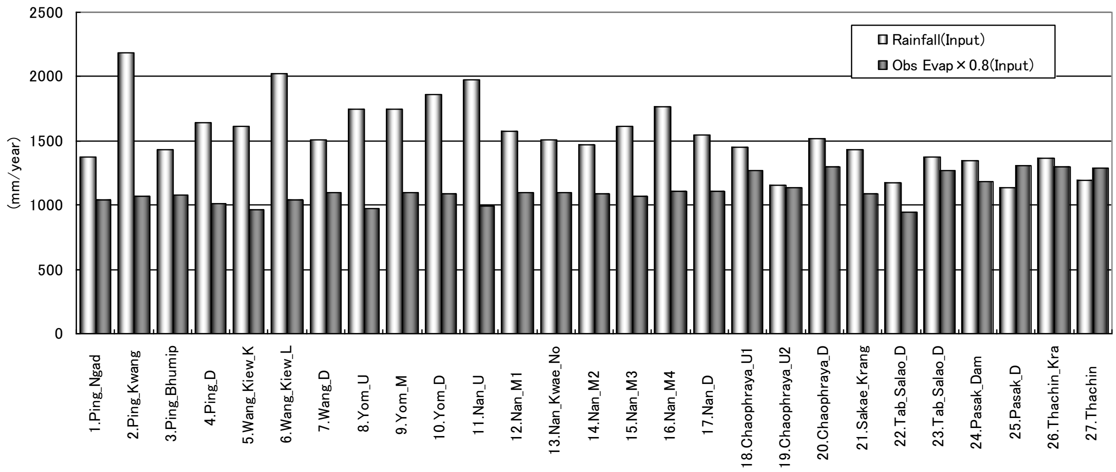


Figure 8.2.6 Amount of Average Rainfall and Evaporation (2011)

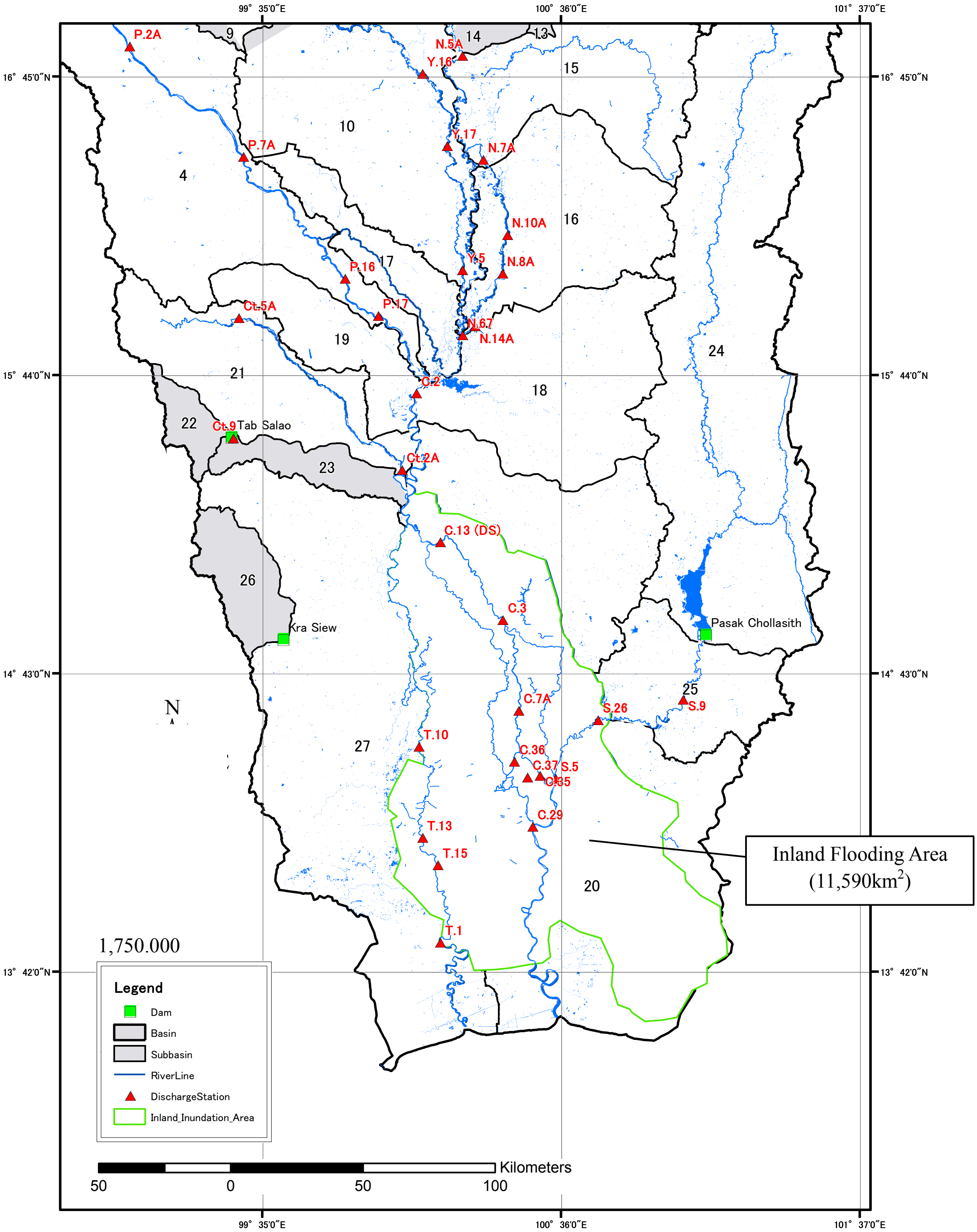


Figure 8.2.7 Estimated Inland Flooding Area (Draft)

8.2.4 Initial Parameters

The initial parameters of the NAM Runoff Model shall be set by reference to the finalized parameters in the 1999 Master Plan Study. Since the 1999 Master Plan Study employed the NAM Runoff Model for 18 divided sub-basins, initial parameters shall be distributed to the overlapped areas of the 27 sub-basins defined in Subsection 8.2.2(1). These values shall be modified according to the results of model calibration.

Table 8.2.5 Model Parameters (Surface-Root Zone)

Surface and root zone parameters	
U_{max}	Maximum water content in surface storage
L_{max}	Maximum water content in root zone storage
CQOF	Overland flow runoff coefficient
CKIF	Time constant for interflow
CK_{12}	Time constant for routing interflow and overland flow
TOF	Root zone threshold value for overland flow
TIF	Root zone threshold value for interflow

Table 8.2.6 Initial Model Parameters (Surface-Root Zone)

Area No	Name	River	Area (km^2)	Surface-Root Zone						
				U_{max}	L_{max}	CQOF	CKIF	$CK_{1,2}$	TOF	TIF
1	PING_NGAD	Ping	1,283	5	50	0.8	1000	100	0	0
2	PING_KWANG		566	5	50	0.8	1000	100	0	0
3	PING_BHUMIPOL		24,305	5	50	0.8	1000	100	0	0
4	PING_D		8,383	5	50	0.6	1000	20	0	0
5	WANG_KIEW_KO_MA	Wang	1,354	20	250	0.4	1000	30	0	0
6	WANG_KIEW_LOM		1,422	20	250	0.4	1000	30	0	0
7	WANG_D		8,017	20	250	0.4	1000	30	0	0
8	YOM_U	Yom	5,580	15	130	0.8	1000	20	0	0
9	YOM_M		12,120	15	150	0.8	1000	20	0	0
10	YOM_D		6,347	10	100	0.6	1000	50	0	0
11	NAN_U	Nan	13,131	15	150	0.5	1000	25	0	0
12	NAN_M1		5,660	25	250	0.2	1000	20	0	0
13	NAN KWAE NOI		3,793	25	250	0.2	1000	40	0	0
14	NAN_M2		2,315	25	100	0.5	1500	100	0.5	0.5
15	NAN_M3		3,962	25	250	0.6	1000	50	0	0
16	NAN_M4		4,103	25	250	0.6	1000	50	0	0
17	NAN D		1,718	5	50	0.6	1000	20	0	0
18	CHAO PHRAYA_U1		4,786	10	100	0.6	1000	30	0	0
19	CHAO PHRAYA_U2	Chao Phraya	1,894	25	250	0.4	1000	30	0	0
20	CHAO PHRAYA_D		7,572	25	250	0.4	1000	30	0	0
21	SAKAE KRANG	Sakae Krang	3,482	25	250	0.4	1000	30	0	0
22	TAB_SALAO_DAM	Tab Salao	543	25	250	0.4	1000	30	0	0
23	TAB_SALAO_D		882	25	250	0.4	1000	30	0	0
24	PASAK DAM	Pasak	12,835	20	200	0.4	1000	100	0	0
25	PASAK_D		2,657	20	200	0.4	1000	10	0	0
26	THACHIN_KRA_SIEW	Ta Chin	1,193	25	250	0.4	1000	30	0	0
27	THA CHIN		11,169	25	250	0.4	1000	30	0	0

Table 8.2.7 Model Parameters (Groundwater)

Groundwater parameters	
CK_{BF}	Baseflow time constant
TG	Root zone threshold value for groundwater recharge
CQ_{LOW}	Recharge to lower groundwater storage
CK_{LOW}	Time constant for routing lower baseflow
C_{area}	Ratio of groundwater catchment to topographical catchment area
GWL_{BF0}	Maximum groundwater depth causing baseflow
S_y	Specific yield
GWL_{FL1}	Groundwater depth for unit capillary flux

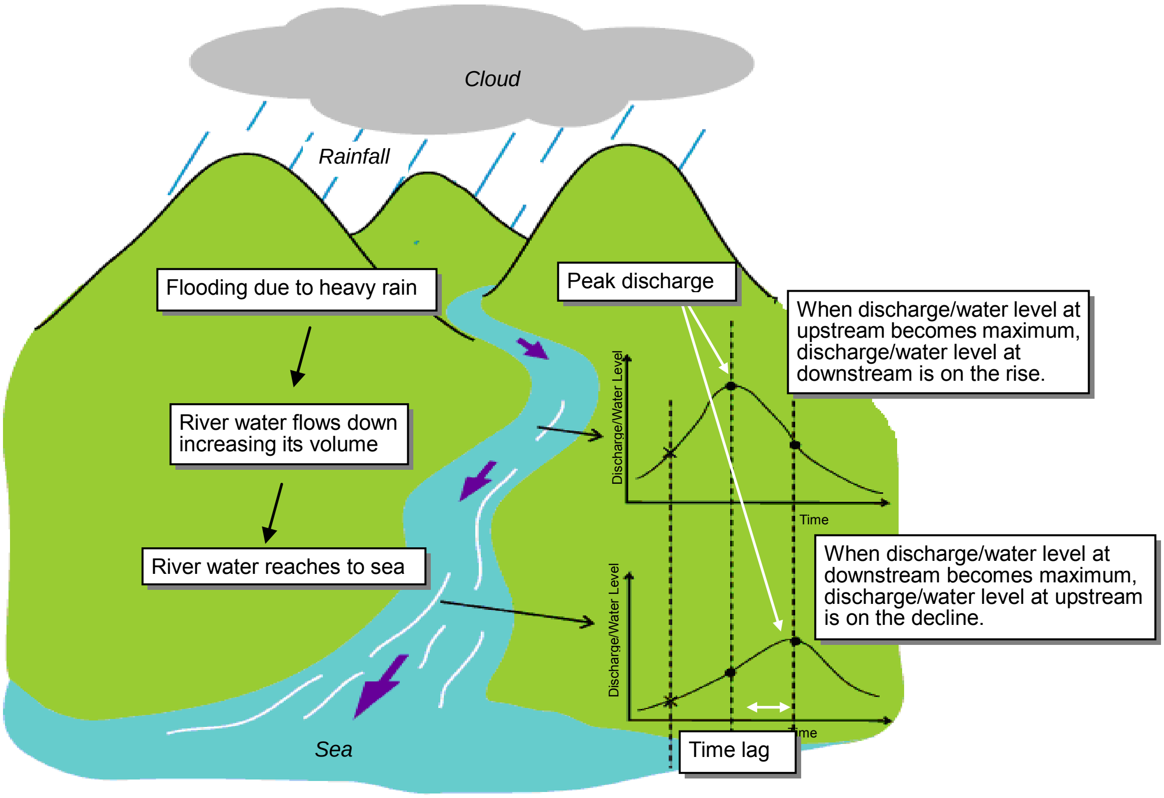
Table 8.2.8 Initial Model Parameters (Groundwater)

Area No	Name	River	Area (km^2)	Groundwater							
				TG	CK_{BF}	C_{area}	Sy	GWL_{BF0}	GWL_{BF1}	Cq_{low}	Ck_{low}
1	PING NGAD	Ping	1,283	0	1500	1	0.1	10	0	0	10000
2	PING KWANG		566	0	1500	1	0.1	10	0	0	10000
3	PING BHUMIPOL		24,305	0	1500	1	0.1	10	0	0	10000
4	PING D		8,383	0	1000	1	0.1	10	0	0	10000
5	WANG KIEW KO MA	Wang	1,354	0.5	1000	0.5	0.1	10	0	0	10000
6	WANG KIEW LOM		1,422	0.5	1000	0.5	0.1	10	0	0	10000
7	WANG D		8,017	0.5	1000	0.5	0.1	10	0	0	10000
8	YOM U	Yom	5,580	0	1000	1	0.1	10	0	0	10000
9	YOM M		12,120	0	800	1	0.1	10	0	0	10000
10	YOM D		6,347	0.6	500	1	0.1	10	0	0	10000
11	NAN U	Nan	13,131	0	1500	1	0.1	10	0	0	10000
12	NAN M1		5,660	0.6	500	1	0.1	10	0	0	10000
13	NAN KWAE NOI		3,793	0.6	500	1	0.1	10	0	0	10000
14	NAN M2		2,315	0.1	1500	1	0.05	10	0	0	10000
15	NAN M3		3,962	0.6	500	1	0.1	10	0	0	10000
16	NAN M4		4,103	0.6	500	1	0.1	10	0	0	10000
17	NAN D		1,718	0	1000	1	0.1	10	0	0	10000
18	CHAO PHRAYA U1		4,786	0.6	500	1	0.1	10	0	0	10000
19	CHAO PHRAYA U2	Chao Phraya	1,894	0.6	500	1	0.1	10	0	0	10000
20	CHAO PHRAYA D		7,572	0.6	500	1	0.1	10	0	0	10000
21	SAKAE KRANG	Sakae Krang	3,482	0.6	500	1	0.1	10	0	0	10000
22	TAB SALAO DAM	Tab Salao	543	0.6	500	1	0.1	10	0	0	10000
23	TAB SALAO D		882	0.6	500	1	0.1	10	0	0	10000
24	PASAK DAM	Pasak	12,835	0	500	1	0.1	10	0	0	10000
25	PASAK D		2,657	0	500	1	0.1	10	0	0	10000
26	THA CHIN KRA SIEW	Ta Chin	1,193	0.6	500	1	0.1	10	0	0	10000
27	THA CHIN		11,169	0.6	500	1	0.1	10	0	0	10000

8.3 River Network Model

8.3.1 Outline

Discharge and water level in target rivers/canals shall be computed with one-dimensional unsteady flow model that calculates a temporal alteration of discharge/water level at each cross section, since river running through lowland area would be affected confluence of tributaries and tidal level (backwater). River network model shall be built with DHI MIKE11. In this study, full dynamic model shall be employed for flood routing calculation.



1) Usually, river discharge, water level and flow velocity would change from hour to hour during flood event.
2) River flow reaches downstream taking time and hydrograph at downstream is different from upstream, which is remarkable in a long and low-sloped river.

Figure 8.3.1 Intellection of Unsteady River Flow

Table 8.3.1 Description of River Network Model

Items	Contents
Hydraulic Model	One-dimensional unsteady flow (fully dynamic) DHI-MIKE11 HD module
River Network	Refer to Figure 8.3.18
Cross Section	Surveyed in 2005and 2006, provided by RID Surveyed in 2012 by JST (mainly primary canals)
Structures	Large dam, weir and regulators
Boundary Condition	Upstream: Calculated hydrograph with the runoff model, observed discharge and released water from dams. Downstream: Observed tide level

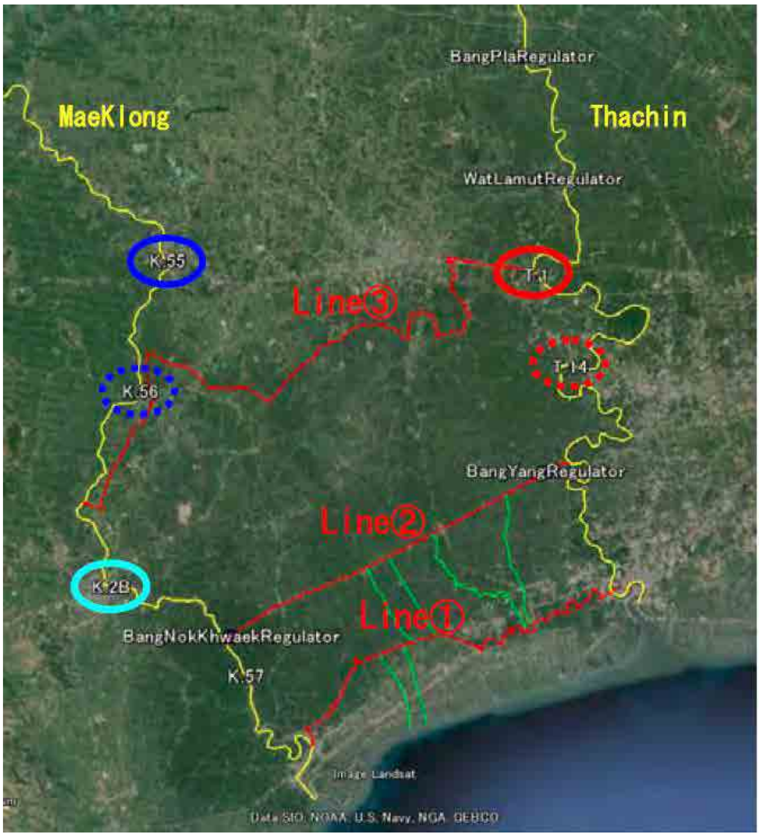
8.3.2 River Network

Table 8.3.2 shows the candidate rivers/canals for the river network model. Basically, all rivers/canals that have cross-section surveys shall be built in the network model. However, Chainat-Ayutthaya Canal (design discharge 65m^3/s) is not included in the network, because it runs along the left side the Chao Phraya River and has a no influence on inundated flow.

Table 8.3.2 Rivers/Canals Built in the River Network Model

No.	River Name	This Study	Previous Study (1999 M/P)	Remarks
1	Chao Phraya	Yes	Yes	
2	Ping	Yes	Yes	
3	Wang	Yes	-	
4	Yom	Yes	Yes	
5	Nan	Yes	Yes	
6	Sakae Krang	Yes	-	In 2005, river is named Mae Wong.
7	Tub Salao	Yes	-	
8	Ta Chin	Yes	Yes	
9	Noi	Yes	Yes	
10	Lop Buri	Yes	Yes	
11	Bang Kaeo	Yes	Yes	
12	Pasak	Yes	Yes	
13	Chainat-Pasak Canal	Yes	-	
14	Phong-Peng Canal	Yes	Yes	In 2005, river is named Bang Luang
15	Yom Koa River	Yes	-	
16	Bang Ban Canal	Yes	-	
17	Bonlue Canal	Yes	-	Surveyed in 2012 by JST
18	Chao Chet Bang Yi Hon Canal	Yes	-	Ditto
19	Mahashat Canal	Yes	-	Ditto
20	Machanthao Uthong Canal	Yes	-	Ditto
21	Pasicharoen Canal	Yes	-	Ditto
23	Phra Phimon Canal	Yes	-	Ditto
24	Prawetburiom East Canal	Yes	-	Ditto
25	Prawetburiom West Canal	Yes	-	Ditto
26	Prem Prachkon Canal	Yes	-	Ditto
27	Raphiphat Canal	Yes	-	Ditto
28	Raphiphat Yeak Tok Canal	Yes	-	Ditto
29	Rung Sitprayunsak Canal	Yes	-	Ditto
30	Saen Saep East Canal	Yes	-	Ditto
31	Saen Saep West Canal	Yes	-	Ditto
32	Sai Si Canal	Yes	-	Ditto
33	West Raphiphat Canal	Yes	-	Ditto

The Mae Klong River located at west-side of Tha Chin River connects to Tha Chin River with some irrigation canals. However, the relation of water level between Mae Klong River and Tha Chin River was not clear in 2006yr flood and it seems that Mae Klong River have no influence to the flood condition of Tha Chin River. Therefore, the irrigation canals connecting both rivers are not built in the river network model.



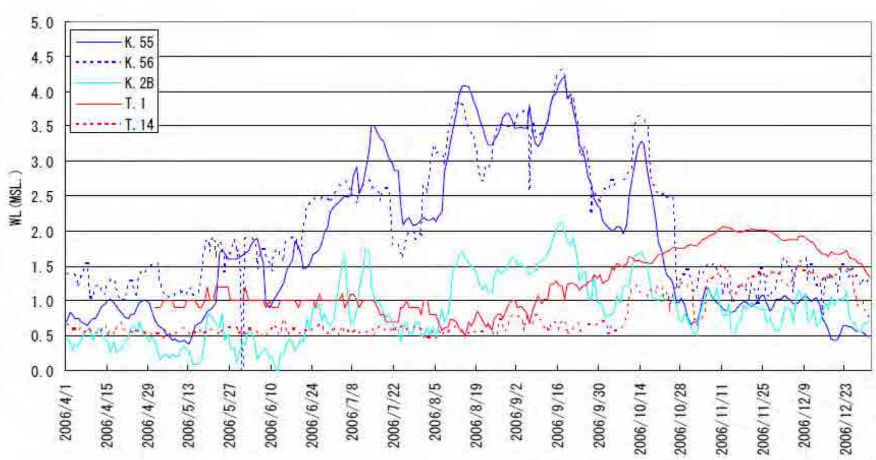


Figure 8.3.2 Observed Water Level in Mae Klong River and Tha Chin River (2006)

8.3.3 Cross Section

(1) Cross Section Data

The cross section data provided by RID is shown in Table 8.3.3. In this study, to check the latest river shape, cross-section survey was conducted downstream of Nakhon Sawan as shown in Figure 8.3.3. As mentioned above, rivers/canals that have cross section data shall be modeled, basically. In addition, the important rivers/canals for flood control pointed out by RID shall be built in as much as possible, such as Yom Koa River which is connected to Yom River and Nan River.

Table 8.3.3 Cross Section Data Provided from RID

No	River/Canal	Measured Year	Length(km)*
1	Chao Phraya River	0-141km (2006) 141-379km (2005)	379
2	Ping River	2005	256
3	Wang River	2005	236
4	Yom River	2005	597
5	Nan River	2005	449
6	Sakae Krang River	2005	141
7	Tub Salao River	2005	99
8	Ta Chin River	2006	318
9	Noi River	2005	166
10	Lop Buri River	2005	99
11	Bang_Kaeo River	2005	15
12	Pasak River	2005	102
13	Chainat-Pasak Canal	2005	166
14	Phong-Peng Canal	2005	13
15	Bang Ban Canal	2005	17

*Length is calculated with observed interval of cross section survey on 2005/2006. Rivers/canals except for a part of downstream of Chao Phraya and Ta Chin were surveyed with 1,000m interval.

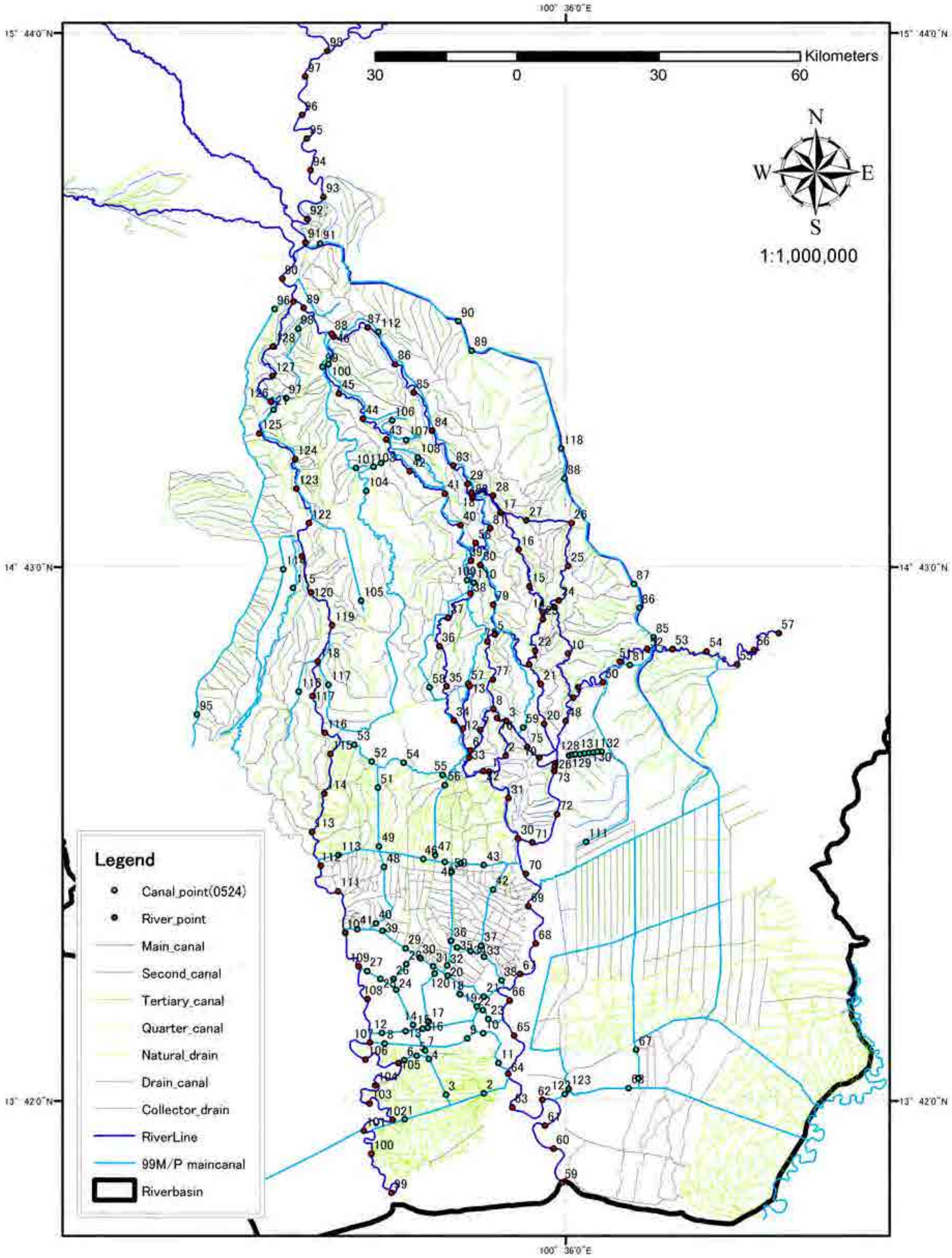


Figure 8.3.3 Location Map of Cross-Section Survey (2012)

(2) Setup of Secondary Dikes

In the lowland area, two types of dike are located along the rivers/canals; one is the embankment produced naturally by river flow (primary dike), and the other one is the road dike which was built along the irrigation canal (secondary dike). Actually, the secondary dike plays the role as river dike; therefore, the river area between the secondary dikes shall be defined as flow zone during flood event. Since the cross section data provided by RID mainly covers the primary dike, they have been complemented with LiDAR data as shown in Figure 8.3.5. Location of secondary dikes were set up longitudinally by extracting an area higher than limb ground from the distribution map with height of 2m grid (LiDAR). In the area where there is no LiDAR data, Google Map was used. Only in the Chao Phraya River, RID has set up the line of secondary dike.

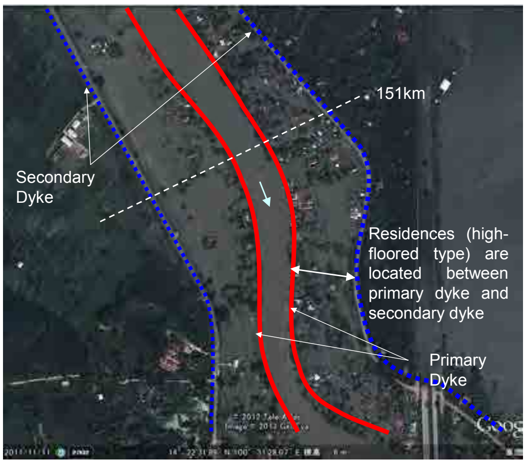


Figure 8.3.4 Secondary Dike

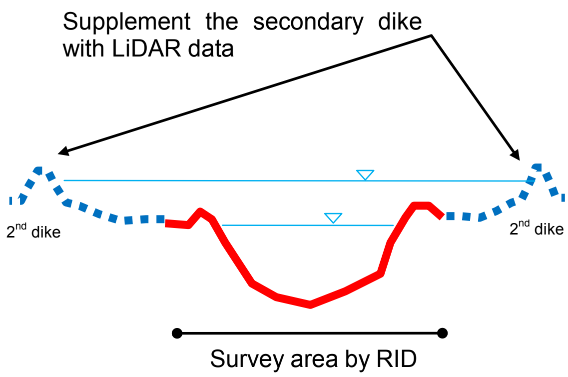


Figure 8.3.5 Revised Cross Section Data

(a) Method of Acquisition of Height of Secondary Dikes

Figure 8.3.6 shows the method of acquisition of height of secondary dikes from LiDAR data.

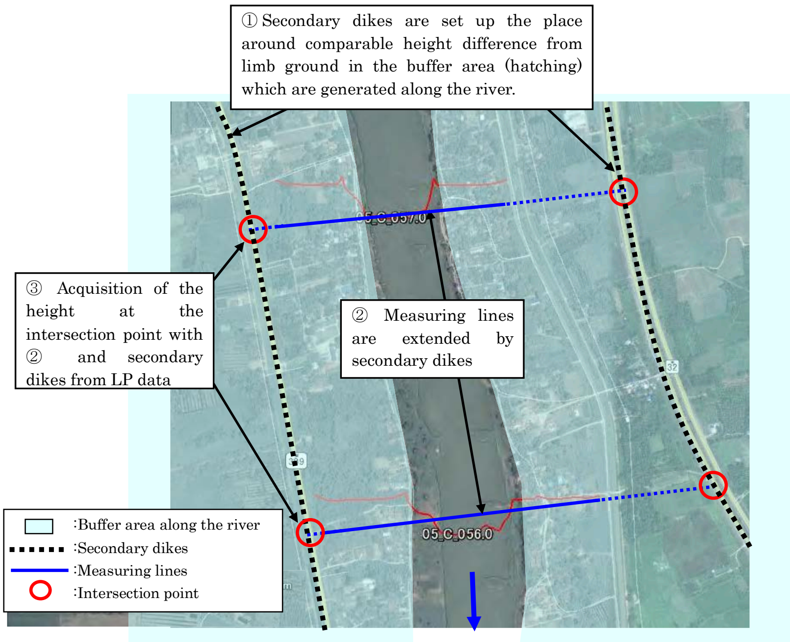


Figure 8.3.6 Setup of Secondary Dike

In case there are two roads along the river, the secondary dike line is set by checking the aerial photograph and elevation of LiDAR data longitudinally. On the other hand, in case the secondary dike set up by LiDAR data is different from that by RID documents shown in Figure 8.3.7, a higher road serves as the secondary dike line, longitudinally, comparing it with the elevation of each secondary dike shown in Figure 8.3.8, considering that flood is dammed up by the higher road. Heights of secondary dike in all rivers are acquired by the above method. The longitudinal profile of height of secondary dikes upstream of Chao Phraya River (141k~379k) is shown in Figure 8.3.9 as an example.

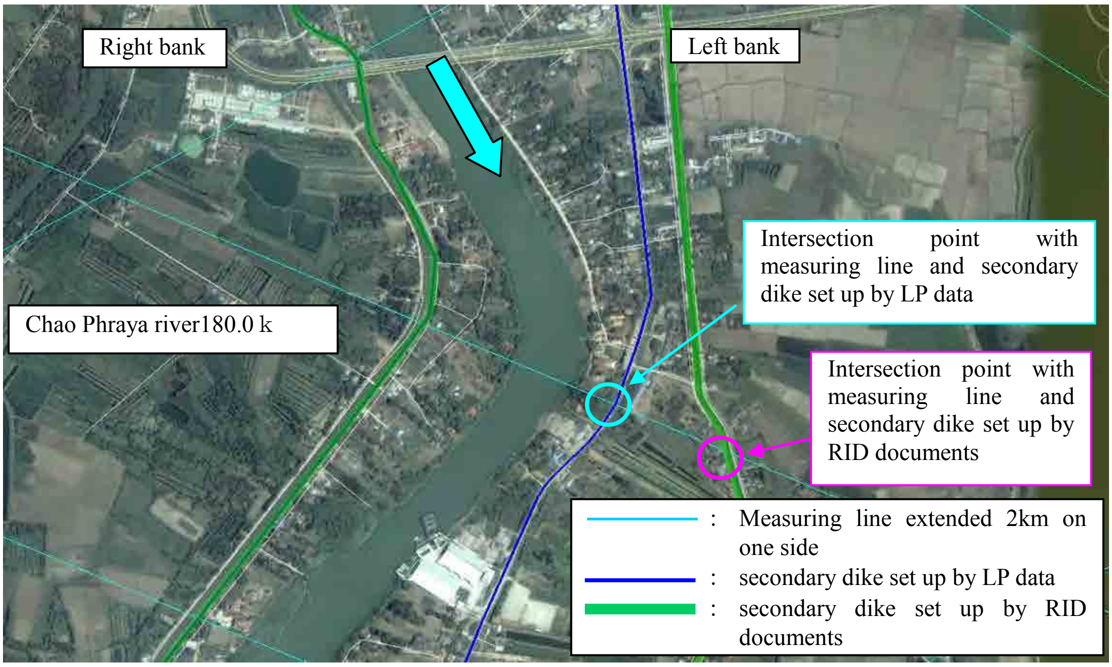


Figure 8.3.7 Example of Different Location of Secondary Dikes Set by LP Data and RID Documents

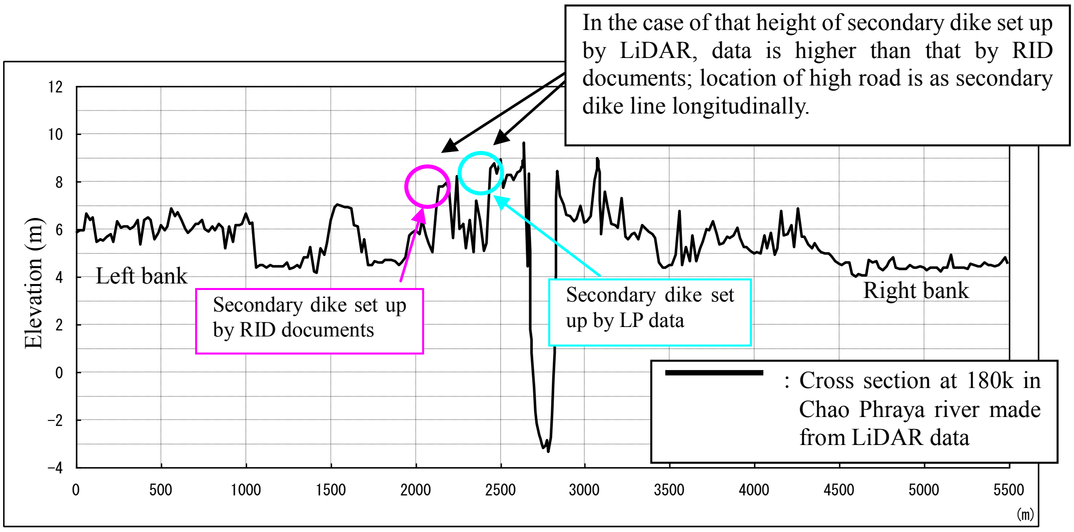


Figure 8.3.8 Example of Cross Section at Different Locations of Secondary Dikes Set by LP Data and RID Documents

CTI Engineering International Co., Ltd.
Oriental Consultants Co., Ltd.
Nippon Koei Co., Ltd.
CTI Engineering Co., Ltd.

In the area where LiDAR data is not available and secondary dike is not clearly acquired, the secondary dike is treated as follows:

- Height of secondary dike is set by interpolation from that of upper and lower cross sections acquired by LiDAR data at cross section in which intersection point with measuring line and secondary dike is not acquired in curved section.
- Height of secondary dike is set by interpolation from that of upper and lower cross sections acquired by LiDAR data in section where there is no local LP data.
- In case that there is no clear secondary dike, river width for calculation is up to highest ground height of flood prone area reached flood as set by LiDAR data .

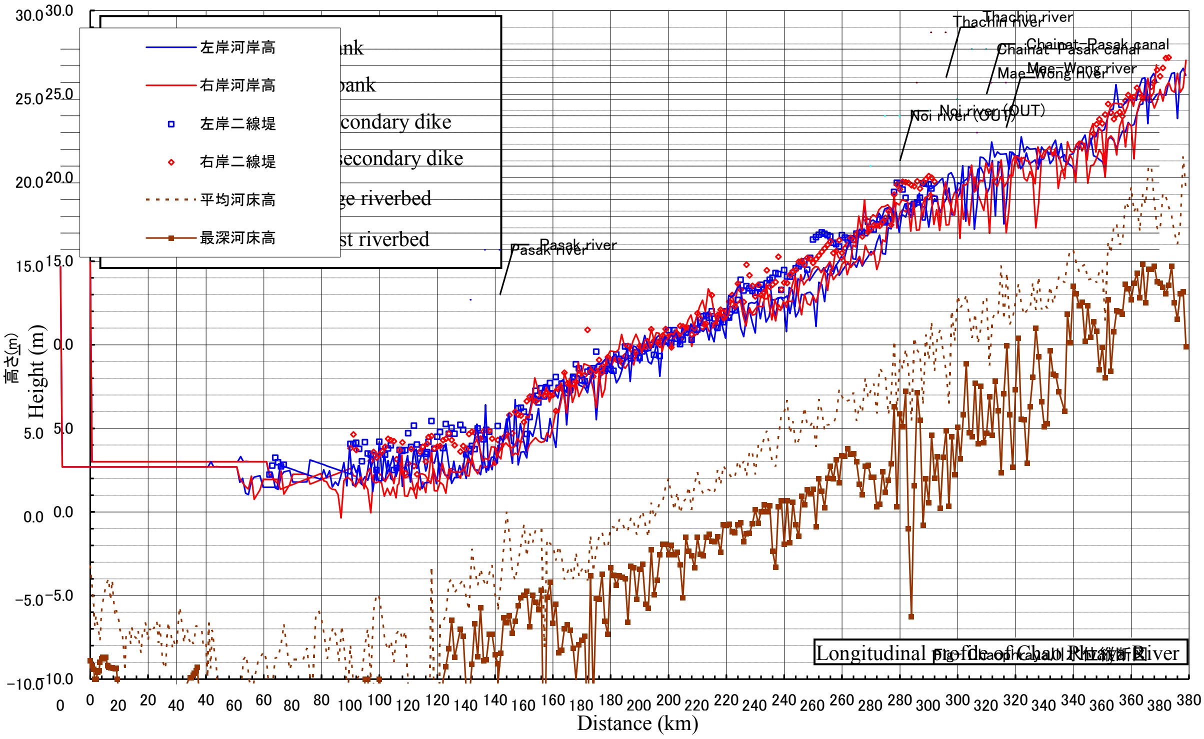


Figure 8.3.9 Longitudinal Profile of Height of Secondary Dike [Upstream of Chao Phraya River (141km - 379km)]

(b) Locations of Secondary Dike

Locations of secondary dikes are as indicated in Figure 8.3.10.

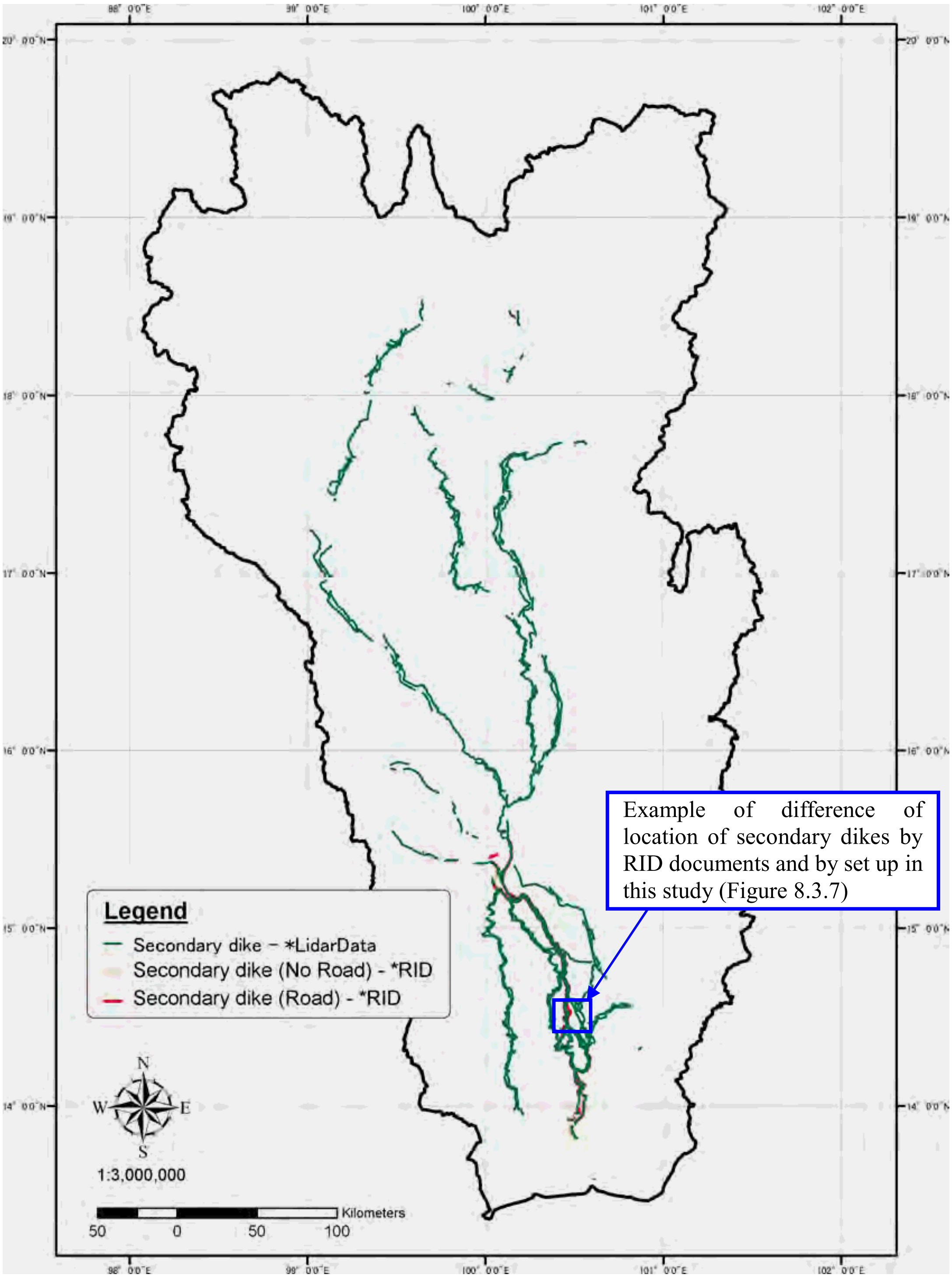


Figure 8.3.10 Location Map of Secondary Dikes

(3) Roughness Coefficient

Manning's *n* in river is set in consideration of high flow channel as shown in Figure 8.3.11. The initial value of roughness coefficient is tabulated in Table 8.3.4. Values of low flow zone are set by reference to the 1999 Master Plan Study. According to the standard values, roughness coefficient of one-dimensional flood simulation is listed in the range of 0.050 to 0.300[3]. Since values of high flow zone shall be in the range of standard values, they are set equivalent to those of low flow zone multiplied by three. These values are just initial values. Roughness coefficients of low/high zone were modified and finalized as tabulated in Table 8.5.27 though the model calibration for the re-production calculation for 2011 flood (water level, discharge and inundation area).

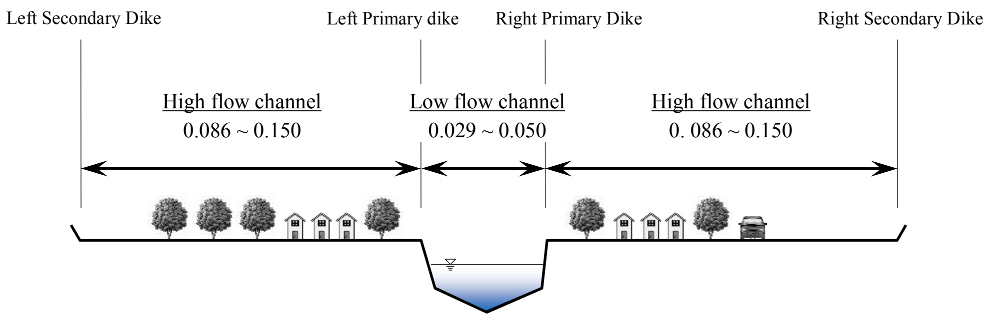


Figure 8.3.11 Schematic Cross Section View for Setting Manning's *n*

Table 8.3.4 Initial Setting of Manning's *n*

No.	River	Reach (km)	Resistance (Manning *n*)	
			Low Flow Zone	High Flow Zone
1	CHAO PHRAYA	0 ~ 141	0.029	0.086
		142 ~ 225	0.044	0.133
		226 ~ 379	0.040	0.120
2	PING	0 ~ 43	0.029	0.086
		44 ~ 135	0.033	0.100
		136 ~ 256	0.050	0.150
3	WANG	0 ~ 286	0.050	0.150
4	YOM	0 ~ 260	0.040	0.120
		261 ~ 597	0.040	0.120
5	NAN	0 ~ 129	0.040	0.120
		130 ~ 449	0.040	0.120
6	SAKAE KRANG	0 ~ 141	0.033	0.100
7	TUB SALAO	0 ~ 99	0.033	0.100
8	THA CHIN	0 ~ 318	0.033	0.100
9	NOI	0 ~ 166	0.033	0.100
10	LOP BURI	0 ~ 99	0.033	0.100
11	BANG KAEW	0 ~ 15	0.033	0.100
12	PASAK	0 ~ 107	0.033	0.100
13	CHAINAT-PASAK CANAL	0 ~ 166	0.033	0.100
14	PHONG PEN CANAL	0 ~ 13	0.033	0.100
15	BANG BAN CANAL	0 ~ 17	0.033	0.100
-	OTHER CANALS	-	0.029	0.086

[3] Simulation Manual on Inundation (draft version) by Public Works Research Institute, Japan 1996

8.3.4 Structures

(1) Weirs/Regulators

Weirs/regulators that have an influence on flood regime and inundation during large flood event shall be built in the river network model. The list of selected weirs/regulators is given in Table 8.3.5.

Table 8.3.5 Major Regulators in Chao Phraya River Basin

No.	TYPE	NAME	RIVER (CANAL)	Discharge regulation (m^3/s)	POINT_X	POINT_Y	Gate information		
							Number	Wide	Height
1	Regulator	HAD SAPAN CHAN RE.	Yom River	1804	587700	1918800	5	12.00	10.25
2	Regulator	KLONG HOK BAHT RE.	Hok Baht Canal (Conneting Yom River to Yom-Nan	280	585800	1921400	3	6.00	6.00
3	Regulator	YOM NAN RE.	Yom-Nan Diversion Channel	100	589900	1920600	3	6.00	5.00
4	Regulator	YOM KAO RE.	Yom Koa River (Old Yom River)	180	589900	1920100	4	6.00	5.00
5	Regulator	DR.15.8 YOM RE.	DR15.8 Canal (connecting Yom and Nan)	60	622775	1852906	2	6.00	4.00
6	Regulator	YANGSAI RE.	Yom River	630	587700	1873985	7	6.00	6.00
7	Regulator	NARESWAN DAM	Nan River	1600	626217	1884844	5	12.50	7.60
8	Regulator	DR.15.8 NAN RE.	DR15.8 Canal (connecting Yom and Nan)	80	633500	1842900	5	3.55	4.00
9	Regulator	DR2.8 RE.	DR2.8 Canal (connecting Yom and Nan)	360	633466	1837686	4	6.00	7.00
10	Regulator	MAKHAMTHAD-UTONG RE.	MAKHAMTHAD -UTONG CANAL	35	614167	1683281	6	1.75	2.00
11	Regulator	PHONLATEP RE..(POLLATHEP RE.)	SUPHAN RIVER (connect to Tha Chin river)	318	615202	1682487	4	6.50	7.30
12	Regulator	BARROMTAT RE..(BORROMTAT RE.)	NOI RIVER	260	624200	1675700	4	6.00	6.00
13	Regulator	MANOROM RE.	CHAINAT PASAK CANAL	210	618411	1695021	6	6.00	3.50
14	Diversion Weir	CHAO PHRAYA DAM	CHAOPHRAYA RIVER	3300	626783	1676221	16	12.50	7.50
15	Regulator	MAHARAJ RE.	CHAINAT AYUTHAYA CANAL (=BANG_PRANAKHON)	75	626050	1676403	6	6.00	2.50
16	Regulator	RAMA VI BARRAGE (PHRARAM 6 DAM)	PASAK RIVER	1800	690100	1609950	6	12.50	7.80
17	Regulator	PHRA NARAI RE.	RAPI PAT Canal (discharged into EAST BANK PROJECT	150	690115	1609945	8	4.20	3.56
18	Regulator	LOPBURI RE.	LOPBURI RIVER	270	652500	1643595	4	6.00	9.20
19	Regulator (Drainage)	BAN CHOM SRI RE.	Drainage Canal in Mahajaj Project Area	120	641856	1664819	3	4.00	6.50
20	Regulator	PAKHAI RE.	NOI RIVER	150	648206	1597023	3	6.00	6.00
21	Regulator	LAD CHADO RE.	SUPAN4 Canal (connecting Ta Chin and Noi)	80	647063	1599918	3	6.00	5.00
22	Regulator	PHO PHRAYA RE.	THA CHIN RIVER	318	620776	1606925	2	12.50	6.00
23	Regulator	SAM CHUK RE.	THA CHIN RIVER	318	617300	1633200	2	12.50	7.00
24	Regulator	BANG PLA MAA RE.	SUPAN4 CANAL (connecting Ta Chin and Noi)	78	625861	1592477	3	6.00	4.80

(2) Dams

Hydraulic analysis of rivers/canals as well as inundation analysis shall be conducted, considering the storage function of ten (10) dams as shown in Table 8.3.6. If reproduction calculation of past flood events are conducted, actual release water from the dams should be given as upper boundary condition in flood analysis. When predictive calculation is conducted, another outflow should be given based on the proposed dam operation rule.

Table 8.3.6 Specification of Major Dams

No.	1	2	3	4	5	6	7	8	9	10
Name of Dam	Bhumibol	Sirikit	Mae Ngat	Mae Kuang	Kiew Lom	Kiew Kor Ma	Kwae Noi	Pasak	Tap Sa Lao	Kra Siew
Agency	EGAT	EGAT	RID	RID	RID	RID	RID	RID	RID	RID
River Name	PING	NAN	PING	PING	WANG	WANG	Kwae Noi (NAN)	PASAK	MANAM SAKAE KRANG	THA CHIN
Province	Tak	Auttradith	Chiang Mai	Chiang Mai	Lam Pang	Lam Pang	Phitsanulok	Lop Buri	Uthai Thani	Suphan Buri
Region	North	North	North	North	North	North	North	Central	Central	Central
Location (WGS84)										
Longitude	98°54′ 0″	100°33′ 53.64″	99°2′ 23.64″	99°7′ 41.88″	99°37′ 38.28″	99°38′ 24″	100°25′ 0.12″	101°5′ 31.2″	99°28′ 38.64″	99°39′ 14.4″
Latitude	17°15′ 54″	17°45′ 54.36″	19°9′ 36″	18°55′ 23.52″	18°31′ 9.48″	18°48′ 0″	17°10′ 59.88″	14°50′ 51.36″	15°31′ 17.76″	14°49′ 56.28″
Dam Type	Gravity Arch	Earth fill	Earth fill	Earth fill	Earth fill	Rock fill	Rock fill	Earth fill	*	*
Dam Height (m)	154.0	113.6	59.0	61.0	26.5	47.0	80.0	23.2	26.8	*
Purpose	Hydropower, Irrigation and Flood control	Hydropower, Irrigation and Flood control	Irrigation	Irrigation	Irrigation	Irrigation and Water Supply	Hydropower, Irrigation and Flood control	Hydropower, Irrigation	Irrigation	Irrigation
Catchment Area (km^2)	26,386	13,130	1,281	569	2,700	1,275	4,254	12,929	534	1,200
Storage (MCM, Million Cubic Meter)										
Maximum	13,462	10,640	325	263	106	209	1,080	960	198	363
Retention	13,462	9,510	265	263	106	170	939	785	160	240
Minimum(=dead volume)	3,800	2,850	22	14	4	6	43	3	8	40
Surface Area (km^2)	316.0	260.0	16.0	12.0	16.0	*	40.5	148.8	19.0	*
Spillway										
Type	Tunnel	2 Tunnels	*	*	*	*	Overflow	Overflow	*	*
Creast Elevation (MSL)	242.9	150.5	393.8	*	*	*	118.5	32.5	*	*
Cotrol Gate	Radial Gate	Radial Gate					Radial Gate			
Number of Gate	4	2					5			
Size	width: 11.0m height: 17.4m	width: 11.85m height: 15.0m					width: 13.0m height: 12.0m			
Design Flood Volume (MCM)	7,670	4,643	261	*	*	*	*	*	*	*
Maximum Discharge Capacity (m^3/s)	6,000	3,250	1,035	*	1,300	2,385	7,046	3,497	*	*
Intake Structure										
Intake Gate	Fixed Wheel	Fixed Wheel					Fixed Wheel			
Number of Gate	7	1					1			
Size	width: 4.2m height: 6.7m	width: 6.0m height: 8.5m					width: 5.0m height: 5.5m			
Power Installed Capacity (MW)	70*6+128=548	125*4=500	4.5*2=9				19*2=38			
Inauguration	1964	1974	1966	*	*	2009	2009	*	*	*
Collected Data (Storage Volume, Inflow, Outflow etc)	1964 to date	1974 to date	2006 to date	1993 to date	1972 to date	2009 to date	2009 to date	1999 to date	2003 to date	1980 to date
Remarks										

Note: Above 10 dams are located in Chao Phraya River Basin and their rule curves are revised in case of large flood like 2011 yr flood.
“ * ” is to be under investigation

Table 8.3.7 Facilities Built in the Flood Analysis Model

No	Type	Name	River (Canal)	Storage (MCM)		Maximum Release (m^3/s)	Remarks
				Maximum	Retention		
1	Dam	Bhumibol Dam	Ping River	13,462	13,462	-	Calibration of runoff from upstream of dam was completed.
2	Dam	Sirikit Dam	Nan River	10,640	9,510	-	Calibration of runoff from upstream of dam was completed. Actual release water from dams is employed as upstream boundary condition.
3	Dam	Kwae Noi Bumrung Dan	Nan River	1,080	939	-	
4	Dam	Pasak Chollasith Dam	Pasak River	960	785	-	
5	Dam	Tab Salao Dam	Sakae Kurang River	198	160	-	
6	Dam	Kra Siew Dam	Ta Chin River	363	240	-	
7	Regulator	Phonlatep Regulator (POLLATHEP RE.)	Suphan River (connect to Ta Chin river)			360	Observed discharge through the regulator was re-created well.
8	Regulator	Barromtat Regulator (BORROMTAT RE.)	Noi River			260	
9	Regulator	Manorom Regulator.	Chainat Pasak Canal			210	
10	Diversion Weir	Chao Phraya Dam	Chao Phraya River			3,300	Water level and discharge at C.13 station located downstream of the Chao Phraya dam was re-created.
11	Regulator	Phra Narai regulator	Rapipat Canal (discharged into East bank project area)			150	Observed discharge through the regulator was re-created.
12	Regulator	Pakhai Regulator	Noi River			150	

(3) Pumping Station

During flood events, inundated water would be drained to rivers/canals by pumping. The location of pump stations is shown in Figure 8.3.12. Since it is difficult to make all small and large pump stations built in the model, the pump stations in a drainage area shall be put together and total drainage capacity would be drained via main canals. The pump stations built in the model are as tabulated in Table 8.3.8.

Table 8.3.8 Pump Stations Built in the Model

No	Outlet	Pump Capacity (m^3/s)			Remarks
		Permanent	Semi-permanent	Total	
East	Chao Phraya R.	167.2	54.0	221.2	
	Nakhon Nayok R.	33.6	54.0	87.6	
	Bang Pakong R.	101.6	90.0	191.6	
	Gulf	336.8	48.0	384.8	
	Internal drain	136.0	114.0	250.0	
	Subtotal	639.2	360.0	999.2	
West	Chao Phraya R.	53.0	93.0	146.0	
	Tha Chin R.	276.4	267.0	543.4	
	Internal Drain	1.6	-	1.6	
	Sub-total	329.4	360.0	689.4	
Total		968.6	720.0	1,688.6	

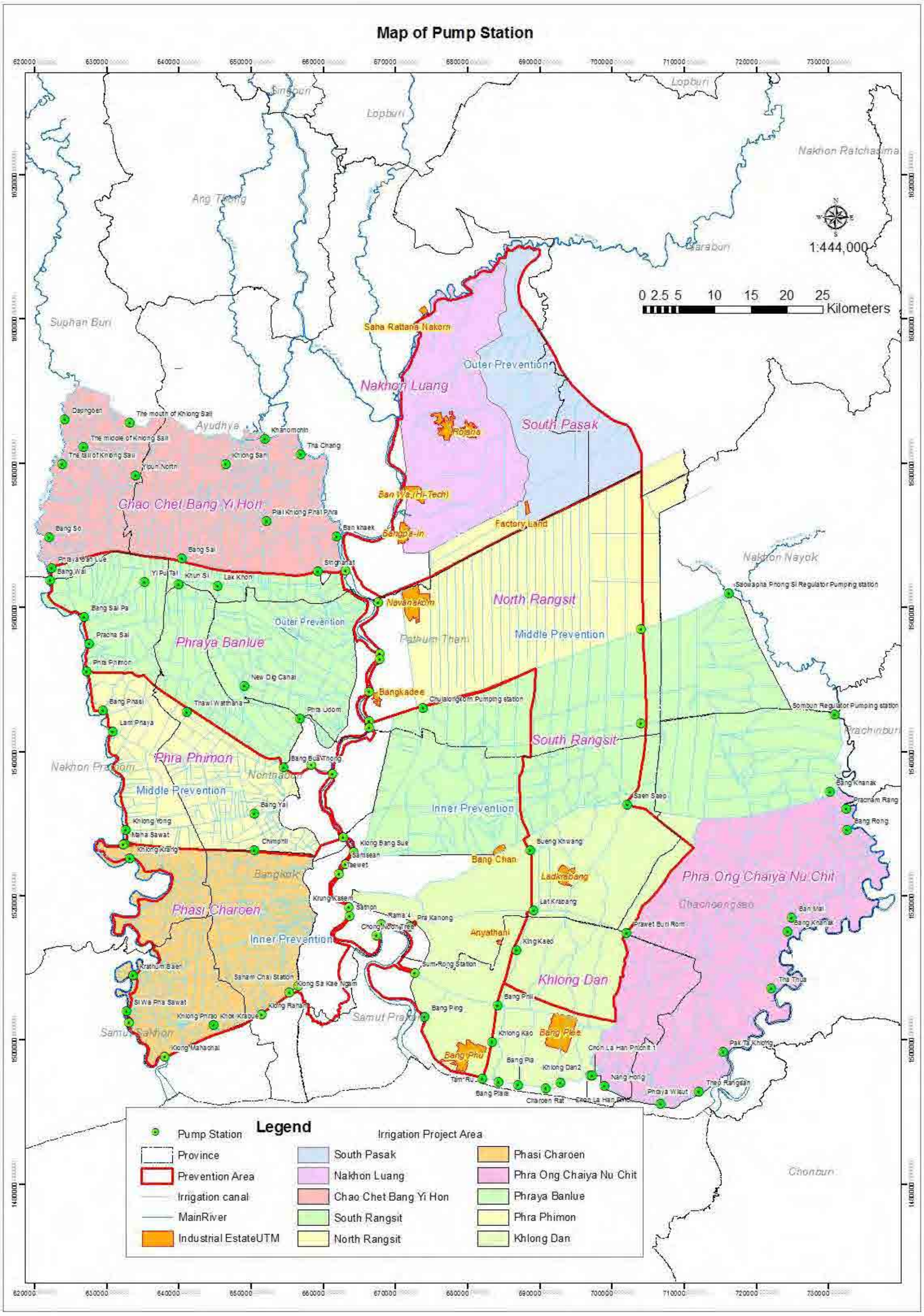


Figure 8.3.12 Location Map of Major Pump Stations (BMA)

It could be assumed that pump stations drain inundated water at maximum capacity if operation records of pump station are not available. In this study, pump stations would start operation under the condition that the pumps start working when water level in the canals rises nearly to the top of embankment and stop after the water level comes down to normal level (e.g., mean sea level). The locations of pump station built in the model, maximum capacity and criteria level of operation (start/stop) are as indicated in Figure 8.3.13.

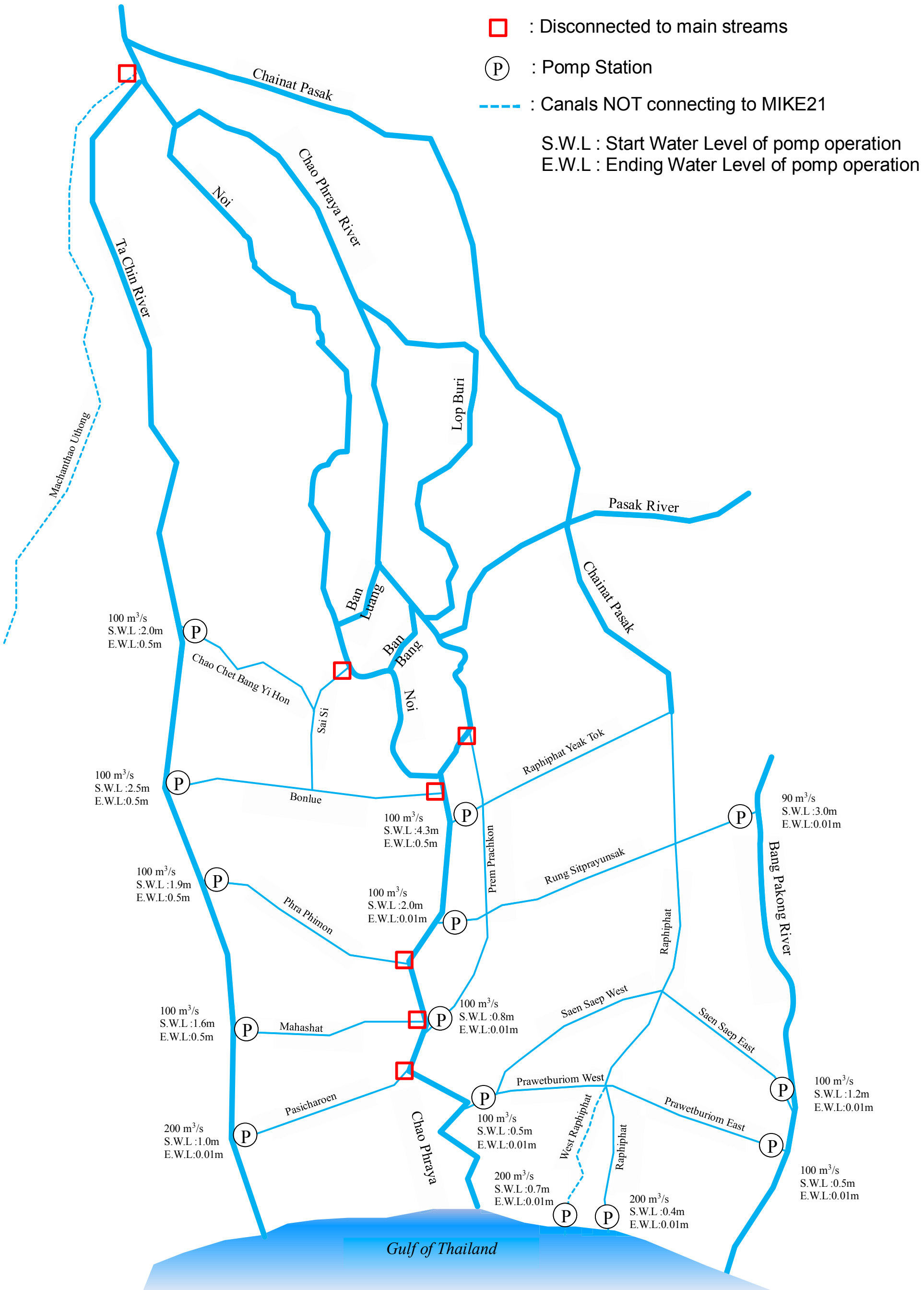


Figure 8.3.13 Location Map of Pump Stations and their Capacity

8.3.5 Boundary Conditions

(1) Boundary Conditions of River Network Model

In unsteady flow analysis, boundary conditions are given at upstream/downstream end and to the middle of river network as shown in Figure 8.3.14. At the riverhead and dam site, calculated hydrograph or released water from dams shall be given as the upper boundary condition. At the lowland area where sub basin runoff flows into the river separately, calculated runoff shall be distributed equally along the rivers/canals (See Figure 8.3.15).

At the estuary of the river, the tidal level of the Gulf of Thailand shall be given as the lower boundary condition. In this study, the observed tidal level at Pom Phurachul Station and Samut Sakhorn Station are given to the estuary of the Chao Phraya River and the Ta Chin River, respectively.

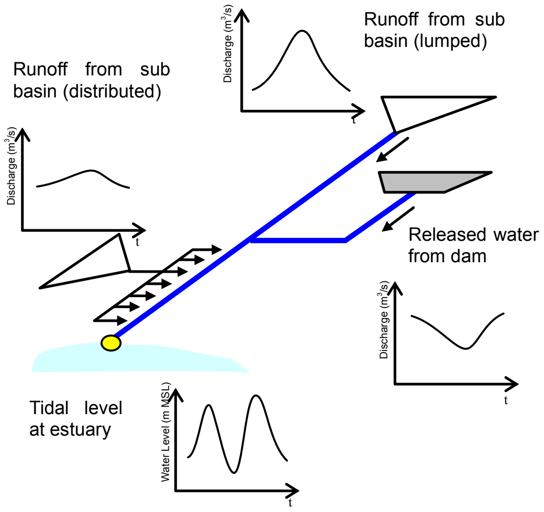


Figure 8.3.14 Intellection of Boundary Condition

(2) Correction of Tidal Data

Table 8.3.9 shows the tidal stations employed as lower boundary. For setting the accurate boundary condition, the observation data at tidal stations were appropriately corrected based on the benchmark survey conducted in 2012.

Table 8.3.9 Boundary Conditions of Downstream

Boundary	Point	Tidal Station
Lower Boundary	Tha Chin river mouth	Samut Sakhorn
	Chao Phraya river mouth	Pomprachul

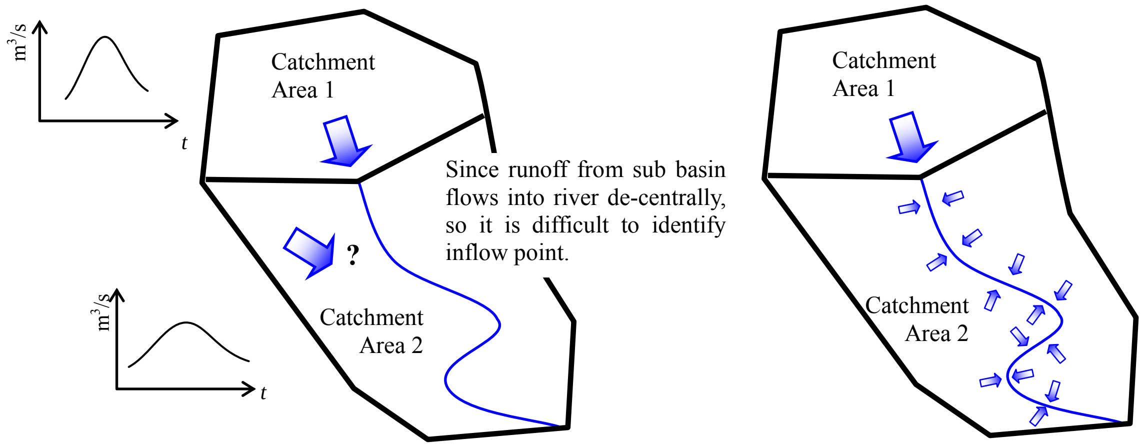
(a) Chao Phraya River

Observed data at RID TC.54 station (called Pom Phrachul) is given to as lower boundary condition for the Chao Phraya River. From the result of benchmark survey by JST, recorded values at TC.54 are supposed to be approximately 16cm higher than the actual values on average. In this study recorded value minus 16cm is given as lower boundary condition of Chao Phraya River. Also, error and missing data in recorded values shall be compensated by the astronomical tide level provided Royal Thai Navy (RTN).

(b) Tha Chin River

Observed data at Samut Sakhorn station is given to the model as lower boundary condition for the Chao Phraya River. From the result of benchmark survey by JST, recorded values at the station are supposed to be approximately 34cm higher than the actual values on average. In this study recorded value minus 34cm is given as lower boundary condition of Tha Chin River. Also, error and missing data in recorded values shall be compensated by the astronomical tide level provided Royal Thai Navy (RTN).

[How to give the calculated runoff to the river network in the remaining basin (residual area)]



Step 1: Calculate runoff from sub-basin with NAM (Runoff Model).

Step 2: If inflow points are not identified, calculated runoff shall be distributed equally along rivers. If hydrological station located in the middle of a basin is used for model calibration, calculated runoff shall be given in proportion to the area of sub catchment area divided at the hydrological station.

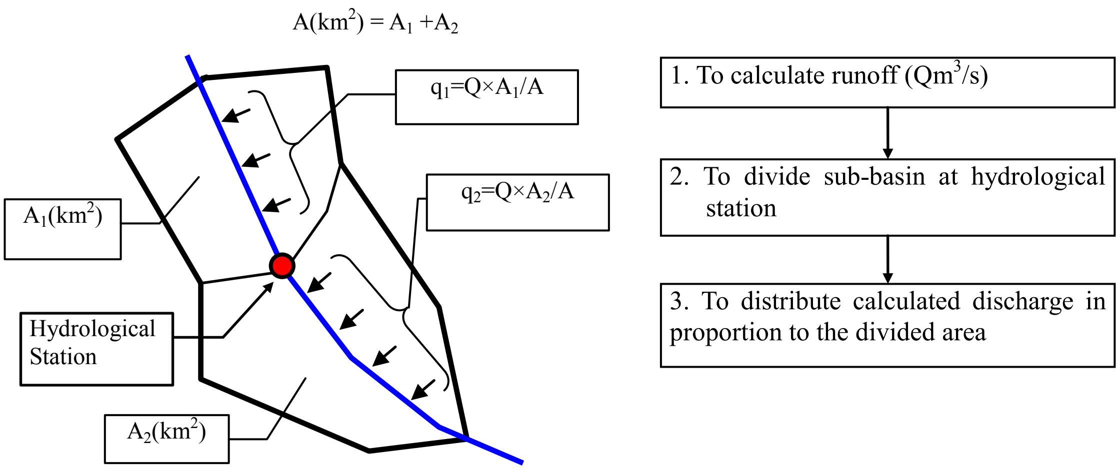


Figure 8.3.15 Distribution of Runoff

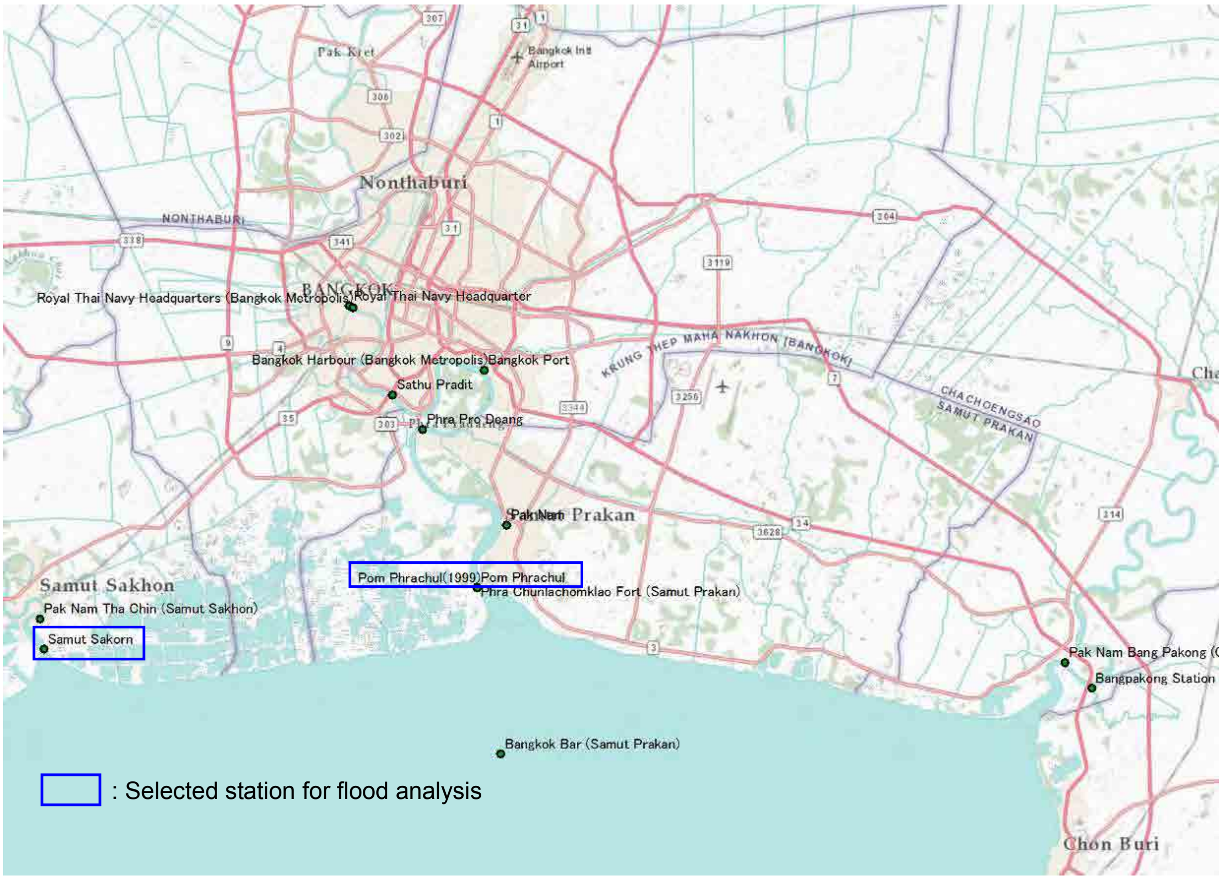
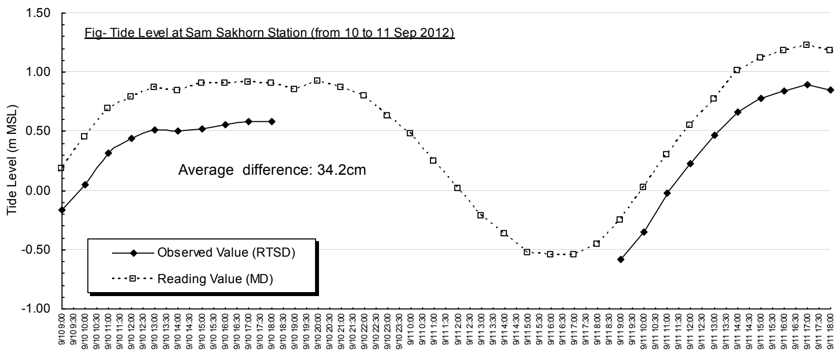


Figure 8.3.16 Location Map of Tide Level Stations near the Gulf of Thailand



*It is regarded that observed tidal data with reference to RTSD's first-order bench mark is proper.

Figure 8.3.17 Benchmark Comparison of Samut Sakhorn (Benchmark Survey on 10-11 Sep 10 2012)

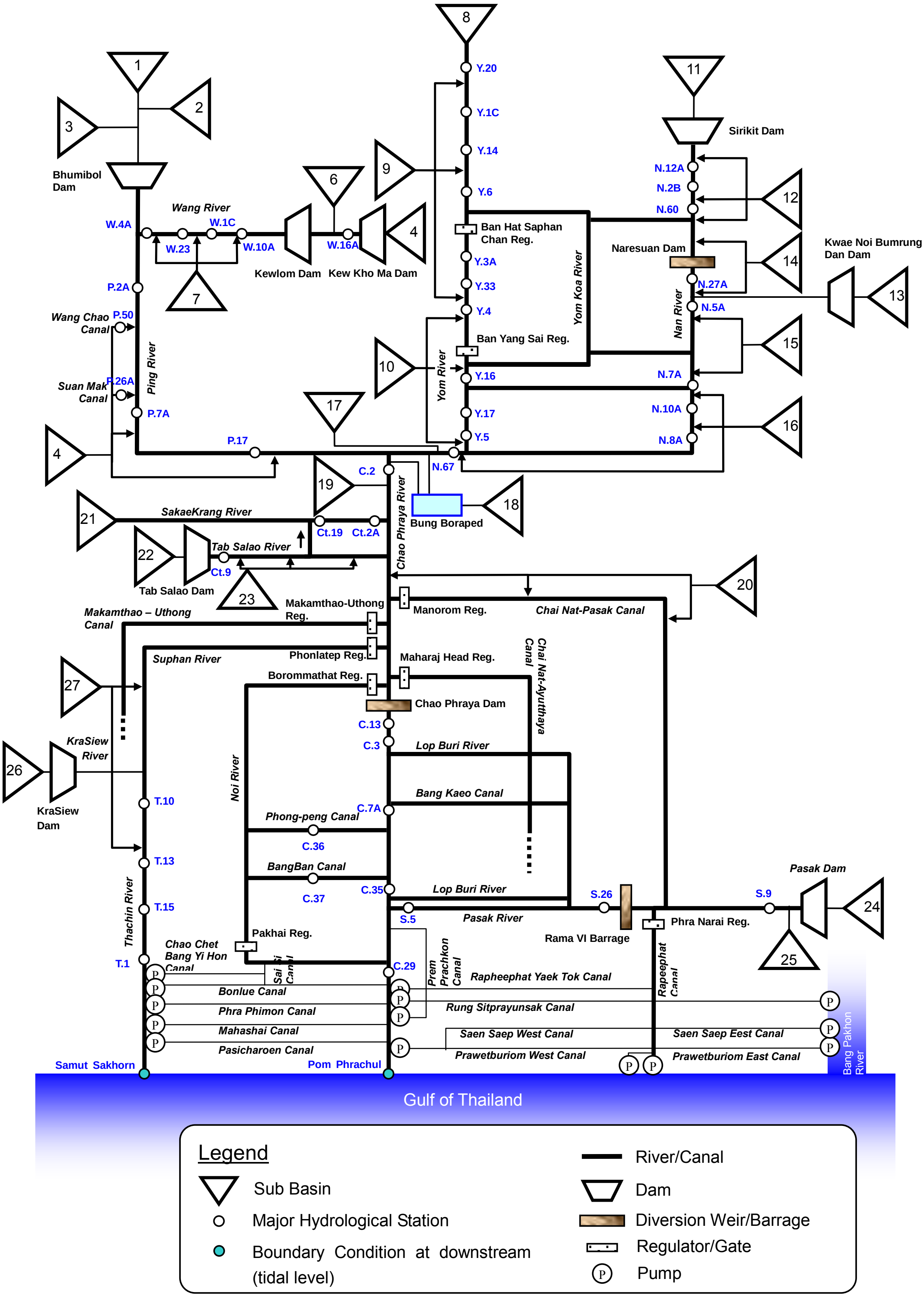


Figure 8.3.18 Proposed River Network Model for M/P Study

8.4 Inundation Model

8.4.1 Outline

For the inundation analysis in flood plain, the two-dimensional unsteady flow analysis model shall be employed. The outline of the model and the schematic diagram of the two-dimensional unsteady analysis are shown in Table 8.4.1 and Figure 8.4.1, respectively.

Table 8.4.1 Outline of the Inundation Model

Items	Contents
Software	DHI-MIKE-FLOOD
Grid Size	2,000m
Modeling Area	X: 338,000 - 838,000 Y: 1,460,000 - 2,210,000 (coordinate system: WGS84 UTM Zone 47N)
Elevation	Average elevation is set up based on the result of aviation survey (LiDAR) conducted on 2012
Roughness Coefficient	Set up by reference to land use (LAND SAT 2009 - 2010)
Continuous Structure	Major roads, King's Dike (Bangkok), Surrounding dike (major urban area). Height of structure is determined from LiDAR data

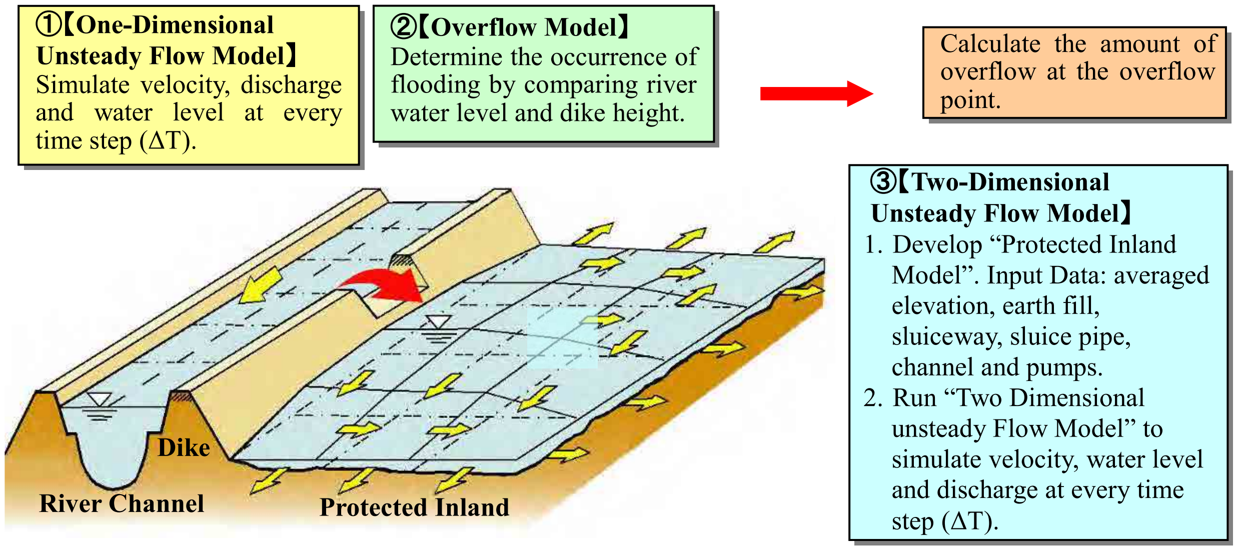


Figure 8.4.1 Schematic Diagram of Inundation Analysis Model

8.4.2 Model Parameters

(1) Elevation of Flood Plain

The average ground elevation of the flood plain model is made from the results of the aerial survey conducted by the JICA LiDAR Team in 2012, which has high density and accuracy. In the study, considering current computing power, inundation analysis shall be conducted with 2,000m grid.

Table 8.4.2 Elevation Data (LiDAR Data)

Items	Description	Remarks
Observation Term	March 2012	
Resolution	Observation Density: point/4m^2	In the study, grid-size of 2,000m is employed for flood analysis.
Area	X: 396,000 - 808,000 m Y: 1,460,000 - 2,044,000 m *Coordination system: WGS1984 UTM Zone 47N	Elevation data in the military area was not provided due to the security regulation. That area and out of the observation area of LiDAR data shall be complemented with spot height of topographic map of 1/50,000 scale.

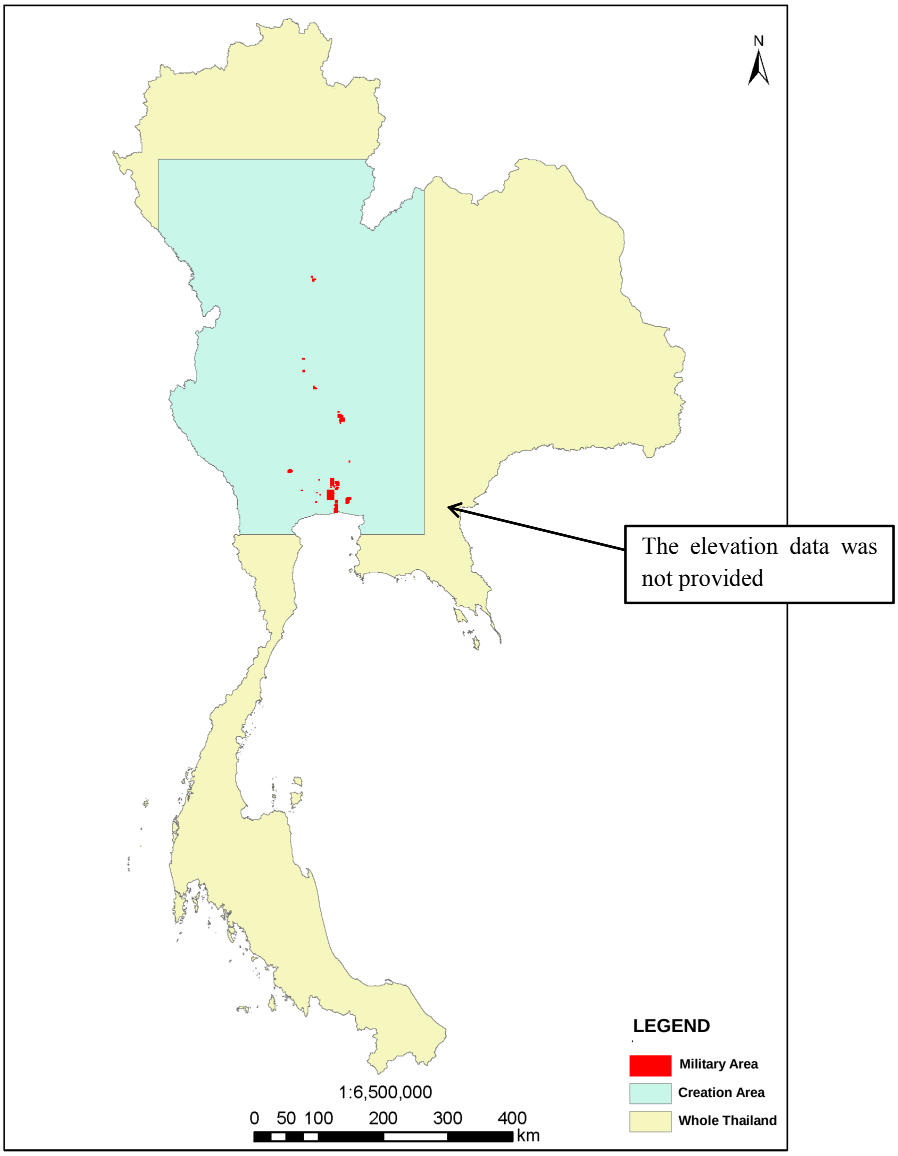


Figure 8.4.2 Produced Area of Elevation Data

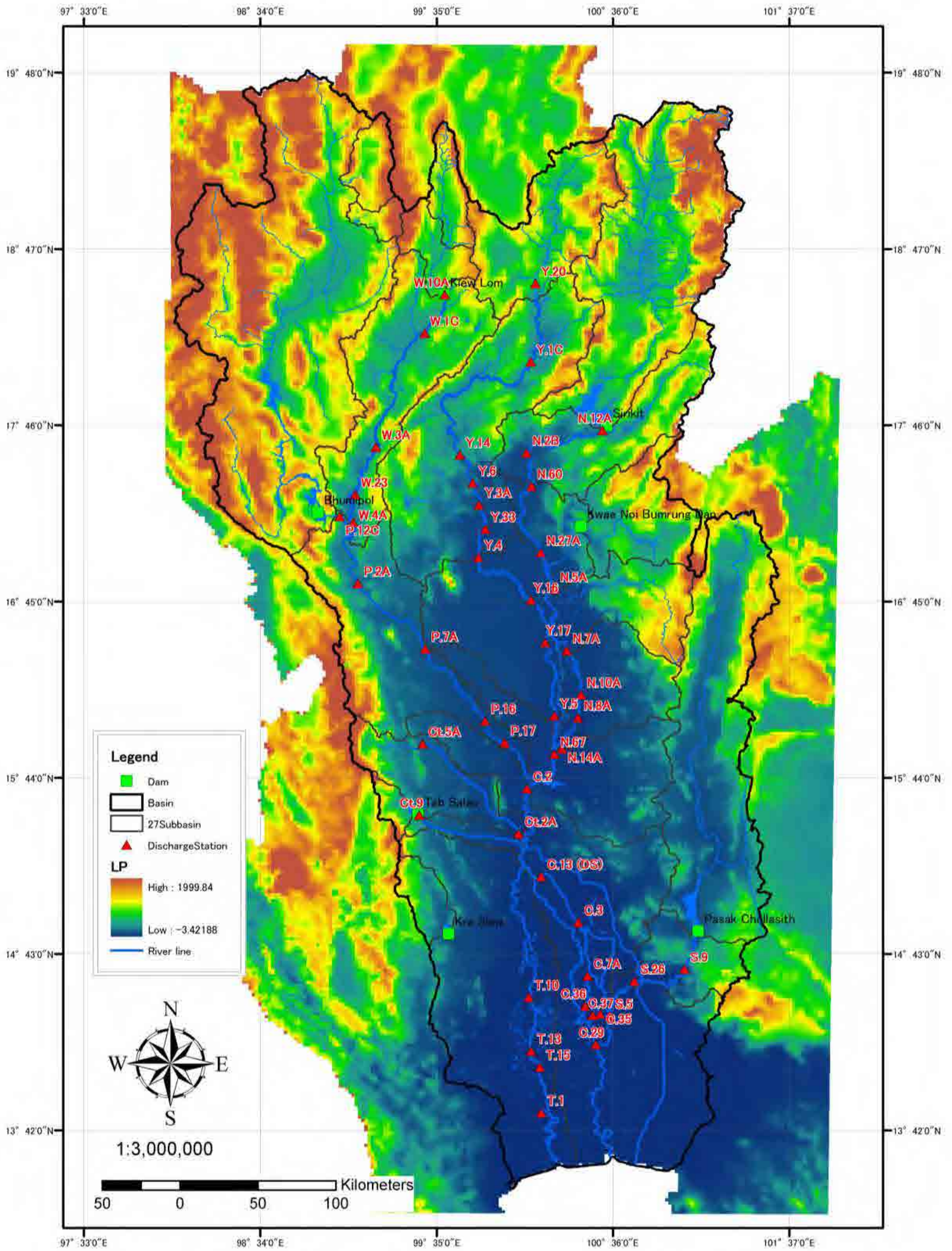


Figure 8.4.3 Ground Elevation from the LiDAR Data (Grid Size: 2,000m)

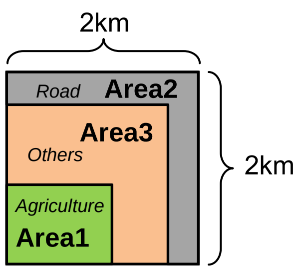
(2) Roughness Coefficient of Flood Plain

Based on the land use condition from LANDSAT 2011 (Observed from 2009 to 2010), roughness coefficient shall be set. According to the standard values[4], the roughness coefficient of flood plain for agriculture, road and others are defined as 0.060, 0.047 and 0.050, respectively. If more than two categories of land use are included in a mesh, roughness coefficient of the mesh shall be calculated in proportion to the ratio of area.

Land use map and initial roughness coefficients are shown in Figure 8.4.5 and Figure 8.4.6.

Table 8.4.3 Data Source of Land Use

Items	Description
Data	LANDSAT LANDUSE DATA 2011
Observation Term	2009 – 2010
Data Type	Raster Data



$$n = \frac{0.060 \times Area1 + 0.047 \times Area2 + 0.050 \times Area3}{Area1 + Area2 + Area3}$$

Figure 8.4.4 Roughness Coefficient of Flood Plain (Grid Size: 2,000m)

(3) Continuous Structure

Continuous structures such as main national roads, King's Dike and ring dike of major urban areas which would have an influence on inundated flows shall be built in the flood inundation model. The outline of modeled continuous structures and the locations are shown in Table 8.4.4 and Figure 8.4.7.

Table 8.4.4 Continuous Structures Built in the Model

Type	Name	Description
Dike	Kings Dike	Total Length: 156km Height of Embankment: 0 to 3 (m MSL)
	Ring Dike	Total Length: 530km Height of Embankment: 0 to 4 (m MSL)
	Economic Zone	Total Length: 126km Height of Embankment: 0 to 3 (m MSL)
Road	Major National Roads Route 1, 2, 3, 4, 7, 9, etc.	Total Length: 1,376km Height of Embankment: 0 to 4 (m MSL)

(4) Infiltration

In this study, 10 mm/day is set as the value of infiltration to each grid of flood plain, which includes infiltration volumes into soils and drainage volumes into small drainage systems (smaller than the canals developed in the model mentioned in Section 8.3).

[4] Simulation Manual on Inundation (draft version) by Public Works Research Institute, Japan 1996

(5) Evaporation

The effect of evaporation from the flood plain shall be considered when the flood plain is inundated. Unlike through the rainfall-runoff process [refer to Subsection 8.2.3(2)], surface water is supposed to evaporate directly from inundated floodplain with minimum loss. Since the amount is nearly equal to the maximum potential value, the pan evaporation amount at the TMD synoptic station (46 stations) shall be given to the grid with the Thiessen Method.

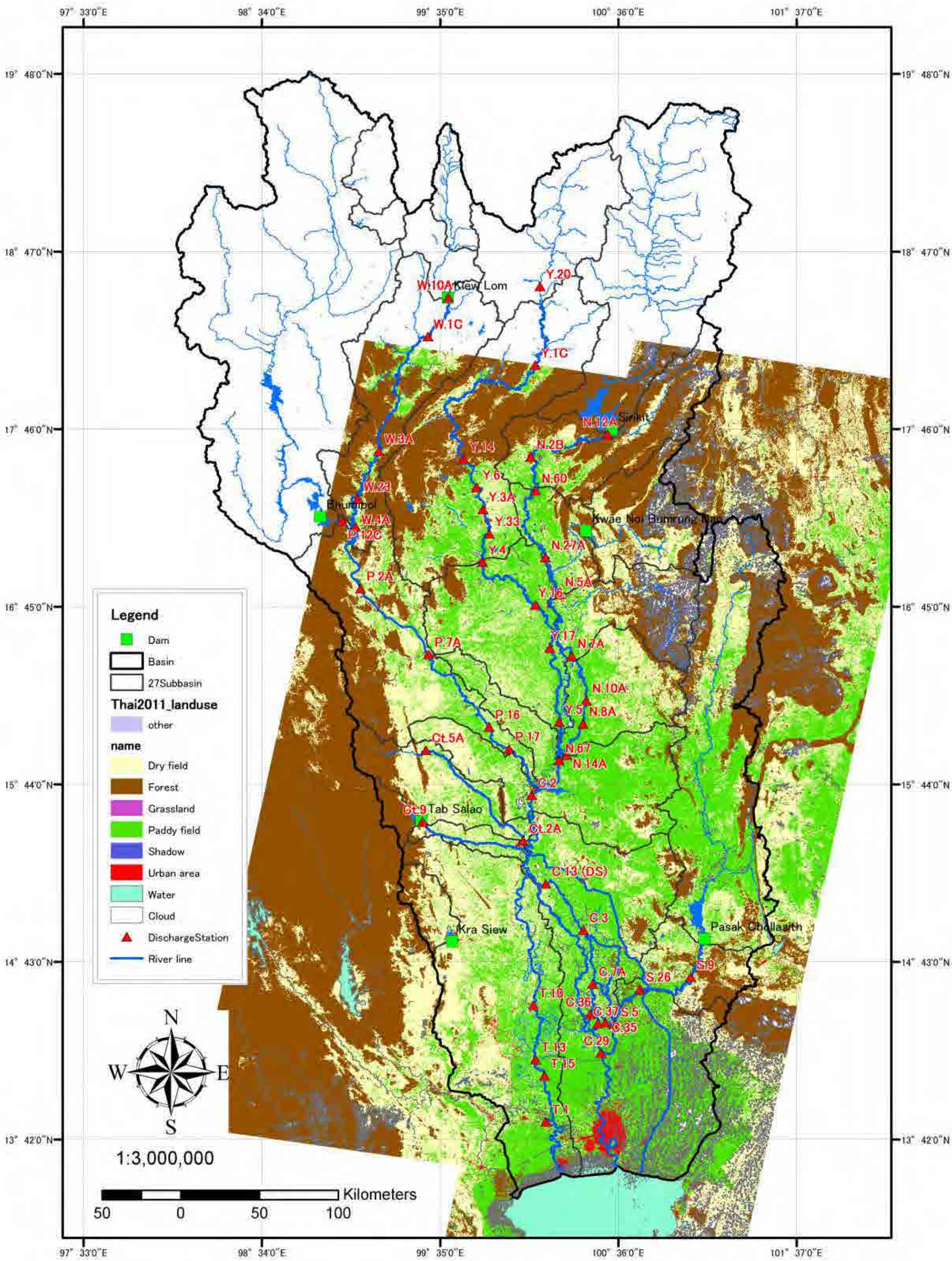


Figure 8.4.5 Land Use Condition Map (from LANDSAT 2009 - 2010)

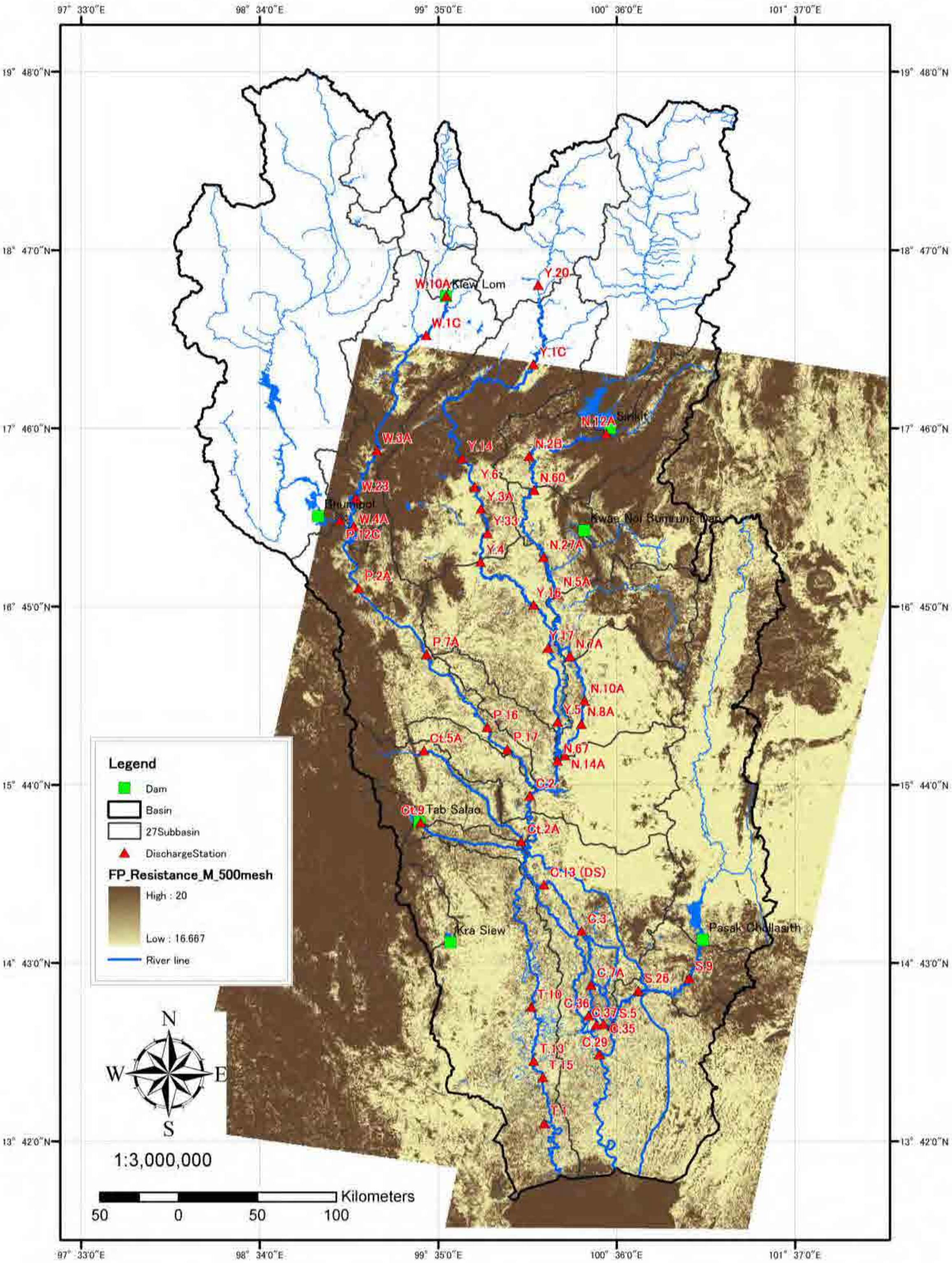


Figure 8.4.6 Map of Roughness Coefficients of Floodplain (1/n)

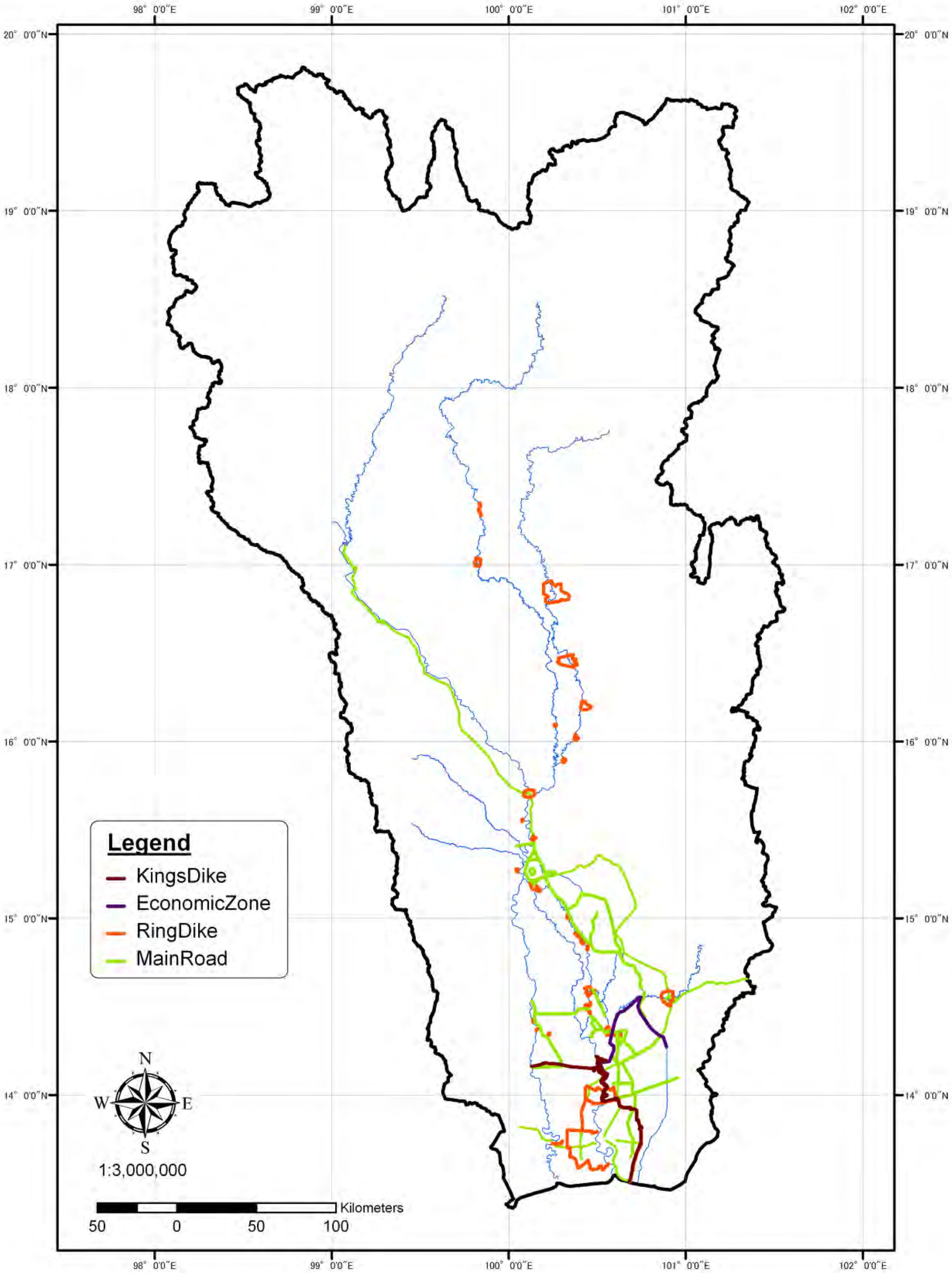


Figure 8.4.7 Location Map of Continous Structures

(6) Dike Break

In the 2011 Flood, dike breaks happened at approximately 10 places on the left side along the Chao Phraya River, as shown in Figure 8.4.8. This model would take account of dike breaks for reproduction calculation since the water volume flowing down to the sea would decrease due to inundation.

In this study, overflow levees shall be built in at dike break points to simulate the phenomenon of dike breaches. When water level exceeds height of overflow levees, part of river water will spill into the flood plain. Height of overflow levees shall be set based on the ground elevation near dike break point, and width of overflow would be determined by reference to the following table about actual dike break condition in 2011yr flood.

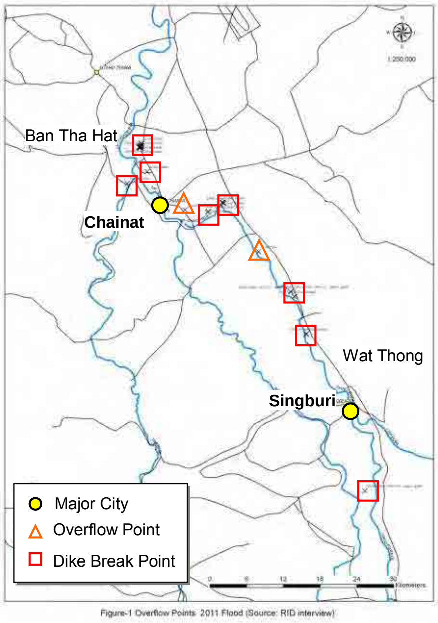


Figure 8.4.8 Dike Break Points (2011)

Table 8.4.5 Results of Site Survey on Dike Break (2011)

No.	Location	Side	Type	Location (upstream)	Location (downstream)	Length of broken dike/overflow	Date	Remarks
1	Chainat front dike_cross-dike	Left	Dike break	N15 16' 09.55" E100 05' 26.41"	N15 16' 09.19" E100 05' 27.00"	20	2011/9/22	
2	Chainat front dike_cross-dike	Left	Dike break	N15 16' 09.05" E100 05' 30.16"	N15 16' 09.18" E100 05' 32.86"	80	2011/9/22	
3	Local road	Left	Dike break	N15 16' 14.53" E100 05' 31.42"	N15 16' 13.55" E100 05' 34.98"	110	2011/9/22	
4	Chainat main dike along route No.1	Left	Dike break	N15 16'30.63" E100 05' 40.69"	N15 16' 27.62" E100 05' 40.32"	100	2011/9/22	
5	Chainat main dike along route No.1	Left	Dike break	N15 16' 20.05" E100 05' 38.26"	N15 16' 17.78" E100 05' 37.96"	70	2011/9/22	
6	Chainat main dike along route No.1	Left	Dike break	N15 16' 13.86" E100 05' 36.88"	N15 16' 13.41" E100 05' 36.75"	15	2011/9/22	
7	Chainat main dike along route No.1	Left	Dike break	N15 16' 08.13" E100 05' 35.27"	N15 16' 07.29" E100 05' 35.07"	30	2011/9/22	
8	Chainat main dike along route No.1, near hill	Left	Dike break	N15 13' 59.50" E100 06' 11.57"	Unknown	100	2011/9/22	length is estimated value
9	Upstream of 2km from Chao Phra Dam, Spillway	Left	Overflow	N15 10' 35.06" E100 09' 36.53"	Unknown	1,000	2011/9/18	Spillway established on the road, 17.0MSL(estimated)
10	Downstream of 2km from Chao Phra Dam	Left	Dike break	N15 10' 22.83" E100 11' 39.65"	N15 10' 26.30" E100 11' 45.13"	200	2011/9/22	
11	Downstream of 5km from Chao Phra Dam	Left	Dike break	N15 11' 13.41" E100 13' 01.43"	N15 11' 14.40" E100 12' 59.47"	65	2011/9/22	
12	Downstream of 5km from Chao Phra Dam	Left	Dike break	N15 11' 09.95" E100 13' 08.22"	N15 11' 11.46" E100 13' 05.37"	100	2011/9/22	
13	Downstream of Chao Phra Dam	Left	Overflow	Downstream of 1km from Chao Phra Dam	N15 06' 49.74" E100 16' 18.56"	14,000	Unknown	coordination of downside is unknown
14	Bang Chom Sri gate in Sing Buri region	Left	Dike break next to water gate	N15 03' 15.70" E100 19' 13.53"	N15 03' 17.22" E100 19 12.15"	60	2011/9/13	
15	Downstream of 1km from Bang Chom Sri gate in Sing Buri district	Left	Dike break	N15 02' 51.38" E100 19' 32.43"	N15 02' 49.77 E100 19' 33.28"	55	2011/9/14	
16	Downstream of 7km from Bang Chom Sri gate in In Buri district	Left	Dike break	N14 59' 31.04" E100 20' 36.01"	N14 59' 29.35" E100 20' 36.48"	55	2011/9/17	
17	Water Gate at the Tha Chin River (regulator)	right	Gate Open	N15 12' 57.81" E100 04' 21.70"				B=7m, 4 gates (estimated), $220m^3/s > 350m^3/s$
18	Phra Ngam Water Gate (Regulator)	right	Dike break next to water gate	N14 45' 33.04" E100 25' 49.87"	Unknown	50	2011/9/15	length is estimated value

8.5 Model Verification

8.5.1 Outline

To prove the reasonability of the model, the model calibration was conducted by comparing calculated valiues and observed ones. In the study, 2006yr and 2011yr which are large scale flooding the last ten years were employed as target floods.

8.5.2 Selection of Verification Points

Many hydrological stations have been installed in the Chao Phraya River Basin. In the study, hydrological stations that have well-observed data and are important points for flood control have been employed as model calibration points. The points painted in white in Figure 8.5.1 were selected as the model calibration points. It was found that the hydrological stations and regulators painted in gray have some margin of observation error and/or missing data, so that they were not treated as calibration points.

<Remarks>

- To study on basin-wide flood control plan, hydrological stations located in main tributaries (8 rivers) were mainly selected at this time.
- Discharge data at W.16A was not used for the calibration because the water released from Kew Kho Ma Dam located upstream of W.16A possibly involves incorrect values in 2011 and reasonability of W.16A could not be proved.
- Discharge data at Y.6 is incorrect because runoff rate (runoff / rainfall depth) at Y.6 shows negative values.
- Seven facilities, Ban Hat Saphan Chan regulator, Ban Yang Sai regulator, Naresuan dam, Makamthao-Uthong regulator, Maharaj Head regulator and Rama VI Barrage, have no observation records, so that calibration calculation could not be made at these facilities.

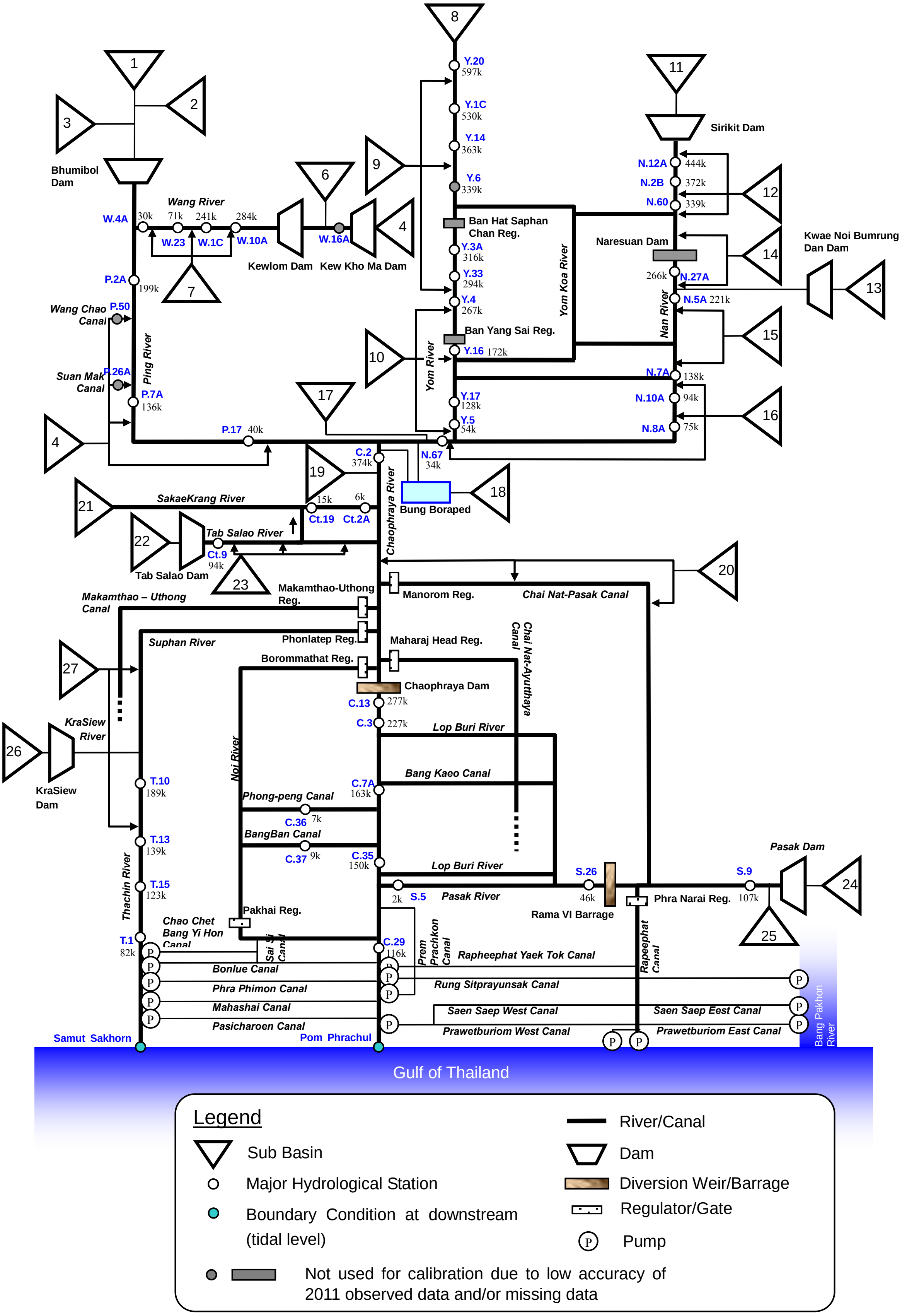


Figure 8.5.1 Selected Calibration Points

8.5.3 Inundation Area

To prove the reasonability of the model, inundation area have been examined. Observed inundation area published by UNOSAT and GISTDA, and the results of flood mark survey conducted in 2012 as shown in Figure 8.5.2, Figure 8.5.3 and Figure 8.5.4 have been used for the verification.

Table 8.5.1 Record of Inundation Information

Data Source	Information	Remarks
UNOSAT	Inundation area in the middle of August, September, October and November 2011.	Reference: United Nations Institute for Training and Research http://www.unitar.org/unosat/
GISTDA	Inundation area in 2006 Flood (yearly) Inundation area in 2011 flood from May to November	Reference: Thailand Flood Monitoring System http://flood.gistda.or.th/
Flood Mark Survey by JST	Maximum inundation depth and inundated time in inundated area in 2011. Number of survey points is approximately 6,600.	This survey was conducted from downstream of Y.4 (Yom River), P.16 (Ping River) and N.27A (Nam River) to Gulf of Thailand. Regarding inundation area, out of the survey area shall be referred to UNOSAT.

<Overflow point>

- At upstream of Nakhon Sawan, overflow occurred at downstream near P.16 (Ping River), downstream of Y.33, and downstream of N.60 (Nan River)
- At downstream of Nakhon Sawan, overflow occurred at right side just downstream of Nakhon Sawan
- From the diversion point of Chainat-Pasak Canal to around Chainat and Sing Buri, there were several dike breaks due to penetration flow in dike body (refer to Figure 8.4.8).

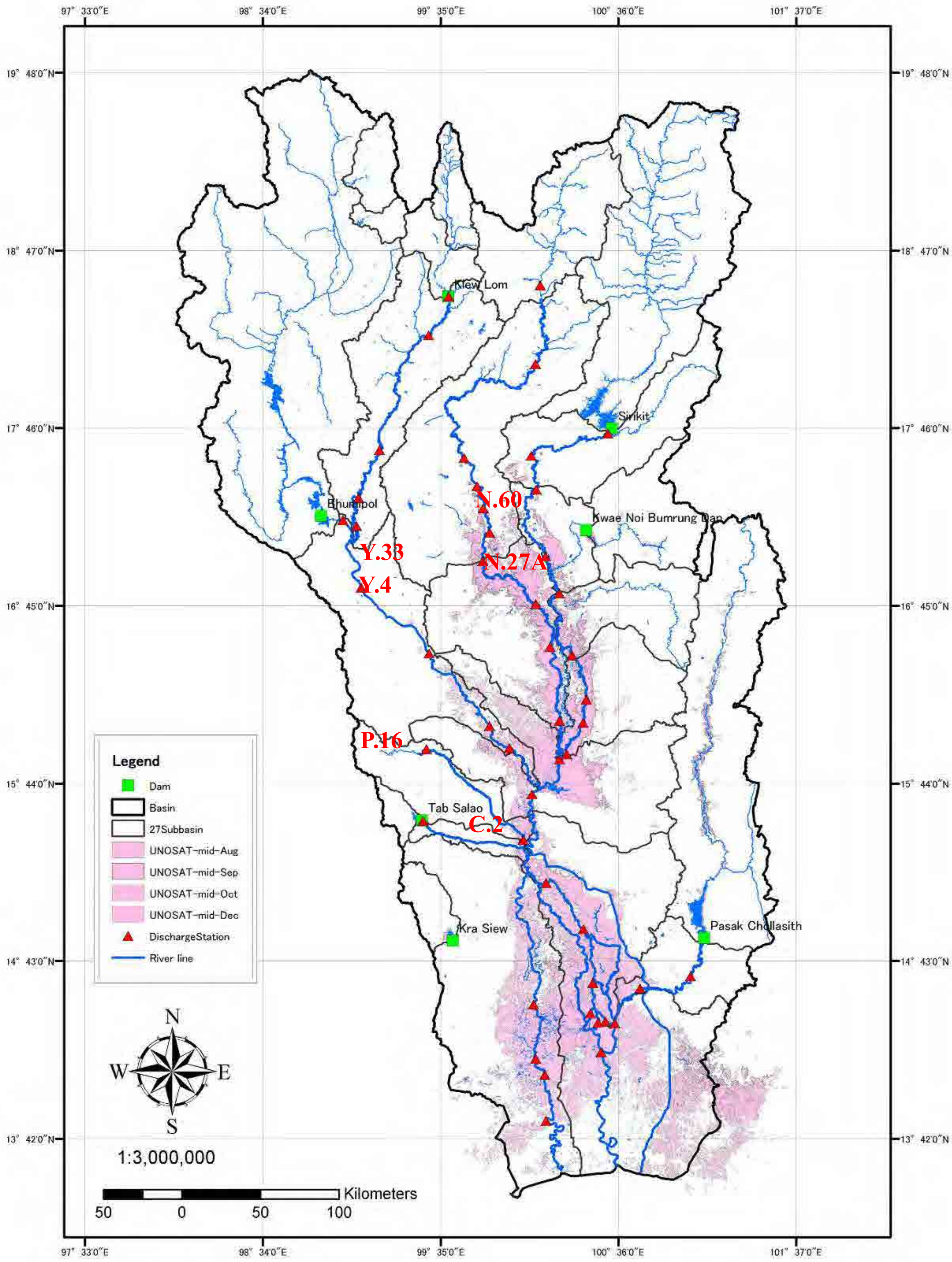


Figure 8.5.2 UNOSAT（from Mid-August to Mid-Deccember)

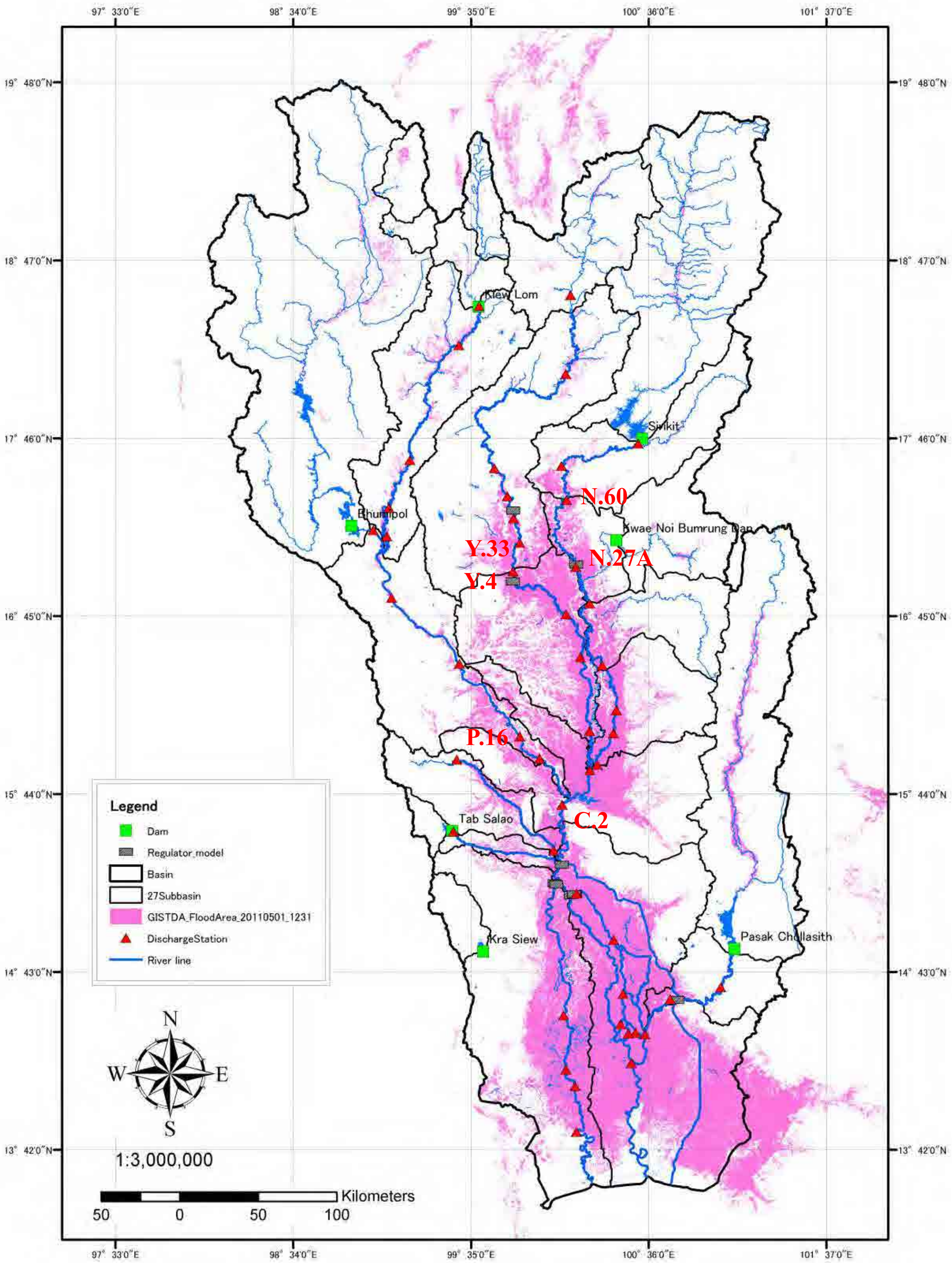


Figure 8.5.3 GISTDA Flood Area (2011/5/1-12/31)

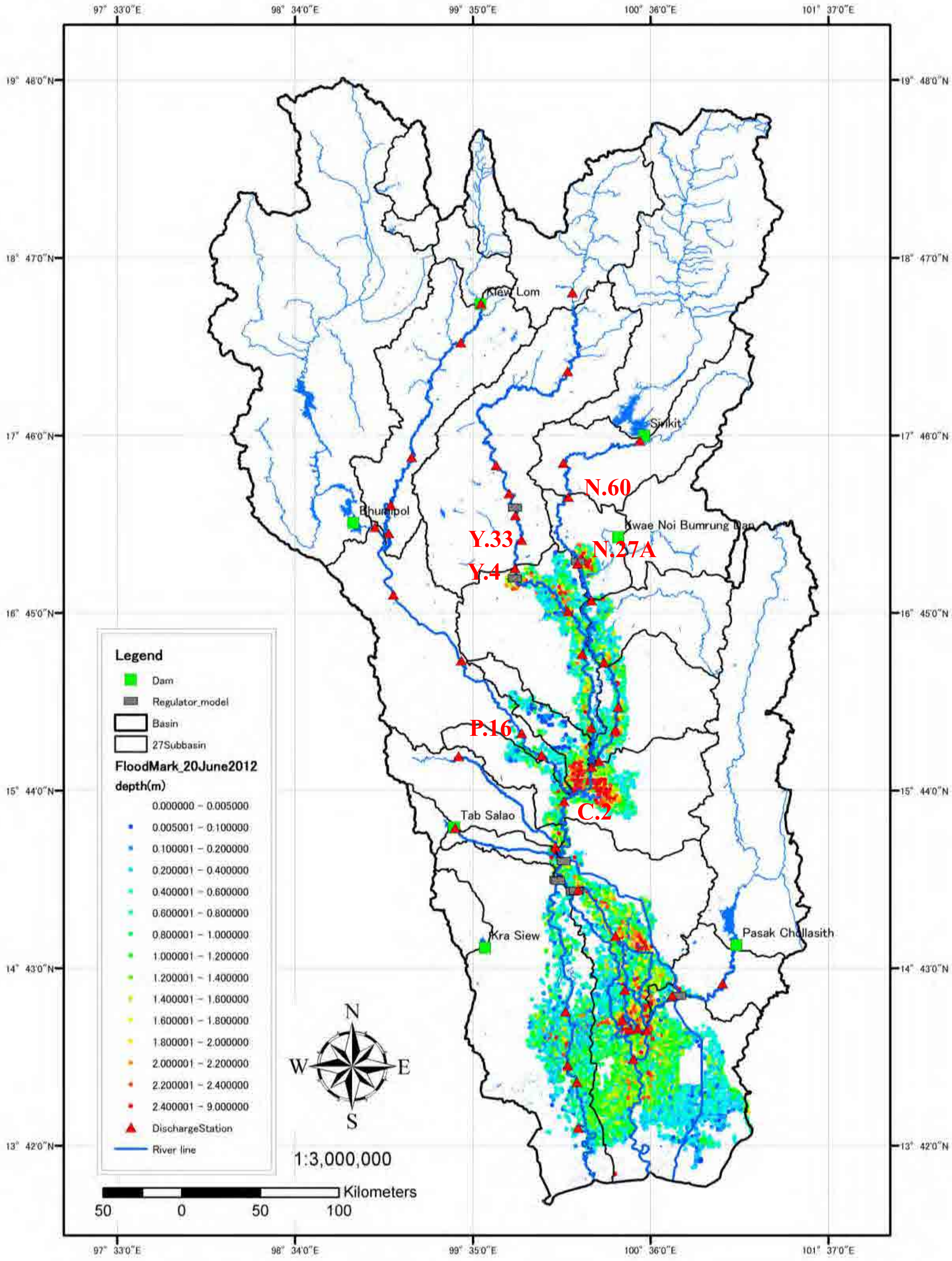


Figure 8.5.4 Result of Flood Mark Survey Conducted in 2012

8.5.4 Verification

Reproduction calculation of the 2006 and 2011 floods were carried out under the initial condition as mentioned above, and then parameter fitting was repeated.

(1) Evaluation Method

Table 8.5.2 shows the evaluation items and method for the evaluation of reasonability of the model.

Table 8.5.2 Evaluation Items for Reproduction Simulation

No.	Evaluation Items	Evaluation Points	Remarks
1	Longitudinal Profile of Water Level	・Chao Phraya River ・Tha Chin River・Pasak River	Compare with observed water level
2	Water Level and Discharge	At validation points	Compare with observed water level and discharge
3	Inundation Area	1) Maximum inundated area 2)monthly inundated area from August to December	Compare among UNOSAT、GISTDA、and Flood Inundation Survey Monthly inundated area of UNOSAT and GISTDA are available only in 2011.
4	Inundation Depth	Maximum inundation depth	Compare with flood mark survey conducted 2012

(2) Evaluation Result

(a) Longitudinal Profile of Water Level

Longitudinal profiles (water level) of the Chao Phraya River, Tha Chin River and Pasak River are shown in the following figures.

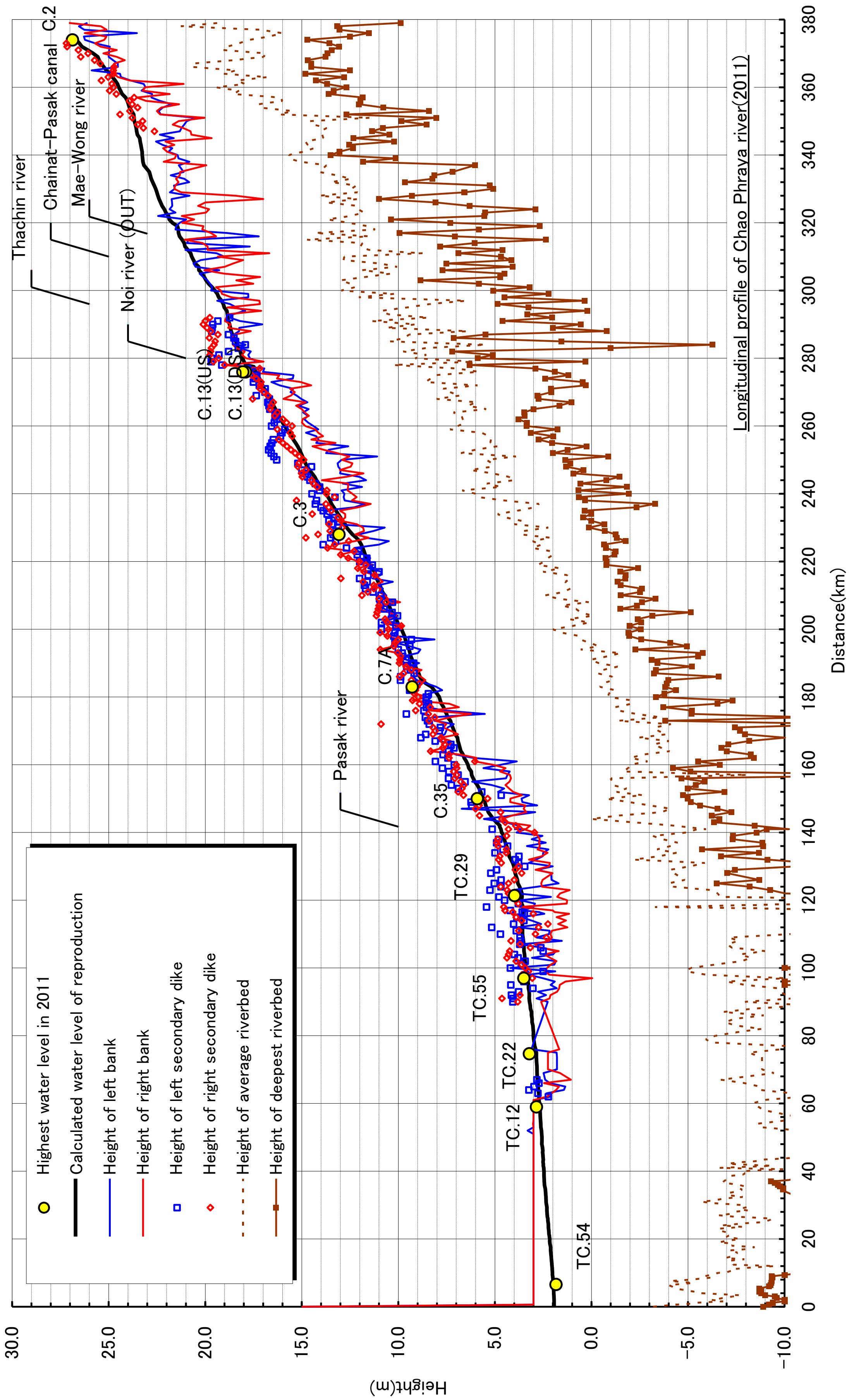


Figure 8.5.5 Longitudinal Water Level Profile for Chao Phraya River (2011)

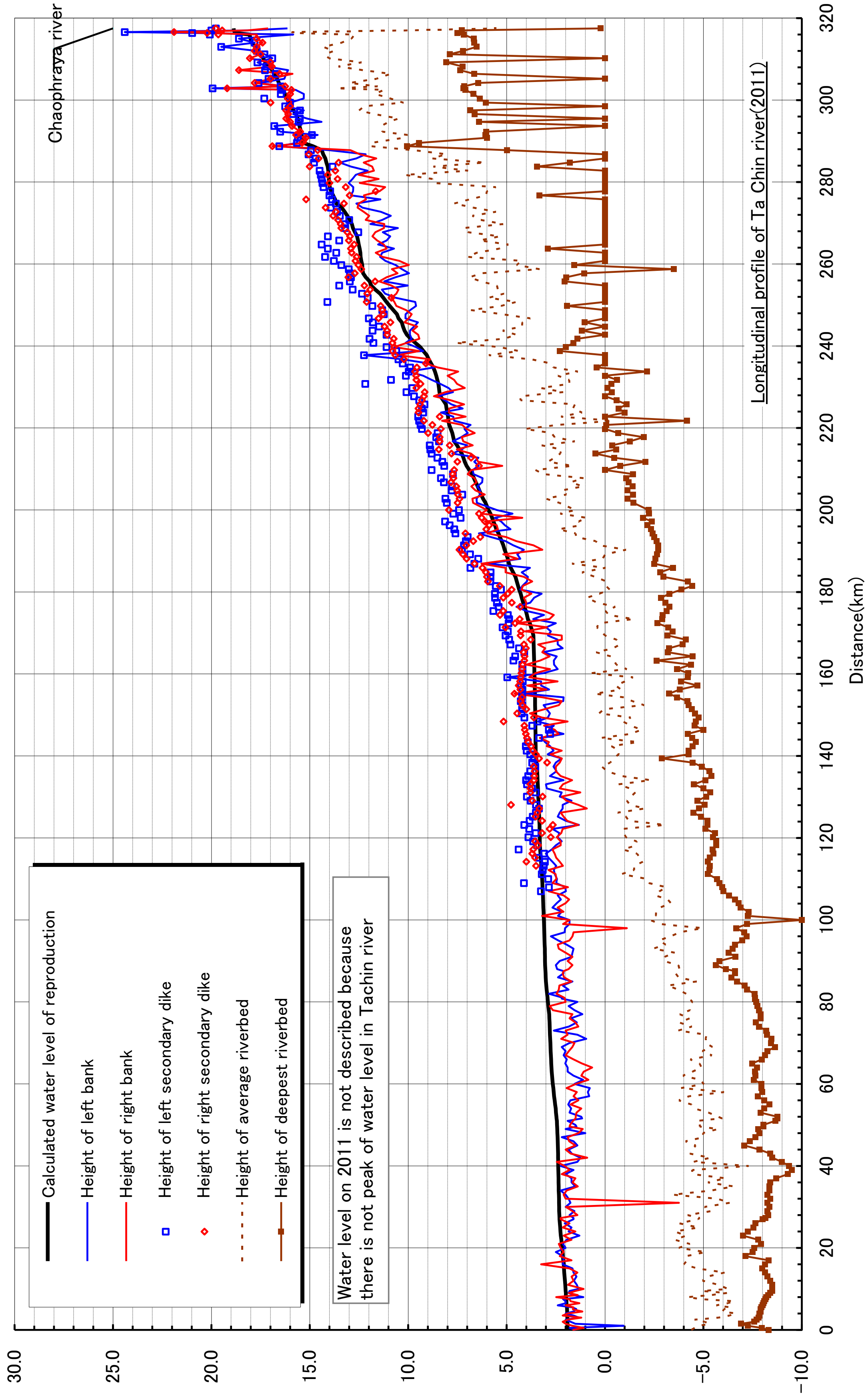


Figure 8.5.6 Longitudinal Water Level Profile for Tha Chin River (2011)

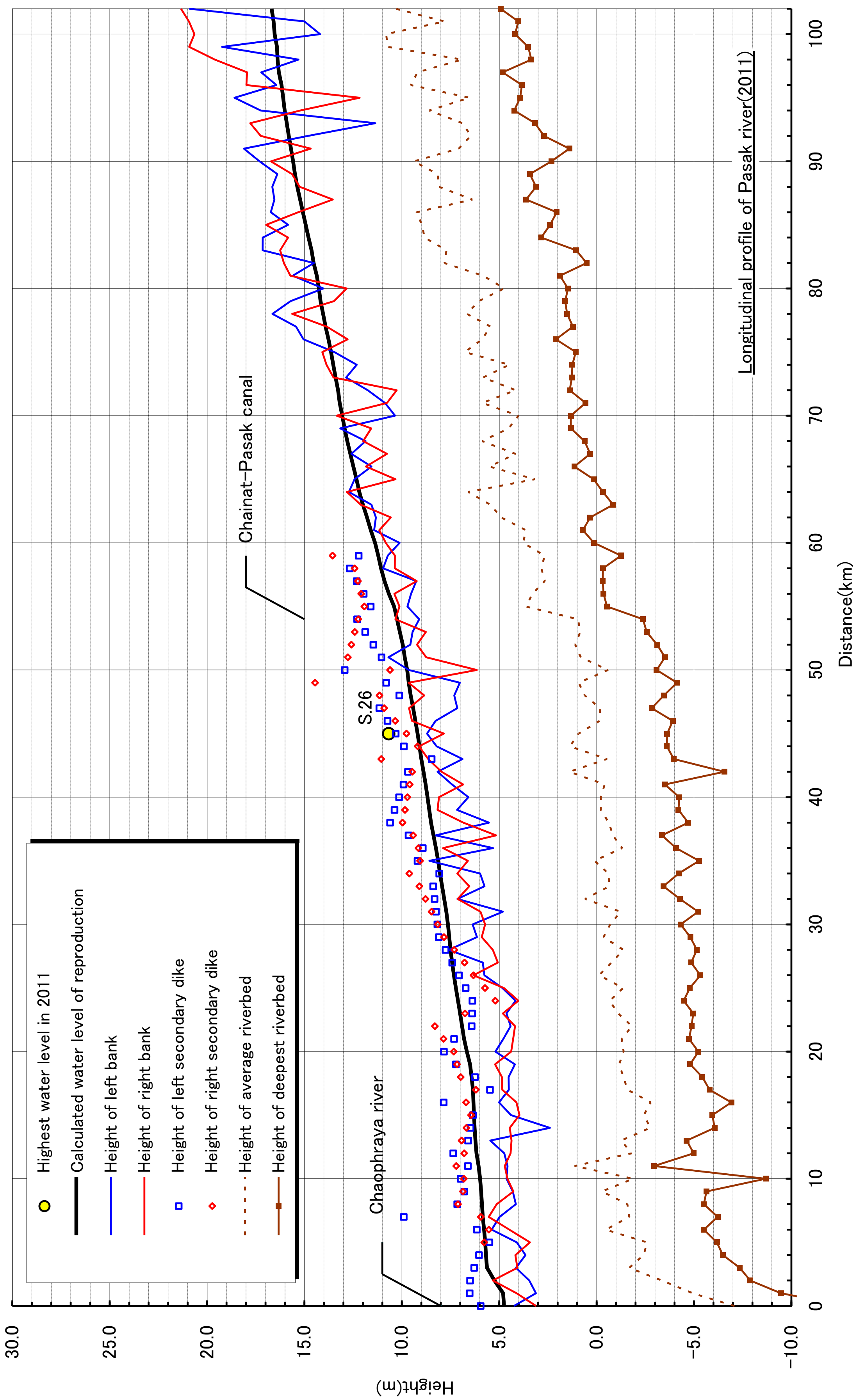


Figure 8.5.7 Longitudinal Water Level Profile for Pasak River (2011)

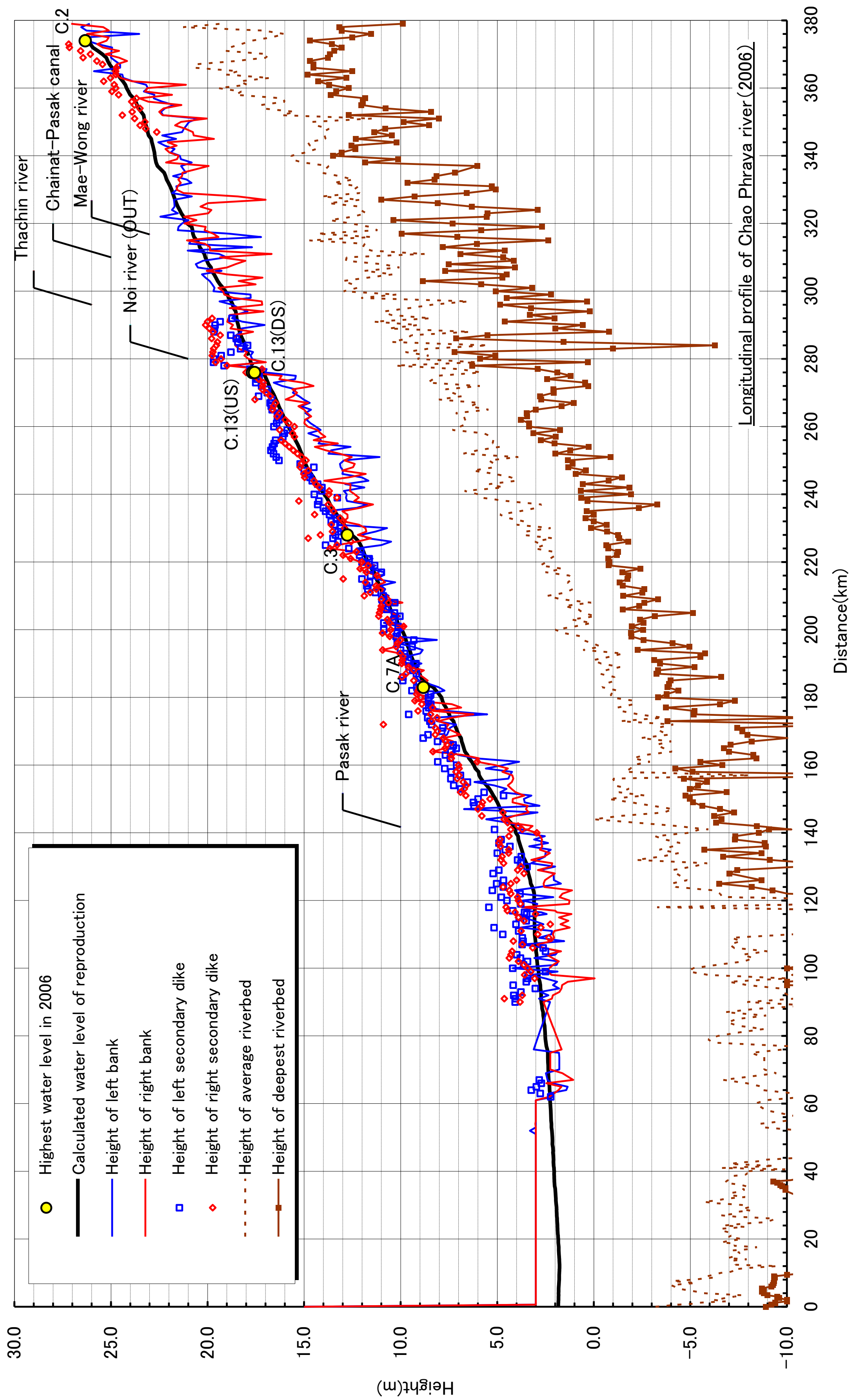


Figure 8.5.8 Longitudinal Water Level Profile for Chao Phraya River (2006)

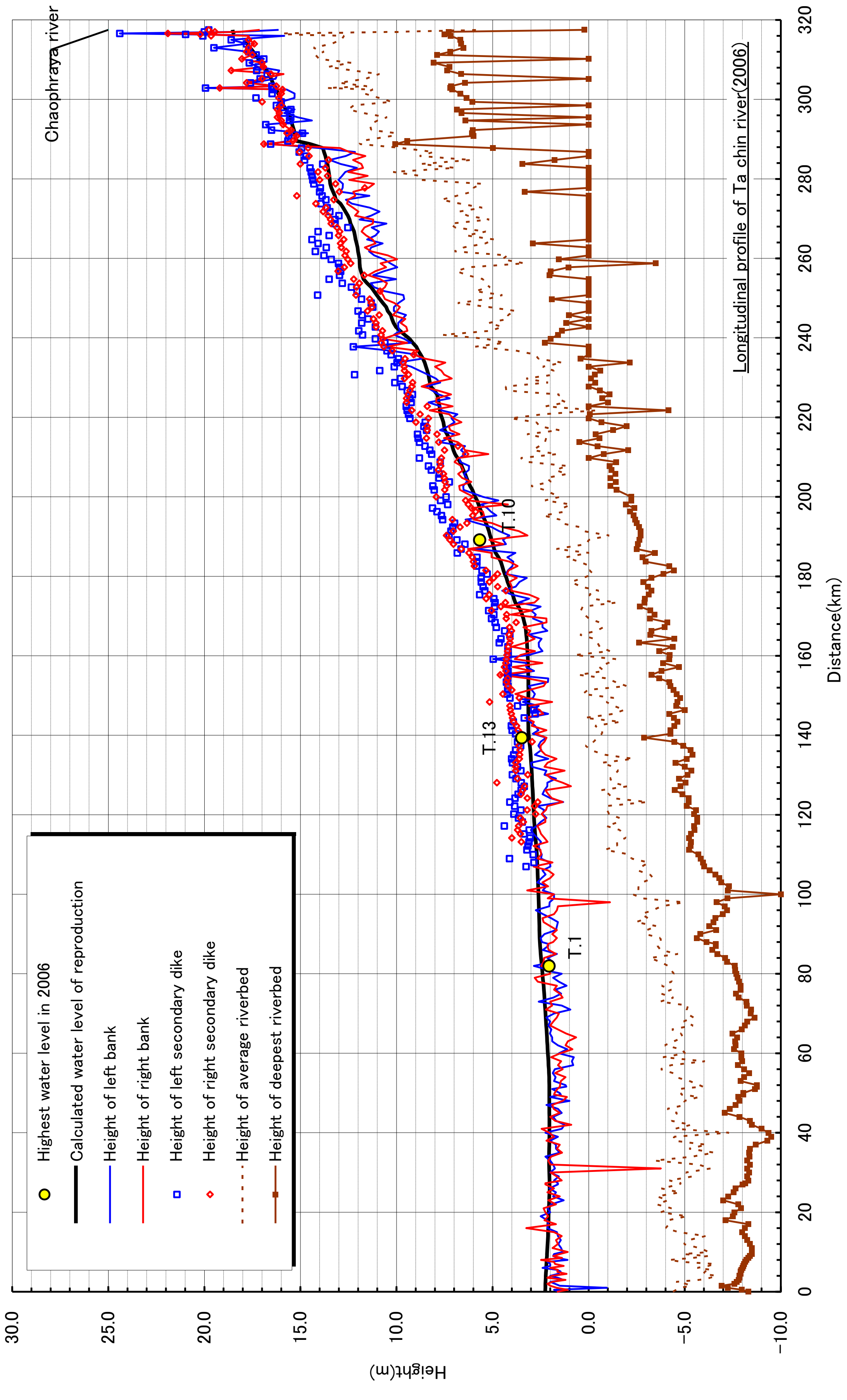


Figure 8.5.9 Longitudinal Water Level Profile for Tha Chin River (2006)

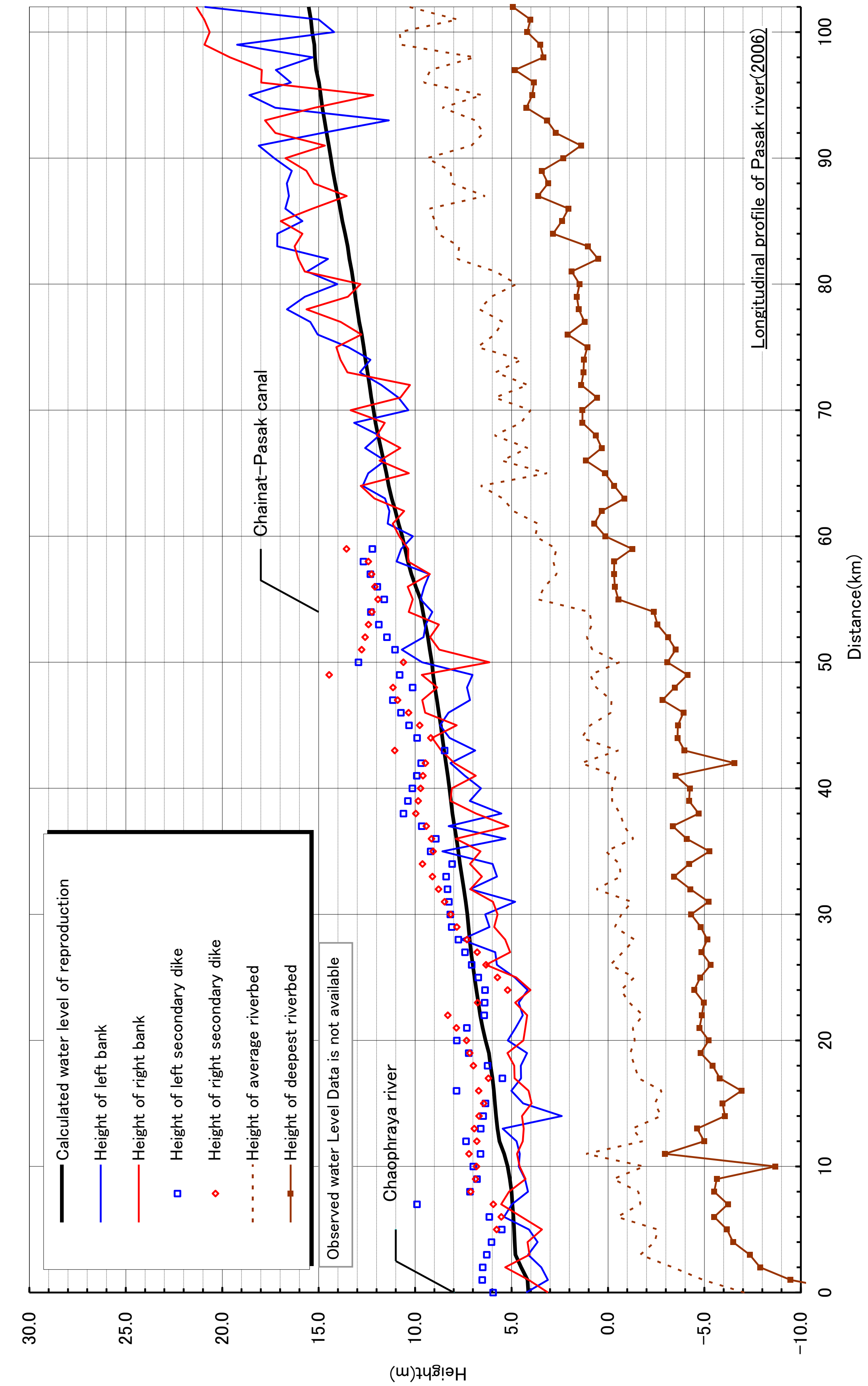


Figure 8.5.10 Longitudinal Water Level Profile for Pasak River (2006)

(b) Water Level and Discharge Hydrograph

The model calculation results are shown in Table 1 to Table 11 for the 9 selected rivers and 2 canals including the Ping River, the Wang River, the Yom River, the Nan River, the Chao Phraya River, the Tab Salao River, the Sakae Krang River, the Pasak River, the Phone-Pen Canal, the Bang Ban Canal and the Tha Chin River.

Table 8.5.3 Model Results for the Ping River (2011)

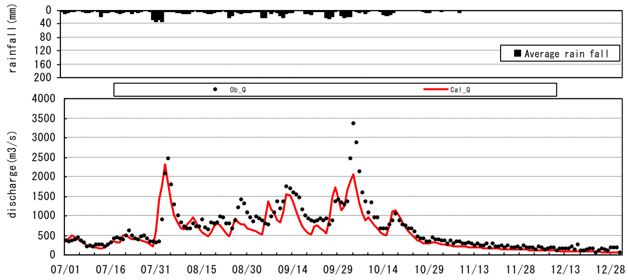
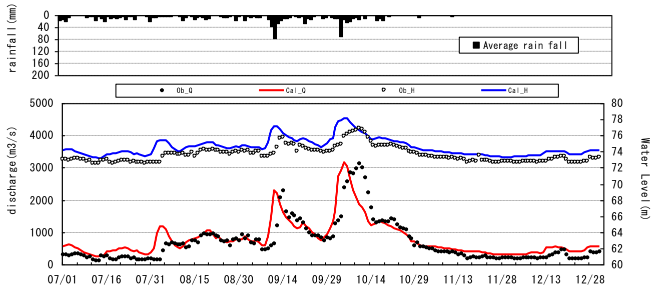
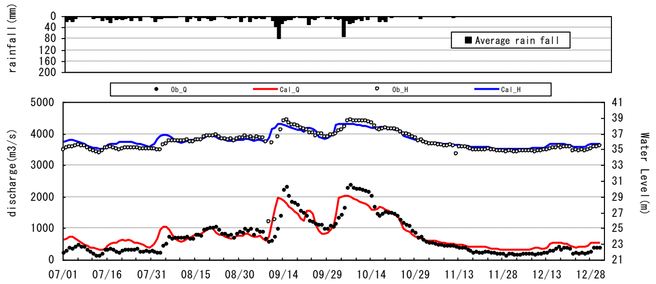
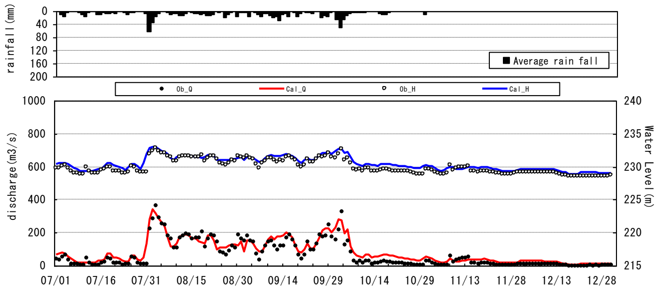
Ping River	Station Name
	Bhumibol Dam Inflow
	Station: P. 7 A
	Station: P.1 7

Table 8.5.4 Model Results for the Wang River (2011)

Wang River	Station Name
	Station: W.1C

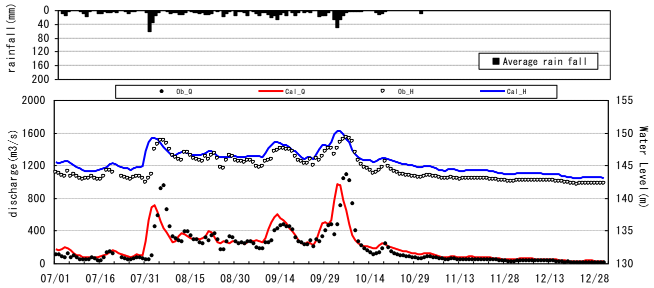
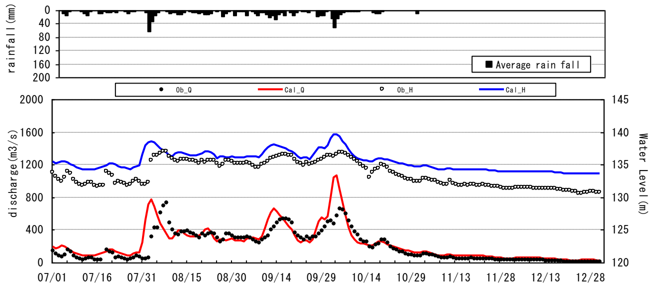
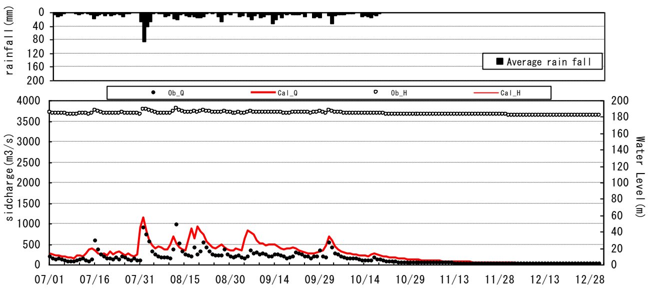
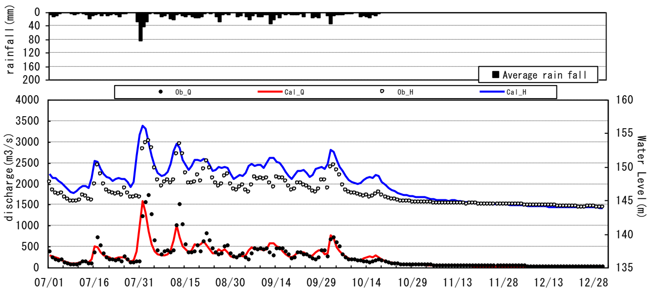
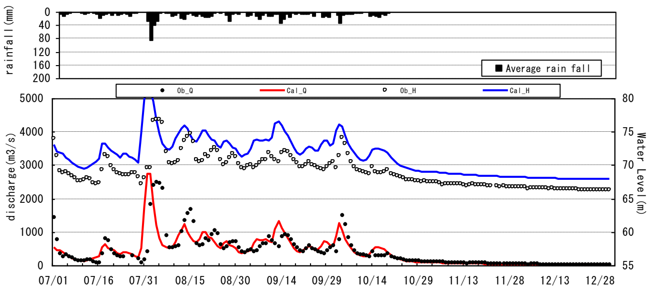
Wang River	Station Name
	Station: W.23
	Station: W.4A

Table 8.5.5 Model Results for the Yom River (2011)

Yom River	Station Name
	Station: Y.20
	Station: Y.1C
	Station: Y.14

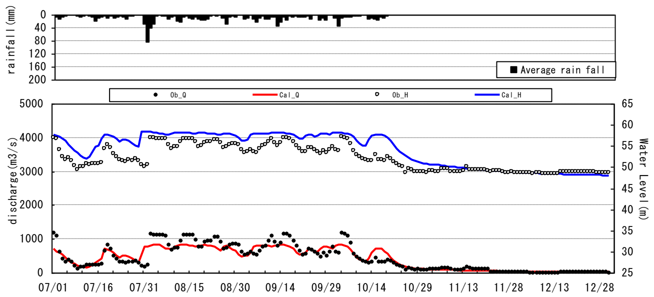
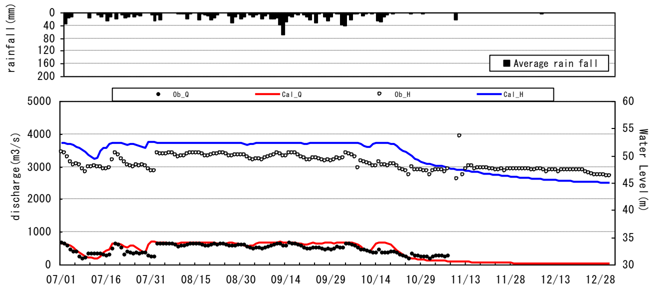
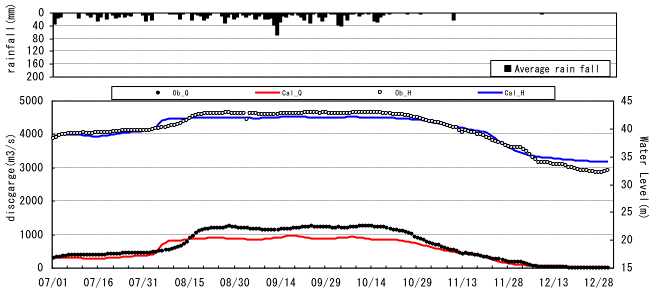
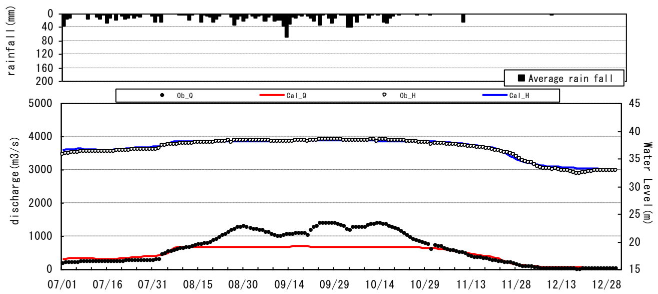
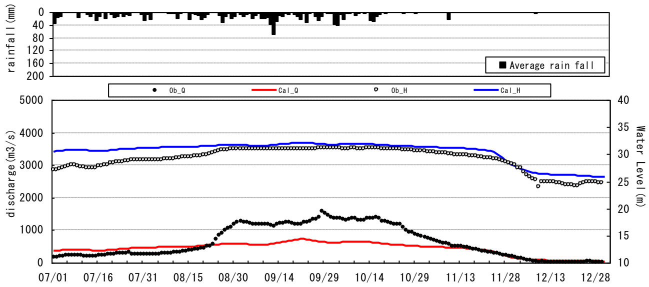
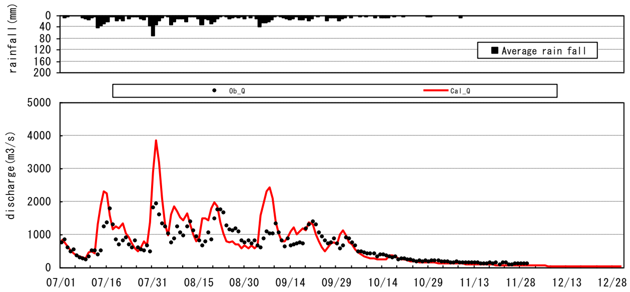
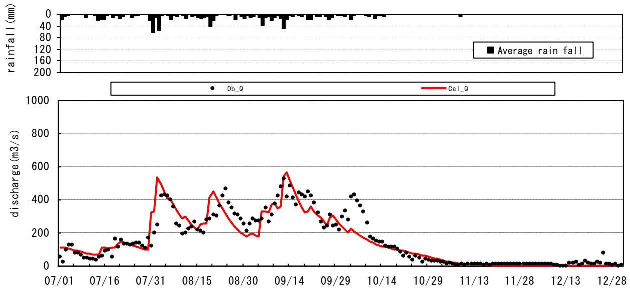
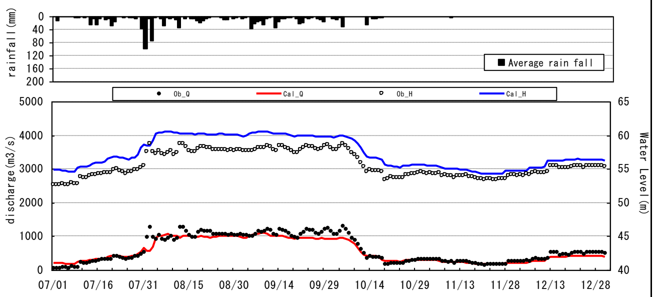
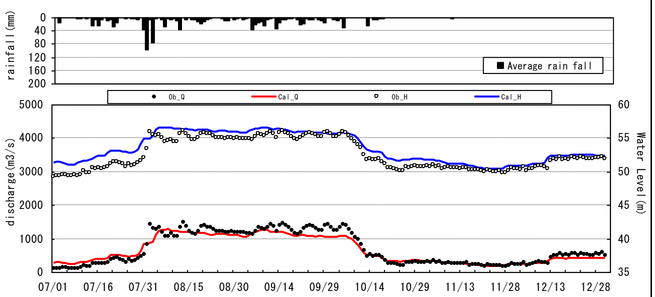
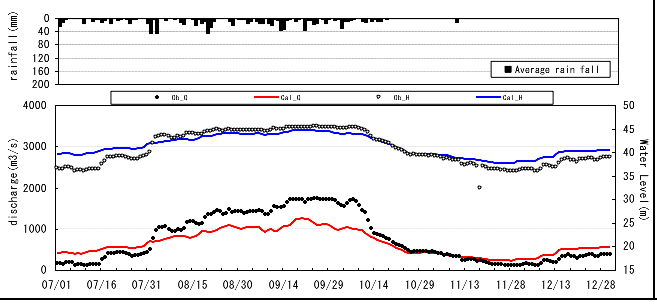
Yom River	Station Name
	Station: Y.33
	Station: Y.4
	Station: Y.16
	Station: Y.17
	Station: Y.5

Table 8.5.6 Model Results for the Nan River (2011)

<table>
<tr><th>Nan River</th><th>Station Name</th></tr>
<tr><td>
</td><td>Sirikit Dam Inflow</td></tr>
<tr><td>
</td><td>Kwae Noi Dam Inflow</td></tr>
<tr><td>
</td><td>Station: N.2B</td></tr>
<tr><td>
</td><td>Station: N.60</td></tr>
<tr><td>
</td><td>Station: N.5A</td></tr>
</table>

CTI Engineering International Co., Ltd.
Oriental Consultants Co., Ltd.
Nippon Koei Co., Ltd.
CTI Engineering Co., Ltd.

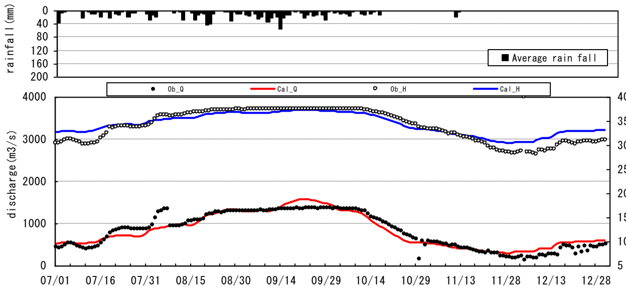
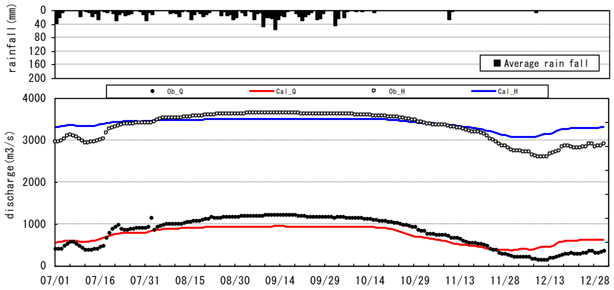
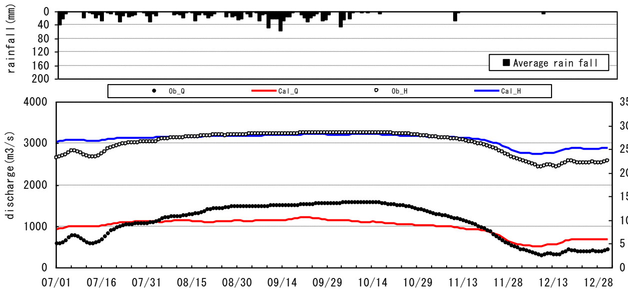
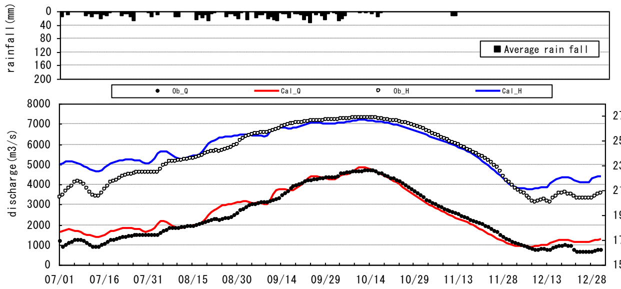
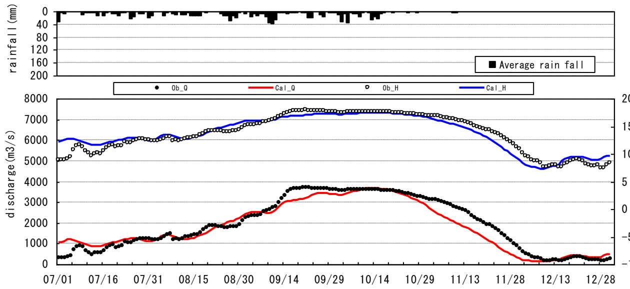
Nan River	Station Name
	Station: N.7A
	Station: N.8A
	Station: N.67

Table 8.5.7 Model Results for the Chao Phraya River (2011)

Chao Phraya River	Station Name
	Station: C.2 (Nakhon Sawan)
	Station: C.13

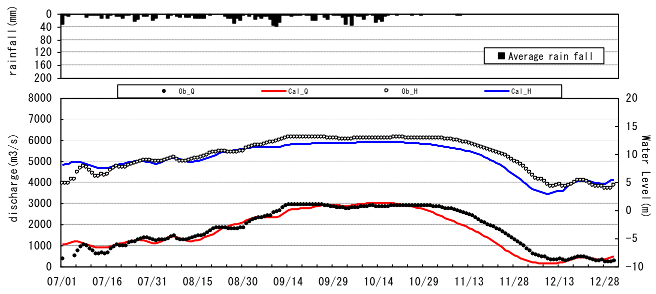
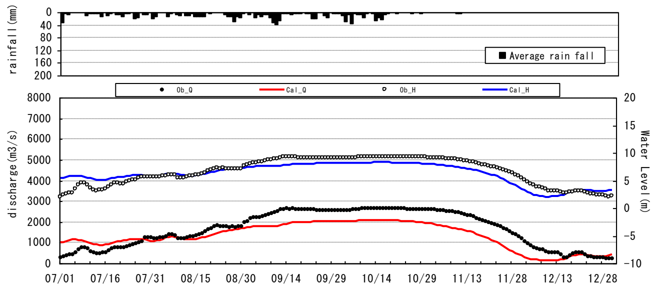
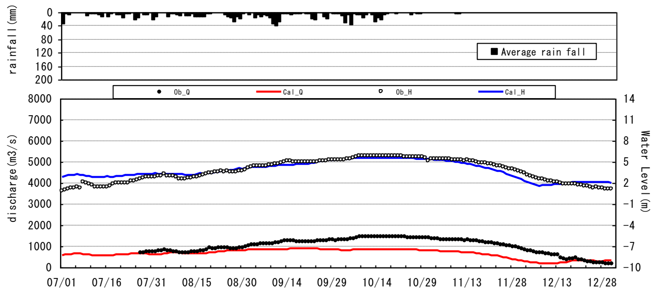
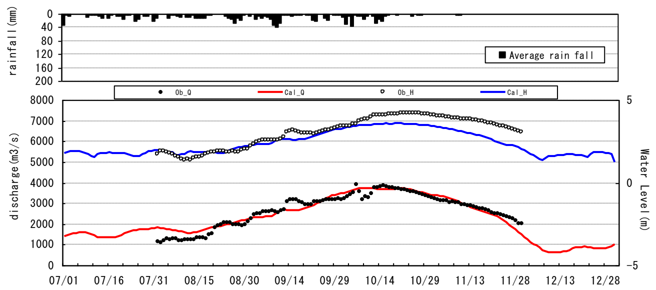
Chao Phraya River	Station Name
	Station: C.3
	Station: C.7A
	Station: C.35
	Station: C.29

Table 8.5.8 Model Results for the Tab Salao River (2011)

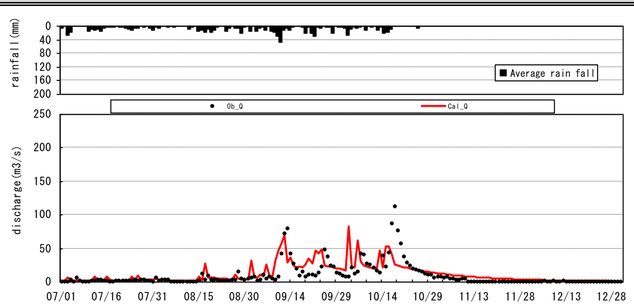
Tab Salao River	Station Name
	Tab Salao Dam Inflow

Table 8.5.9 Model Results for the Sakae Krang River (2011)

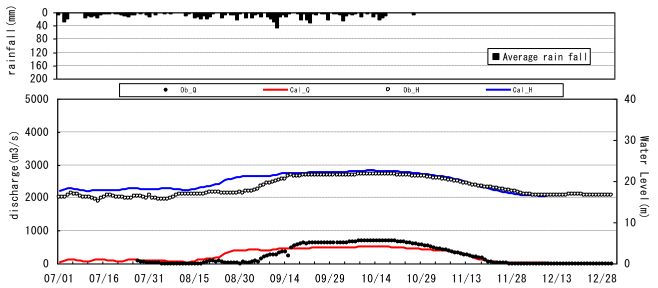
SakaeKrang River	Station Name
	Station: Ct.2A

Table 8.5.10 Model Results for the Pasak River (2011)

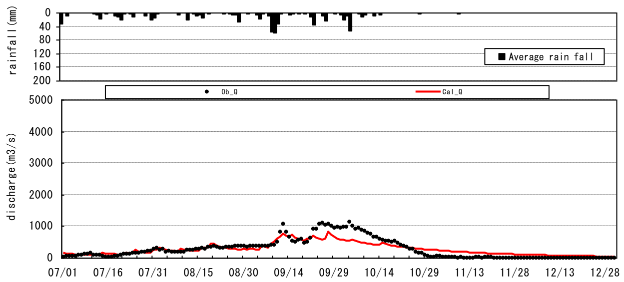
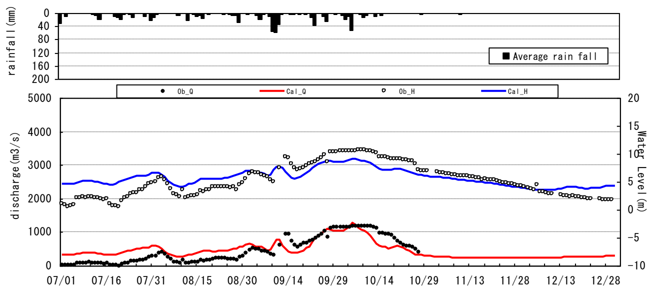
Pasak River	Station Name
	Pasak Dam Inflow
	Station: S.26

Table 8.5.11 Model Results for the Phon-Pen Canal (2011)

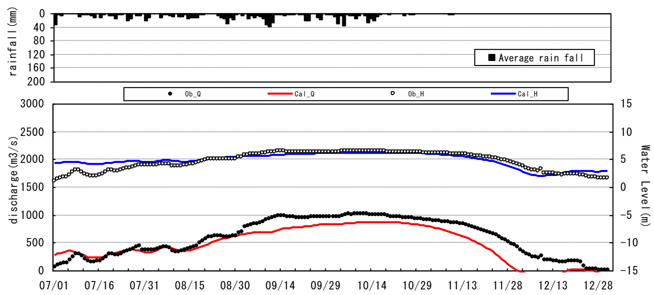
Phon-Pen Canal	Station Name
	Station: C.36

Table 8.5.12 Model Results for the Bang Ban Canal (2011)

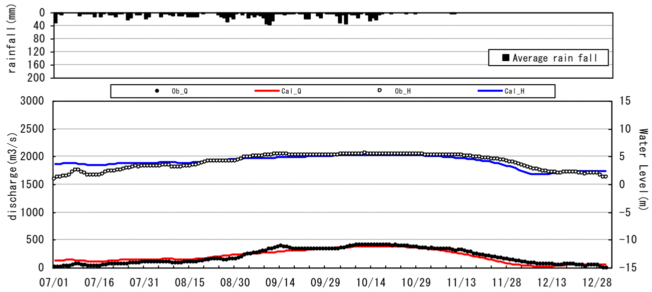
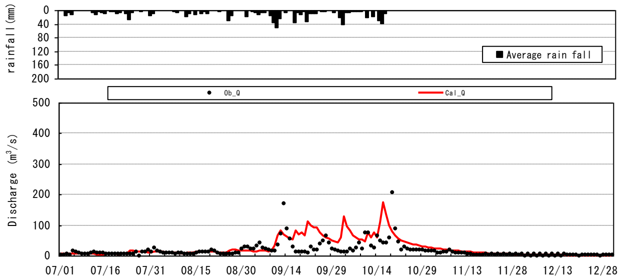
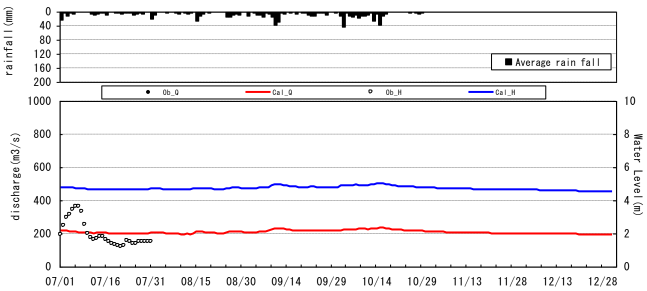
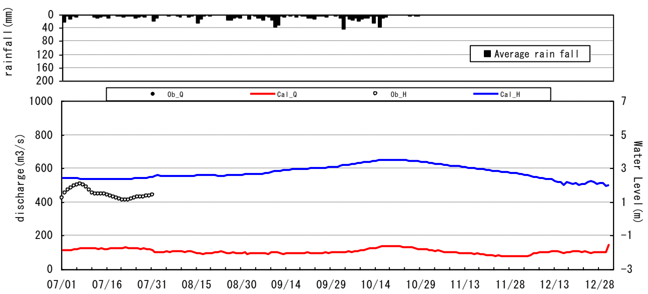
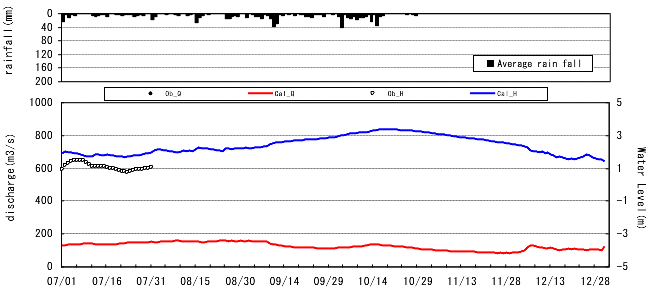
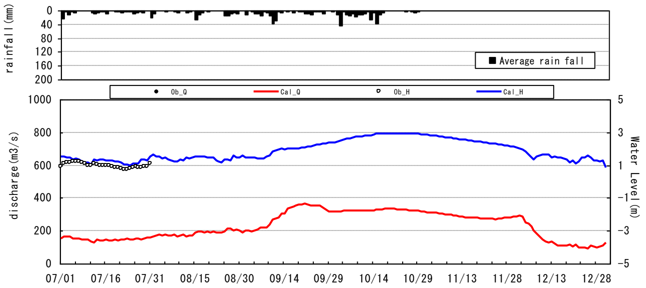
Bang Ban Canal	Station Name
	Station: C.37

Table 8.5.13 Model Results for the Tha Chin River (2011)

Tha Chin River	Station Name
	Kra Siew Dam Inflow
	Station: T.10
	Station: T.13
	Station: T.15

Tha Chin River	Station Name
	Station: T.1

※Observed Water Level Data for Tha Chin River are Yes by the end of July 2012

Table 8.5.14 Model Results for the Ping River (2006)

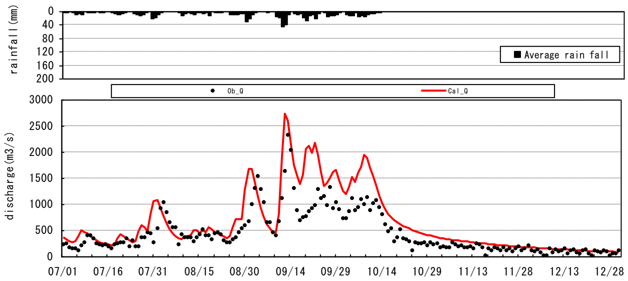
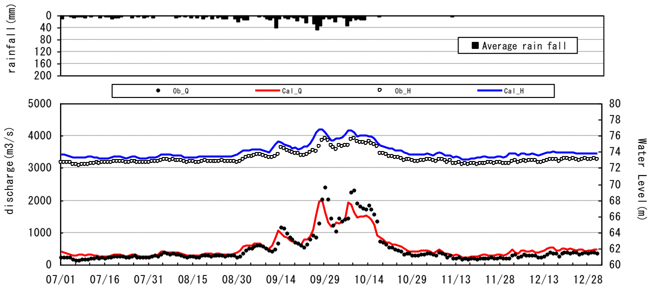
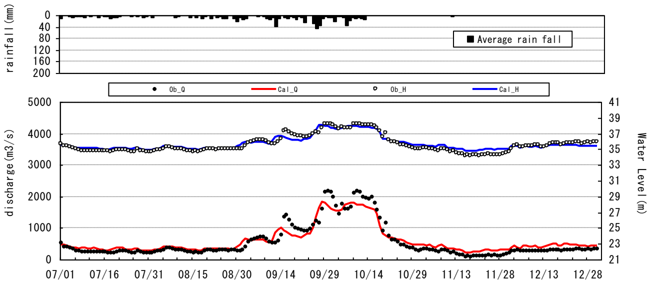
Ping River	Station Name
	Bhumibol Dam Inflow
	Station: P. 7 A
	Station: P.1 7

Table 8.5.15 Model Results for the Wang River (2006)

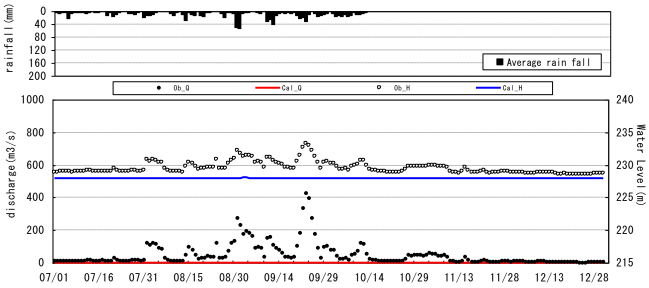
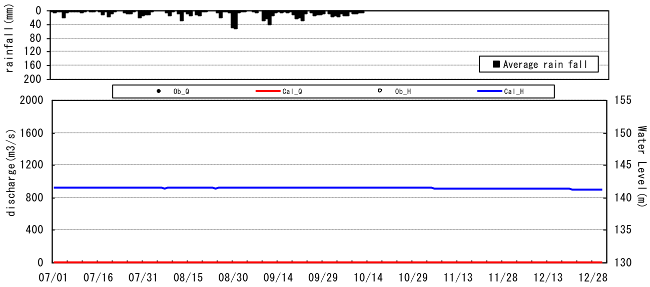
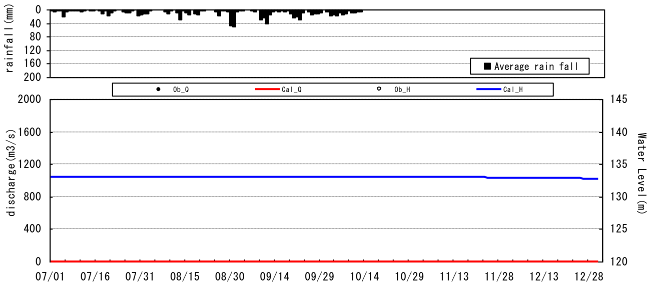
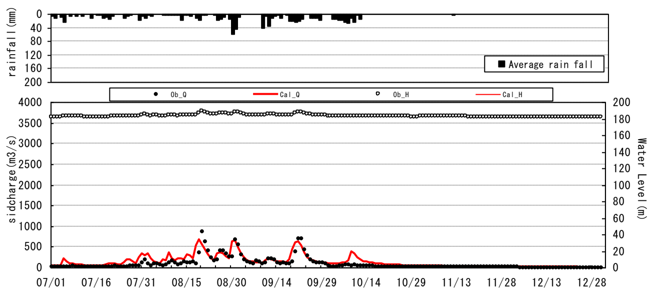
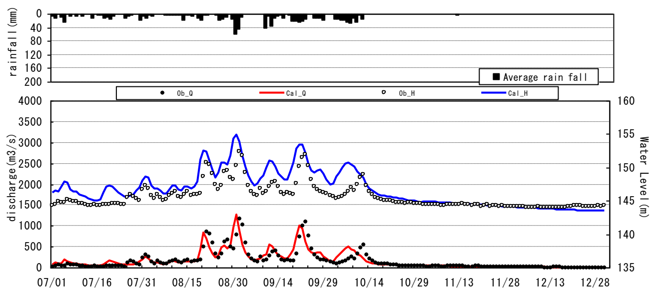
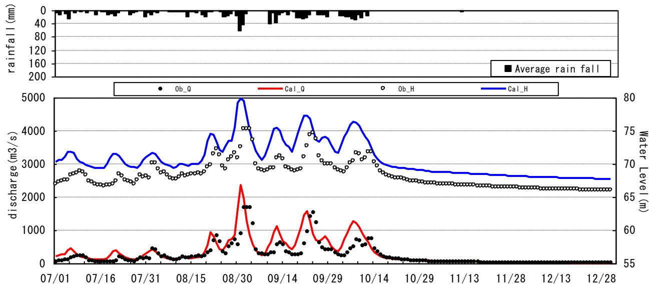
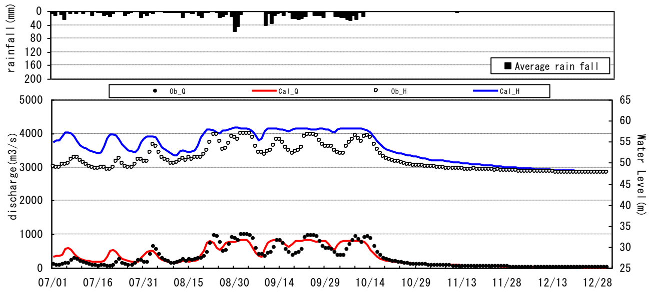
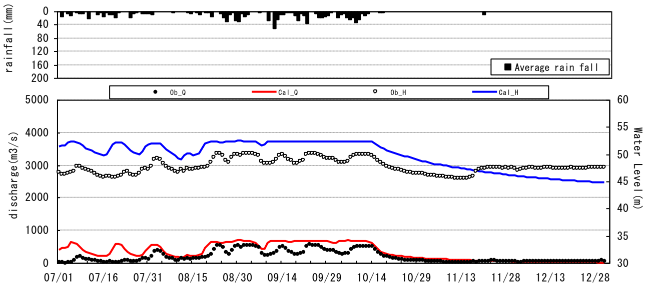
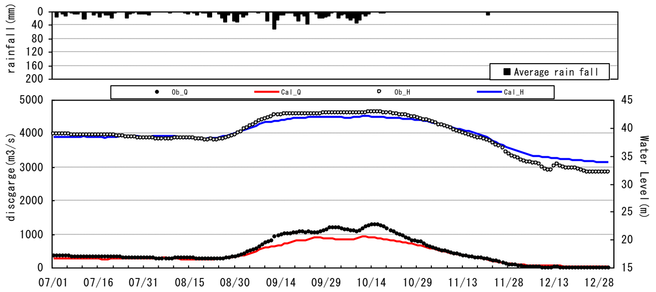
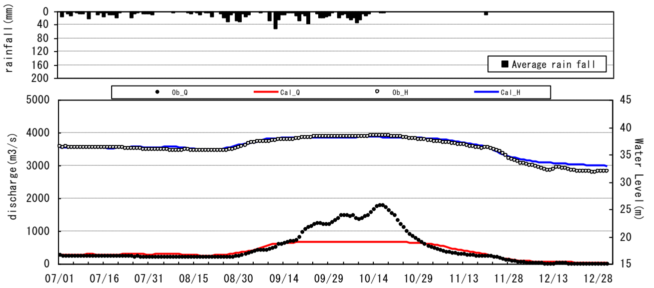
Wang River	Station Name
	Station: W.1C
	Station: W.23
	Station: W.4A

Table 8.5.16 Model Results for the Yom River (2006)

Yom River	Station Name
	Station: Y.20
	Station: Y.1C

<table>
<tr><th>Yom River</th><th>Station Name</th></tr>
<tr><td></td><td>Station: Y.14</td></tr>
<tr><td></td><td>Station: Y.33</td></tr>
<tr><td></td><td>Station: Y.4</td></tr>
<tr><td></td><td>Station: Y.16</td></tr>
<tr><td></td><td>Station: Y.17</td></tr>
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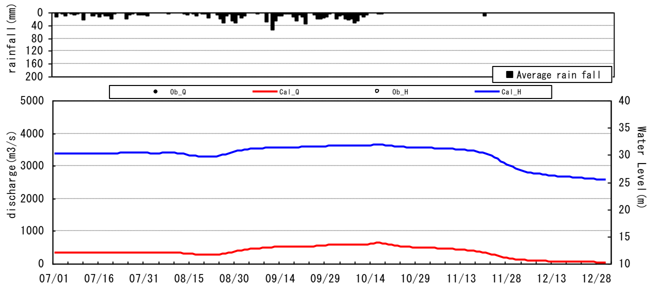
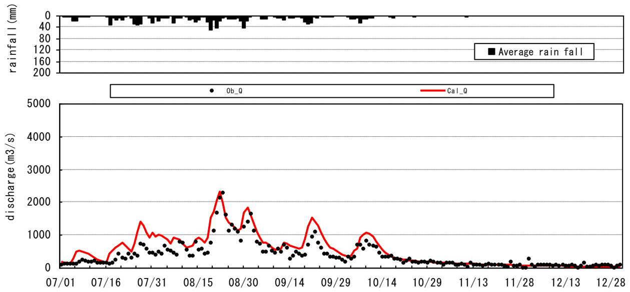
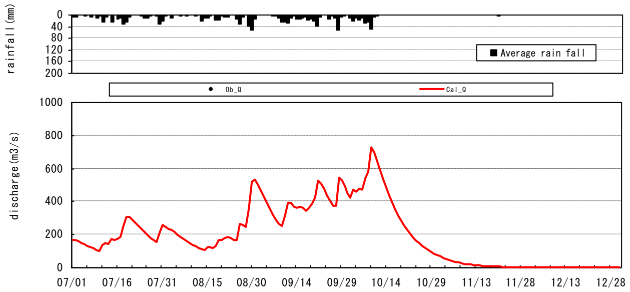
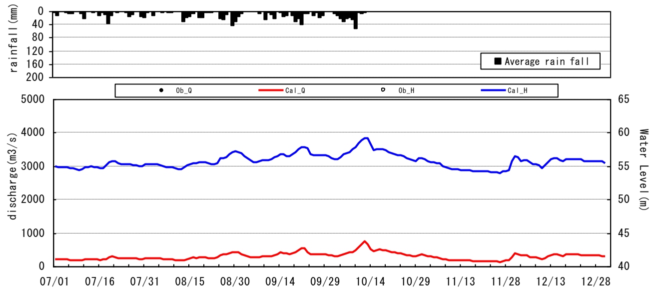
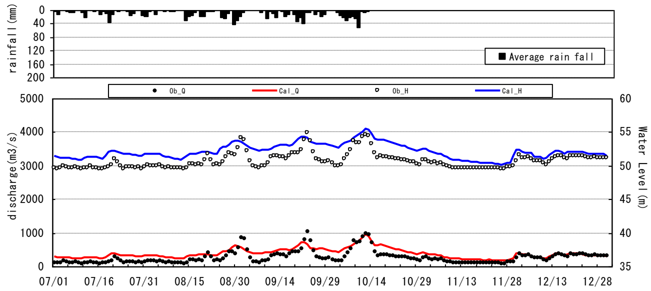
Yom River	Station Name
	Station: Y.5

Table 8.5.17 Model Results for the Nan River (2006)

Nan River	Station Name
	Sirikit Dam Inflow
	Kwae Noi Dam Inflow
	Station: N.2B
	Station: N.60

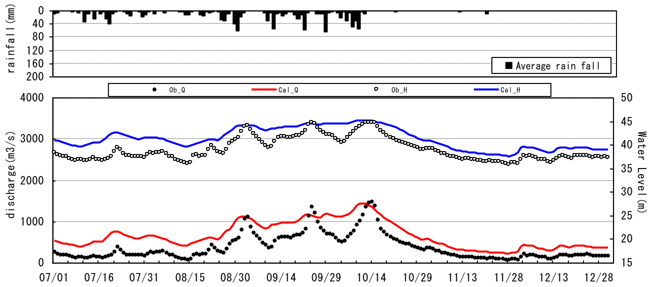
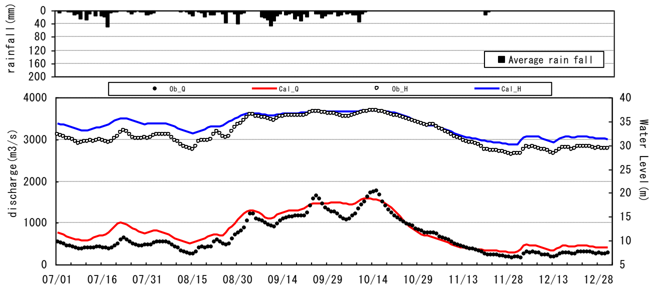
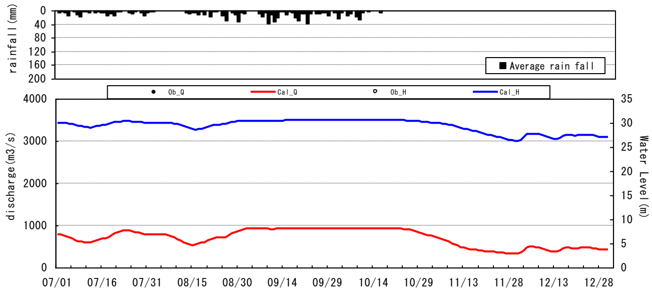
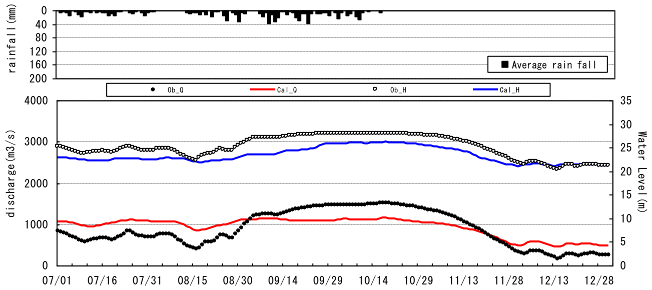
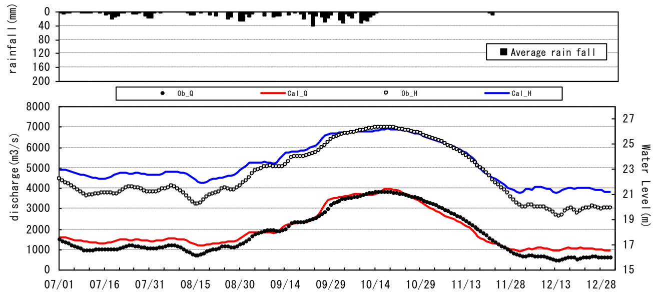
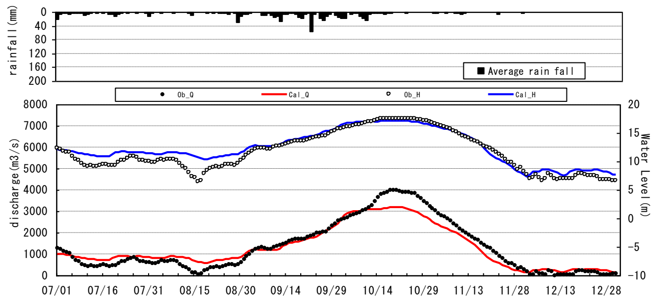
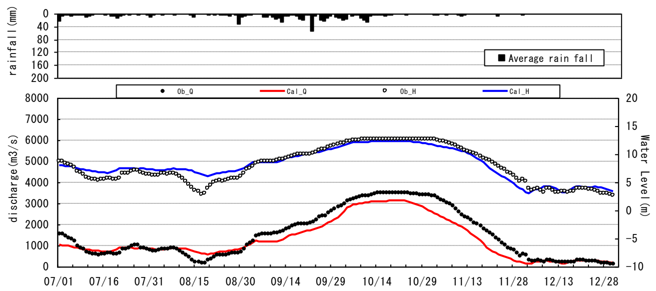
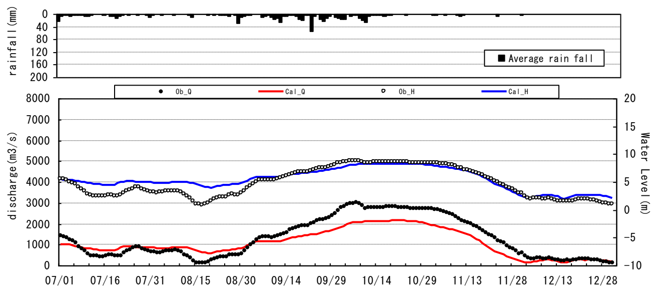
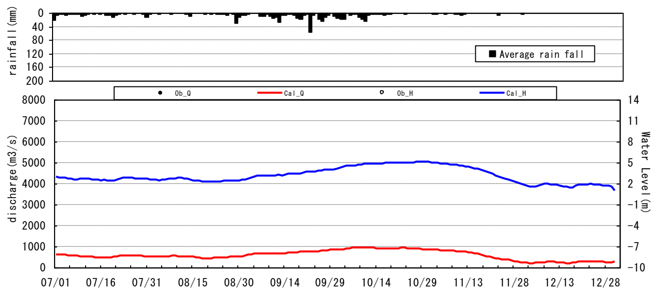
Nan River	Station Name
	Station: N.5A
	Station: N.7A
	Station: N.8A
	Station: N.67

Table 8.5.18 Model Results for the Chao Phraya River (2006)

Chao Phraya River	Station Name
	Station: C.2 (Nakhon Sawan)
	Station: C.13
	Station: C.3
	Station: C.7A
	Station: C.35

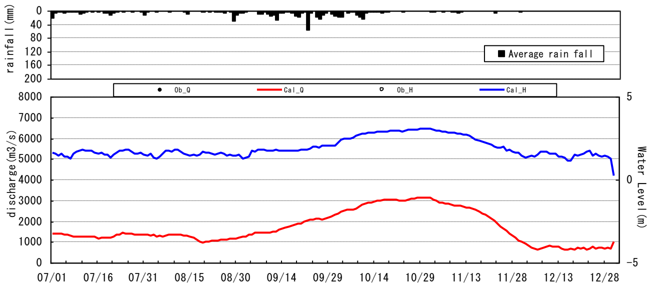
Chao Phraya River	Station Name
	Station: C.29

Table 8.5.19 Model Results for the Tab Salao River (2006)

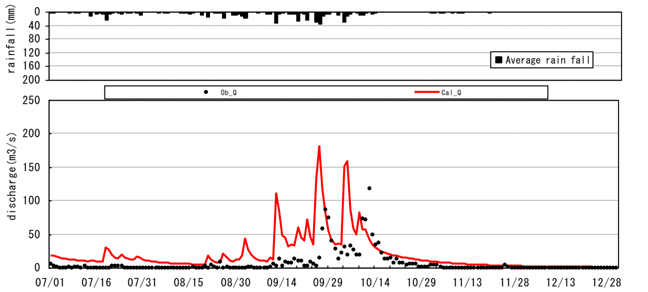
Tab Salao River	Station Name
	Tab Salao Dam Inflow

Table 8.5.20 Model Results for the Sakae Krang River

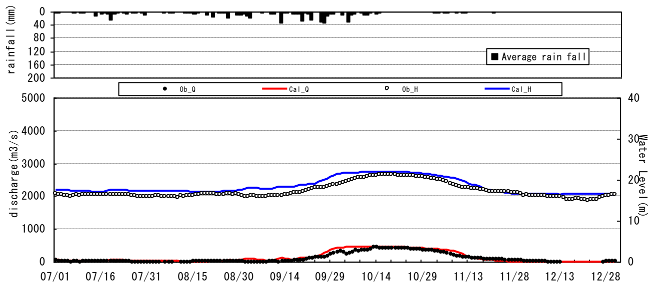
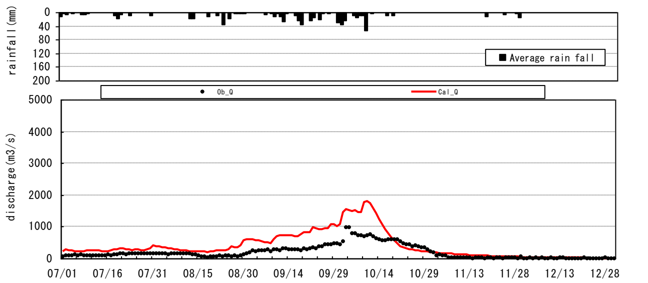
SakaeKrang River	Station Name
	Station: Ct.2A

Table 8.5.21 Model Results for the Pasak River (2006)

Pasak River	Station Name
	Pasak Dam Inflow

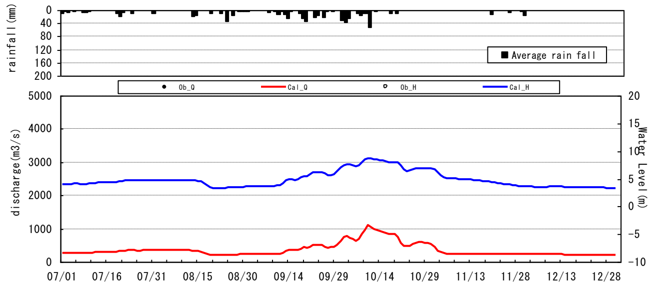
Pasak River	Station Name
	Station: S.26

Table 8.5.22 Model Results for the Phon-Pen Canal (2006)

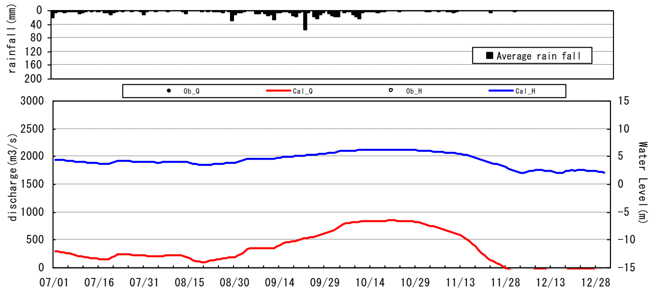
Phon-Pen Canal	Station Name
	Station: C.36

Table 8.5.23 Model Results for the Bang Ban Canal (2006)

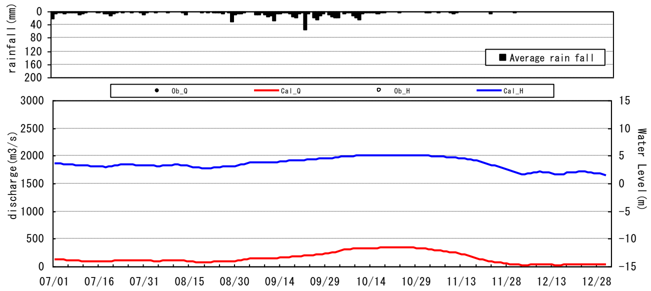
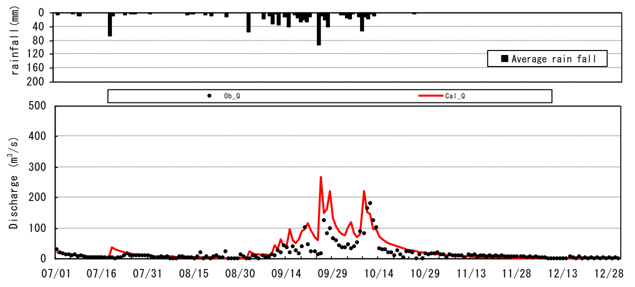
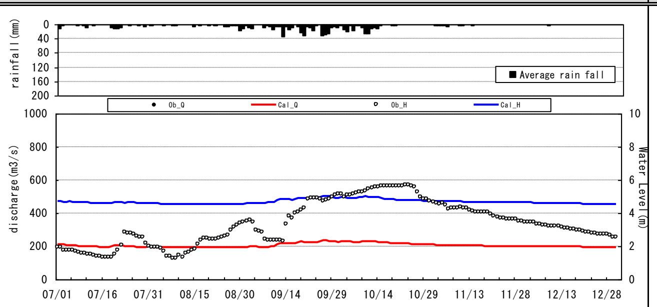
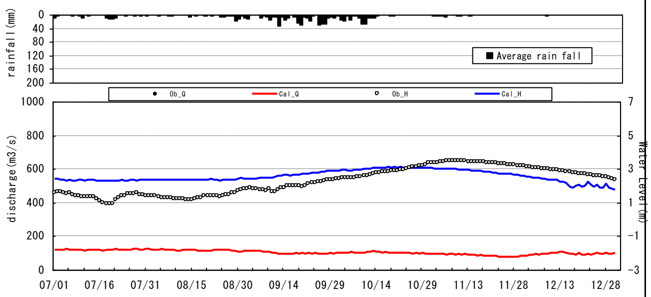
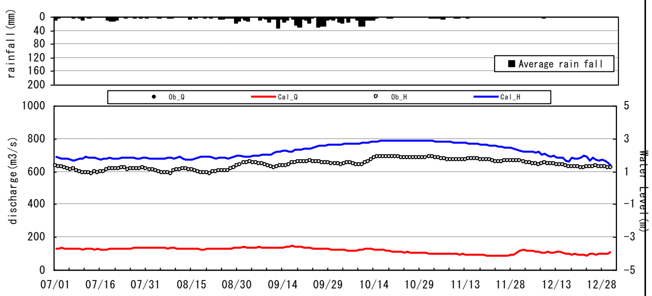
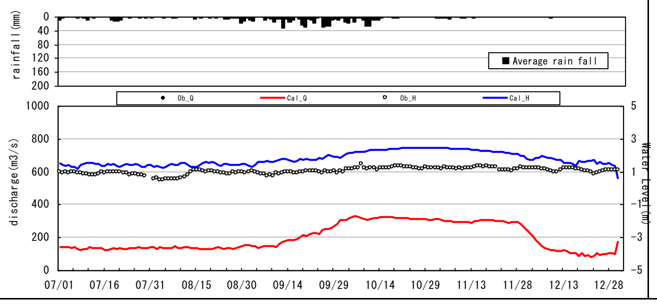
Bang Ban Canal	Station Name
	Station: C.37

Table 8.5.24 Model Results for the Tha Chin River (2006)

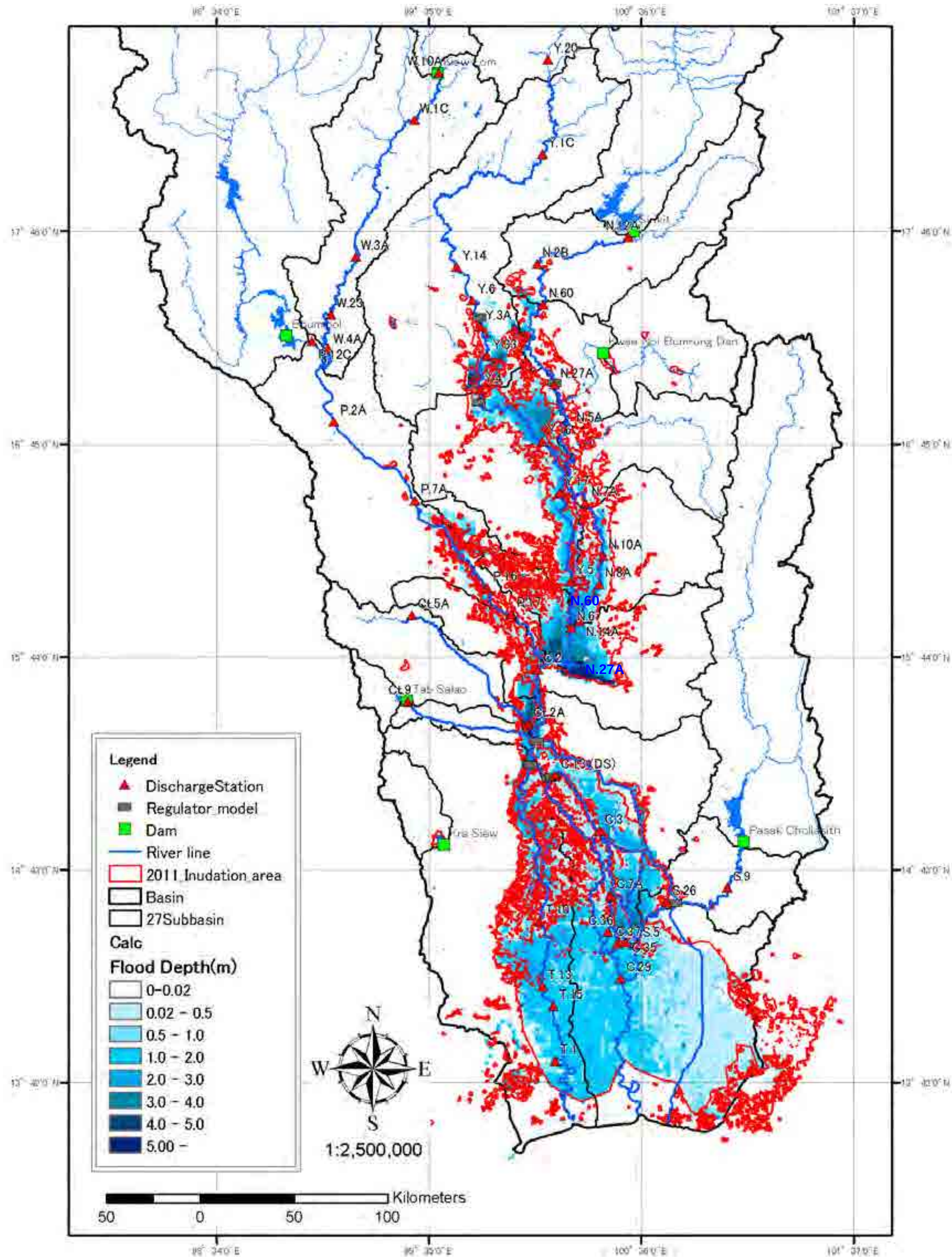
Tha Chin River	Station Name
	Kra Siew Dam Inflow

CTI Engineering International Co., Ltd.
Oriental Consultants Co., Ltd.
Nippon Koei Co., Ltd.
CTI Engineering Co., Ltd.

Tha Chin River	Station Name
	Station: T.10
	Station: T.13
	Station: T.15
	Station: T.1

(c) Inundation Area Analysis

Inundation area maps generated from the simulation results of flood analysis model are shown in Figure 8.5.11 to Figure 8.5.17. Overall, the inundated areas based on the simulation results match with the UNOSAT inundation.



*「2011_Inundataion_Area」 is made by combining 2011 inundation area of UNOSAT (mid-Aug, Sep, Oct and Dec) with 0.01m higher inundated area by flood mark survey.

Figure 8.5.11 Result of Reproduction of 2011 Flood

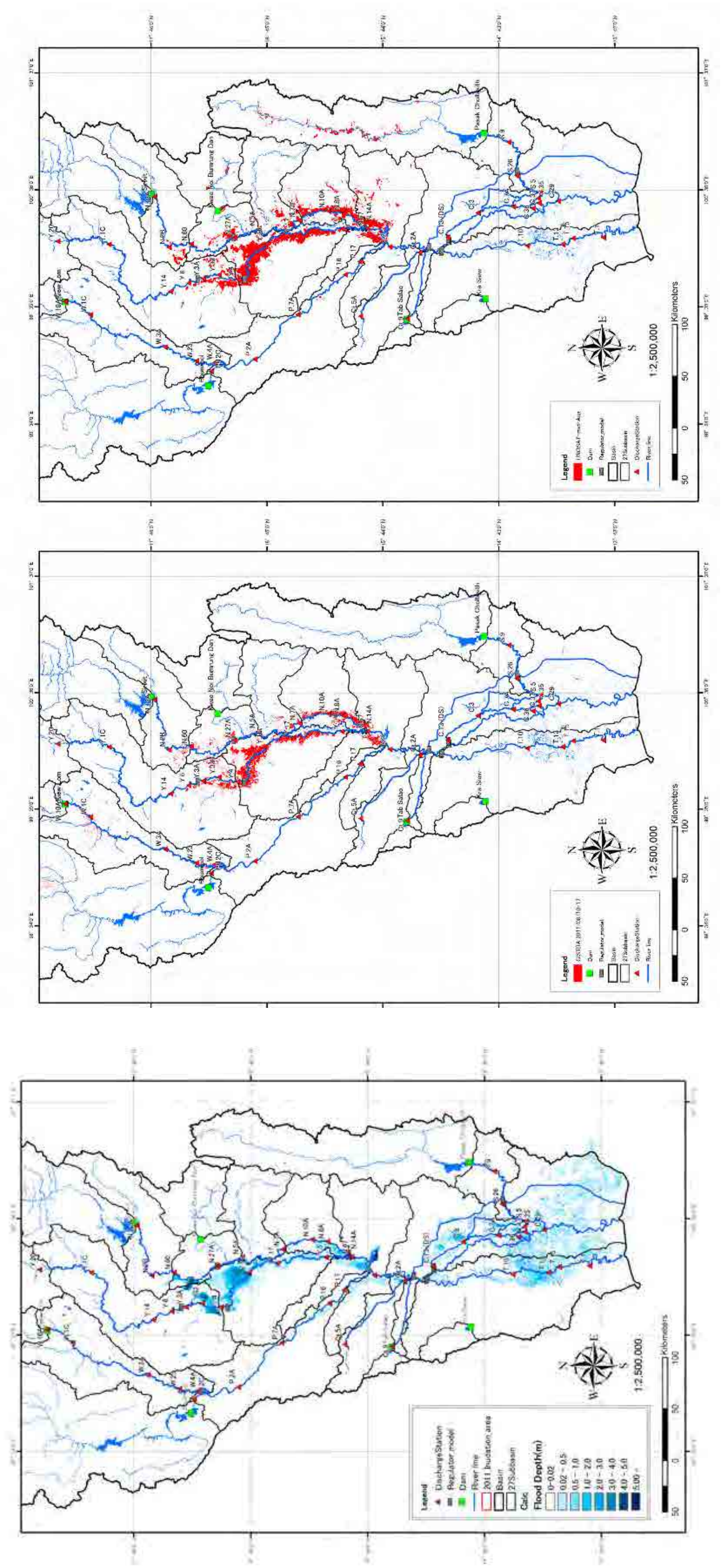


Figure 8.5.12　　Mid-Aug 2011 Figure of Comparison with Inundation Area
（Left：analysis 8/12、Middle：UNOSAT mid-Aug、GISTDA8/10-17）*(GISTDA) Data of near date is adopted

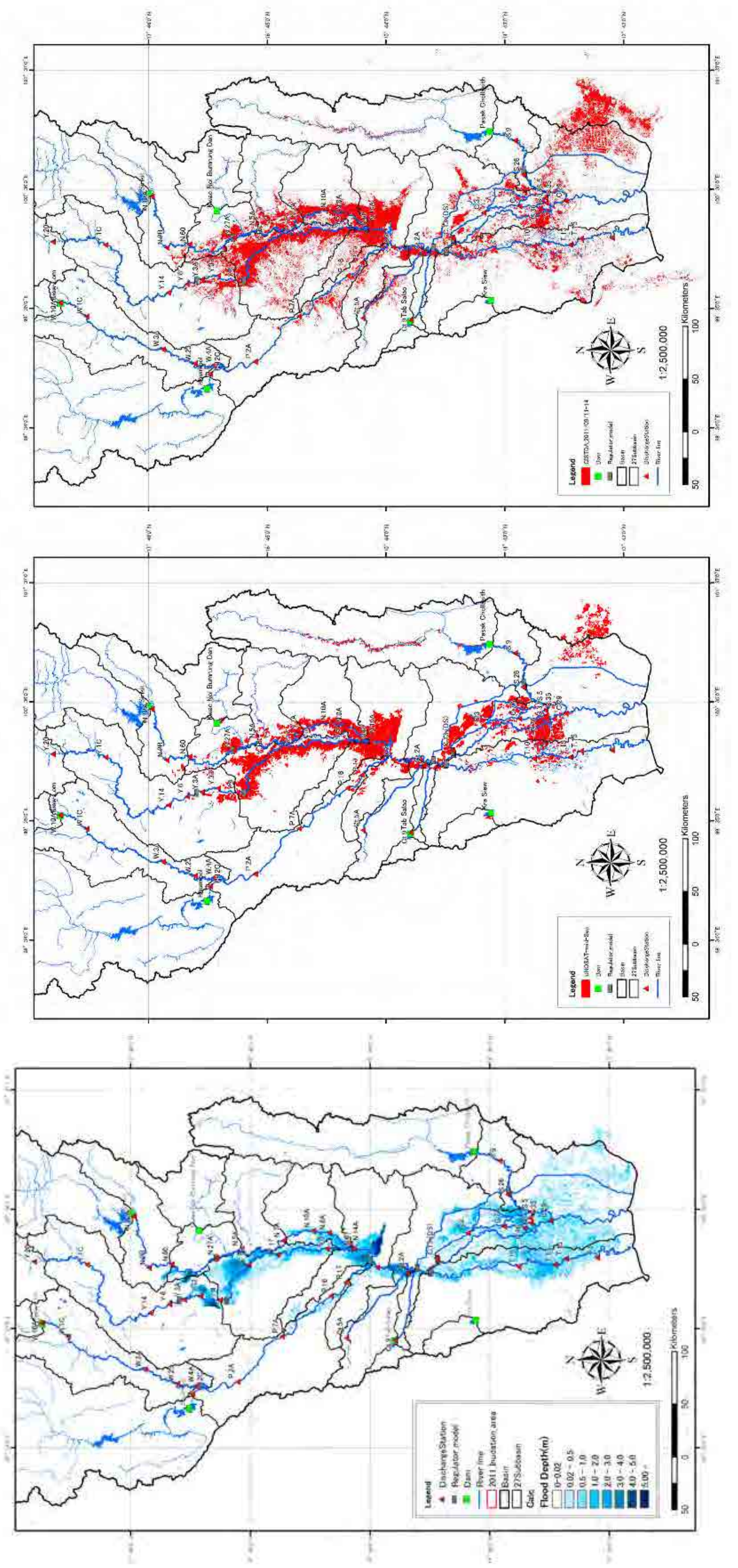


Figure 8.5.13 Mid-Sep 2011 Figure of Comparison with Inundation Area
(Left : analysis 9/13、Middle : UNOSAT mid-Sep、Right : GISTDA9/11-14) *(GISTDA) Data of near date is adopted

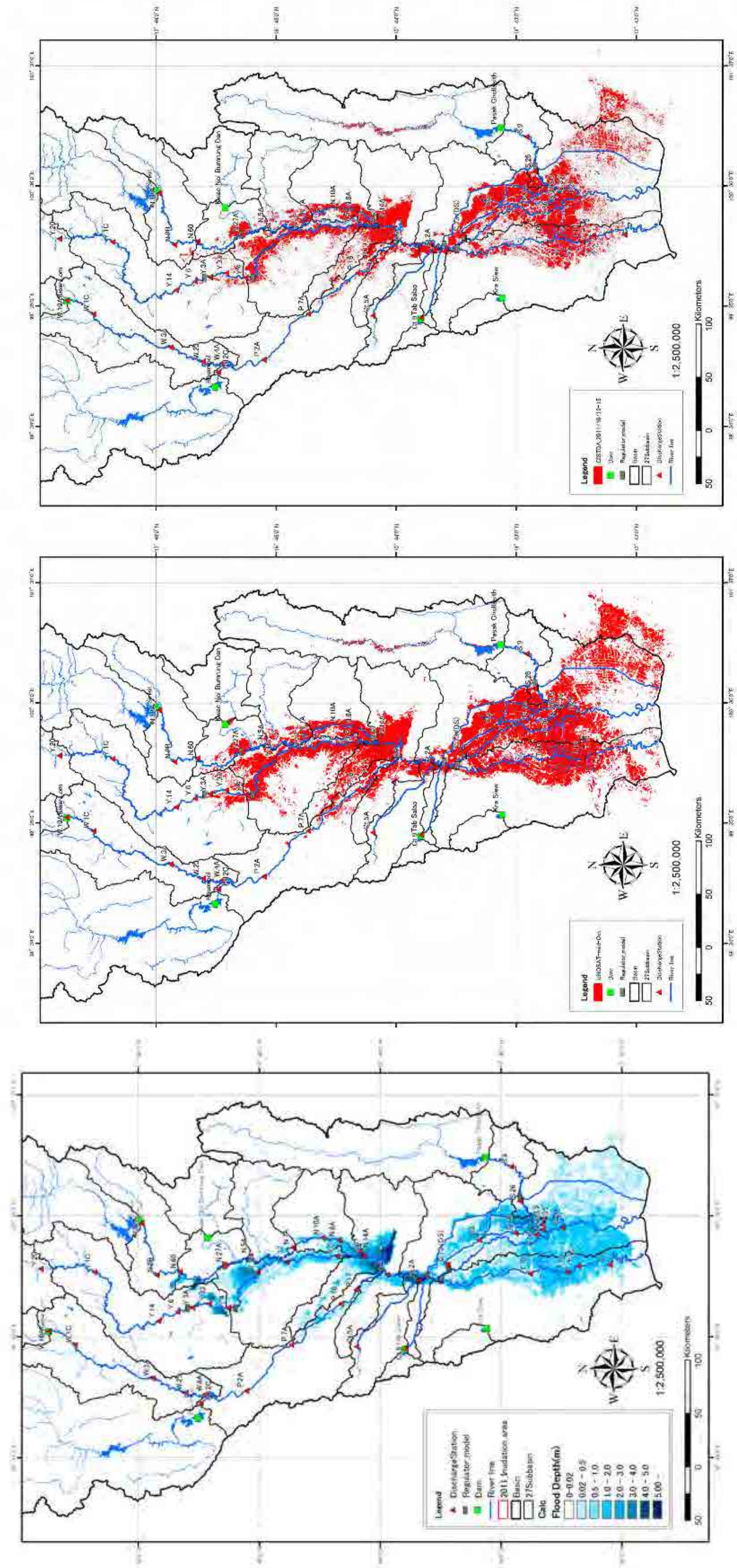


Figure 8.5.14 Mid-Oct 2011 Figure of Comparison with Inundation Area
(Left : analysis 10/13, Middle : UNOSAT mid-Oct、 Right : GISTDA10/12-15)*(GISTDA) Data of near date is adopted

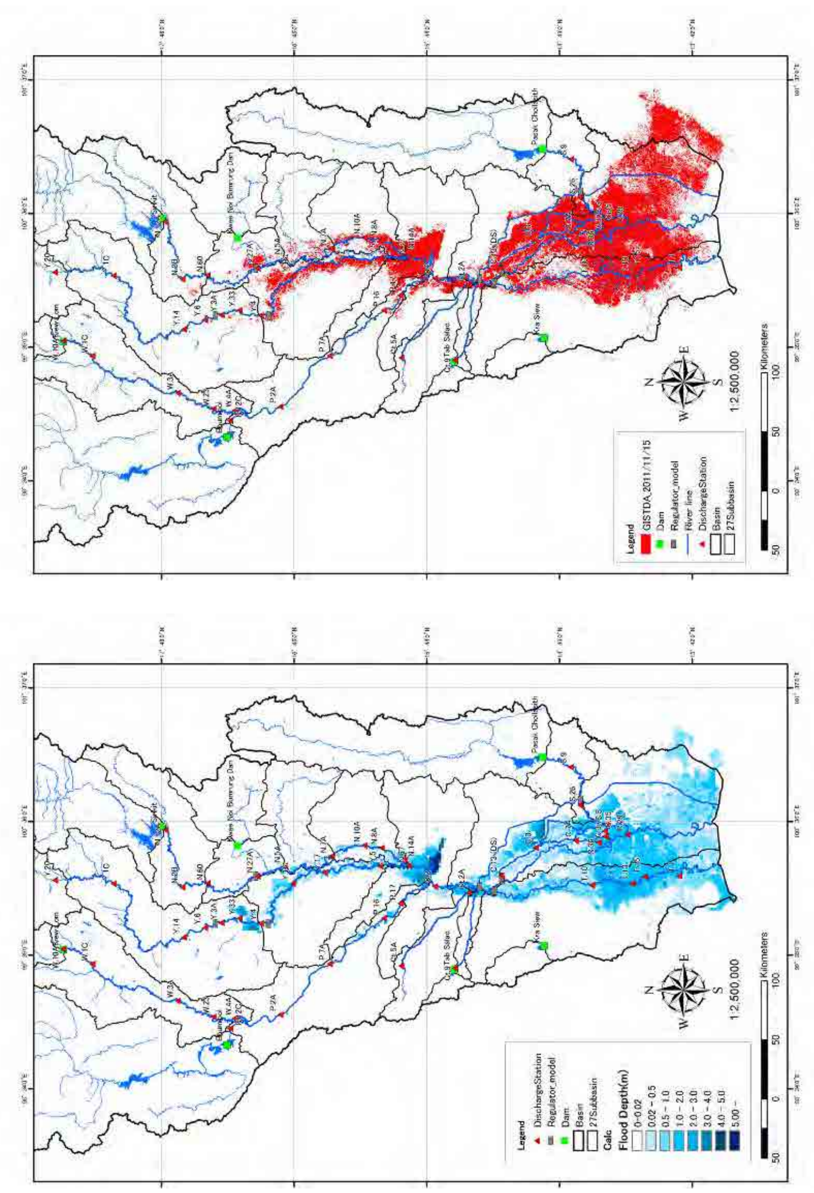


Figure 8.5.15 Mid-Nov 2011 Figure of Comparison with Inundation Area
(Left : analysis 11/15、Right : GISTDA11/15) *(GISTDA) Data of near date is adopted, (UNOSAT) No data of mid-Nov

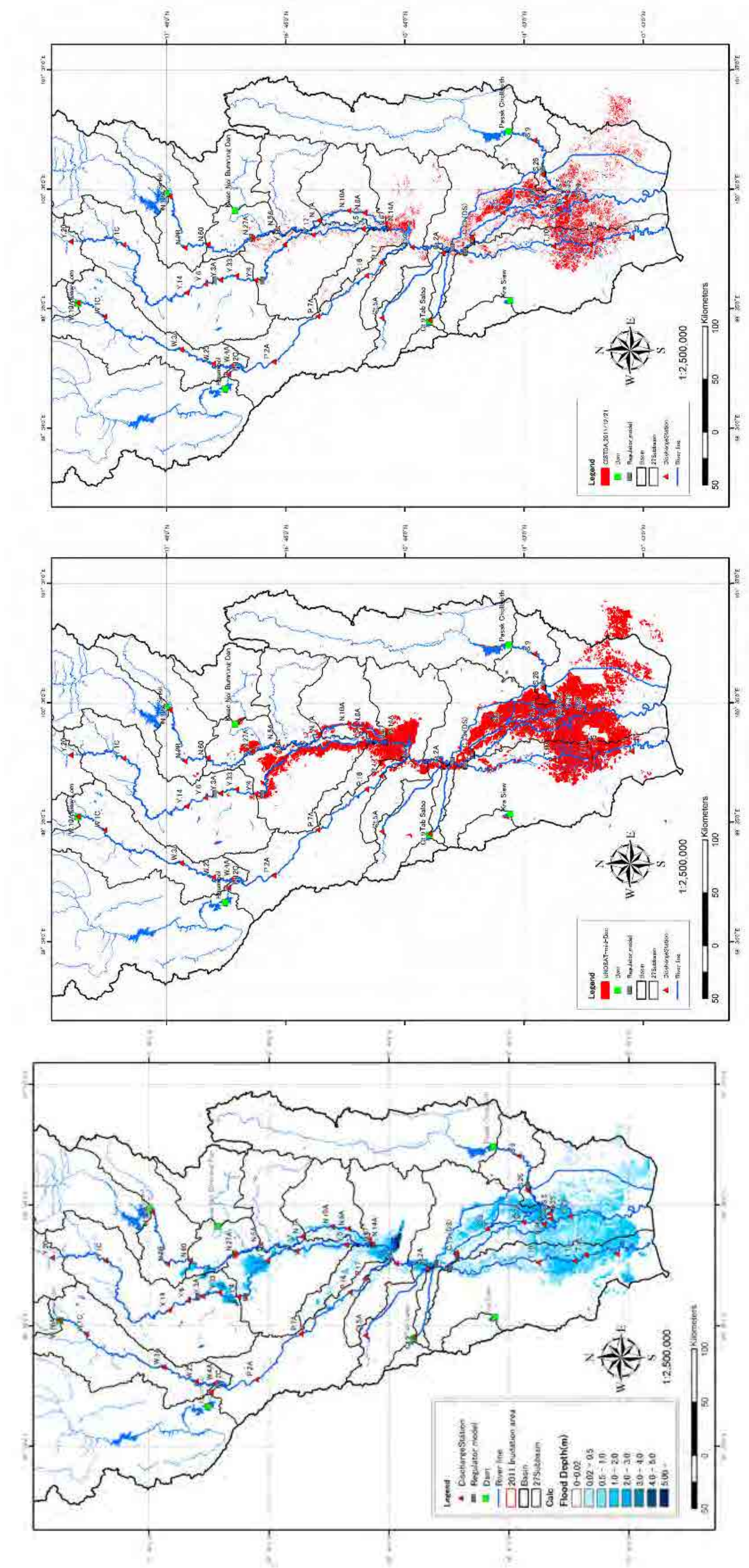


Figure 8.5.16 Mid-Dec 2011 Figure of Comparison with Inundation Area
(Left : analysis 12/21、Middle : UNOSAT mid-Dec、Right : GISTDA12/21) *(GIS TDA) Data of near date is adopted

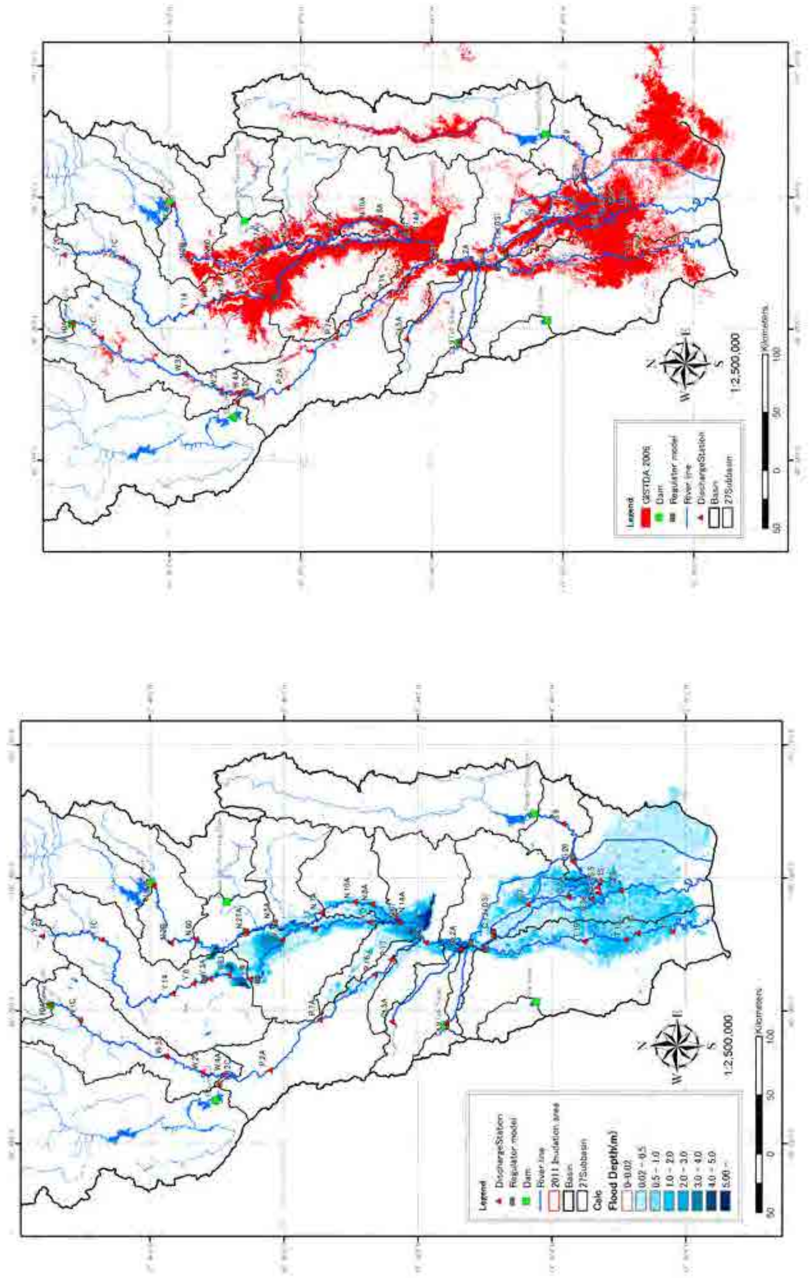


Figure 8.5.17 2006 Figure of Comparison with Inundation Area
(Left : analysis (maximum depth)、Right : GISTDA 2006)

(d) Inundation Depth

Maximum inundation depth maps generated from the simulation results of 2011 flood analysis model is shown in Figure 8.5.18. Overall, the maximum inundated depth based on the simulation results matches with the result of Flood Mark Survey conducted in 2012.

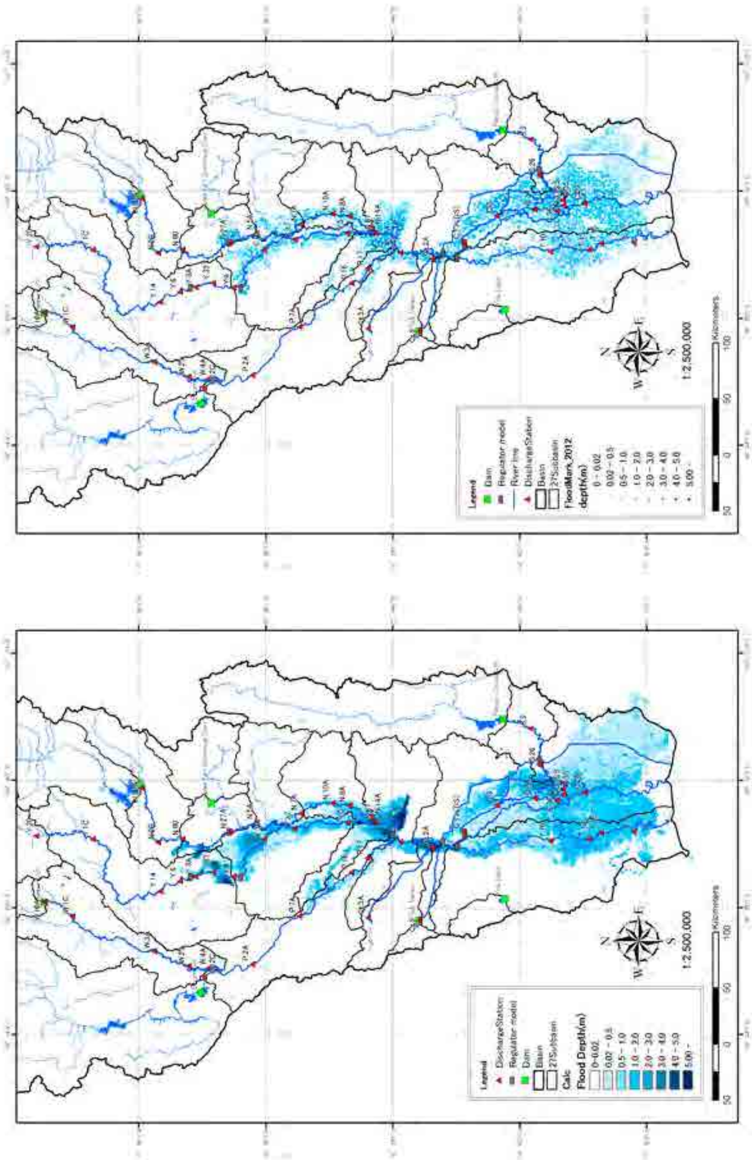


Figure 8.5.18 2011 Figure of Comparison with Inundation depth
(Left : analysis (maximum depth), Right : Flood Mark Survey conducted in 2012)

(3) Evaluation

According to the result of evaluation, it is confirmed that the flood analysis model made in this study is reasonable and has enough accuracy for examination of countermeasures.

(4) Final Parameters

As the result of evaluation, parameters of the NAM Run-off Model, River Network Model and Inundation Model are finalized as follows:

(a) NAM Run-off Model Parameters

Table 8.5.25 and Table 8.5.26 show final model parameters of the NAM Run-off model.

Table 8.5.25 Model Parameters (Final) – Surface-Root Zone

Area No	Name	River	Area (km^2)	Surface-Root Zone						
				U_{max}	L_{max}	CQOF	CKIF	$CK_{1,2}$	TOF	TIF
1	PING NGAD	Ping	1,283	10	100	0.6	1000	30	0.2	0.3
2	PING KWANG		566	20	200	0.6	900	30	0.2	0.3
3	PING BHUMIBOL		24,305	20	800	0.6	300	30	0.2	0.1
4	PING D		8,383	30	300	0.8	1000	20	0.6	0.6
5	WANG KIEW KO MA	Wang	1,354	40	1000	0.6	1000	20	0.2	0.7
6	WANG KIEW LOM		1,422	50	1500	0.9	1000	20	0	0.8
7	WANG D		8,017	20	100	0.5	800	30	0.4	0.4
8	YOM U	Yom	5,580	20	200	0.3	1000	20	0.2	0.2
9	YOM M		12,120	20	200	0.9	500	15	0	0.1
10	YOM D		6,347	20	300	0.9	1000	150	0.5	0.5
11	NAN U	Nan	13,131	10	1000	0.9	1000	30	0.1	0.4
12	NAN M1		5,660	10	50	0.5	1000	100	0.2	0.3
13	NAN KWAE NOI		3,793	80	130	0.1	1000	100	0	0
14	NAN M2		2,315	10	100	0.5	1500	100	0.5	0.5
15	NAN M3		3,962	10	100	0.5	1500	150	0.3	0.3
16	NAN M4		4,103	50	500	0.3	1500	150	0.5	0.2
17	NAN D		1,718	20	500	0.6	1500	150	0.5	0.5
18	CHAO PHRAYA U1		4,786	30	200	0.3	1000	50	0.7	0.5
19	CHAO PHRAYA U2	Chaophraya	1,894	10	100	0.2	1000	50	0.9	0.3
20	CHAO PHRAYA D		7,572	10	150	0.5	1500	20	0.7	0.5
21	SAKAE KRANG	Sakae Krang	3,482	10	100	0.4	1000	30	0.5	0.5
22	TAB SALAO DAM	Tab Salao	543	30	700	0.3	500	5	0.5	0.99
23	TAB SALAO_D		882	10	100	0.6	1200	30	0.3	0.3
24	PASAK DAM	Pasak	12,835	10	1000	0.1	1000	30	0.3	0.5
25	PASAK D		2,657	10	200	0.6	1000	20	0.5	0.5
26	THA CHIN KRA SIEW	Ta Chin	1,193	10	300	0.6	1000	20	0.7	0.9
27	THA CHIN		11,169	10	50	0.3	1000	30	0.3	0.3

Table 8.5.26 Model Parameters (Final) – Groundwater

Area No	Name	River	Area (km2)	Ground Water							
				TG	CK_{BF}	C_{area}	Sy	GWL_{BF0}	GWL_{BF1}	Cq_{low}	Ck_{low}
1	PING NGAD	Ping	1,283	0.1	1000	1	0.15	10	0	10	1500
2	PING KWANG		566	0.1	1000	1	0.15	10	0	10	1500
3	PING BHUMIPOL		24,305	0.3	1000	1	0.15	10	0	10	1500
4	PING D		8,383	0.1	500	1	0.15	10	0	10	1500
5	WANG KIEW KO MA	Wang	1,354	0.3	700	1	0.15	10	0	10	1000
6	WANG KIEW LOM		1,422	0	1000	1	0.15	10	0	10	1000
7	WANG D		8,017	0.4	1000	1	0.15	10	0	10	1000
8	YOM U	Yom	5,580	0.6	700	1	0.1	10	0	50	1000
9	YOM M		12,120	0	500	1	0.05	10	0	50	8000
10	YOM D		6,347	0.1	1000	1	0.05	10	0	50	1000
11	NAN U	Nan	13,131	0.1	800	1	0.2	10	0	0	10000
12	NAN M1		5,660	0.4	600	1	0.15	10	0	0	10000
13	NAN KWAE NOI		3,793	0.5	200	1	0.05	10	0	0	10000
14	NAN M2		2,315	0.1	1500	1	0.05	10	0	0	10000
15	NAN M3		3,962	0.4	1500	1	0.05	10	0	0	10000
16	NAN M4		4,103	0.5	1500	1	0.05	10	0	0	10000
17	NAN D		1,718	0.1	1000	1	0.05	10	0	0	10000
18	CHAO PHRAYA U1		4,786	0.1	1000	1	0.05	10	0	0	10000
19	CHAO PHRAYA U2	Chaophraya	1,894	0.1	1000	1	0.05	10	0	0	10000
20	CHAO PHRAYA D		7,572	0.1	500	1	0.1	10	0	0	10000
21	SAKAE KRANG	Sakae_Krang	3,482	0.1	500	1	0.1	10	0	0	10000
22	TAB SALAO DAM	Tab_Salao	543	0.5	500	1	0.1	10	0	0	10000
23	TAB SALAO D		882	0.3	800	1	0.1	10	0	0	10000
24	PASAK DAM	Pasak	12,835	0.1	800	1	0.15	10	0	0	10000
25	PASAK D		2,657	0.1	1000	1	0.1	10	0	0	10000
26	THA CHIN KRA SIEW	Tachin	1,193	0.1	400	1	0.1	10	0	0	10000
27	THA CHIN		11,169	0.8	300	1	0.1	10	0	0	10000

(b) River Roughness Coefficient

Table 8.5.27 shows finalized Manning's n of river roughness coefficient.

Table 8.5.27 Final Setting of Manning's *n*

No.	River	Reach (km)	Resistance (Manning *n*)	
			Low Flow Zone	High Flow Zone
1	CHAO PHRAYA	0 ~ 141	0.022	0.066
		142 ~ 225	0.033	0.099
		226 ~ 379	0.040	0.120
2	PING	0 ~ 43	0.028	0.084
		44 ~ 135	0.033	0.099
		136 ~ 256	0.050	0.150
3	WANG	0 ~ 286	0.033	0.099
4	YOM	0 ~ 260	0.033	0.099
		261 ~ 597	0.050	0.150
5	NAN	0 ~ 129	0.050	0.150
		130 ~ 449	0.040	0.120
6	SAKAE KRANG	0 ~ 141	0.033	0.099
7	TUB SALAO	0 ~ 99	0.033	0.099
8	THA CHIN	0 ~ 318	0.033	0.099
9	NOI	0 ~ 166	0.029	0.087
10	LOP BURI	0 ~ 99	0.029	0.087
11	BANG KAEW	0 ~ 15	0.029	0.087
12	PASAK	0 ~ 107	0.033	0.099
13	CHAINAT-PASAK CANAL	0 ~ 166	0.033	0.099
14	PHONG PEN CANAL	0 ~ 13	0.029	0.087
15	BANG BAN CANAL	0 ~ 17	0.029	0.087
-	OTHER CANALS	-	0.033	0.099

(c) Floodplain Roughness Coefficient

The final parameter of floodplain roughness coefficient is consequently the same as the initial values shown in Subsection 8.4.2(2).